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SHORT COMMUNICATION

Green manuring effects on crop morpho-physiological characters, rice yield and soil properties

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Abstract A field experiment was carried out to evaluate the effect of green manure and nitrogen fertilizer on morpho-physiological traits, yield and post-harvest nutrient status of the soil during *kharif* season of 2017. The experiment was laid out with a randomized complete block design with twelve treatments, and was replicated thrice. The treatments were T1 [Control (no green manure + no fertilizer)], T2 (*Sesbania aculeata* + N0), T3 (*Sesbania aculeata* + N15), T4 (*Sesbania aculeata* + N30), T5 (*Sesbania aculeata* + N45), T6 (*Sesbania aculeata* + N60), T7 (*Crotalaria juncea* + N0), T8 (*Crotalaria juncea* + N15), T9 (*Crotalaria juncea* + N30), T10 (*Crotalaria juncea* + N45), T11 (*Crotalaria juncea* + N60), and T12 (N60). Incorporation of green manure with nitrogen fertilizer generated consistently positive responses in important morpho-physiological traits such as chlorophyll content (SPAD value), leaf area index (LAI), light interception percent (%LI), and net assimilation rate (NAR), which may result in higher grain yield compared to control, and N60 due to greater contribution of yield determining traits. Treatment comprising green manure with N60 produced significantly the higher grain yield even over the N60. The results of this research indicated that balanced nutrients supply increased leaf chlorophyll content, LAI, %LI, NAR, and finally led to higher dry matter production and yield of rice. Incorporation of green manure also had significantly increased the macro- and micronutrient content of post-harvest soil. These results suggest that continuous use of fertilizer might lead to a yield loses of rice, and that situation could be escaped by a combined application of green manure and judicial nitrogen fertilizer management.

Keywords Green manure · SPAD · Leaf area index · Light interception · Growth · Rice yield

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Introduction

Rice is the vital food for more than two billion people in Asia and four hundred millions of people in Africa and Latin America (IRRI 2006). Bangladesh is one of the major rice growing countries of the world. Bangladesh is in fourth position among the top rice growing countries. In Bangladesh, total rice production was 34.55 million tons (BBS 2016). Agriculture contributes 14.79% of national economy of Bangladesh (BBS 2016) and only the rice sector contributes one-half of the agricultural GDP and about one-sixth of the national income in Bangladesh. Although modern rice variety has the highest yield but still there is a serious yield gap. In Bangladesh, lack of judicial nutrient management is considered as the major causes of yield gap in rice production.

Soil fertility has deteriorated over the years and the productivity of major crops have either stagnated or declined in Bangladesh. Increase in the cropping intensity, and higher rates of organic matter decomposition under the existing hot and humid climate, lesser application of organic manure and negligible dependence on green manure practice etc. (BARC 2005) has led to decline in the crop productivity due to depletion of soil nutrients. As the fertility status of Bangladesh soils are very low, farmers normally apply higher rate of chemical fertilizers (especially nitrogen fertilizers) as the principal source of plant nutrients for rice production but their loss is very high. Higher dose of chemical fertilizers (especially inorganic nitrogen fertilizers) result in soil acidification and structure damage, water depletion, and alteration in the populations of soil microbes as well as their activities (Liu et al. 2010; Guo et al. 2010; Liu et al. 2013). Hence over-fertilization damages soil quality and thereby decrease productivity. Therefore, any alternative means has to be suggested to the farmers to maintain the high level of productivity. That's why, integrated use of organic manure and chemical fertilizers can be an effective solution for nutrient management in rice as well as to sustain long term productivity and to enhance ecological sustainability.

Green manuring (GM) crops generally have a considerable amount of biomass which comprises of above-ground and belowground biomass. They also have the ability to increase solar energy harvest and C flux into the soil and provide food for soil macro- and micro-organisms (Dabney et al. 2001). Green manuring with nitrogen fixing legume crop can provide a substantial portion of N requirement for rice and also add organic matter (OM) to maintain soil fertility (Latt et al. 2009) which is essential for sustainable agriculture. Green manuring crops not only transfer nutrients to soil but also can lead to deep root system for nutrient uptake from deeper soil causing absorbtion of less available nutrients, thereby increasing concentration of plant nutrients in the surface soil (Noordwijk et al. 2015), and reducing the use of fertilizer (especially N). Hence GM can prevent the environmental risks related to $NO3^-$ leaching. Dhaincha (*Sesbania aculeata*) and sunhemp (*Crotalaria juncea*) are well known in South Asia for their capability of nodule formation and nitrogen fixation and produce relatively higher organic matter (Panneerselvam and Manuel 2004). Well nodulated *Sesbania* plants can derive up to 90% N from fixation (Pareek et al. 1990) and consequently contribute N in rice cultivation. Sunhemp is also a vigorous upright legume growing 2 m tall and like other legumes, has the ability to fix nitrogen symbiotically.

