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# Green manuring: its effect on soil properties and crop growth under rice–wheat cropping system

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**Abstract**

A field experiment was conducted on rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) during rainy and winter seasons of 1994–95 in a clay loam soil (Typic Ustochrept) at the experimental farm of Indian Agricultural Research Institute, New Delhi, India. The objectives were to study the influence of different green manuring (*Sesbania rostrata, Sesbania aculeata*, green gram (*Vigna radiata*) residues) and in combination with different levels of nitrogen (0, 60, and 120 kg N ha$^{-1}$) on physical properties, organic matter and total nitrogen contents of soil and on root growth and spectral response of rice and wheat crop. The organic matter and total soil nitrogen concentrations were found to be higher under green manuring treated plots than summer fallow. The magnitude of reduction in bulk density due to green manuring over fallow was 0.03–0.07 Mg m$^{-3}$ in 0–15 cm soil layer and 0.05–0.09 Mg m$^{-3}$ in 15–30 cm soil layer during the growth of rice and wheat. Green manuring improved the soil physical environments as was evident from higher values of mean weight diameter and saturated hydraulic conductivity than fallow. The better physical and chemical environment in *Sesbania* (*S*) and green gram residue incorporated plots influenced higher Normalized Difference Vegetation Index (NDVI) than under fallow. The NDVI attained peak values at 62 days after transplanting of rice and 90 days after sowing of wheat. The root length density (RLD) and yields were higher in green manure plots than in fallow both in rice as well as in succeeding wheat crop. In all cases, in both rice and wheat the application of 120 kg N ha$^{-1}$ treatment resulted in higher RLD than 60 kg N ha$^{-1}$ and no nitrogen treatments. Poor soil conditions were mainly responsible for restricted root growth and its distribution in surface soil layer in summer fallow plots.


*Keywords:* Green manuring; *Sesbania*; Soil physical properties; Root growth; Rice–wheat system

## 1. Introduction

Rice–wheat is the most predominant cropping system in India and covers an area of approximately, 10.5 million ha. However, the productivity of crops under this cropping-system has reached a plateau and in fact is showing a decreasing trend in

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many areas of India where this cropping system is being practiced for a long time. There are reports of declining factor productivity, i.e. increased rate of fertilisers are needed to maintain the current yield level (Hobbs et al., 1990) which is cited as the evidence of unsustainability of the rice–wheat cropping system. The puddling practice, so essential for optimising production of rice, destroys the soil structure, increases bulk density and reduces hydraulic conductivity, thus leading to a non-conducive soil physical environment for the subsequent wheat crop (Lal, 1985; Painuli et al., 1988). Continuous cultivation of rice can result in the formation of a hard pan below the plough layer which would act as barrier to normal root growth of following wheat crop. The importance of leguminous green manure crops in improving soil fertility and soil physical properties has received increasing attention in recent times (Ladha et al., 1992; Whitbread et al., 2000; Ray and Gupta, 2001). The improvement in soil physical conditions as a result of build up of organic matter by incorporation of green manure or crop residue is associated with a decrease in bulk density, increase in total pore space, water stable aggregates and hydraulic conductivity of the soil (Tirlok Singh et al., 1980; Boparai et al., 1992). Dhaincha (*Sesbania aculeata*) and green gram or mung bean (*Vigna radiata*) are some of the important leguminous green manuring plants. Fast growing leguminous green manures with their adaptability to different rice based cropping pattern and their ability to fix atmospheric nitrogen may offer opportunities to increase and sustain productivity and income in the rice based cropping system (Buresh and De Datta, 1991; Yadvinder Singh et al., 1991; Dey and Jain, 2000; Bar et al., 2000). A new and promising alternative to *S. aculeata* for green manuring is the use of nitrogen fixing stem nodulating legume *Sesbania rostrata*. However, the changes in soil physical properties due to incorporation of *S. rostrata* in soil have not been studied in detail. In recent times the knowledge of spectral reflectance of crops has been utilised in monitoring crop growth and grain yield. Biomass, root growth and leaf area index (LAI) are some of the important plant growth parameters. The spectral reflectance of the crop canopy is primarily influenced by the LAI and there exists a significant correlation between reflectance percentage and the LAI. The spectral indices such as Infrared/Red ratio, Normalized Difference Vegetation Index (NDVI), greenness index etc. have been used to correlate plant growth parameters such as LAI, biomass and to predict yield (Das et al., 1993; Ma et al., 1996). Since the crop growth is influenced by green manuring, the latter may influence the spectral reflectance of the crop. Keeping in view the beneficial role of green manuring in improving the physical and chemical properties of soil, the present investigation has been undertaken with the objectives of studying the effect of green manuring on physical properties, organic matter and nitrogen status of soil in rice–wheat cropping system and how these treatments influenced the root growth and spectral characteristics of rice and wheat.

## 2. Materials and methods

Field experiments were conducted during 1994–95 at the experimental farm of the Indian Agricultural Research Institute (IARI) New Delhi, India. The farm is situated between the latitudes 28°37′N to 28°39′N and the longitudes 77°9′E–77°11′E and the elevation ranges from 217 to 241 m above mean sea level. The climate of Delhi is subtropical semi-arid with hot dry summers and cool winters (Sehgal et al., 1992). The mean maximum temperature during summer months (May, June and July) varies from 43.9 °C to 45 °C. The minimum temperature during winter goes down to as low as 1 °C. The period from December to February is the winter season. The mean annual temperature is 25.5 °C and the mean summer and mean winter temperatures are 33 °C and 17.3 °C, respectively. The mean annual rainfall is 710 mm (average of past 30 years) of which as much as 75% is received during monsoon months (July–September). The soil of the experimental field belongs to the major group of Indo-Gangetic Alluvium (Typic Ustochrept) which is clay loam up to 30 cm depth and sandy clay loam from 30 to 45 cm depth and belongs to the Holambi series (Table 1).

