Maximizing yields in rice–groundnut cropping sequence through integrated nutrient management

P.V.V. Prasad\textsuperscript{a,}\textsuperscript{*}, V. Satyanarayana\textsuperscript{b}, V.R.K. Murthy\textsuperscript{b}, K.J. Boote\textsuperscript{a}

\textsuperscript{a}Agronomy Department, University of Florida, 304 Newell Hall, P.O. Box 110500, Gainesville, FL 32611-0500, USA
\textsuperscript{b}Department of Agronomy, College of Agriculture, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad 500030, India

Received 10 December 2001; accepted 12 December 2001

Abstract

Integrated use of organic and inorganic fertilizers can improve crop productivity and sustain soil health and fertility. The present research was conducted to study the effects of application of green manures [sesbania (\textit{Sesbania aculeata} Poiret) and crotalaria (\textit{Crotalaria juncea} L.)] and farmyard manure on productivity of rice (\textit{Oryza sativa} L.) and its residual effects on subsequent groundnut (\textit{Arachis hypogaea} L.) crop. Rice and groundnut crops were grown in sequence during rainy and post-rainy seasons with and without green manure in combination with different fertilizer and spacing treatments under irrigated conditions. The results showed that application of green manures sesbania and crotalaria at 10 t ha\textsuperscript{-1} to rice compared to no green manure application significantly increased grain yield of rice by 1.6 and 1.1 t ha\textsuperscript{-1}, and pod yields of groundnut crop succeeding rice by 0.25 and 0.16 t ha\textsuperscript{-1}, respectively. There was no significant difference between the application of crotalaria or farmyard manure at 10 t ha\textsuperscript{-1} on grain yields of rice, but pod yields of subsequent groundnut crop were greater with application of green manure. There was no significant effect of different spacing 20 × 15, 15 × 15, 15 × 10 cm\textsuperscript{2} (333 000; 444 000; 666 000 plant ha\textsuperscript{-1}, respectively) on grain yield of rice. Pod yields of groundnut were significantly greater with closer spacing 15 × 15 cm\textsuperscript{2} (444 000 plants ha\textsuperscript{-1}) as compared to spacing of 30 × 10 cm\textsuperscript{2} (333 000 plants ha\textsuperscript{-1}). Maximum grain of rice was obtained by application of 120:26:37 kg NPK ha\textsuperscript{-1} in combination with green manures, whereas maximum pod yield of groundnut was obtained by residual effect of green manure applied to rice and application of 30:26:33 kg NPK ha\textsuperscript{-1} in combination with gypsum applied to groundnut crop. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Rice; Groundnut; Green manure; Fertilizer; Integrated nutrient management

1. Introduction

Organic materials particularly farmyard manure and green manures have traditionally been used on rice (Pieters, 1927). However, after the industrial revolution widespread introduction of inorganic fertilizers led to a decline in the use of organic material in the cropping systems (Rosegrant and Roumasset, 1988). The impact of increased fertilizer use on crop production has been large and important (Hossain and Singh, 2000). It has been estimated that fertilizer use growth contributed to about 25% of the total increase in rice production in Asia between 1965 and 1980 (Barker et al., 1985). However, in recent years there has been serious concern about long-term adverse effect of continuous and indiscriminate use of inorganic fertilizers on deterioration of soil structure, soil
health and environmental pollution (Ghosh and Bhat, 1998; Shukla et al., 1998; Singh, 2000). The fact that use of green manures and other organic matter can improve soil structure, improve nutrient exchange and maintain soil health has again raised interest in organic farming (Ayoub, 1999; Becker et al., 1995). Use of organic manures alone, as a substitute to chemical inorganic fertilizer is not profitable and will not be enough to maintain the present levels of crop productivity of high yielding varieties (Garrity and Flinn, 1988). Therefore, integrated nutrient management in which both organic manures and inorganic fertilizers are used simultaneously is probably the most effective method to maintain healthy sustainable soil system while increasing crop productivity (Janssen, 1993).