So far, most of the studies on the green manuring crops have concentrated on the fate of N in the soil or in succeeding main crops. Light is one of the main growth and biomass production factors in plant population. Increasing leaf area index (LAI) leads to more light interception in plants. Scientist believe that the radiation use efficiency is controlled genetically (Monteith 1972), however, environment factors such as variety, climatic changes, density and soil fertility particularly available nitrogen have an important role on photosynthesis (Akmal and Janssens 2004; Rosati et al. 2004). It has been reported that sunlight radiation received by plants, is converted to chemical energy and lead to growth and yield of crops (Purcell et al. 2002). Nitrogen is an important component of chlorophyll, protein and nucleic acid (FAO 2000) and regulates LAI, light interception and finally lead to increase yield of crops. *Sesbania aculeata* and *Crotalaria juncea* are well known as nitrogen fixing green manuring crops. However, the performance of *Sesbania aculeata* and *Crotalaria juncea* alone or combination with N on morpho-physiological characters of rice has not been studied in the scientific literature. Therefore, the present study was conducted to examine the effect of green manure with *Sesbania aculeata* and *Crotalaria juncea* on morpho-physiological characters and yield of rice, as well as to study their influence on post-harvest soil properties.

Materials and methods

The experiment was carried out at the research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh, during *kharif* season (March to August) of 2017. The experimental site is located at the agro-ecological zone (AEZ) Madhupur tract ($24^0 09'$N latitude and $90^0 26'$E longitude with an elevation of 8.2 m above sea level; AEZ 28). The soil of the study area belongs to salna series and has been classified as Shallow Red Brown Terrace soil in the soil classification system of Bangladesh and Inceptisol in the United States Department of Agriculture (USDA) classification system. The soil is characterized by clay within 50 cm of the surface and is acidic in nature and the climate of the site is sub-tropical, wet and humid. The soil of the experimental field was silty clay loam in texture, bulk density (g/cc) 1.35, particle density (g/cc) 2.66, soil pH 5.76, organic carbon (%) 0.81, total nitrogen (%) 0.064, available P (mg kg^{-1} soil) 4.86, exchangeable K (meq/100 g soil) 0.138, available S (ppm) 21.21.

The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments and three replications. The treatments were T1 [Control (no green manure + no fertilizer)], T2 (*Sesbania aculeata* + N0), T3 (*Sesbania aculeata* + N15), T4 (*Sesbania aculeata* + N30), T5 (*Sesbania aculeata* + N45), T6 (*Sesbania aculeata* + N60), T7 (*Crotalaria juncea* + N0), T8 (*Crotalaria juncea* + N15), T9 (*Crotalaria juncea* + N30), T10 (*Crotalaria juncea* + N45), T11 (*Crotalaria juncea* + N60), and T12 (N60). Unit plot size was 4 m × 2.5 m.

After land preparation, seeds of both dhaincha (*Sesbania aculata*) and sunhemp (*Crotalaria juncea*) were sown on 1 March 2017. *Sesbania aculata* and *Crotalaria juncea* were cut, chopped by sharp knives after 50 days of emergence and incorporated with soil through plowing and laddering. Initial soil properties were collected before incorporation of green manure. At final land preparation, the full amount of triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate were applied as the sources of phosphorus (P), potassium (K), sulfur (S) and zink (Zn) at the rates of 13, 38, 8 and 1 kg ha^{-1}, respectively as recommended dose of fertilizers (RDF) according to Fertilizer Recommendation Guide of Bangladesh (BARC 2012). Different doses of nitrogen (0, 15, 30, 45 and 60 kg N ha^{-1} from Urea) were applied in three equal splits. First split of urea was applied immediately after seedling establishment, second split was applied at early tillering stage and the third split of urea was applied at 5–7 days before panicle initiation (PI) stage. BRRI dhan48, a popular rice variety for rain fed condition, was used as test crop. Twenty-five days old seedlings were transplanted. Standard crop management practices were practiced.