Table 1
Physical and chemical properties of soil of the experimental field at the beginning of the study (1992)

| Soil properties | Soil layer (cm) | |
|---|---|---|
| | 0–15 | 15–30 |
| Sand (2–0.02 mm)g $kg^{-1}$ soil | 505 | 491 |
| Silt (0.02–0.002 mm)g $kg^{-1}$ soil | 239 | 231 |
| Clay ( < 0.002 mm)g $kg^{-1}$ soil | 256 | 278 |
| Soil texture | Clay loam | Clay loam |
| MWD (mm) | 0.556 | 0.492 |
| Bulk density (Mg $m^{-3}$) | 1.49 | 1.52 |
| Hydraulic conductivity (cm $day^{-1}$) | 2.95 | 3.71 |
| Organic matter (g $kg^{-1}$ soil) | 8.31 | 5.21 |
| PH | 7.7 | 7.7 |
| Cation exchange capacity (cmol $kg^{-1}$ soil) | 14.5 | 14.5 |
| Electrical conductivity (desi-siemen $m^{-1}$) | 0.47 | 0.47 |
| Total soil nitrogen (g $kg^{-1}$) | 0.56 | 0.42 |

### 2.1. Experimental lay out and treatments

The cropping sequence of the experimental field for the preceding 25 years was rice followed by wheat. Rice–wheat rotation with a green manure crop during summer has been practiced for the last 2 years i.e. 1992–93 and 1993–94 from the commencement of the present study in 1994–95. The weekly meteorological parameters during 1994–95 showed that the maximum and minimum temperature during the rice growing season varies between 31.2–34.2 °C and 14–26.9 °C and during wheat growing season 17–37.7 °C and 4.1–23.4 °C, respectively. The total rainfall in 1994–95 was 621.7 mm during rice growing season and 101.2 mm during wheat growing season. The experiment was laid out in a split plot design with 3 replications. The main plot treatments constituted fallow (F), *Sesbania rostrata* (SR), *Sesbania aculeata* (SA), and green gram residue incorporation (GGI) after harvesting the grain during summer and sub plot ($12 \times 3.7$ $m^2$) treatments were three nitrogen levels 0 (N0), 60 kg N $ha^{-1}$ (N60), and 120 kg N $ha^{-1}$ (N120) applied to the rice grown during rainy season (July–October). Summer crops (main plot treatments) were seeded in the second week of May, 1994 except in the fallow treatment plot. The green manure crops were allowed to grow up to the second week of July. The pods of green gram were harvested. Fresh biomass yields of green gram, *S. rostrata* and *S. aculeata* were 15.6, 18.3 and 20.2 Mg $ha^{-1}$, respectively. The residue of green gram and *Sesbania* were ploughed down by a tractor drawn disc plough at the time of land preparation for rice. Puddling was also done in fallow plots by the same disc plough. The 30 days old, medium duration paddy variety Pusa 169 was transplanted on July 14, 1994. The spacing was maintained at $20 \times 10$ $cm^2$. Nitrogen was applied as Urea in three equal splits at the time of transplanting, 25 days after transplanting (DAT) and 53 DAT, in the nitrogen treatment plots, P @ 26.2 kg $ha^{-1}$ as single superphosphate and K @ 33.2 kg $ha^{-1}$ as muriate of potash applied at the time of transplanting in all plots. Regular irrigation at 4–5 days interval was applied except on rainy days and the irrigation was stopped 15 days before the harvest. Inter-culture operations like hand weeding were carried out from time to time. The crop was harvested on October 31, 1994. For the succeeding wheat crop, the field was prepared with a tractor drawn disc plough followed by harrowing and planking. The wheat, variety DL 153-2 (Kundan) was sown on November 24, 1994 with the help of a bullock drawn plough keeping row to row distance of 20 cm and seeds were placed at 4–5 cm soil depth. No fertiliser was applied for wheat and a pre sowing irrigation at 7 days before sowing along with six irrigations each of about 5 cm water at 5, 21, 62, 83, 103 and 127 days after sowing (DAS) were applied. The crop was harvested on April 24, 1995.

### 2.2. Organic matter and total soil nitrogen

A part of the representative soil sample was air dried and powdered with wooden pestle and mortar and passed through 0.2 mm sieve for the determination of organic matter and total nitrogen. Organic carbon was determined by Walkley and Black's method (Jackson, 1967a) and organic matter was calculated by multiplying the organic carbon values by a conversion factor 1.724, on the assumption that soil organic matter contains 58%

organic carbon (Biswas and Mukherjee, 1994). The total nitrogen in soil was determined by using Digestion system 20 and Kjeltec Auto 1030 Analyzer of Tecator, Sweden based on the modified Kjeldahl method (Jackson, 1967b).

### 2.3. Soil physical properties

For determination of bulk density and saturated hydraulic conductivity, undisturbed soil core samples were collected in a metal core of 6.99 cm diameter and 7.93 cm height from 0–15 and 15–30 cm soil layers. Saturated hydraulic conductivity was determined by the constant head method (Klute, 1965). A constant water head was maintained on top of each core in the laboratory and the rate of water flow through the soil was measured at steady state. Darcy's law was utilised to calculate the saturated hydraulic conductivity. The soil cores were then oven-dried to calculate bulk density by the method suggested by Blake (1965). The aggregate size distribution was determined by wet sieving (Yoder, 1936) and the values were expressed as mean weight diameter (MWD) after oven drying (van Bavel, 1949).

### 2.4. Root growth, root length density and yield

Root samples were collected with core sampler having 5.35 cm internal diameter at progressive depth of 15 cm up to 30 cm depth for rice and up to 60 cm depth for wheat. The soil from each depth was washed over a 0.1 mm screen and the separated roots were stored in bottles containing 5% formalin solution. The clean roots thus collected were spread over a glass plate with graph sheet attached below and root length was determined by following the line intersection method given by Newman (1966) as modified by Tennant (1975) by using the relationship.

$$R = \frac{\pi}{4} N$$

where $R$, total root length (in cm); $N$, number of intersection between the root and random lines; $\pi = 3.14$ (constant).

Root length density (RLD) was calculated by using the formula:

$$\text{RLD} = R/V \text{ cm cm}^{-3},$$

where, $V$ is the volume of the soil core from which the roots were separated for root length measurement.

The net sub plot area was harvested after removing the border rows and threshed. The grain yield was recorded after cleaning and drying at 140 g kg$^{-1}$ moisture and expressed in Mg ha$^{-1}$.