Rice and rice based cropping systems are of prime importance in global food production especially in South East Asia (Huke and Huke, 1997). There has been a decline in productivity of paddy rice in India; this decline has been attributed to continuous mono cropping of rice and excessive dependence on chemical fertilizers that has lead to decrease in soil N and degradation of soil. This problem can be partly solved by changing from continuous rice production systems to growing rice–legume cropping systems. Legumes such as groundnut, mung bean (Vigna radiata (L.) Wilczek), soybean (Glycine max L.) and cowpea (Vigna unguiculata (L.) Walp) are well suited for rice based cropping systems in peninsular India (Gowda et al., 2001). Groundnut because of its high oil and protein contents is becoming a major crop grown in the post-rainy or summer season crop in rice-fallow in Andhra Pradesh, India (Pratibha et al., 1997) particularly in coarse textured soils and in regions where irrigation water is limited to grow only one crop of rice. The present research was therefore conducted to evaluate impact of integrated nutrient management in a rice–groundnut cropping sequence. Our objectives were to study the effects of application of green manure and/or farmyard manure in combination with inorganic fertilizers on productivity of rice and its residual effect of subsequent groundnut crop.

2. Materials and methods

This research was conducted between June 1991 and May 1994 at College Farm, Acharya N.G. Ranga Agricultural University (formerly Andhra Pradesh Agricultural University), Rajendranagar, Hyderabad, India (17°10’N, 78°28’E and 543 m above mean sea level). The soil at the experimental site was sandy loam with pH 7.6, low organic carbon 0.4%, 232 kg available N, 18.2 kg available P and 167 kg K ha\(^{-1}\). The irrigation water was of good quality devoid of any salinity with a pH 7.2. The weather data of all 4 years and the growing seasons are presented in Fig. 1.

2.1. Experimental details

In the first year (1991–1992) rice (cv. Satya) was grown during the rainy season (June–October). The treatments consisted of three spacings (20 × 15; 15 × 15; 15 × 10 cm\(^2\)), with population densities of 333 000, 444 000 and 666 000 plant ha\(^{-1}\), respectively and three fertilizer doses (80:18:25, 120:26:37, and 160:35:50 kg NPK ha\(^{-1}\), respectively) as subplots and with and without green manure sesbania as main plots in a split-plot design replicated three times. After the harvest of rice, groundnut (cv. TMV-2) was planted in the post-rainy season (November–March) in the same plots in a split–split-plot design with three replicates. The treatments consisted of two main plots with and without green manure applied to rice crop. The subplots consisted of two spacings (30 × 10 and 15 × 15 cm\(^2\)), with population densities of 333 000 and 444 000 plant ha\(^{-1}\), respectively) and sub–sub plots consisted of nine fertilizer treatments (30:18:33, 30:26:33, 30:35:33, and 30:35:50 kg NPK ha\(^{-1}\), respectively, with and without gypsum plus and an additional treatment of 30:35:66 kg NPK ha\(^{-1}\)). Gypsum (calcium sulfate; CaSO\(_4\),2H\(_2\)O) was used as a source of calcium and sulfur.

All treatments during the second year (1992–1993) were similar to the first year except that crotalaria was used as a source of green manure. During the third year (1993–1994) rice (cv. Tellahamsa) was grown during the post-rainy season (October–February), and treatments consisted of two spacings (20 × 15 and 15 × 10 cm\(^2\)) and three fertilizer doses (80:18:35, 120:26:37, and 160:35:50 kg NPK ha\(^{-1}\), respectively) as subplots and with crotalaria and farmyard manure as main plots in a split-plot design replicated three times. After the harvest of rice, groundnut (cv. TMV-2) was planted in summer season (March–May) in the
same plots in a split–split-plot design with three replicates. The treatments consisted of two main plots with green manure and farmyard manure applied to rice crop. The subplots consisted of two spacing (30 × 10 and 15 × 15 cm²) and sub–sub plots consisted of six fertilizer treatments (30:26:33, 30:35:33, and 30:35:50 kg NPK ha⁻¹, respectively, with and without gypsum).

2.2. Plant husbandry

Crop management practices for rice and groundnut crops were similar during all the years except for the treatment differences discussed above. The green manure crops sesbania (1991–1992) and crotalaria (1992–1993 and 1993–1994) were grown in the adjacent field and harvested 45–50 days after sowing. The fresh foliage was chopped, weighted and incorporated at 10 t ha⁻¹ into rice field 1 day before transplantation in selected plots as per the treatments. Similarly, farmyard manure (1993–1994) collected from a nearby farm was incorporated into rice field 1 day before transplanting at 10 t ha⁻¹. All the inorganic phosphorus and potassium and one-third of the inorganic N were applied as a basal dose during transplantation. The remaining two-thirds of inorganic N was applied in two equal splits at maximum tillering and panicle initiation stages.