The yield data such as plant height, number of effective tillers $hill^{-1}$, panicle length, number of filled grain $panicle^{-1}$, 1000-seed weight and grain yield were recorded from five randomly selected hills in each plot, excluding border hills. Dry matter productions of rice were recorded at different days after transplanting (DAT). Leaf area index (LAI) and net assimilation rate (NAR) were calculated following the standard formulae (Radford 1967). Chlorophyll meter, also known as Soil Plant Analysis Development (SPAD) (SPAD-502, Minolta Co. Ltd., Japan) was used to obtain readings estimating leaf chlorophyll concentration (SPAD value). Ten plants from each treatment were selected randomly and SPAD values were recorded from the fully matured leaves counted from the top of the plants. Three SPAD readings were taken from each plant. SPAD values were recorded at 50, 60, 70, 80 and 90 DAT. Photosynthetically active radiation (PAR) of rice canopy was recorded at 60, 70, 80 and 90 DAT by Sunfleck Ceptometer (LP-80, Decagon Devices, Inc. USA). Measurements were taken every ten days at 10:00 am under clear skies in the same sample area in each plot during the crop season. Light interception percent of rice canopy was calculated by the following formulae.

$$\text{Light Transmission Percentage (LTP)} = \frac{\text{PAR below the crop canopy}}{\text{PAR above the crop canopy}} \times 100$$

% light intercepted (%LI) = 100 − LTP.

Post-harvest soils were also collected (up to 0–15 cm depth) from four different spots in each plot. The composite soil sample of each plot was brought to the laboratory for different analysis following the standard procedure (Page et al. 1982).

Data analysis

The collected data were analyzed to assess their statistical significance. Statistix 10 and SPSS program were used to perform statistical analysis. Means were separated by least significant difference (LSD).

Results and discussion

SPAD meter reading fairly correlate with leaf greenness and N contents in crop and thus, can be used to estimate leaf chlorophyll content (Rorie et al. 2011; Hakim et al. 2015). Gholizadeh et al. (2017) showed a linear relationship between SPAD readings and fully expanded leaf N in the rice. Incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly increased the SPAD reading at different growth stages of rice (Table 1). According to the SPAD value, the chlorophyll content was consistently high during the period from 50 to 70 DAT in all the treatment. However, the maximum SPAD value (40.9) was found from the T6 treatment at 70 DAT which was statistically similar to T11 at same DAT, and the lowest (22.5) was recorded from the T1 (control) treatment at 90 DAT (Table 1). The chlorophyll content was increased up to 70 DAT with the progress of plant age, thereafter it declined regardless of treatments. However, the decreasing trend was slower in GM treated plants. Green manuring (GM) crops has the ability to nodulate and fix atmospheric nitrogen and converts atmospheric nitrogen into a plant–usable form. It has been reported that higher doses of nitrogen fertilizer showed significantly higher SPAD meter reading at different growth stages of rice (Gholizadeh et al. 2009). Xie et al. (2017) found that combining of chinese milk vetch as a GM with N fertilizer significantly increased the chlorophyll content (SPAD readings) compared to applying N fertilizer alone in rice. Green manure might be substitute of the N and other plant nutrients and helped in maintaining the higher chlorophyll content in rice. The SPAD values at 70 DAT demonstrated a notably higher SPAD values than the SPAD values at 50 DAT. The higher SPAD values at 70 DAT might be due to the leaf thickness and accumulation of more chlorophyll and N in the leaf. After 70 days of transplanting, the chlorophyll content was decreased regardless of treatments. This was probably because of the transferring of nutrient elements of the green leaves to the seeds. Chlorophyll meter values were closely related to grain yield of rice (Table 2). Ramesh et al. (2002) observed highly significant correlations between SPAD readings and grain yield of direct wet seeded rice. Many researchers also observed a significant and positive correlation between leaf N content as well as SPAD values and rice grain yield (Singh et al. 2002; Swain and Sandip

Table 1 Effect of green manuring crops and nitrogen levels on leaf chlorophyll content (SPAD value) at different growth stages of rice