### 2.5. The spectral reflectance

The spectral reflectance of rice and wheat was measured from the field using a hand held Spectro radiometer (Delphi Model 102, Delphi Industries Limited, Auckland, New Zealand) in the visible and near infrared range of electromagnetic spectrum. The radiometer was kept at a height of 2 m above the ground surface with 20° field of view. The canopy reflectance was monitored at weekly intervals throughout the crop growth. The percent reflectance values was calculated by dividing the canopy reflectance value by that of standard. Barium sulphate plate reflectance was used for standard. Reflectance values on 670 nm ($R_r$) and 860 nm ($IR_r$) were used to calculate the NDVI (Deering et al., 1975)

$$\text{NDVI} = \frac{IR_r - R_r}{IR_r + R_r}.$$

## 3. Results and discussion

### 3.1. Organic matter and total soil nitrogen

As green manure is an organic material, incorporation of green plant material obviously, increased the accumulation of soil organic matter during the growth period of rice and wheat (Table 2). The overall relative increase of organic matter concentration by green manuring over fallow were 117.7, 113.7, 118.1 for *S. rostrata, S. aculeata* and GGI, respectively, for 0–15 cm soil depth and it

Table 2
Effect of green manuring and nitrogen treatments on organic matter concentration (g $kg^{-1}$) of soil under rice and wheat

| Treatments | Nitrogen level | At 65 DAT of rice | | At rice harvest | | At wheat harvest | |
|---|---|---|---|---|---|---|---|
| | | Soil depth (cm) | | | | | |
| | | (0–15) | (15–30) | (0–15) | (15–30) | (0–15) | (15–30) |
| Fallow | N0 | 8.65 | 5.84 | 8.63 | 5.97 | 8.10 | 4.68 |
| | N60 | 8.74 | 5.97 | 8.71 | 6.01 | 8.19 | 4.77 |
| | N120 | 8.86 | 6.12 | 8.81 | 6.05 | 8.48 | 4.97 |
| | mean | 8.75 | 5.98 | 8.72 | 6.01 | 8.26 | 4.81 |
| *S. rostrata* | N0 | 9.98 | 7.12 | 9.03 | 6.78 | 8.61 | 5.11 |
| | N60 | 10.33 | 7.28 | 9.19 | 6.89 | 8.89 | 5.16 |
| | N120 | 10.60 | 7.54 | 10.28 | 7.31 | 9.14 | 5.48 |
| | Mean | 10.30 | 7.31 | 9.50 | 6.99 | 8.88 | 5.25 |
| *S. aculeata* | N0 | 9.61 | 7.10 | 8.78 | 6.51 | 8.48 | 5.10 |
| | N60 | 10.06 | 7.19 | 9.08 | 6.68 | 8.80 | 5.13 |
| | N120 | 10.19 | 7.22 | 10.19 | 6.92 | 9.11 | 5.43 |
| | Mean | 9.95 | 7.17 | 9.35 | 6.70 | 8.80 | 5.22 |
| Green gram incorporation | N0 | 10.12 | 7.31 | 9.00 | 6.38 | 8.44 | 5.09 |
| | N60 | 10.31 | 7.46 | 9.06 | 6.56 | 8.78 | 5.18 |
| | N120 | 10.55 | 7.73 | 10.14 | 7.00 | 9.02 | 5.34 |
| | Mean | 10.33 | 7.50 | 9.40 | 6.65 | 8.75 | 5.20 |
| LSD (0.05) | | | | | | | |
| Treatment (T) | | 0.44 | 0.27 | 0.47 | 0.41 | 0.51 | 0.32 |
| Nitrogen (N) | | 0.45 | 0.29 | 0.51 | NS | NS | NS |
| T × N | | 0.74 | 0.46 | NS | NS | NS | NS |

NS, non significant at $P > 0.05$.

was 122.2, 119.9 and 125.4, respectively, for 15–30 soil depths at 65 DAT of rice. But at harvesting stage of rice as well as wheat organic matter concentration was highest for *S. rostrata* followed by *S. aculeata,* GGI, and fallow. The thin stems of green gram might decompose very quickly and relatively hard stem of *S. rostrata* might hinder its quick decomposition. Warman (1980) also reported that the green manuring maintained an elevated soil organic matter level. However, organic matter concentration was considerably reduced in all treatments and in almost at all the soil depths at the time of the harvest of the wheat crop (Table 2) possibly due to the prevailing high temperature which resulted in an accelerated decomposition of soil organic matter.

Similar to organic matter, there was an increase in total nitrogen concentrations of soil in green manuring along with nitrogen treated plots (Table 3). Highest total soil nitrogen among the green manure plots was found in *S. rostrata* treated plots followed by *S. aculeata*, and GGI. Total nitrogen slightly decreased with the growth of subsequent wheat crops. Possible benefit of legumes to soil nitrogen may be due to nitrogen released from roots and nodules during their growth (Poth et al., 1986). *S. rostrata* treated plots had slightly higher total soil nitrogen concentration than green gram incorporated plots probably due to its profuse stem nodulation and higher biomass incorporation. Green manuring also increased the recovery of fertiliser nitrogen by reducing the nitrogen losses from urea possibly due to reduction in pH of flood water (Diekmann et al., 1993).

### 3.2. *Physical properties of soil*

#### 3.2.1. *Bulk density*

Bulk density of 0–15 cm soil layer was less than that of 15–30 cm soil layer. *Sesbania* and GGI

Table 3
Effect of green manuring and nitrogen treatments on total nitrogen concentration (g $kg^{-1}$) of soil under rice and wheat