Field preparation was done by discing followed by flooding with water and puddling 3–4 times. Thereafter individual plots of equal size (25 m²) were prepared and separated by bunds. Organic manure and inorganic fertilizers were uniformly applied and incorporated at 15 cm to each plot as per treatment. The plots were leveled using a wooden plank. One day after the application of organic manure rice seedlings
(24 days old in rainy season and 47 days old in post-rainy season) were transplanted at different spacing as per the treatments and plots were saturated with water. The water level in the field was always maintained at 15 cm until 30 days after transplanting. The field was then drained of all water for 2 days (mid season drainage) at late tillering stage, thereafter the water level was maintained at 10–15 cm until a week before final harvest, when the field was allowed to dry for easy harvesting.

After harvesting rice individual plots were ploughed and harrowed separately for planting groundnut. All N, P and K fertilizer for the groundnut crop was applied as a basal dose by evenly broadcasting throughout the plot as per the treatments. Post-rainy season and summer season groundnut crops received 4–6 irrigations. Gypsum (14% S and 17.6% Ca) was applied in designated plots at the time of pod initiation. Urea (46% N), single super phosphate (16% P and 12% S) and muriate of potash (58% K) were used as sources of inorganic nutrients for both rice and groundnut crops.

There was no serious incidence of pests and diseases or nutrient deficiencies. Crops were kept healthy by prophylactic sprays of recommended insecticides and/or fungicides as necessary. Fields were kept weed free by hand weeding at 20–25 days intervals.

2.3. Data collection and analysis

At maturity all the plants from net plot area (20 m² for rice and 10 m² for groundnut) were harvested at physiological maturity and data on grain and straw yield for rice and pod and haulm yield for groundnut crop were measured. The data were expressed in t ha⁻¹ for both rice and groundnut. Sub-samples of plants were selected randomly and harvested to measure the data on number of tillers per hill, number of filled spikelets, threshing percentage, and 1000-grain weight for rice and data on shelling percentage and 100-seed weight for groundnut. Seed samples of groundnut were collected and analyzed for oil content (Jambunathan et al., 1985).

Sub-samples of green manure plants collected at harvest (45–50 days) were oven dried, finely ground and analyzed for N, P and K content. Plant samples were analyzed for N by micro-Kjeldahl method, total P by vanadomolybdophosphoric yellow color method using spectrophotometer method and K by mix acid (perchloric acid and nitric acid) digestion and flame photometry as described by Jackson (1973). Similarly, sub-samples of farmyard manure were also collected and analyzed for N, P and K contents.

All data were statistically analyzed by standard analysis of variance technique for a split-plot design for rice and split–split-plot design for groundnut as suggested by Gomez and Gomez (1984). Wherever treatment differences were found significant based on results of F-test, least significant differences were calculated at 5% level of probability.

3. Results

The details of the nutrient concentrations and supply from various organic sources are presented in Table 1. The nutrient composition of sesbania applied during 1991–1992 was 2.89% N, 0.37% P and 1.27% K on dry weight basis. Whereas, for crotalaria it was 2.58% N, 0.32% P and 1.25% K during 1992–1993, and 2.72% N, 0.34% P and 1.20% K during 1993–1994. The composition of farmyard manure applied during 1992–1993 was 1.42% N, 0.52% P and 0.50% K. The nutrient supply from sesbania was

<table>
<thead>
<tr>
<th>Organic material</th>
<th>Application rate (t ha⁻¹)</th>
<th>Nutrient concentration (%)</th>
<th>Nutrient supply (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
<td>Dry</td>
<td>N</td>
</tr>
<tr>
<td>Sesbania (1991)</td>
<td>10</td>
<td>2.7</td>
<td>2.89</td>
</tr>
<tr>
<td>Crotalaria (1992)</td>
<td>10</td>
<td>2.8</td>
<td>2.58</td>
</tr>
<tr>
<td>Crotalaria (1993)</td>
<td>10</td>
<td>2.6</td>
<td>2.72</td>
</tr>
<tr>
<td>Farmyard manure (1993)</td>
<td>10</td>
<td>5.3</td>
<td>1.42</td>
</tr>
</tbody>
</table>
Table 2

