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Effects of green manure crops and tillage practice on maize and rice yields and soil properties

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Abstract

Improper tillage with no manure may cause a range of undesirable processes (destruction of soil structure, accelerate erosion, depletion of organic matter and fertility). A field experiment was conducted to observe the change in soil properties after incorporation of green manure crops and to find out the residual effect of green manure crops along with tillage on maize and rice - yields during 2010-2011 and 2011-2012 at grey terrace soil (poorly drained, grey and clay loam). Three kinds of tillage practices and four types of green manures were tested in a split-plot design with three replications. Tillage practice was assigned in the main plot and green manure crop in the sub-plot. The test crops were maize and transplanted rice (T. aman rice). Three kinds of tillage practices were: T_1 (Minimum tillage), T_2 (Tillage depth up to 10-12 cm), and T_3 (Tillage depth up to 20-25 cm). Four types of green manures were: G_1 (*Sesbania aculeata*), G_2 (*Mimosa invisa*), G_3 (*Vigna radiata*) and G_4 (Control, no green manure crop). The results showed that green manure has significantly increased soil organic matter, soil health and crop growth. The *S. aculeata* produced more biomass and was superior to other two green manure crops. Soil densities, porosity, texture, field capacity and soil moisture were influenced due to the green manure crops and tillage practices. The lowest bulk density (1.45 g cm^{-3}) and particle density (2.48 g cm^{-3}) were found in *S. aculeata* and deep tillage practice. The highest porosity (41.73%) and field capacity (24.24%) were also observed in *S. aculeata* and deep tillage practice. The incorporation of *S. aculeata* and deep tillage practice also showed the highest yield of T. aman and maize. Therefore, application of *S. aculeata* and deep tillage practice may be recommended as green-manure cultivation strategy in T. aman (*O. sativa*) and maize (*Z. mays*) cropping to maintain soil health and sustainable crop production.

Keywords: *Sesbania aculeata*, *Mimosa invisa*, *Vigna radiata*, soil fertility, crop productivity, tillage operation, wheat, maize.

Abbreviations: AEZ _ Agro-ecological zone; ANOVA_Analysis of variance; B_Boron; BARC_ Bangladesh Agricultural Research Council; BARI_Bangladesh Agricultural Research Institute, BD_ Bulk density; BRRI_Bangladesh Rice Research Institute; Ca_Calcium; Cu_copper; DAS_days after sowing; DAT_days after transplanting; DMRT_ Duncan's Multiple Range Test; DTPA_Di-ethelene Triamine Penta Acetic Acid; E longitude_ East longitude; FC_ Field capacity; Fe_Iron; FRG_ Fertilizer recommendation guide;; ha_ hectare; K_ Potassium; Kg_Kilogram; Mg_Magnesium; Mn_Manganese; MoP_ muriate of potash; N latitude_ North latitude; N_ Nitrogen; NFTA_National Forage Testing Association; OM_Organic matter; P_ Phosphorous; PD_ Particle density; RDF_ Recommended dose of fertilizer; S_ Sulphur; T.aman_Transplanted aman; t_ Tonne; TSP_ triple super phosphate.

Introduction

The present decline or stagnation of major crop yields in Bangladesh is the cumulative effect of many soil related constraints. On the other hand, soils of Bangladesh are low in organic matter and horizontal expansion of agricultural land is almost impossible. The soil conservation at moderate levels is one of the serious problems in soil management (Bhuiya, 1987; BARC, 2005). The main reasons of low crop yields are depletion of soil organic matter, nutrient mining, and scant use of bio- and organic-fertilizer and poor organic management (Martius et al., 2002; Jahiruddin and Sattar, 2010). The depletion of soil organic matter caused by high cropping intensity is the main cause of low productivity, which is considered as one of the most serious threats to future sustainability of agriculture in Bangladesh. In Bangladesh most soils have less than 17g kg^{-1} organic matter and some other even less than 10 g kg^{-1} (BARC, 2005). Crop residues and dung are widely used as fuel and fodder which are not returned to soil. Eighty-one percent of total biomass fuel is consumed for domestic cooking (Martius et al., 2002; Khan et al., 2008; Jahiruddin and Sattar, 2010). Decreased organic matter leads to the degradation of soil physical properties including soil water holding capacity and reduced nutrient retention capacity leading to the lower release of nutrients from mineralization of organic matter (Bonari et al., 1994 and Bonini and Alves, 2010). According to recent studies (Khan et al., 2008 and Jahiruddin and Sattar, 2010), almost same amount of organic carbon and total N depletion (%) are observed in different intensive cropping areas of Bangladesh during 1967-2007. Bangladesh has a tropical monsoon climate. Organic-matter content in soil is dependent on agro-climatic conditions and is difficult to conserve at a high level in tropical and subtropical conditions (Bhuiya, 1987 and BARC, 2005). In addition, intensive cropping promotes high levels of nutrient extraction from soils without natural replenishment. Limited practices of legume, green manure and jute based cropping patterns have led to depletion of soil organic matter content in Bangladesh. This may be compensated through maximum return of crop and animal residues to soil, balanced use of chemical fertilizers, use of bio-fertilizers, green manure in crop rotation; and proper utilization of farm manure, night soil, composts and nitrogenous organic materials (Bhuiya, 1987).