Treatments	Chlorophyll content (SPAD values)				
	50 DAT	60 DAT	70DAT	80 DAT	90 DAT
T1 = Control	32.4f	34.3f	34.5e	31.2e	22.5f
T2= *S. aculeata* + N0	34.6ef	37.1de	36.9cd	32.9de	24.7def
T3 = *S. aculeata* + N15	35.6cde	38.4bcde	38.8abc	33.4cde	26.4cd
T4 = *S. aculeata* + N30	36.7bcde	39.5abc	39.6ab	34.8abcd	27.6abc
T5= *S. aculeata* + N45	38.1abc	39.7abc	39.7ab	36.0abc	28.9ab
T6 = *S. aculeata* + N60	39.4a	40.5a	40.9a	37.0a	29.9a
T7= *C. juncea* + N0	34.3ef	36.4e	36.2de	32.2de	23.5ef
T8= *C. juncea* + N15	35.4de	37.8cde	37.9bcd	32.5de	25.4cde
T9= *C. juncea* + N30	36.1cde	39.1abcd	39.4ab	34.2bcd	26.7bcd
T10= *C. juncea* + N45	37.9abcd	39.5abc	39.6ab	35.8abc	27.7abc
T11= *C. juncea* + N60	38.7ab	40.1ab	40.4a	36.8ab	29.1ab
T12 = N60	36.8bcde	38.9abcd	39.5ab	34.6abcd	27.4bc
CV (%)	4.16	3.08	3.48	4.75	5.35
LSD $_{(0.05)}$	2.56	2.00	2.28	2.76	2.41

*Values followed by different letters in the same column are significantly different from each other at 5% level of significance. Averages from three independent experiments are shown

Table 2 Correlation between grain yield and chlorophyll content (SPAD values) of rice as influenced by green manures and different levels of nitrogen

Parameters	SPAD50	SPAD60	SPAD70	SPAD80	SPAD90	GY
SPAD50	1.000					
SPAD60	0.957**	1.000				
SPAD70	0.950**	0.993**	1.000			
SPAD80	0.981**	0.926**	0.920**	1.000		
SPAD90	0.980**	0.968**	0.971**	0.970**	1.000	
GY	0.955**	0.958**	0.938**	0.909**	0.932**	1.000

SPAD50, SPAD60, SPAD70, SPAD80 and SPAD90 are the SPAD values at 50, 60, 70, 80 and 90 DAT respectively and GY = rice grain yield (t ha^{-1})

**Indicate correlation is significant at 1% level

2010). Parvizi et al. (2004) obtained significant correlations between SPAD readings and dry matter production and yield of wheat.

Crop canopy is the spatial arrangement of the above ground portion of a plant community. Solar radiation provides free energy for plant growth through photosynthesis and yield of crops depend on the solar radiation received by the canopy. However, only the photosynthetically active part of the spectrum (400–700) known as photosynthetically active radiation (PAR) can directly drive photosynthesis. Maruyama et al. (2007) reported that interception of light by the rice canopy depends on the transmissivity and the reflectivity of the rice canopy and its leaf inclination. The canopy leaf area has a major role in the amount of light intercepted. The higher canopy leaf area results in greater interception of light and hence faster crop growth. The leaf area index (LAI) is widely used to characterize the canopy light climate. Incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly influenced the LAI and light interception percent (%LI) of rice (Fig. 1; Table 3). The highest LAI (6.11) and %LI (86.82) was obtained from the T6 treatment at 80 DAT which was statistically similar to T11 treatment at same DAT and the lowest LAI (1.50) and %LI (50.18) was recorded from the T1 (control) treatment. The results of these experiment showed that both LAI and %LI was gradually increased from 60 DAT to 80 DAT, and then decreased regardless of treatments (Fig. 1; Table 3). The reduction of LAI and %LI during reproductive stage might be due to decline in leaf nitrogen concentration for grain filling. This might have reduced the capacity of leaf to accumulate carbon. Moreover, a decline in leaf area also contributed to the reduction in PAR during reproductive phase. The light transmission is affected by leaf angle, the thickness and chlorophyll concentration, leaf phyllotaxis and vertical stratification, and elevation of the sun. LAI and