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (t ha⁻¹)</th>
<th>Straw yield (t ha⁻¹)</th>
<th>Tiller number/hill</th>
<th>Filled spikelets/panicle</th>
<th>1000-Grain weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No green manure</td>
<td>3.7</td>
<td>5.7</td>
<td>13</td>
<td>74</td>
<td>25.3</td>
</tr>
<tr>
<td>Sesbania manure</td>
<td>5.3</td>
<td>7.5</td>
<td>15</td>
<td>81</td>
<td>26.8</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2</td>
<td>3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No green manure</td>
<td>4.6</td>
<td>6.6</td>
<td>13</td>
<td>77</td>
<td>25.5</td>
</tr>
<tr>
<td>Crotalaria manure</td>
<td>5.1</td>
<td>7.6</td>
<td>14</td>
<td>83</td>
<td>26.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crotalaria manure</td>
<td>6.1</td>
<td>9.0</td>
<td>21</td>
<td>84</td>
<td>26.8</td>
</tr>
<tr>
<td>Farmyard manure</td>
<td>5.8</td>
<td>8.2</td>
<td>20</td>
<td>78</td>
<td>27.2</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>0.7</td>
<td>NS</td>
<td>3.7</td>
<td>NS</td>
</tr>
</tbody>
</table>

78:10:34 kg NPK ha⁻¹, respectively, whereas, from crotalaria it was estimated as 72:9:35 kg NPK ha⁻¹ (1992) and 71:9:31 kg NPK ha⁻¹ (1993), respectively. The corresponding supply from farmyard manure was 75:28:27 kg NPK ha⁻¹, respectively.

3.1. Rice

Application of green manure significantly improved all the traits measured (Table 2). Grain yields of rice were significantly increased by 1.6 and 1.1 t ha⁻¹, through application of sesbania and crotalaria, respectively, over no green manure control. Green manuring also resulted in a significant increase in straw yield, number of tillers, filled spikelets and 1000-grain weight. There were no significant differences in grain yield, tiller numbers and 1000-grain weight with application of green manure crotalaria or farmyard manure (Table 2). However, application of green manure significantly increased number of filled spikelets and straw yields when compared to application of farmyard manure.

There was no significant effect of different spacing on grain or straw yield of rice (Table 3). However, wider spacing of 20 × 15 cm² (333 000 plants ha⁻¹) resulted in significantly higher tiller number, filled spikelets and 1000-grain weight than a closer spacing of 15 × 10 cm² (666 000 plants ha⁻¹).

Different fertilizer levels significantly influenced grain and straw yield, tiller numbers, filled spikelets and 1000-grain weight of rice (Table 4). Application of 120:26:37 kg NPK ha⁻¹ gave significantly greater grain yield (4.8 t ha⁻¹) over the lower fertilizer dose of 80:18:25 kg NPK ha⁻¹ (4.0 t ha⁻¹) or higher fertilizer dose of 160:35:50 kg NPK ha⁻¹ (4.6 t ha⁻¹) during 1991–1992. Similar effects were also observed during 1992–1993 and 1993–1994, where application of 120:26:37 kg NPK ha⁻¹ gave significantly greater yields and yield attributes than other fertilizer treatments (Table 4).

There was significant interaction between green manure and fertility levels for grain yield and straw yield during 1991–1992 (Fig. 2a) and for grain yield and 1000-grain weight during 1992–1993 (Fig. 2b). In all cases, the response of green manures was greater at lower fertility levels when compared to highest level (160:35:50 kg NPK ha⁻¹) and maximum yields were observed at a fertility level of 120:26:37 kg NPK ha⁻¹ (Fig. 2). There were no interactions between the organic manures and fertility levels during 1993–1994.

3.2. Groundnut

Application of green manures to previous rice crop significantly increased pod yield of groundnut by 0.25 and 0.16 t ha⁻¹, during 1991–1992 and 1992–1993, respectively, over no green manure controls (Table 5). Similar significant increases on haulm yield, shelling percentage and oil content were also observed. Comparison of green manure and farmyard manure
Table 3
Effects of different spacing on yield and yield attributes of rice grown during different seasons (data are the mean of green manure and fertilizer treatments)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (t ha⁻¹)</th>
<th>Straw yield (t ha⁻¹)</th>
<th>Tiller number/hill</th>
<th>Filled spikelets/panicle</th>
<th>1000-Grain weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 × 15 cm²</td>
<td>4.5</td>
<td>7.0</td>
<td>14</td>
<td>79</td>
<td>26.3</td>
</tr>
<tr>
<td>15 × 15 cm²</td>
<td>4.5</td>
<td>6.9</td>
<td>14</td>
<td>77</td>
<td>26.1</td>
</tr>
<tr>
<td>15 × 10 cm²</td>
<td>4.4</td>
<td>6.6</td>
<td>13</td>
<td>75</td>
<td>25.6</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>0.7</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 × 15 cm²</td>
<td>4.5</td>
<td>6.5</td>
<td>14</td>
<td>82</td>
<td>27.1</td>
</tr>
<tr>
<td>15 × 15 cm²</td>
<td>4.7</td>
<td>6.9</td>
<td>14</td>
<td>79</td>
<td>24.0</td>
</tr>
<tr>
<td>15 × 10 cm²</td>
<td>4.6</td>
<td>6.9</td>
<td>12</td>
<td>76</td>
<td>24.6</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>0.4</td>
<td>1.6</td>
<td>0.27</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 × 15 cm²</td>
<td>5.6</td>
<td>7.9</td>
<td>15</td>
<td>83</td>
<td>26.4</td>
</tr>
<tr>
<td>15 × 10 cm²</td>
<td>5.9</td>
<td>8.3</td>
<td>12</td>
<td>79</td>
<td>25.1</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>2.3</td>
<td>2.6</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Applied to rice during 1993–1994 showed a significant increase in pod yields, haulm yields, shelling percentage, 100-seed weight and oil content in the range of 2 and 6% with application of green manure over application of farmyard manure (Table 5).