Green manures are the crops which are returned into the soil in order to improve the growth of subsequent crops. Green manures offer considerable potential as a source of plant nutrients and organic matter (Yadvinder-Singh et al., 1991). Green manure crops improve the physical, chemical and biological condition of clay soils. It is known that improvement of soils physical condition by adding green manure crops into the soil create the potential for crop growth. The long term benefit of green manure crops is to stabilize yields of subsequent crops during dry seasons (MacRae and Mehuys, 1988). Leguminous crops are the potential crops for their capability of nodule formation and nitrogen fixation. As for example, mungbean can fix nitrogen in the range of 30-40 Kg N ha^{-1} (Rupella and Saxena, 1989).

Tillage is a practice which changes the soil properties, environment and crop production in general. To ensure normal plant growth, the soil must be in such conditions that roots can have enough air, water and nutrients. Tillage techniques are used in order to provide a good seed bed, root development, weed control and manage crop residues, leveling the surface for uniform irrigation and incorporation of manures and fertilizers (Cabeda, 1984). Some contradictory findings have been reported, in which tillage improves soil conditions by altering the mechanical impedance to root penetration, aggregate size distribution, hydraulic conductivity and water holding capacity, which in turn, affects plant growth (Dexter and Woodhead, 1985). Therefore, use of green manures in a cropping pattern can help to restore crop productivity. Compost, cover crops and green manure crops need to be included in the cropping patterns and conservation agriculture to maintain soil physical, chemical and biological properties which is also very important for better production of each component crop in the cropping pattern (Alam, 2010).

A comprehensive and systematic research effort on residual effect of green manure crops into soil along with tillage on subsequent crop yields under green manure crops- maize-rice sequence have not been reported yet. Therefore, the present study was initiated to observe the changes in soil properties after incorporation of green manure crops and tillage practices as well as to find out the residual effect of green manure crops along with tillage on maize and rice yields.

Results and discussion

Biomass production of green manure crops

Weight of fresh and dry biomass was significantly varied among different green manure crops in both years (Table 1). The fresh biomass of green manure crops ranged from 14.20 to 34.80 t ha^{-1} in 2010 and 10.71 to 24.45 t ha^{-1} in 2011. The *Sesbania aculeata* species produced significantly higher fresh biomass (34.80 t ha^{-1} in 2010 and 24.45 t ha^{-1} in 2011) followed by *Mimosa invisa* (20.30 t ha^{-1} in 2010 and 15.12 t ha^{-1} in 2011). The minimum fresh weight was noted in *Vigna radiata* (14.2 t ha^{-1} in 2010 and 10.71 t ha^{-1} in 2011). Among green manure crops, highest dry biomass was also found in *S. aculeata* (6.80 t ha^{-1} in 2010 and 4.18 t ha^{-1} in 2011) and the lowest in *V. radiata* (2.68 t ha^{-1} in 2010 and 2.06 t ha^{-1} in 2011).

Nutrient concentration in green manure crops

Nutrient concentration was varied among the different green manure crops. The *S. aculeata* showed the highest concentration of P (0.98 %), S (0.53%), B (54.6 ppm), Cu (14.2 ppm), Mg (0.22%) and Fe (922 ppm) than the other green manure crops. The highest N concentration (2.88 %) was found in *Mimosa invisa* followed by *S. aculeata* (2.16%) and the lowest was in *V. radiata* (1.54%). *Mimosa invisa* also showed highest Zn concentration (24.2ppm) followed by *V. radiata* (17.0%). The minimum concentration (16.0%) was recorded in *S. aculeata*. The *V. radiata* had higher concentration of K (2.81%) and Ca (4.0%) than other green manure crops. It was observed that *S. aculeata* is rich in micronutrients except Zn than other green manure crops.

Nutrients recycled by green manure crops

The result showed that green manure crops provide a significant source of total N, P, K, S, Zn, B, Ca, Mg, Cu and Fe to the subsequent crop (Table 2). The recycled nutrient was significantly varied among different green manure crops.The highest total N (90.29 kg ha^{-1}) was recycled by *S. aculeata*, which was statistically similar to *M. invisa*. The lowest total N (31.72 kg ha^{-1}) was recycled in *V. radiata*. The *S. aculeata* also showed the highest total recycled P (40.96 kg ha^{-1}) followed by mimosa (24.75 kg ha^{-1}) and the minimum (17.51 kg ha^{-1}) was in *V. radiata*. The highest K, S, Ca and Mg were also recycled in *S. aculeata* and the minimum was in *V. radiata*. Other micronutrients also followed the same trend.

Effect of green-manure crops on soil physical properties

Soil physical properties were influenced by incorporation of green manure crops. The *S. aculeata* showed the lowest bulk density (1.44 g cm^{-3}) and particle density (2.48 g cm^{-3}) followed by mimosa (1.46 cm^{-3} BD and 2.49 cm^{-3} PD) and *V. radiata* (1.49 cm^{-3} BD and 2.50 cm^{-3} PD). The highest bulk (1.55 cm^{-3}) and particle density (2.54 cm^{-3}) were recorded in the control (Table 4a). Bulk density was lower in green manure, which can be attributed to improvement of physical environment of soil (Narayan and Lal, 2006). Sultani et al. (2007) also reported that green manure through *S. aculeata* reduced soil bulk density. A significant decrease in bulk density with an associated increase in total porosity of soil under *S. aculeata* is probably related to greater amount of organic matter deposition and loosening of soil by root action (Haynes, 2000; Lampurlanes and Cantero- Martinez, 2003). The particle density was also followed the same trends like bulk density of soil (Table 3).