| Treatments | Nitrogen level | At 65 DAT of rice | | At rice harvest | | At wheat harvest | |
|---|---|---|---|---|---|---|---|
| | | Soil depth (cm) | | | | | |
| | | (0–15) | (15–30) | (0–15) | (15–30) | (0–15) | (15–30) |
| Fallow | N0 | 0.59 | 0.41 | 0.56 | 0.36 | 0.53 | 0.35 |
| | N60 | 0.65 | 0.59 | 0.59 | 0.39 | 0.54 | 0.37 |
| | N120 | 0.75 | 0.64 | 0.63 | 0.41 | 0.59 | 0.39 |
| | Mean | 0.66 | 0.55 | 0.59 | 0.39 | 0.55 | 0.37 |
| *S. rostrata* | N0 | 0.68 | 0.49 | 0.62 | 0.41 | 0.60 | 0.39 |
| | N60 | 0.77 | 0.63 | 0.63 | 0.43 | 0.60 | 0.39 |
| | N120 | 0.83 | 0.71 | 0.67 | 0.46 | 0.61 | 0.42 |
| | Mean | 0.76 | 0.61 | 0.64 | 0.43 | 0.60 | 0.40 |
| *S. aculeata* | N0 | 0.66 | 0.48 | 0.62 | 0.41 | 0.60 | 0.37 |
| | N60 | 0.76 | 0.63 | 0.62 | 0.43 | 0.60 | 0.39 |
| | N120 | 0.82 | 0.69 | 0.67 | 0.44 | 0.61 | 0.42 |
| | Mean | 0.75 | 0.60 | 0.64 | 0.43 | 0.60 | 0.39 |
| Green gram incorporation | N0 | 0.67 | 0.48 | 0.61 | 0.40 | 0.60 | 0.37 |
| | N60 | 0.75 | 0.62 | 0.62 | 0.42 | 0.58 | 0.39 |
| | N120 | 0.81 | 0.69 | 0.66 | 0.44 | 0.59 | 0.41 |
| | Mean | 0.74 | 0.60 | 0.63 | 0.42 | 0.59 | 0.39 |
| LSD (0.05) | | | | | | | |
| Treatment (T) | | 0.039 | 0.017 | 0.031 | 0.026 | NS | NS |
| Nitrogen (N) | | 0.049 | 0.019 | 0.037 | 0.034 | NS | NS |
| T × N | | 0.067 | 0.042 | NS | NS | NS | NS |

NS, non significant at $P > 0.05$.

resulted in a reduction of soil bulk density in both 0–15 and 15–30 cm soil depths (Table 4). The extent of reduction in bulk density due to green manuring over fallow was 0.03–0.07 Mg $m^{-3}$ in 0–15 cm soil layer and 0.05–0.09 Mg $m^{-3}$ in 15–30 cm soil layer during the growth of rice and wheat. Incorporation of green manure increased total pore space, which in turn decreased bulk density of soil. Similar findings were reported by Yadvinder Singh et al. (1991), Boparai et al. (1992) and Joshi et al. (1994). The effect of green manuring on bulk density was also retained at the harvesting stage of wheat. The bulk density values increased with the passage of time at all soil depths irrespective of treatments. The increase in bulk density with the advancement of rice crop growth may be due to resettling of soil particles and over burden pressure of ponded water (De Datta and Kerim, 1974).

### 3.2.2. Soil aggregation

Incorporation of green plant materials improved the soil structure as was evident from higher values of MWD of aggregates in *Sesbania* and green gram residue incorporated plots (Table 5). There was significant difference (0.05 level) of MWD between each green manure plot and fallow, but within the three green manure treatments the values were not significant. The relative increase of MWD of aggregates in 0–15 cm soil layer by *Sesbania* green manuring and GGI over fallow was by 122–130 at 65 DAT and 137–147 at rice harvest. Whereas the relative increase in MWD as influenced by green manuring over fallow ranged between 132 and 137 at wheat harvest. For 15–30 cm soil depth, over all relative increase of MWD for green manuring over fallow varied between 110–118 throughout rice and wheat crop growth. The results of MWD in fallow plots clearly showed

Table 4
Effect of green manuring and nitrogen treatments on bulk density (Mg m$^{-3}$) of soil under rice and wheat

| Treatments | Nitrogen level | At 65 DAT of rice | | At rice harvest | | At wheat harvest | |
|---|---|---|---|---|---|---|---|
| | | Soil depth (cm) | | | | | |
| | | (0–15) | (15–30) | (0–15) | (15–30) | (0–15) | (15–30) |
| Fallow | N0 | 1.45 | 1.57 | 1.54 | 1.62 | 1.56 | 1.63 |
| | N60 | 1.45 | 1.56 | 1.51 | 1.60 | 1.55 | 1.60 |
| | N120 | 1.44 | 1.55 | 1.51 | 1.60 | 1.55 | 1.59 |
| | Mean | 1.45 | 1.56 | 152 | 1.61 | 1.55 | 1.61 |
| *S. rostrata* | N0 | 1.42 | 1.52 | 1.46 | 1.54 | 1.51 | 1.53 |
| | N60 | 1.41 | 1.50 | 1.45 | 1.53 | 1.51 | 1.51 |
| | N120 | 1.41 | 1.50 | 1.45 | 1.52 | 1.50 | 1.51 |
| | Mean | 1.41 | 1.51 | 1.45 | 1.53 | 1.51 | 1.52 |
| *S. aculeata* | N0 | 1.42 | 1.52 | 1.47 | 1.55 | 1.52 | 1.55 |
| | N60 | 1.41 | 1.51 | 1.46 | 1.53 | 1.51 | 1.54 |
| | N120 | 1.41 | 1.51 | 1.46 | 1.53 | 1.51 | 1.52 |
| | Mean | 1.41 | 1.51 | 1.46 | 1.54 | 1.51 | 1.54 |
| Green gram incorporation | N0 | 1.41 | 1.51 | 1.47 | 1.54 | 1.52 | 1.55 |
| | N60 | 1.41 | 1.50 | 1.45 | 1.53 | 1.52 | 1.54 |
| | N120 | 1.41 | 1.50 | 1.46 | 1.52 | 1.52 | 1.54 |
| | Mean | 1.41 | 1.50 | 1.46 | 1.53 | 1.52 | 1.54 |
| LSD (0.05) | | | | | | | |
| Treatment (T) | | NS | NS | 0.042 | 0.044 | 0.031 | NS |
| Nitrogen (N) | | NS | NS | NS | NS | NS | NS |
| T × N | | NS | NS | NS | NS | NS | NS |

NS, non significant at $P > 0.05$.

that puddling caused considerable disintegration of the aggregates. The increase in soil aggregates due to the incorporation of organic matter especially green manuring is supported by the fact that organic substances added to soil through green manuring are capable of binding the soil particles together (Biswas and Khosla, 1971; MacRae and Mehuys, 1985). The improvement of soil structure with nitrogen treatments as compared with no nitrogen might have resulted from increased root residues (Latif et al., 1992). The beneficial effect of green manuring on soil aggregation was sustained till the harvest of the subsequent wheat crop.