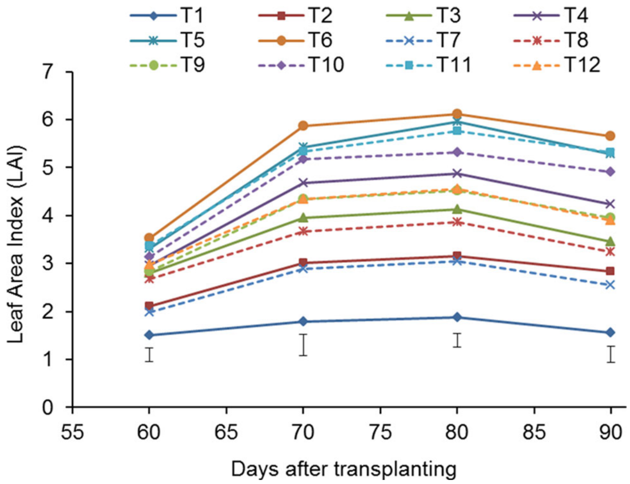

Fig. 1 Effects of green manuring on leaf area index at different growth stage of rice. Averages from three independent experiments are shown. Vertical lines represent LSD at 5% level of significance. Note: T1 = Control; T2= *S. aculeata* + N0; T3 = *S. aculeata* + N15; T4 = *S. aculeata* + N30; T5= *S. aculeata* + N45; T6 = *S. aculeata* + N60; T7= *C. juncea* + N0; T8= *C. juncea* + N15; T9= *C. juncea* + N30; T10= *C. juncea* + N45; T11= *C. juncea* + N60; T12 = N60

Table 4 Correlation between grain yield and leaf area index (LAI) of rice as influenced by green manures and different levels of nitrogen

Parameters	LAI 60	LAI 70	LAI 80	LAI 90	GY
LAI 60	1.000				
LAI 70	0.985**	1.000			
LAI 80	0.983**	0.997**	1.000		
LAI 90	0.969**	0.994**	0.995**	1.000	
GY	0.949**	0.949**	0.950**	0.942**	1.000

LAI 60, LAI 70, LAI 80 and LAI 90 are the leaf area index (LAI) at 60, 70, 80 and 90 DAT respectively and GY = rice grain yield (t ha^{-1})

**Indicate correlation is significant at 1% level

%LI were also closely related to grain yield of rice (Table 4; Table 5). If other resources are enough to a plant, the light is only factor that can have effective result on yield (Tohidi et al. 2012). These indicate that as light interception is high, the yield will be more. Increasing leaf area index leads to more light interception which subsequently leads to more yield. It was observed that solar radiation is positively associated with dry matter production (Eloy et al. 2018), and interception of radiation by crops closely related to their leaf area index (Behling et al. 2015). Monteith (1972) reported that interception of radiation by canopy is also related to nutritional status of the soil. Nitrogen causes vegetative growth though increases leaf area index. Therefore, increased nitrogen available to plant can increase LAI. Green manuring can deliver considerable amount of nitrogen and increase the LAI of crops (Islam et al. 2015). Many researchers also reported that nitrogen fertilizer increase leaf numbers, LAI, light interception and led to higher yield of crops (Kibe et al. 2006; Liu et al. 2014). Green manuring with *Sesbania aculeata* and *Crotalaria juncea* might increase nitrogen in soil and

Table 3 Effect of green manuring crops and nitrogen levels on percent light intercepted (% LI) and net assimilation rate (NAR) at different growth stages of rice

Treatments	% Light intercepted (% LI)				Net assimilation rate (mg cm^{-2} day^{-1})		
	60 DAT	70 DAT	80 DAT	90 DAT	60 DAT	80 DAT	100 DAT
T1 = Control	50.18g	59.95f	67.90g	61.00g	0.251e	0.297d	0.229c
T2= *S. aculeata* + N0	61.24ef	67.28de	75.94f	73.00f	0.362cd	0.385bc	0.352ab
T3 = *S. aculeata* + N15	65.44de	73.33bc	77.53ef	76.4de	0.365bcd	0.386abc	0.354ab
T4 = *S. aculeata* + N30	68.17bcd	79.05ab	82.16cd	75.99e	0.372bcd	0.390abc	0.357ab
T5= *S. aculeata* + N45	72.16abc	81.3a	85.31ab	83.28ab	0.379ab	0.396ab	0.362ab
T6 = *S. aculeata* + N60	76.41a	83.86a	86.82a	84.70a	0.382a	0.398a	0.364a
T7= *C. juncea* + N0	56.40f	66.19e	76.07f	72.66f	0.360d	0.382c	0.350b
T8= *C. juncea* + N15	64.12de	72.67cd	79.2e	74.69ef	0.362cd	0.384bc	0.353ab
T9= *C. juncea* + N30	67.77cd	78.05abc	81.57d	78.79cd	0.369bcd	0.387abc	0.355ab
T10= *C. juncea* + N45	71.55abc	80.52a	84.12bc	82.96ab	0.377abc	0.393abc	0.361ab
T11= *C. juncea* + N60	75.49a	82.74a	86.55a	84.28a	0.380ab	0.396ab	0.362ab
T12 = N60	72.97ab	80.55a	84.15bc	80.68bc	0.368bcd	0.385bc	0.353ab
CV (%)	4.38	4.65	1.49	2.01	2.08	1.44	1.62
LSD $_{(0.05)}$	4.95	5.93	2.03	2.63	0.017	0.012	0.12