The porosity was also influenced due to incorporation of green plant materials. The porosity ranged from 40.00 to 42.51%, having the highest (42.51%) in *S. aculeata* treated plot and the lowest was in the control. Incorporation of green plant biomass improved the soil physical properties was evident from values of bulk density and porosity of soil. Total porosity is inversely related to bulk density, which provides a measure of the porous space left in the soil for air

Table 1. Fresh and dry biomass weight of various green manure crops as influenced by the different treatments.

Treatment	Fresh biomass (t ha^{-1}) 2010	Fresh biomass (t ha^{-1}) 2011	Dry biomass (t ha^{-1}) 2010	Dry biomass(t ha^{-1}) 2011
G_1	34.8 a	24.5 a	6.80 a	4.18 a
G_2	20.3 b	15.1 b	3.72 b	2.72 b
G_3	14.2 c	10.7 c	2.68 c	2.06 c
F value	501**	634**	18.6**	70.7**
CV (%)	6.61	14.5	8.68	10.1

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control. * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT

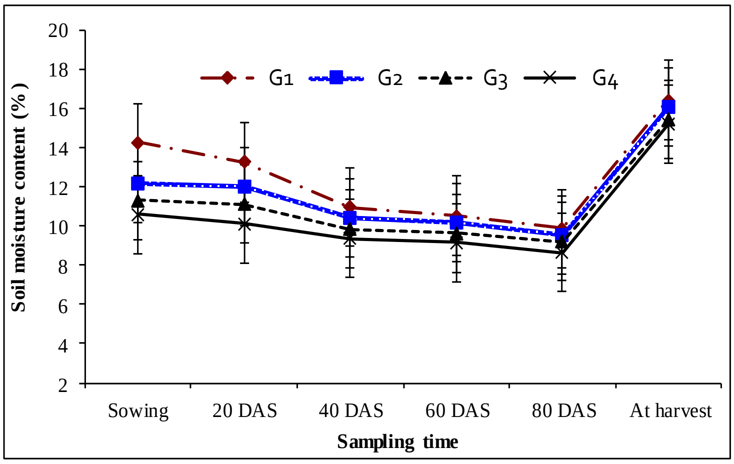

Fig 1. Effect of green manure crops on soil moisture content (%) during maize growing period. Means ± SE are shown in error bar ($p \leq 0.05$).[Note: DAS=days after seedling, G_1= *Sesbania aculeata*, G_2=*Mimosa invisa*, G_3=*Vigna radiata*; G_4= control; F value for sowing (91.36**), for 20DAS (56.77**), for 40 DAS (4.48*), for 60 DAS (25.74**), for 80 DAS (17.22**) and for At harvest (4.41*), where ** denotes significant at the 0.01 probability level].

Table 2. Nutrients uptake by various green manure crops as influenced by the different treatments.

Treatment	Total N (kg ha^{-1})	Total P (kg ha^{-1})	Total K (kg ha^{-1})	Total S (kg ha^{-1})	Total Ca (kg ha^{-1})	Total Mg (kg ha^{-1})	Total Zn (kg ha^{-1})	Total B (kg ha^{-1})	Total Cu (kg ha^{-1})	Total Fe (kg ha^{-1})
G_1	90.3a	40.9a	22.2a	107a	146a	9.19a	0.10	0.22a	0.04a	1.89a
G_2	78.3a	24.7b	11.4b	74.0b	106b	5.44b	0.05	0.14b	0.03b	1.69b
G_3	31.7b	17.5b	9.68b	57.9c	82.4c	4.33b	0.03	0.11b	0.02c	0.97c
F value	261**	237**	253**	70.6**	127**	137**	0.18^{ns}	993**	110*	55.7**
CV (%)	9.15	15.7	14.4	2.51	6.46	18.3	17.3	1.70	12.1	2.52

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control. * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT.

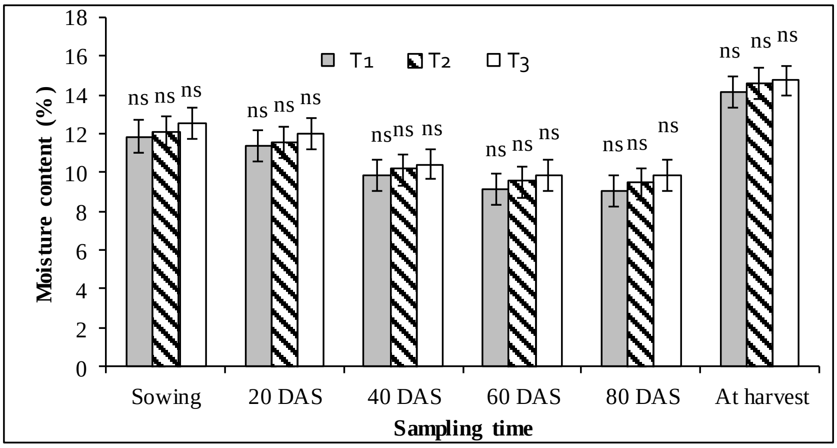

Fig 2. Effect of tillage practices on soil moisture content (%) during maize growing period. Means ± SE are shown in error bar ($p \geq 0.05$). [Note: DAS=days after seedling, T_1= Minimum tillage, T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough) F value for sowing, 20DAS, 40 DAS, 60 DAS, 80 DAS and At harvest was ns (not significant)].

and water movement (Min et al., 2003; Tester, 1990). Maximum increase in total porosity was observed in surface soil, where *S. aculeata* was incorporated as green manure crop. The order of effectiveness of green manure treatments improving total porosity of soil was *S. aculeata* > *M. invisa* >*V. radiata* > control. The results are in agreement with the findings of Sultani et al. (2007). Moisture content at field capacity (FC) was also found variable as influenced by incorporation of green manure crops in soil (Table 3). Moisture content at FC also followed similar trends as of other physical properties.