#### 3.2.3. Hydraulic conductivity

The changes in soil aggregation and bulk density under different green manuring and nitrogen treatments were well reflected in the hydraulic conductivity of soil of both 0–15 and 15–30 cm soil layer (Table 6). An increase in hydraulic conductivity by *Sesbania* green manuring and GGI was due to the reduction in bulk density and increase in organic carbon concentration of soil as reported by MacRae and Mehuys (1985), Boparai et al. (1992). Thus, the *Sesbania* green manure and GGI improved the soil physical condition conducive to better transmission properties.

### 3.3. Spectral reflectance

The temporal changes of NDVI during the growth period of rice (Fig. 1) and wheat (Fig. 2) showed that the values in general increased gradually with advance in age, attained a maximum and thereafter decreased during senescence. Bera (1994) also reported similar results in case of wheat and Khawas et al. (1993) for rice. A rapid

Table 5
Effect on green manuring and nitrogen treatments on MWD (mm) of soil aggregates during rice and wheat

| Treatments | Nitrogen level | At 65 DAT of rice | | At rice harvest | | At wheat harvest | |
|---|---|---|---|---|---|---|---|
| | | Soil depth (cm) | | | | | |
| | | (0–15) | (15–30) | (0–15) | (15–30) | (0–15) | (15–30) |
| Fallow | N0 | 0.579 | 0.499 | 0.483 | 0.483 | 0.517 | 0.488 |
| | N60 | 0.617 | 0.511 | 0.531 | 0.502 | 0.527 | 0.491 |
| | N120 | 0.643 | 0.532 | 0.543 | 0.531 | 0.549 | 0.529 |
| | Mean | 0.613 | 0.514 | 0.519 | 0.505 | 0.531 | 0.503 |
| *S. rostrata* | N0 | 0.745 | 0.561 | 0.732 | 0.559 | 0.718 | 0.564 |
| | N60 | 0.791 | 0.578 | 0.770 | 0.567 | 0.722 | 0.602 |
| | N120 | 0.822 | 0.611 | 0.781 | 0.586 | 0.743 | 0.618 |
| | Mean | 0.786 | 0.583 | 0.761 | 0.571 | 0.728 | 0.595 |
| *S. aculeata* | N0 | 0.723 | 0.551 | 0.681 | 0.548 | 0.669 | 0.550 |
| | N60 | 0.752 | 0.565 | 0.716 | 0.550 | 0.712 | 0.579 |
| | N120 | 0.783 | 0.603 | 0.742 | 0.571 | 0.717 | 0.607 |
| | Mean | 0.753 | 0.573 | 0.713 | 0.556 | 0.699 | 0.579 |
| Green gram incorporation | N0 | 0.766 | 0.574 | 0.676 | 0.551 | 0.660 | 0.559 |
| | N60 | 0.779 | 0.588 | 0.725 | 0.559 | 0.712 | 0.591 |
| | N120 | 0.841 | 0.633 | 0.741 | 0.567 | 0.729 | 0.611 |
| | Mean | 0.795 | 0.598 | 0.714 | 0.559 | 0.700 | 0.587 |
| LSD (0.05) | | | | | | | |
| Treatment (T) | | 0.082 | 0.052 | 0.101 | 0.048 | 0.111 | 0.044 |
| Nitrogen (N) | | NS | NS | NS | NS | NS | NS |
| T × N | | NS | NS | NS | NS | NS | NS |

NS, non significant at $P > 0.05$.

decrease in red reflectance was noticed as crop growth advanced due to increase in leaf area or canopy and chlorophyll concentration. There was an enhanced absorption of the incident flux at red (0.69 nm) along with green band (0.46 nm) which led to a decreased reflectance throughout the visible range. But in the infrared portion, spectral reflectance continued to increase and showed a maximum followed by a decrease as crop approached maturity (Tucker, 1979; Kimes et al., 1981). Spectral vegetation indices exhibited temporal variation throughout the crop growth stages. The NDVI attained the peak value at 62 DAT of rice and 90 DAS of wheat. Thereafter, the values decreased because of the crop senescence. Green manuring caused a better physical and chemical environment in the soil, which led to better crop growth. Thus, crop in the green manuring treatment exhibited higher NDVI values than under the fallow treatment.

### 3.4. Root growth and yield

Green manure and nitrogen application improved the soil physical and chemical properties which promoted root growth (Figs. 3 and 4) and increased yields (Table 7) both in rice and wheat. In green manuring treated plots, root mass per unit volume of soil increased which, resulted in a larger total root surface available for the uptake of nutrients. The favorable effect of these treatments on root growth and yield was likely due to the increase in organic matter leading to better physical and chemical conditions (Boparai et al., 1992). The reduced porosity due to puddling and unfavorable soil conditions was responsible for the

Table 6
Effect of green manuring and nitrogen treatments on saturated hydraulic conductivity (cm $day^{-1}$) of soil under rice and wheat

| Treatments | Nitrogen level | At 65 DAT of rice | | At rice harvest | | At wheat harvest | |
|---|---|---|---|---|---|---|---|
| | | Soil depth (cm) | | | | | |
| | | (0–15) | (15–30) | (0–15) | (15–30) | (0–15) | (15–30) |
| Fallow | N0 | 3.38 | 3.16 | 3.45 | 3.23 | 3.65 | 3.51 |
| | N60 | 3.44 | 3.27 | 3.61 | 3.29 | 3.71 | 3.66 |
| | N120 | 3.56 | 3.31 | 3.89 | 3.36 | 3.86 | 3.69 |
| | Mean | 3.46 | 3.25 | 3.65 | 3.29 | 3.74 | 3.62 |
| *S. rostrata* | N0 | 4.21 | 4.01 | 4.60 | 4.27 | 4.31 | 4.26 |
| | N60 | 4.39 | 4.19 | 4.65 | 4.39 | 4.38 | 4.31 |
| | N120 | 4.46 | 4.21 | 4.68 | 4.46 | 4.47 | 4.36 |
| | Mean | 4.35 | 4.14 | 4.64 | 4.37 | 4.39 | 4.31 |
| *S. aculeata* | N0 | 4.28 | 4.10 | 4.48 | 4.12 | 4.22 | 4.19 |
| | N60 | 4.33 | 4.21 | 4.57 | 4.21 | 4.28 | 4.23 |
| | N120 | 4.48 | 4.33 | 4.60 | 4.33 | 4.33 | 4.28 |
| | Mean | 4.36 | 4.21 | 4.55 | 4.22 | 4.28 | 4.23 |
| Green gram incorporation | N0 | 4.32 | 4.10 | 4.52 | 3.99 | 4.08 | 4.01 |
| | N60 | 4.41 | 4.31 | 4.55 | 4.09 | 4.21 | 4.11 |
| | N120 | 4.51 | 4.37 | 4.61 | 4.11 | 4.24 | 4.12 |
| | Mean | 4.41 | 4.26 | 4.56 | 4.06 | 4.18 | 4.08 |
| LSD (0.05) | | | | | | | |
| Treatment (T) | | 0.636 | 0.666 | 0.700 | 0.747 | 0.421 | NS |
| Nitrogen (N) | | NS | NS | NS | NS | NS | NS |
| T × N | | NS | NS | NS | NS | NS | NS |

NS, non significant at $P > 0.05$.