Averages from three independent experiments are shown

*Values followed by different letters in the same column are significantly different from each other at 5% level of significance

Table 5 Correlation between grain yield and percent light intercepted (%LI) of rice as influenced by green manures and different levels of nitrogen

Parameters	% LI 60	% LI 70	% LI 80	% LI 90	GY
% LI 60	1.000				
% LI 70	0.984**	1.000			
% LI 80	0.977**	0.980**	1.000		
% LI 90	0.966**	0.949**	0.976**	1.000	
GY	0.959**	0.931**	0.968**	0.983**	1.000

% LI 60, %LI 70, %LI 80 and %LI 90 are the percent light intercepted (%LI) at 60, 70, 80 and 90 DAT respectively and GY = rice grain yield (t ha^{-1})

**Indicate correlation is significant at 1% level

subsequently increase LAI and %LI which led to higher rice yield.

The mean photosynthetic efficiency of plant is best indicated by net assimilation rate (NAR) under a particular environment. The NAR was also significantly influenced by the integration of *Sesbania aculeata* and *Crotalaria juncea* with N (Table 3). However, the highest NAR was found from the T6 treatment at 80 DAT which was statistically similar to the T11 treatment at the same DAT and the lowest was recorded from the T1 (control) treatment at 100 DAT (Table 3). As increased nitrogen produces more leaf area and leaf area harvest that may accumulate more dry matter assimilation. The NAR was gradually increased from 60 DAT to 80 DAT and then decreased regardless of different treatment (Table 3). The mutual leaf shading by older leaves which have lost photosynthetic ability lead to decreased NAR with increasing age of the plants.

Incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly influenced the dry matter (DM) production of rice (Table 6). During the entire growing periods, the maximum DM production was found from the T6 treatment. This might be due to balanced supply of nutrients in soil through addition of GM which improve plant growth and increase DM production. The results of the Table 6 showed that DM production increased rapidly before flowering stage and then increased slowly up to maturity. It might be due to decrease in chlorophyll content, photosynthetic capacity and shedding of leaves at the latter stage of the crops. Data regarding yield contributing characters and yield as influenced by integration of *Sesbania aculeata* and *Crotalaria juncea* with N is shown in Table 7. Analysis of the data revealed that the treatments had significant effect on plant height, tillers $hill^{-1}$, panicle length, number of filled grain $panicle^{-1}$ and grain yield of rice. However, among the treatments, the highest plant height, tillers $hill^{-1}$, panicle length, number of filled grain $panicle^{-1}$ and grain yield was recorded from the T6 treatment and the lowest was recorded from T1 (control) treatment (Table 7). The results of this research indicate that application of N60 was inefficient for optimizing rice yield compared to the combined application of GM and N fertilizers. Lee et al. (2010) and Shah et al. (2017) found that incorporation of GM in soil dramatically increased the number of effective tiller per hill, panicle length, filled grain per panicle, and yield of rice. It has been reported that the balanced supply of nutrients is important for improving plant growth and also for increasing rice yield (Caballero et al.1996). In addition to the macro-nutrients (N, P, and K), green manuring plants also contains micro-nutrients (e.g. Ca, Mg, Si, and Zn, etc.) (Chen and Zhao 2009; Lu et al. 2011), which may promote and maintain the sustainable nutrients supply to the soil. Efthimiadou et al. (2010) found that combining GM with N enhanced the photosynthetic rate and stomatal conductance of rice, and led to increase in the dry matter accumulation as well as rice yield versus N fertilizers alone. These positive effects of GM may be the result of the aboveground and/or belowground plant biomass, with high amount of N and a relatively low carbon-to-nitrogen ratio (C/N), leading to release of plant-available N (Gilmour et al. 1998; Blanco-Canqui et al. 2012). Due to deep root system, GM crops also increase P and K availability in plough layer of paddy soil which is favorable to promote the N absorption of rice (Bullock 1992; Fageria et al. 2005) and may increase the plumpness of rice grains. Xie et al. (2017) showed that combining GM (chinese milk vetch) with N promoted plant growth due to its positive role in mitigation of oxidative damages by increasing antioxidant activity in rice roots.