Effect of tillage on soil physical properties

The physical properties of the soil were influenced by the tillage practices. Soil bulk density varied due to various tillage practices after two cropping cycles. The bulk density ranged from 1.45 to 1.48 g cm^{-3}. The minimum bulk density (1.45 g cm^{-3}) was found in T_3 (Tillage depth up to 20-25 cm, maintained by chisel followed by three times laddering by rotavator) and the highest (Minimum tillage, a slit was opened by hand rake with an adjustment to sow seeds or transplant seedlings) was in T_1 (Table 3). It was observed that bulk density decreased with the increase in tillage depth, which was helpful to the downward growth of crop roots. Ding and Hann (2000); and Domzal and Slowinska (1987) reported that the minimum tillage can increase the soil bulk density. The present results are also consistent with the findings of Katsvairo et al. (2002), Oquist et al. (2006) and Jabro et al. (2008) who reported that bulk density varied non-significantly among different tillage practices. Soil particle density also varied to a very little extent due to various tillage practices after two years of cropping cycles. Particle density ranged from 2.48 to 2.52 g cm^{-3}, having the lowest (2.48 g cm^{-3}) in T_3 and the highest (2.52 cm^{-3}) was in T_1 (Table 3). The observations are in agreement with the findings of Scotter et al. (1979) and Tollner, et al.(1984).

Soil porosity was also influenced by the tillage practices. The maximum porosity (41.53%) was observed in T_3 (tillage up to 20-25 cm depth) and the minimum (41.20%) was in T_1 (minimum tillage). Field capacity was variable at different tillage practices. The field capacity ranged from 23.95 to 24.29%. The minimum field capacity (23.95%) was recorded in T_1 and the maximum (24.29%) was in T_3 (Table 3). Li and Huang (2013) reported that deep tillage broke plough pan, decreased bulk density of tilth soil, increased soil permeability, porosity, field capacity and promoted soil water retention capacity, which corroborated our findings. This was mainly due to under chisel plough, the compact sub-surface soil was loosened which made the soil physical environment more favorable for vigorous and extensive root growth.

Effects of green manure crops on soil moisture

Soil moisture content was significantly ($p \leq 0.05$) influenced by different green manures (Fig. 1). The significantly highest soil moisture content was found in G_1 (*S. aculeata*) followed by G_2 (*M. invisa*) and G_3 (*V. radiata*). The lowest moisture content was observed in the control (Fig. 1). The soil moisture increased in G_1, which might be due to addition of more organic matter to the soil by *S. aculeata* that improves water holding capacity. Soil moisture was decreased gradually from sowing to 80 DAS and the highest moisture (14.7%) was found in April 2012 due to heavy rainfall (141 mm). Bunch (1995) reported that green manures add organic matter into the soil, which improves water holding capacity. These results are in agreement with the findings of our study. Similar results were also observed by Triplett et al. (1968), Zerega et al. (1995) and Pradit et al. (1993) who found that moisture content and infiltration rate were increased after addition of green manure. Sur et al. (1993) also reported that water intake and retention in a clay loam soil were increased significantly due to green-manure in maize.

Effects of tillage on soil moisture

The soil moisture content was influenced due to different tillage practices (Fig. 2). In the whole growing season, the highest soil moisture was recorded in T_3 followed by T_2 and T_1. The lowest moisture content was found in the control (Fig. 2). Soil moisture was gradually decreased with time. In last sampling, there was no significant difference among the tillage practices due to heavy rainfall (141 mm) in April, 2012. It was observed that soil moisture content changed due to tillage practices, having the highest in T_3. These results are in agreement with the findings of Bonari et al. (1994) and Bhatt et al. (2004) who reported that soil moisture content was substantially higher with chisel plowing than the minimum tillage. Cogle et al. (1997) also reported that deep tillage increases the soil porosity and manipulate surface roughness to improve water intake. The deep tillage decreased soil bulk density and penetration resistance up to the tilled depth 40 cm and encouraged more root growth in the deeper soil layers, which in turn, increased water holding capacity (Meherban and Chaudhury, 1998).

Interaction effect of tillage and green manures on physical properties of post-harvest soil

Bulk density, particle density, porosity and soil moisture content at field capacity were varied due to interaction of tillage and green manures (Table 4). The lowest bulk density (1.45 g cm^{-3}) and particle density (2.48 g cm^{-3}) were recorded from *S. aculeata* and deep tillage combination (G_1T_3). The highest BD (1.51 g cm^{-3}) and PD (2.53 g cm^{-3}) were found in the control with minimum tillage (G_4T_1). On the contrary, the highest porosity (41.73%) and moisture content at field capacity (24.24%) were found in *S. aculeata* and deep tillage combination (G_1T_3) and the lowest porosity (40.48%) and moisture content at field capacity (22.96%) were in the control with minimum tillage (G_4T_1).