Among the two spacing tested pod yield, haulm yield, shelling percent, 100-seed weight and oil content were significantly greater with closer spacing of 15 × 15 cm² (444 000 plants ha⁻¹) compared to a wider spacing of 30 × 10 cm² (333 000 plants ha⁻¹) during 1991–1992 and 1992–1993 (Table 6). However, during 1993–1994 there were no significant differences between the two populations densities on 100-seed weight and oil content.

Table 4
Effects of different fertilizer doses on yield and yield attributes of rice during different seasons (data are the mean of green manure and spacing treatments)

<table>
<thead>
<tr>
<th>Fertilizer dose (kg NPK ha⁻¹)</th>
<th>Grain yield (t ha⁻¹)</th>
<th>Straw yield (t ha⁻¹)</th>
<th>Tiller number/hill</th>
<th>Filled spikelets/panicle</th>
<th>1000-Grain weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80:18:25</td>
<td>4.0</td>
<td>6.6</td>
<td>13</td>
<td>74</td>
<td>25.0</td>
</tr>
<tr>
<td>120:26:37</td>
<td>4.7</td>
<td>7.3</td>
<td>14</td>
<td>78</td>
<td>26.6</td>
</tr>
<tr>
<td>160:35:33</td>
<td>4.6</td>
<td>7.1</td>
<td>14</td>
<td>81</td>
<td>26.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>2.4</td>
<td>0.69</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80:18:25</td>
<td>4.3</td>
<td>6.8</td>
<td>13</td>
<td>74</td>
<td>25.1</td>
</tr>
<tr>
<td>120:26:37</td>
<td>4.9</td>
<td>7.5</td>
<td>14</td>
<td>80</td>
<td>26.7</td>
</tr>
<tr>
<td>160:35:33</td>
<td>4.8</td>
<td>7.3</td>
<td>13</td>
<td>81</td>
<td>25.8</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
<td>1.6</td>
<td>0.27</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80:18:25</td>
<td>5.47</td>
<td>7.5</td>
<td>13</td>
<td>77</td>
<td>25.9</td>
</tr>
<tr>
<td>120:26:37</td>
<td>6.12</td>
<td>8.3</td>
<td>18</td>
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<tr>
<td>160:35:33</td>
<td>5.84</td>
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<td>79</td>
<td>26.1</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.42</td>
<td>0.6</td>
<td>2.3</td>
<td>2.6</td>
<td>0.67</td>
</tr>
</tbody>
</table>
There was significant effects of different fertilizer doses on yield and yield attributes of groundnut (Table 7). Application of 30:26:33 kg NPK ha\(^{-1}\) along with gypsum produced significantly greater pod yield (2.0 t ha\(^{-1}\)), haulm yield (3.7 t ha\(^{-1}\)), shelling percentage (76%) and oil content (53.5%) over other treatments. This was in spite of the fact that higher dose of applied P (up to 35 kg ha\(^{-1}\)) and K (up to 50 kg ha\(^{-1}\)) increased yields significantly over lower dose of P (18 kg ha\(^{-1}\)) and K (33 kg ha\(^{-1}\)) applied during 1991–1992. Similarly, during 1992–1993 and 1993–1994 also application of 30:26:33 kg NPK ha\(^{-1}\) along with gypsum gave higher pod yields and yield attributes when compared to other treatments (Table 7).