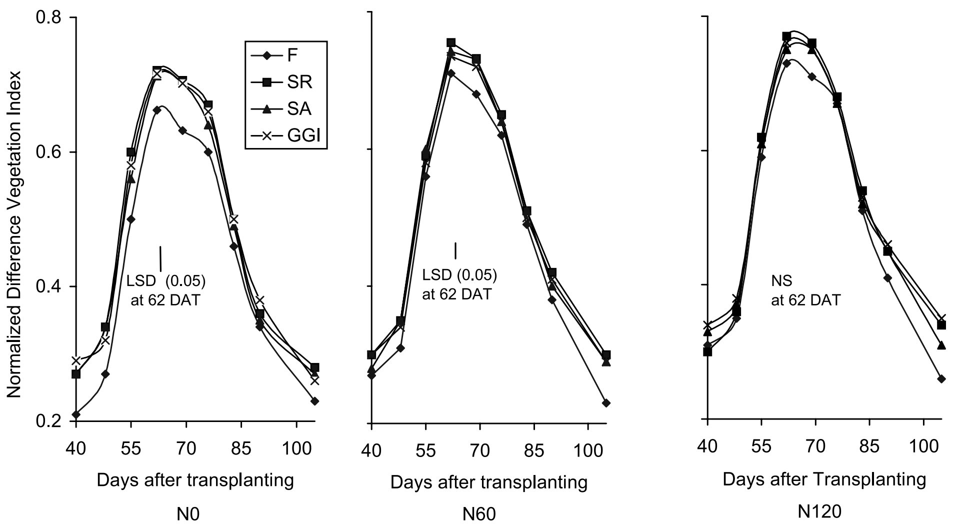


Fig. 1. Temporal variation of NDVI of rice under different green manuring and nitrogen treatments.

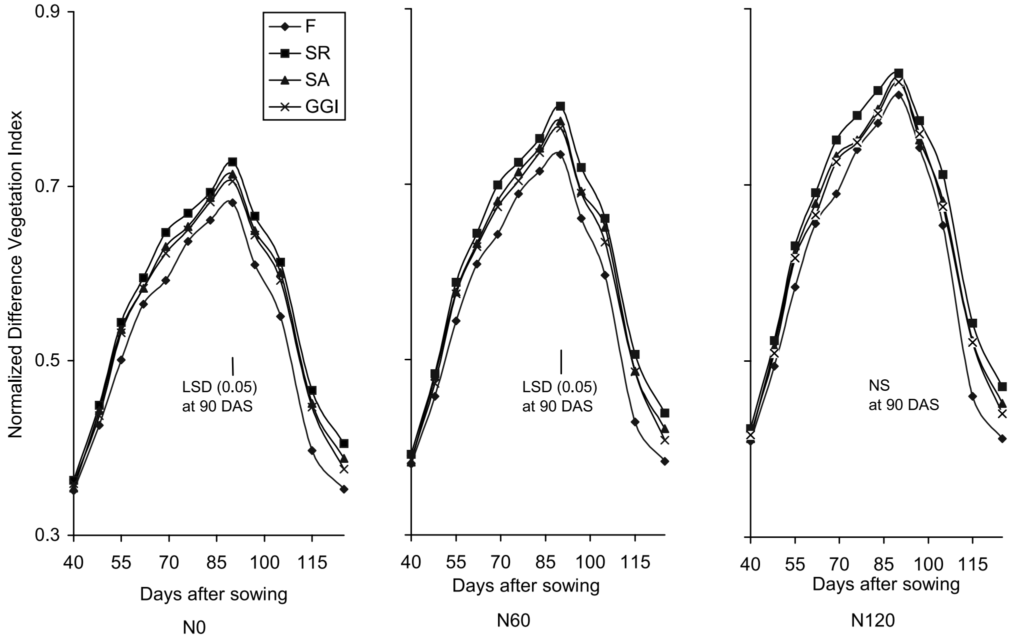


Fig. 2. Temporal variation of NDVI of wheat under different green manuring and nitrogen treatments.

restricted root growth and yield in the fallow treatment. In all the cases, both in rice and wheat 120 kg N ha$^{-1}$ resulted in higher RLD than 60 kg N ha$^{-1}$ and no nitrogen. In case of rice, more than 87% of roots were confined in 0–15 cm soil depth in all the treatments. In case of wheat, in summer fallow plots, about 72% of root density was confined in 0–15 cm soil layer, 15% in 15–30 cm soil layer, 8% in 30–45 cm soil layer and 5% in 45–60 cm soil layer whereas, in *Sesbania* and

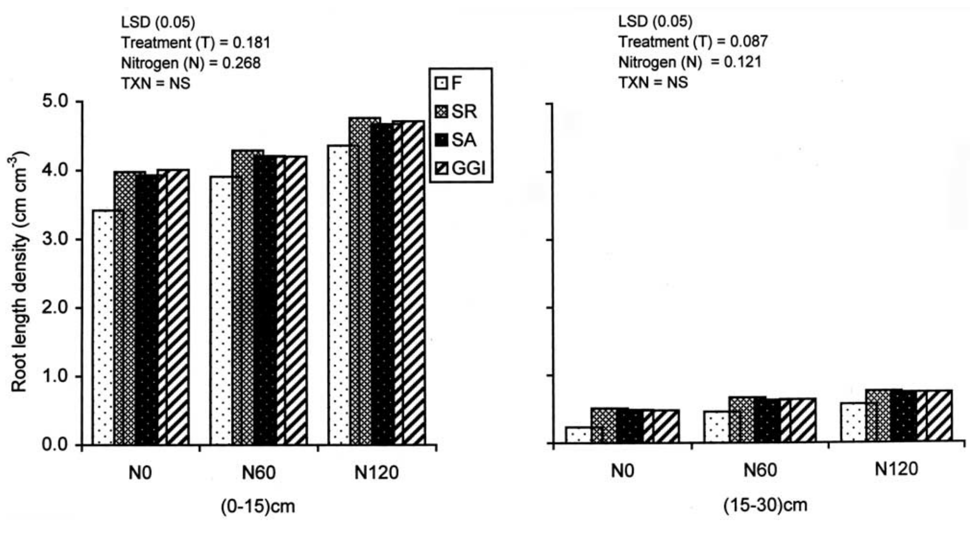


Fig. 3. Root length density of rice (65 DAT) at different soil depths under different green manuring and nitrogen treatments.