Effect of green manures on chemical properties of soil after two cropping cycles

Soil pH

Incorporation of green manure crops for consecutive two years reduced the soil pH from initial level of 7.20 in 2010 to 6.52 in 2012 (Table 5). The highest pH (7.48) was observed in control plot, whereas the lowest (6.52) was in *S. aculeata* treated plots. The decrease may be attributed to the higher production of CO_2 and organic acids during decomposition of incorporated green manure crops, but a slight increase of soil pH in no green manure plot. Swarup (1991) also reported that decrease in soil pH resulted from the application of green manure in soil.

Soil organic matter and total N

After crop harvest, organic matter and total N were increased in soil (Table 5). The highest organic matter (1.36%) and total N (0.068%) were found in G_1 (*S. aculeata*) followed by G_2 (mimosa) and G_3 (*V. radiata*). The lowest organic matter

Table 3. Changes of physical properties of post-harvest soil due to different treatments.

Treatment	Bulk density ($g\ cm^{-3}$)	Particle density ($g\ cm^{-3}$)	Porosity (%)	Field capacity (%)	Textural class
Effect of green manures					
G_1	1.44	2.48	42.5	24.2	Clay loam
G_2	1.46	2.49	41.8	23.8	Clay loam
G_3	1.49	2.50	41.2	23.5	Clay loam
G_4	1.53	2.54	40.0	22.9	Clay loam
F value	0.26^{ns}	0.01^{ns}	-	0.16^{ns}	-
Effect of tillage practices					
T_1	1.48	2.52	41.20	23.0	Clay loam
T_2	1.47	2.50	41.27	23.6	Clay loam
T_3	1.45	2.48	41.53	24.3	Clay loam
F value	3.99^{ns}	1.01^{ns}	-	0.18^{ns}	-
CV (%)	2.49	1.82	-	9.93	-
Initial value	1.52	2.48	38.71	23.4	Clay loam

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control; T_1= Minimum tillage; T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough). * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT

Table 4. Interaction effect of tillage practices and green manure crops on soil physical properties.

Treatment	Bulk density ($g\ cm^{-3}$)	Particle density ($g\ cm^{-3}$)	Porosity (%)	Field capacity (%)
G_1T_1	1.46	2.50	41.6	23.6
G_1T_2	1.46	2.49	41.6	23.9
G_1T_3	1.45	2.48	41.7	24.2
$G2T_1$	1.47	2.51	41.3	23.4
G_2T_2	1.47	2.50	41.3	23.7
G_2T_3	1.46	2.49	41.5	24.0
G_3T_1	1.49	2.51	40.8	23.2
G_3T_2	1.48	2.50	40.8	23.5
G_3T_3	1.47	2.49	41.0	23.9
G_4T_1	1.51	2.53	40.5	23.0
G_4T_2	1.50	2.52	40.5	23.3
G_4T_3	1.49	2.51	40.6	23.6
F value	0.44^{ns}	0.07^{ns}	-	1.56^{ns}
CV (%)	2.49	1.82	-	9.93

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control; T_1= Minimum tillage; T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough). * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT

Table 5. Changes of chemical properties of post-harvest soil as influenced by different treatments.

Treatment	pH	OM (%)	Total N (%)	P (ppm)	S (ppm)	B (ppm)	Zn (ppm)	K (ppm)
Effect of green manures								
G_1	6.52d	1.36 a	0.07 a	17.0a	47.0a	0.43a	1.90a	58.5a
G_2	6.77c	0.99 b	0.05 ab	18.0a	45.0a	0.42a	1.61a	50.7a
G_3	7.09b	0.85 c	0.04 ab	19.0a	44.0a	0.42a	1.54a	48.6a
G_4	7.48a	0.65 d	0.03 b	10.0b	36.0b	0.13b	0.88b	31.2b
F value	26.1**	167**	28.5**	429**	33.2**	157**	205**	117**
Effect of tillage practice								
T_1	6.90	1.12a	0.056	16.5	46.0	0.22a	1.53a	62.4a
T_2	6.92	0.91b	0.045	15.0	45.0	0.18b	1.23b	46.8b
T_3	7.08	0.85b	0.043	15.0	42.0	0.15c	1.07c	35.1b
F value	0.47^{ns}	140**	2.18^{ns}	1.80^{ns}	6.10^{ns}	49.3*	51.8*	50.5*
CV (%)	0.73	6.74	6.50	6.50	3.10	4.99	3.73	5.9
Initial	7.20	0.66	0.035	11.0	40.0	0.10	1.18	35.1
Critical level		-	-	14.0	14.0	0.20	2.0	78.0

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control; T_1= Minimum tillage; T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough). * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT

(0.65%) and Total N (0.033%) were found in the control. The increase of organic matter and total N contents in green manure treated plots might be due to addition of more biomass. Several authors reported higher organic matter and N contents due to incorporation of green manures (Biswas and Mukherjee, 1991). Similar results were also observed by Mandal et al. (2003). The control plots showed declining trends of soil organic matter and total N status after two years.

Other nutrients

All other nutrients showed slight increasing trends after incorporation of green manure crops. The highest P content (19.0) was found in G_3 (*V. radiata*) which was statistically similar to G_1 (*S. aculeata*) and G_2 (*M. invisa*) but superior to G_4 (control) (Table 5).The highest S (47 ppm), B (0.43 ppm), Zn (1.90 ppm) and K (58.5 ppm) contents were found in G_1 (*S. aculeata* treated plots) which were identical to G_2 (*M. invisa*) and G_3 (*V. radiata*). In all the cases, control plots gave the lowest values of nutrients.