**Table 5**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pod yield (t ha(^{-1}))</th>
<th>Haulm yield (t ha(^{-1}))</th>
<th>Shelling (%)</th>
<th>100-Seed weight (g)</th>
<th>Oil content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No green manure</td>
<td>1.66</td>
<td>3.36</td>
<td>73.8</td>
<td>36.2</td>
<td>50.6</td>
</tr>
<tr>
<td>Sesbania manure</td>
<td>1.91</td>
<td>3.50</td>
<td>74.9</td>
<td>46.7</td>
<td>51.6</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.03</td>
<td>0.05</td>
<td>0.65</td>
<td>NS</td>
<td>0.53</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No green manure</td>
<td>1.51</td>
<td>3.12</td>
<td>69.2</td>
<td>35.3</td>
<td>51.3</td>
</tr>
<tr>
<td>Crotalaria manure</td>
<td>1.67</td>
<td>3.31</td>
<td>70.3</td>
<td>36.9</td>
<td>51.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.03</td>
<td>0.04</td>
<td>0.6</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crotalaria manure</td>
<td>1.86</td>
<td>3.67</td>
<td>74.3</td>
<td>33.5</td>
<td>49.5</td>
</tr>
<tr>
<td>Farmyard manure</td>
<td>1.79</td>
<td>3.59</td>
<td>72.6</td>
<td>31.6</td>
<td>48.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.4</td>
<td>0.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Table 6
Effects of different spacing on yield and yield attributes of groundnut during different seasons (data are the mean of green manure and fertilizer treatments)

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Pod yield (t ha⁻¹)</th>
<th>Haulm yield (t ha⁻¹)</th>
<th>Shelling (%)</th>
<th>100-Seed weight (g)</th>
<th>Oil content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 × 10 cm²</td>
<td>1.71</td>
<td>3.85</td>
<td>74.1</td>
<td>35.9</td>
<td>50.6</td>
</tr>
<tr>
<td>15 × 15 cm²</td>
<td>1.88</td>
<td>3.50</td>
<td>74.7</td>
<td>40.0</td>
<td>51.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.02</td>
<td>0.06</td>
<td>0.49</td>
<td>0.50</td>
<td>0.22</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 × 10 cm²</td>
<td>1.61</td>
<td>3.52</td>
<td>68.3</td>
<td>36.3</td>
<td>50.9</td>
</tr>
<tr>
<td>15 × 15 cm²</td>
<td>1.77</td>
<td>3.42</td>
<td>70.2</td>
<td>37.9</td>
<td>51.8</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.05</td>
<td>0.06</td>
<td>0.40</td>
<td>0.40</td>
<td>0.20</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 × 10 cm²</td>
<td>1.81</td>
<td>3.58</td>
<td>72.9</td>
<td>34.4</td>
<td>49.4</td>
</tr>
<tr>
<td>15 × 15 cm²</td>
<td>1.73</td>
<td>3.68</td>
<td>74.0</td>
<td>32.7</td>
<td>49.7</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.05</td>
<td>0.08</td>
<td>0.7</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Applications of gypsum improved yield and yield attributes of groundnut all cropping sequences (Table 7 and Figs. 3 and 4).

The interactions between application of green manure to rice and fertilizer levels applied to groundnut crop were significant for pod yields, haulm yields and 100-seed weights during 1991–1992 (Fig. 3) and for pod yield during 1992–1993 and 1993–1994 (Fig. 4). The responses of green manure were greater at lower fertility levels than at higher fertility levels. Maximum yields were obtained with application of green manure to rice along with fertility levels of 30:26:33 kg NPK ha⁻¹ plus gypsum applied to groundnut.

Table 7
Effects of different fertilizer doses on yield and yield attributes of groundnut during different seasons (data are the mean of green manure and spacing treatments)