The data of this research revealed that incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly reduced soil bulk density (Table 8). The lowest bulk density (1.11) was recorded from the T6 treatment, while the highest (1.32) was recorded from the T1 (control) treatment. This might be due to increase in soil organic matter (OM) resulting from the degraded GM by microorganisms. Green manure may increase the soil microbial activities for OM decomposition which led to enhancement of soil porosity and reduction in soil bulk density. Soil pH was not significantly influenced by the different treatments (Table 8). Although, incorporation of GM had slightly lower soil pH compared with T1 (control) treatment. The decrease in soil pH may be due to production of CO_2 and organic acids during decomposition of incorporated GM. Some other authors also reported that application of different types of GM also decreased soil pH (Dhar et al. 2014; Adekiya et al. 2017). At pH below 7.0, R-OH might have dissociated as R^+ and OH^- and the H^- decreased soil pH eventually. The results of this study showed that incorporation of *Sesbania aculeata* and *Crotalaria juncea* with N significantly increased soil organic carbon, N, P, K, Ca, and S (Table 8). In most of the cases, the highest

Table 6 Effect of green manuring crops and nitrogen levels on dry matter production at different growth stages of rice

Treatments	Dry matter production (g m^2)					
	60 DAT	70 DAT	80 DAT	90 DAT	100 DAT	110 DAT
T1 = Control	195i	231j	327l	431j	507k	589k
T2= *S. aculeata* + N0	435g	484h	552j	687h	781i	853i
T3 = *S. aculeata* + N15	471f	514g	589h	734f	823h	915g
T4 = *S. aculeata* + N30	621d	658e	719f	846e	933f	1062f
T5= *S. aculeata* + N45	711b	755b	833c	985c	1057c	1134c
T6 = *S. aculeata* + N60	755a	815a	929a	1095a	1184a	1277a
T7= *C. juncea* + N0	414h	462i	535k	637i	755j	819j
T8= *C. juncea* + N15	473f	509g	581i	721g	819h	896h
T9= *C. juncea* + N30	597e	643f	712g	841e	917g	1055f
T10= *C. juncea* + N45	716b	743c	817d	979c	1038d	1121d
T11= *C. juncea* + N60	751a	817a	903b	1068b	1173b	1261b
T12 = N60	681c	721d	803e	941d	1008e	1083e
CV (%)	2.43	2.74	1.37	1.56	1.44	1.46
LSD $_{(0.05)}$	9.1	10.03	5.59	10.29	8.80	10.07

Averages from three independent experiments are shown

*Values followed by different letters in the same column are significantly different from each other at 5% level of significance

Table 7 Effect of green manuring crops and nitrogen levels on yield contributing characters and yield of rice

Treatments	Plant height (cm)	Number of effective tillers $hill^{-1}$	Panicle length (cm)	Filled grain $panicle^{-1}$	1000 seeds wt. (g)	Grain yield (t ha^{-1})
T1 = Control	92.7d	7.3f	18.17d	83.56d	21.12	2.31g
T2= *S. aculeata* + N0	98.9bcd	9.8de	21.83bc	96.24c	22.13	3.87e
T3 = *S. aculeata* + N15	100.7bcd	10.4bcde	22.01bc	97.55bc	22.17	4.09cd
T4 = *S. aculeata* + N30	104.6abc	11.1abcde	22.66ab	103.11ab	22.25	4.23c
T5= *S. aculeata* + N45	106.8abc	11.7ab	23.11a	105.46a	22.41	4.88a
T6 = *S. aculeata* + N60	109.2a	12.4a	23.77a	106.74a	22.46	5.01a
T7= *C. juncea* + N0	98.4cd	9.6e	21.71bc	95.05c	22.09	3.65f
T8= *C. juncea* + N15	99.8bcd	10.1cde	21.89bc	96.22c	22.13	3.97de
T9= *C. juncea* + N30	104.1abc	10.9bcde	22.47b	102.45ab	22.20	4.12c
T10= *C. juncea* + N45	105.4abc	11.4abc	22.98ab	104.86a	22.37	4.65b
T11= *C. juncea* + N60	108.4ab	11.8ab	23.46a	106.13a	22.42	4.90a
T12 = N60	105.2abc	11.2abcd	22.79ab	104.16a	22.32	4.51b
CV (%)	4.33	6.57	5.01	2.62	3.51	2.71
$LSD_{(0.05)}$	9.01	1.54	1.41	5.77	1.63	0.15