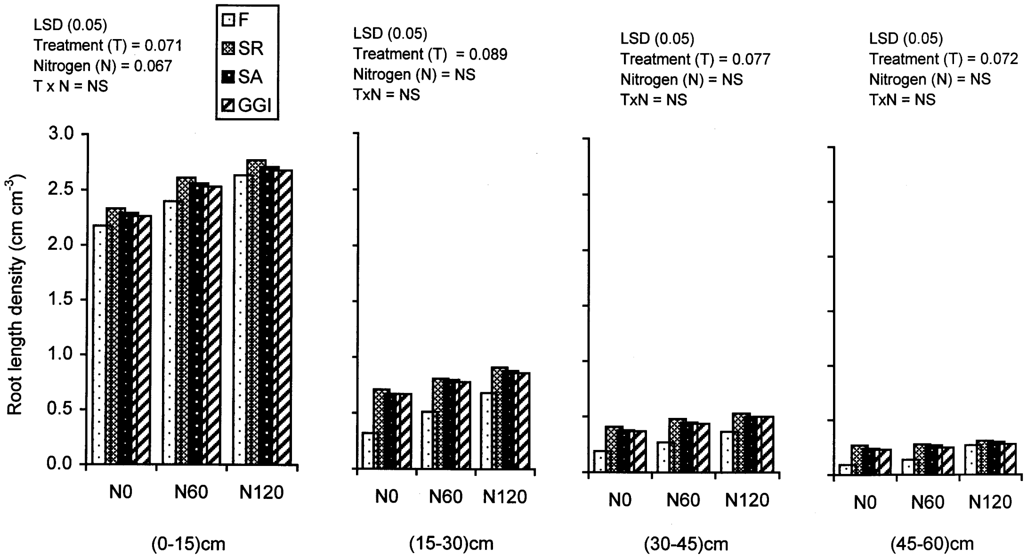


Fig. 4. Root length density of wheat (90 DAS) at different soil depths under different green manuring and nitrogen treatments.

green gram residue incorporated plots, the distribution was 62–63, 20, 11 and 6–7% in 0–15, 15–30, 30–45, and 45–60 cm soil layers, respectively. The favorable effect of green manuring and nitrogen on root growth was likely due to increased organic matter leading to better physical and chemical soil conditions (Boparai et al., 1992). Poor soil physical conditions were mainly responsible for the restricted root growth and rooting depth in summer fallow plots (Oussible et al., 1992).

## 4. Conclusions

It was shown that the addition of green manure in the form of *Sesbania* and green gram resulted in an improved organic matter status, which led to a

Table 7
Effect of green manuring and nitrogen treatments on grain yield (Mg ha$^{-1}$) of rice and wheat

| Treatment | Rice | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen level | | | | Nitrogen level | | | |
| | N0 | N60 | N120 | Mean | N0 | N60 | N120 | Mean |
| Fallow | 3.15 | 4.61 | 5.19 | 4.32 | 2.75 | 3.89 | 4.07 | 3.57 |
| *S. rostrata* | 4.25 | 5.51 | 5.78 | 5.18 | 3.86 | 4.41 | 4.51 | 4.26 |
| *S. aculeata* | 4.19 | 5.49 | 5.73 | 5.14 | 3.74 | 4.36 | 4.49 | 4.20 |
| Green gram incorporation | 4.17 | 5.47 | 5.72 | 5.12 | 3.68 | 4.34 | 4.48 | 4.17 |
| Mean | 3.94 | 5.27 | 5.61 | | 3.51 | 4.25 | 4.39 | |
| | | | LSD (0.05) | | | | LSD (0.05) | |
| Treatment (T) | | | 0.495 | | | | 0.287 | |
| Nitrogen (N) | | | 0.632 | | | | 0.41 | |
| T × N | | | 1.109 | | | | NS | |

NS, non significant at $P < 0.05$.

better soil aggregation, reduced bulk density and improved water flow characteristics which ultimately increased the crop growth of rice. *S. rostrata* treated plots produced slightly better soil conditions than *S. aculeata* and green gram residue. Apart from beneficial effects on rice, adoption of green manuring practice on rice–wheat rotation will result in better soil properties improving growth and yield of the following wheat crop.

## References

Bar, A.R., Baggie, I., Sanginga, N., 2000. The use of sesbania (*Sesbania rostrata*) and urea in lowland rice production in Sierra Leone. Agroforestry system 48 (2), 111–118.

Bera, A.K., 1994. Effect of tillage and rice straw on soil physical properties and energy requirement of wheat crop. M.Sc. Thesis. Division of Agricultural Physics, IARI, New Delhi, India.

Biswas, T.D., Khosla, B.K., 1971. Building up of organic matter status of the soil and its relation to soil physical properties. Int. Symp. Soil Fert. Evaluation Proc. 1, 831–843.

Biswas, T.D., Mukherjee, S.K., 1994. Carbon and nitrogen in soil organic matter. In: Text Book of Soil Science, second ed.. Tata McGraw-Hill Publishing Company Limited, New Delhi, p. 95.

Blake, G.R., 1965. Bulk density. In: Black, C.A. (Ed.), Methods of Soil Analysis, Part 1, Agronomy 9. American Society of Agronomy Inc, Madison, Wisconsin, USA, pp. 374–377.

Boparai, B.S., Yadvinder Singh, Sharma, B.D., 1992. Effect of green manure (*Sesbania aculeata*) on physical properties of soil and growth of rice–wheat and maize-wheat cropping system. Int. Agrophys. 6, 95–101.