<table>
<thead>
<tr>
<th>Fertilizer dose (kg NPK ha⁻¹)</th>
<th>Pod yield (t ha⁻¹)</th>
<th>Haulm yield (t ha⁻¹)</th>
<th>Shelling (%)</th>
<th>100-Seed weight (g)</th>
<th>Oil content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-Gypsum</td>
<td>+Gypsum</td>
<td>-Gypsum</td>
<td>+Gypsum</td>
<td>-Gypsum</td>
</tr>
<tr>
<td>1991–1992</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30:18:33</td>
<td>1.52</td>
<td>1.65</td>
<td>3.19</td>
<td>3.27</td>
<td>71.9</td>
</tr>
<tr>
<td>30:26:33</td>
<td>1.86</td>
<td>2.01</td>
<td>3.36</td>
<td>3.66</td>
<td>74.3</td>
</tr>
<tr>
<td>30:35:33</td>
<td>1.70</td>
<td>1.88</td>
<td>3.36</td>
<td>3.48</td>
<td>74.4</td>
</tr>
<tr>
<td>30:35:50</td>
<td>1.79</td>
<td>1.88</td>
<td>3.44</td>
<td>3.60</td>
<td>74.5</td>
</tr>
<tr>
<td>30:35:66</td>
<td>1.85</td>
<td>–</td>
<td>3.52</td>
<td>–</td>
<td>74.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.07</td>
<td>0.03</td>
<td>0.50</td>
<td>0.34</td>
<td>0.70</td>
</tr>
<tr>
<td>1992–1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30:18:33</td>
<td>1.61</td>
<td>1.59</td>
<td>3.21</td>
<td>3.32</td>
<td>70.2</td>
</tr>
<tr>
<td>30:26:33</td>
<td>1.81</td>
<td>1.92</td>
<td>3.39</td>
<td>3.63</td>
<td>74.4</td>
</tr>
<tr>
<td>30:35:33</td>
<td>1.81</td>
<td>1.81</td>
<td>3.42</td>
<td>3.50</td>
<td>73.3</td>
</tr>
<tr>
<td>30:35:50</td>
<td>1.71</td>
<td>1.81</td>
<td>3.54</td>
<td>3.64</td>
<td>74.8</td>
</tr>
<tr>
<td>30:35:66</td>
<td>1.76</td>
<td>–</td>
<td>3.54</td>
<td>–</td>
<td>75.3</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.05</td>
<td>0.03</td>
<td>0.60</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>1993–1994</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>30:26:33</td>
<td>1.81</td>
<td>1.94</td>
<td>3.61</td>
<td>3.80</td>
<td>73.4</td>
</tr>
<tr>
<td>30:35:33</td>
<td>1.78</td>
<td>1.81</td>
<td>3.57</td>
<td>3.61</td>
<td>72.7</td>
</tr>
<tr>
<td>30:35:50</td>
<td>1.80</td>
<td>1.81</td>
<td>3.57</td>
<td>3.63</td>
<td>72.4</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.07</td>
<td>0.01</td>
<td>0.33</td>
<td>1.35</td>
<td>1.07</td>
</tr>
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</table>
Fig. 3. Residual effects green manure sesbania (solid bars) and no green manure (hatched bars) applied to rice on: (a) pod yield; (b) 100-seed weight; (c) haulm yield of succeeding groundnut crop grown under different fertilizer treatments during 1991–1992. Vertical bar shows least significant difference for comparing treatment means at 5% level of significance.
4. Discussion

The results from this study demonstrate that integrated use of organic manures and inorganic N fertilizers increased productivity of rice–groundnut cropping systems. This is in agreement with other studies where combined application of organic and inorganic fertilizer increased productivity of rice–rice (Bar et al., 2000; Ghosh and Sharma, 1999) or rice–wheat (Yadav et al., 2000) cropping sequences.

Application of gypsum produced higher pod yields and kernel oil content than those receiving no gypsum (Table 7 and Figs. 3 and 4). Gypsum typically supplies the two essential nutrients Ca and S particularly important to groundnuts for healthy growth of the plant and developing properly filled pods with a high seed quality and oil content (Gascho and Davis, 1995).

The improved growth and yields of rice and groundnut crops under integrated nutrient management could
have been due to increased nutrient uptake. Research has shown that integrated use of organic and fertilizer N lead to increased nutrient uptake and greater grain yield of rice than application of fertilizer alone (Diekmann et al., 1993; Yadav et al., 2000). Results from a 4 year field study with irrigated rice–wheat cropping systems showed that supply of nutrient through integrated use of green manure and fertilizer N resulted in significantly greater yields over inorganic fertilizer alone, and reduced the use of fertilizer N by >50% in rice and 25% in wheat (Aulakh et al., 2000). Increased nutrient uptake could be attributed to improvement in soil physical and chemical properties. It was observed that combined application of manure and fertilizer reduces bulk density, resistance to penetration, improves water soluble aggregates, total porosity, hydraulic conductivity, water holding capacity and reduces nutrient losses (Patra et al., 2000; Mondal et al., 1994). Yadav et al. (2000) reported that efficiency of inorganic fertilizer is improved when used in conjunction with green manures because: (a) green manure N is as efficient as fertilizer (urea) N in rice (Ladha and Kundu, 1997); (b) high root density due to improved physical conditions of the soil enhances nutrient absorption capacity of the crop (Boparai et al., 1992), thereby improving biological yield at a given level of fertilizer application.