Effect of tillage on chemical properties of soil after maize harvest

Soil pH, soil organic matter and total N

The soil pH ranged from 6.90 to 7.08. The minimum tillage showed the increasing trends of SOM and total N accumulation compared to deep tillage (Table 5). These results are similar with the studies of Hulugalle and Entwistle (1997), who reported that soil organic matter was lower in extensive/conventional tillage plots compared to reduced tillage plots. Standley et al. (1990) also observed that losses in soil organic matter were less in zero/minimum tillage than disc or blade ploughs. These studies are in agreement with the findings of our study.

Other nutrients

Other nutrients were also influenced by the different tillage practices (Table 5). The highest P content (16.5 ppm) was found in T_1 (minimum tillage, 0-4 cm depth) and the lowest (15 ppm) was in T_3 (tillage up to 20-25 cm depth). Similar trends were also found for S, B, Zn and K, where T_3 (tillage up to 20-25 cm depth) gave the lowest values of nutrients.

Effect of green manure on T. aman yield

The green manure had a considerable residual effect on first succeeding crop, T. aman (Table 6). The highest grain (5.19 and 5.09 t ha^{-1} in 2010 and 2011, respectively) and straw (5.43 and 5.29 t ha^{-1} in 2010 and 2011, respectively) yield of rice were found in G_1 (*S. aculeata*), which was significantly higher than the other treatments. The highest grain yields were recorded in the treatment receiving green manure of *S. aculeata*. The lowest grain (3.83 and 3.48 t ha^{-1} in 2010 and 2011, respectively) and straw (4.06 and 3.97 t ha^{-1} in 2010 and 2011, respectively) yields were in the control. The increases of grain yield in 2010 due to green manure of *S. aculeata*, *M. invisa* and *V. radiata* were about 36, 26 and 14%, respectively, whereas the increases were 46, 30 and 24%, respectively in 2011 over the control.

Effect of green manure on maize yield

The 2nd succeeding crop, maize was influenced by green manure crops (Table 6). The highest grain yields (9.13 t ha^{-1} in 2010-11 and 9.38 t ha^{-1} in 2011-12) were found in the treatment which received green manure of *S. aculeata*, which were significantly higher than the other treatments. The lowest yields (7.54 t ha^{-1} in 2010-11 and 6.78 t ha^{-1} in 2011-12) were recorded in the control. The increases of grain yield in 2010-11 due to green manure of *Sesbania aculeata*, *Mimosa invisa* and *Vigna radiata* were about 21, 14 and 4%, respectively, whereas the increases were 38, 27 and 13%, respectively, in 2011-12 over the control. The straw yields were also followed the same trends.

Effect of tillage practices on the yield of T. aman

The yield of T. aman was significantly influenced due to different tillage practices in the first year (2010) but was not significant in the 2nd year (2011) (Table 7). The highest grain (4. 76 t ha^{-1} in 2010 and 4.66 t ha^{-1} in 2011) and straw yield (4.99 t ha^{-1} in 2010 and 5.45 t ha^{-1} in 2011) of T. aman were recorded in T_3 (tillage up to 20-25 cm depth) followed by T_2 (tillage depth up to 10-12 cm) and the lowest yields were in T_1 (minimum tillage depth).

Effect of *tillage practices on the yield of maize*

Maize yield was varied due to different tillage practices (Table 7). The highest grain (8.47 t ha^{-1} in 2010-11 and 8.43 t ha^{-1} in 2011-12) and straw yield (21.86 t ha^{-1} in 2010-11 and 19.76 t ha^{-1} in 2011-12) of maize were found in T_3 (tillage up to 20-25 cm depth) followed by T_2 (tillage depth up to 10-12 cm) and the lowest yields were in T_1 (minimum tillage depth) in both the years. This might be due to deep tillage (T_3) created favorable soil physical condition, for which root was able to proliferate in the deeper soil layer for storing soil water by this tillage method. These findings are in agreement with the findings of Rahman and Islam (1988) and Barzegar et al. (2004).

Interaction effect of green manures and tillage on the yield of T. aman and maize

The yields of T. aman and maize were influenced by the combination of green manures and tillage practices (Table 8). The grain yield of T. aman ranged from 4.08 to 4.98 t ha^{-1} in 2010 and 3.72 to 4.88 t ha^{-1} in 2011. The highest rice grain yield was found in *S. aculeata* and deep tillage combination (G_1T_3) and the lowest was in the control with minimum tillage (G_4T_1) in both the years of study. The same trend was observed in case of rice straw. The grain yield of maize ranged from 7.82 to 8.80 t ha^{-1} in 2010-2011 and 7.34 to 8.91 t ha^{-1} in 2011. While the highest maize grain yield was found from *S. aculeata* and deep tillage combination (G_1T_3), the lowest was from control with minimum tillage (G_4T_1) in both the years of study. The maize straw yield was the same trend in both the year of experimentation.

Materials and methods

Plant materials

The green manure crops of this cropping system were *Sesbania aculeata, Mimosa invisa and Vigna radiata*. These are fast growing leguminous plants cultivated annually and can accumulate more than 80 Kg Nha^{-1} when grown as green manures (Ghai and Thomas, 1989).

Table 6. Yield of T. aman and maize as influenced by various green manure crops.