Buresh, R.J., De Datta, S.K., 1991. Nitrogen dynamics and management in rice-legume cropping system. Adv. Agron. 45.

Das, D.K., Mishra, K.K., Kalra, N., 1993. Assessing growth and yield of wheat using remotely-sensed canopy temperature and spectral indices. Int. J. Remote Sens. 94, 3081–3092.

De Datta, S.K., Kerim, M.S.A.A.A., 1974. Water and nitrogen economy of rainfed rice as affected by soil puddling. Soil Sci. Soc. Am. Proc. 38, 515–518.

Deering, D.W., Rouse Jr., J.W., Hass, R.H., Schell, H.H., 1975. Measuring 'forage production' of grazing units from Landsat MSS Data. Proceedings Tenth International Symposium Remote Sensing Envionment. ERIM, Ann Arbor, Michigan, pp. 1169–1198.

Dey, P., Jain, J.M., 2000. Evaluation of urea enriched green manures for their efficiency to sustain productivity of rice–wheat system. J. Indian Soc. Soil Sci. 48, 102–107.

Diekmann, K.H., De Datta, S.K., Ottow, J.C.G., 1993. Nitrogen uptake and recovery from urea and green manure in lowland rice measured by $^{15}N$ and non-isotope techniques. Plant Soil 148, 91–99.

Hobbs, P.R., Hettel, G.P., Singh, Y., Harrington, L., Fujisaka, S., 1990. Diagnostic survey of farmers' practices and problems and needs for future research: rice–wheat cropping system in tarai areas of Nainital, Rampur and Pilibhit districts in Uttar Pradesh. Indian Council of Agricultural Research, New Delhi, pp. 35–38.

Jackson, M.L., 1967. Organic matter determinations for soils. In: Soil Chemical Analysis. Prentice-Hall of India Private Limited, New Delhi, pp. 205–225.

Jackson, M.L., 1967. Nitrogen determinations for soils and plant tissue. In: Soil Chemical Analysis. Prentice–Hall of India Private Limited, New Delhi, pp. 183–192.

Joshi, R.C., Haokip, D.D., Singh, K.N., 1994. Effect of green manuring on the physical properties of soil under the rice–wheat cropping system. J. Agric. Sci. 122, 107–113.

Khawas, B., Bhattacharjee, I., Sutradhar, A.K., 1993. Response of rice crop to biofertilisers by canopy reflectance. Ann. Agric. Res. 14, 500–502.

Kimes, D.S., Markham, B.L., Tucker, C.J., 1981. Temporal relationships between spectral response and agronomic variables of a corn canopy. Remote Sens. Environ. 11, 401–411.

Klute, A., 1965. Laboratory measurement of hydraulic conductivity of saturated soil. In: Black, C.A. (Ed.), Method of Soil Analysis, Part 1, Agronomy 9. American society of Agronomy Inc, Madison, Wisconsin, USA, pp. 210–211.

Ladha, J.K., Pareek, R.P., Becker, M., 1992. Stem-nodulating legume-*Rhizobium* symbiosis and its agronomic use in lowland rice. Adv. Soil. Sci. 20.

Lal, R., 1985. Tillage in lowland rice based cropping systems. In: Soil Physics and Rice. International Rice Research Institute, Los Banos, Philippines, pp. 283–307.

Latif, M.A., Mehuys, G.R., Mackenzie, A.F., Alli, I., Faris, M.A., 1992. Effects of legumes on soil physical quality in a maize crops. Plant Soil 140, 15–23.

Ma, B.L., Morrison, M.J., Dwyer, M.L., 1996. Canopy light reflectance and field greenness to assess nitrogen fertilization and yield of maize. Agron. J. 88, 915–920.

MacRae, R.J., Mehuys, G.R., 1985. The effect of green manuring on the physical properties of temperate area soils. Adv. Soil Sci. 3.

Newman, J., 1966. A method of estimating the total length of root in a sample. J. Appl. Ecol. 3, 139–145.

Oussible, M., Crookston, R.K., Larson, W.E., 1992. Subsurface compaction reduces the root and shoot growth and grain yield of wheat. Agron. J. 84, 34–38.

Painuli, D.K., Woodhead, T., Pagliai, M., 1988. Effective use of energy and water in rice-soil puddling. Soil Tillage Res. 12, 149–161.

Poth, M., La Favre, J.S., Focht, D.D., 1986. Quantifications by direct $^{15}N$ dilution of fixed $N_2$ incorporation into soil by *Cajanus cajan* (Pigeon pea). Soil Biol. Biochem. 18, 125–127.

Ray, S.S., Gupta, R.P., 2001. Effect of green manuring and tillage practices on physical properties of puddled loam soil under rice–wheat cropping system. J. Indian Soc. Soil Sci. 49 (4), 670–678.

Sehgal, J.L., Mandal, D.K., Mandal, C., Vadivelu, S. (Eds.), 1992. Agroecological Zones of India. Oxford and IBH Pub. Co. Pvt. Ltd, New Delhi, p. 130.

Tennant, D., 1975. A test of modified line intersect method of estimating root length. J. Ecol. 63, 995–1001.

Tirlok Singh, Nagarajarao, Y., Sadaphal, M.N., 1980. Effect of legumes on physical properties of soil in mixed cropping with maize. Indian J. Agron. 25 (4), 592–599.

Tucker, C.J., 1979. Red photographic infrared linear combinations for monitoring vegetation. Remote Sens. Environ. 8, 127–150.

van Bavel, C.H.M., 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Sci. Soc. Am. Proc. 14, 20–23.

Warman, P.R., 1980. The basics of green manuring. Macdonald J. 41, 3–6.

Whitbread, A.M., Blair, G.J., Lefroy, R.D.B., 2000. Managing legume leys, residues and fertilisers to enhance the sustainability of wheat cropping systems in Australia 1. The effects on wheat yields and nutrient balances. Soil Tillage Res. 54 (1/2), 63–75.

Yadvinder Singh, Khind, C.S., Bijay Singh, 1991. Efficient management of leguminous green manures in wetland rice. Adv. Agron. 45.

Yoder, R.E., 1936. A direct method of aggregate analysis and study of the physical nature of erosion losses. J. Am. Soc. Agron. 28, 337–351.