In the present study integrated use of inorganic fertilizer (120:26:37 kg NPK ha\(^{-1}\)) and green manures at 10 t ha\(^{-1}\) (fresh weight) produced greater yields compared to highest doses of inorganic NPK (160:35:50) fertilizers (Fig. 2). This was possible because green manure typically has the potential to contribute about 70–80 kg of additional N ha\(^{-1}\), which was available to growth and development of rice and subsequent groundnut crop. However, the fact that treatment combination of green manure and 160:35:50 kg NPK ha\(^{-1}\) inorganic fertilizer produced slightly lower yield than compared to 120:26:37 kg NPK ha\(^{-1}\) suggests that nutrient other than NPK which are supplied by organic manures could have been made unavailable. Studies have shown that application of high doses of inorganic fertilizers alone can exacerbate micronutrient deficiency by reducing their availability (Marschner, 1995; Prasad et al., 2000). Furthermore, the yield advantage due to application of green manure could have been because of their capability to supply essential nutrients other than NPK. Application of green manure or farmyard manure is known to increase concentrations of Fe, Mn, Cu, and Zn in rice based cropping systems (Nayar and Chhibba, 2000).

Despite potential advantages of integrated nutrient management to improve crop productivity very little information is available on the long-term effects of integrated use of organic manures and inorganic fertilizer on soil physical and chemical properties, soil microbial activities, interactions with other macro and micronutrients availability. The economics of integrated nutrient management on small and large farms are scarce and need attention. Few studies on the evaluation of green manure technology in tropical lowland rice systems (Becker et al., 1995; Ali and Narciso, 1996; Ali, 1999) suggests that despite the beneficial and positive effects of green manures, adoption by farmers is slow and the use of green manures in lowland rice production has declined dramatically world-wide over the last 30–40 years. The major constraints identified were non-availability of seeds, high cost of establishment and incorporation of green manure, rapidly increasing cost of land and labor wages. Furthermore, it was concluded that application of green manures was uneconomical (Ali, 1999). Recent study on the economic analysis of green manures in rice–wheat cropping systems showed that when total yield of the system (rice + wheat) were >10 t ha\(^{-1}\), the marginal benefits increased with application of green manures, suggesting that under high yield situations green manuring with sesbania was a profitable practice (Yadav, 2001). In contrast, it is general observation that adoption of green manures or farmyard manures is more in regions where the soils are poor and crop productivity is low, this is particularly true for farmers with small land holding (ILEIA, 1997).

Ali (1999) suggested that grain legume crops which has food value in addition to their N\(_2\) fixing abilities have high potential for adoption when compared to green manure crops which do not have food value. However, this depends upon the availability of growing season and irrigation water. This is particularly important in rice–rice cropping systems. In the present experiment rice crop grown in rainy season (June–October) is mainly dependent on rainfall but with supplemental irrigation, while the post-rainy season (November–February) is mainly irrigated. Similarly,
groundnut crop grown during post-rainy and summer season is dependent on irrigations. Green manure
crops are grown in short and dry periods (45–50 days)
available between the two main crops. This period is
not sufficient to grow other grain legume crops due to
lack of growing season and sufficient irrigation water.
Therefore, in such regions, where the farmers do not
have alternatives to produce other grain legume crops,
there is potential for growing green manure crops that
would be beneficial for maintaining soil health. The
choice of grain legume or green manure legume
depend on local rainfall and irrigation facilities, growing
season, economics of legume cultivation, cost of N
fertilizer and opportunity cost of alternative crops
(Ali, 1999; Timsina and Conner, 2001). Future
research should consider the reasons why farmers
are not adopting these technologies and find ways
to make adoption easier. It may be possible to improve
future adoption of green manures by improving seed
supply, reducing production cost of green manures,
increasing nutrient composition of green manures, and
identifying new species that also have alternative uses
as food, fodder, fuel or other economic importance. If
inorganic fertilizers prices, use of fossil fuels, concern
about environment and organic farming keeps on
increasing at the present trend, use of alternative
sources of nutrients would become inevitable.

Acknowledgements

This research was fully funded by the Potash and
Phosphate Institute of Canada (India Program). We
thank Drs. G. Dev, V. Santaram and M.M. Hussain
for their constant encouragement and support and Ms.
Kusuma Kumari and Mr. G. Srinivas for conducting a
part of this research. We also thank anonymous refer-
ees for their valuable suggestions.

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