Treat.	T. aman 2010				T. aman 2011				Maize 2010-2011				Maize 2011-2012			
	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain increase (%)	Straw increase (%)	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain increase (%)	Straw increase (%)	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain increase (%)	Straw increase (%)	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain increase (%)	Straw increase (%)
G_1	5.19a	5.43 a	35.5	33.7	5.09a	5.29a	46.26	33.3	9.13 a	24.1a	21.1	58.5	9.38a	22.2a	38.4	59.1
G_2	4.84b	5.07 b	26.4	24.9	4.54b	5.23b	30.46	31.7	8.60 b	22.4b	14.1	47.0	8.59b	20.6b	26.7	48.3
G_3	4.35b	4.58 c	13.6	12.8	4.32c	4.62bc	24.14	16.4	7.85 c	19.9c	4.11	31.3	7.69c	17.7c	13.4	27.4
G_4	3.83d	4.06 d	-	-	3.48c	3.97c	-	-	7.54 d	15.2d	-	-	6.78d	13.9d	-	-
F value	20.93**	49.42**	-	-	26.9**	27.0**	-	-	7.00**	24.5**	-	-	12.5**	59.2**	-	-
CV (%)	12.34	3.70	-	-	3.81	8.01	-	-	3.29	4.66	-	-	6.47	7.57	-	-

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control. * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT

Table 7. Effect of tillage practices on the yield of T.aman and maize.

Tillage treat	T. aman 2010		T. aman 2011		Maize yield 2010-2011		Maize yield 2011-2012	
	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})
T_1	4.33 c	4.56 c	3.96	4.49	8.10	19.2	7.89	17.5
T_2	4.58 b	4.82 b	4.45	5.15	8.27	20.5	8.01	18.6
T_3	4.76 a	4.99 a	4.66	5.45	8.47	21.9	8.43	19.8
F value	4.51*	30.5**	21.0^{ns}	449^{ns}	1.23^{ns}	5.31^{ns}	0.59^{ns}	15.08^{ns}
CV (%)	12.34	3.70	3.81	8.01	3.29	4.66	6.47	7.57

Notes: T_1= Minimum tillage; T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough). * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT.

Table 8. Interaction effect of tillage practices and green manure crops on yield of T. aman and maize

Treatment	T. aman 2011		T. aman 2010		Maize 2011-2012		Maize 2010-2011	
	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain (t ha^{-1})	Straw (t ha^{-1})
G_1T_1	4.53	4.89	4.76	5.00	8.64	19.84	8.62	21.7
G_1T_2	4.77	5.22	4.89	5.13	8.70	20.4	8.70	22.3
G_1T_3	4.88	5.37	4.98	5.21	8.91	21.0	8.80	23.0
G_2T_1	4.25	4.86	4.59	4.82	8.24	19.1	8.35	20.8
G_2T_2	4.50	5.19	4.71	4.95	8.30	19.6	8.44	21.4
G_2T_3	4.60	5.34	4.80	5.03	8.51	20.2	8.54	22.1
G_3T_1	4.14	4.56	4.34	4.57	7.79	17.6	7.98	19.6
G_3T_2	4.39	4.89	4.47	4.70	7.85	18.2	8.06	20.2
G_3T_3	4.49	5.04	4.56	4.79	8.06	18.8	8.16	20.9
G_4T_1	3.72	4.23	4.08	4.31	7.34	15.7	7.82	17.2
G_4T_2	3.97	4.56	4.21	4.44	7.40	16.2	7.91	17.9
G_4T_3	4.07	4.71	4.30	4.53	7.61	16.8	8.01	18.5
F value	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	3.81	8.01	12.34	3.70	6.47	7.57	3.29	4.66

Notes: G_1= *Sesbania aculeata*; G_2=*Mimosa invisa*; G_3=*Vigna radiata*; G_4= control; T_1= Minimum tillage; T_2= Tillage up to 10-12 cm depth (power tiller) and T_3=Tillage up to 20-25 cm depth (chisel plough). * Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not significantly different at 5% level of DMRT.

The seeds of green manure crops were collected from Pulse Research Centre (PRC) of BARI, Gazipur, while seeds of maize (cv. BARI Hybrid Maize 5) (*Zea mays*) were collected from the Genetics and Plant Breeding Division, BARI, Gazipur. Maize is the most widely grown grain crop throughout the Americas (FAO, 2009). The seeds of T. aman (cv. BRRI dhan 39) rice (*Oryza sativa* L.) were obtained from the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. Transplanted aman (T. aman) rice (*Oryza sativa* L.) is the major crop usually grown throughout Bangladesh during July-October (TECA, 2013). BRRI dhan 39, is a short life duration (early mature) rice variety and has been released by the BRRI in 1999. Its height is 106 cm, stem strong (which prevent lodging), grain long and narrow. Due to long and narrow grain, early maturity and export quality its market price is high. As early variety, after harvest of BRRI dhan 39, winter crops (maize/ wheat) can easily be cultivated.