Averages from three independent experiments are shown

*Values followed by different letters in the same column are significantly different from each other at 5% level of significance

Table 8 Effect of green manuring crops and nitrogen levels on physical and chemical properties of postharvest rice soil

Treatment	Bulk density (g/cc)	pH	Organic C (%)	Total N (%)	Available P (mg/kg)	Exchangeable K (meq/100 g soil)	Available S (mg/kg)
Initial value	1.35	5.76	0.81	0.064	4.86	0.138	21.21
T1 = Control	1.32a	5.73	0.83e	0.055i	4.69f	0.129f	20.57h
T2= *S. aculeata* + N0	1.19bcd	5.60	0.90cd	0.073g	5.75de	0.205de	22.38fg
T3 = *S. aculeata* + N15	1.17cde	5.60	0.92bcd	0.081f	6.11cd	0.219c	22.61def
T4 = *S. aculeata* + N30	1.15def	5.60	0.93bc	0.093d	6.23bcd	0.223c	22.83cd
T5= *S. aculeata* + N45	1.13ef	5.61	0.93bc	0.098c	6.43abc	0.248b	23.01bc
T6 = *S. aculeata* + N60	1.11f	5.62	0.97a	0.106a	6.71ab	0.269a	23.19ab
T7= *C. juncea* + N0	1.19bc	5.61	0.89d	0.069h	5.86de	0.194e	22.53ef
T8= *C. juncea* + N15	1.19bcd	5.61	0.89d	0.075g	6.16cd	0.216cd	22.76cde
T9= *C. juncea* + N30	1.17cde	5.62	0.90cd	0.088e	6.38abc	0.219c	22.91bc
T10= *C. juncea* + N45	1.15cdef	5.63	0.91bcd	0.095d	6.55abc	0.242b	23.13ab
T11= *C. juncea* + N60	1.12f	5.62	0.94ab	0.103b	6.83a	0.261a	23.36a
T12 = N60	1.22b	5.67	0.84e	0.083f	5.58e	0.248b	22.15g
CV (%)	2.25	2.01	2.55	2.05	4.95	3.060	2.23
LSD $_{(0.05)}$	0.04	0.19	0.039	0.003	0.51	0.011	0.28

*Values followed by different letters in the same column are significantly different from each other at 5% level of significance

Averages from three independent experiments are shown

nutrients content of the post-harvest soil were found from the T6 treatment and the lowest from the T1 (control) treatment (Table 8). Noordwijk et al. (2015) observed that GM not only adds N in soil profile but also uptake residual N from deep soil profile to top soil by their downward root growth. Green manuring significantly increased the NH_4 content and decreased the NO_3^- content in paddy field. Incorporation of GM in paddy soil also increased total N contents, and the quantity and quality of soil organic C (Zotarelli et al. 2012; Xie et al. 2017). Green manures are rich in different nutrients and affirmed that these nutrients are released into the soil by decomposed GM. Our results were supported by many other researchers (Dhar et al. 2014; Adekiya et al. 2017) who reported higher soil OM, organic carbon, N, P, K, Ca, Mg and S contents due to incorporation of GM. It has also been reported that in addition to the macro-nutrients (N, P, and K), GM also contains micro-nutrients (e.g. Ca, Mg, Si, and Zn, etc.) (Chen and Zhao 2009; Lu et al. 2011), which may promote and maintain the sustainable nutrients supply to the soil.

Conclusion

Green manuring is an important practice for sustainable agriculture. This study was conducted to understand the role of green manure in the morpho-physiology characters and yield of rice as well as how the application of these GM can help to manage soil fertility issues. Incorporation of *Sesbania aculeata* and *Crotalaria juncea* as GM with N significantly influenced the SPAD reading, LAI, %LI, net assimilation rate, dry matter production, plant height, tillers hill^{-1}, panicle length and number of filled grain panicle^{-1}, which ultimately enhanced the grain yield of rice. Combining *Sesbania aculeata* and *Crotalaria juncea* with N also had a significant role on macro and micro-nutrients status of post-harvest soil.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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