Experimental site

An experiment was conducted at the Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh during 2010-2011 and 2011-2012 to observe the changes in soil properties after incorporation of green manure crops and to find out the residual effect of green manure crops incorporation into soil along with tillage on crop yields under Green manure - T. aman- Maize cropping pattern. The study area was in the centre of the agro-ecological zone of Modhupur Tract (AEZ-28) at about $24^0$23´ north latitude and $90^0$08´ east longitude and about 34 km north of Dhaka city. The soil belongs to the Grey Terrace Soils (*Aeric Albaquept*) under the order Inceptisols. The soils were poorly drained, grey and clay loam and overlie heavy, grey, little-altered, deeply weathered Madhupur or Piedmont clay. The major part of the subsoil was an E-horizon (FAO, 1988; Brammer, 1988).The experiment site was a high land having clay loam soil. Bulk density and particle density were 1.52 and 2.48 g cm^{-3}, respectively, while porosity, moisture content and field capacity were 38.7, 18.0 and 23.2%, respectively. The soil was slightly alkaline (pH-7.2) in reaction and low in organic matter (0.66%), total N (0.035%), available P (11 ppm), exchangeable K (35 ppm), Zinc (1.18 ppm) and boron (0.10 ppm) while S, Cu, Mn, Ca and Mg were above critical level (critical levels of P, S, B, Zn, Cu, Mn, K, Ca and Mg were 14, 14, 0.20, 1.0, 5.0, 78, 400 and 96 ppm, respectively). The climate of the experimental area is sub-tropical, wet and humid. Heavy rainfall occurs in the monsoon and scanty in the other times.

Treatments and design

Three kinds of tillage practices and four types of green manures were tested on maize and T. aman rice in a split-plot design with three replications, where tillage was assigned in the main plot and green manure crops in the sub-plot. Three kinds of tillage practices were: T_1 (Minimum tillage, a slit was opened by hand rake with an adjustment to sow seeds or transplant seedlings), T_2 (Tillage depth up to 10-12 cm, maintained by depth control lever of power tiller followed by two times laddering by rotavator) and T_3 (Tillage depth up to 20-25 cm, maintained by chisel followed by three times laddering by rotavator). Four types of green manures were: G_1 (Local dhaincha, *Sesbania aculeata)*, G_2 (*Thornless lozzaboti*, *Mimosa invisa)*, G_3 (Mungbean, *Vigna radiata*) and G_4 (Control, No green manure crop was grown).

Fertilizer rate and application method

Fertilizer rate of Maize and T. aman were N_{250} P_{80} K_{100} S_{20} and N_{70} P_{20} K_{40} S_{15} B_1 kg ha^{-1}, respectively, while, no fertilizer was applied in the green manure crops. Urea, triple superphosphate, mureate of potash and gypsum were applied as chemical source of N, P, K and S, respectively. All fertilizers except urea were applied in 1st crop (T. aman) during final land preparation. Urea was applied in three splits; one third 12 days after transplanting (DAP) and one third at maximum vegetative growth stage (32 DAP) and rest of the urea was applied before panicle initiation stage (45 DAP). In maize, one third nitrogen as urea along with all fertilizers was applied at the final land preparation and remaining urea was applied in two equal splits at 30 and 55 days after sowing. The dose of chemical fertilizer for each component crop was calculated based on soil test results using the fertilizer recommendation guide-2005 (FRG 2005) (BARC, 2005).

Land preparation, seed sowing/transplanting and harvesting

In minimum tillage depth (0-4 cm) seeds were placed just by making furrow with a hand rake. The tillage depth up to 10-12 cm was maintained by a power tiller, whereas the tillage depth up to 20-25 cm was maintained by a chisel plough. The unit plot size was 5m x 4m. Green manure crops (*S. aculeata*, *M. invisa* and *V. radiata*) were broadcasted by hands on 09 April in each year of experimentation and the total biomass of green manure crops was incorporated into soil on 03 June. The seedlings of first subsequent crop, T. aman (*cv.* BRRI dhan 39) (*Oryza sativa*) were transplanted maintaining a spacing of 25 cm × 15 cm on 05 July and harvested on 12 November. After harvesting the T. aman, seeds of second succeeding crop, maize (*cv.* BARI Hybrid Maize 5) (*Zea mays*) were sown with spacing of 75 cm × 25 cm on 13 December and harvested on 11 May. The unit plot size was 5m x 4m and varieties used in the experiment were *cv.* BRRIdhan 39 for T. aman rice and *cv.* BARI Hybrid Maize 5 for maize with corresponding spacing 25cm x 15cm and 75cm x 25cm, respectively.

Intercultural operations

Necessary gap filling in case of rice (T. aman rice) was done at 8 days after transplanting (DAP), whereas gap filling and thinning for maize at 18 days after sowing (DAS). Intercultural operations such as weeding, insecticide spraying, earthing-up (especially for maize) were done as and when necessary.

Data collection

For data collection of maize and T. aman rice, ten plants and ten hills were sampled randomly from each plot. Data of green manure crops and T. aman were recorded from one (1) m^2 area and maize data was recorded from ten randomly selected plants from each plot and then converted into yield per hectare. Both the crop (maize and rice) were cut at the ground level. Threshing, cleaning, and drying of grain were done separately plot wise. The weights of grain and straw were recorded plot wise. Soil samples were collected at 0-25 cm depth from each plot before sowing/ planting and at the end of three cropping cycles.

Plant and soil samples analysis

The soil as well as green manure crop samples were analyzed in the laboratory following standard methods. Soil pH was measured by a combined glass calomel electrode (Ghosh, 1983). Soil organic matter was determined by wet oxidation method (Jackson, 1973), total N by modified Kjeldahl method (Page et al., 1989), available phosphorus by the Olsen method (Olsen et al., 1954), K, Ca and Mg by NH_4OAC method (Black, 1965), Cu, Fe Mn and Zn by DTPA extraction followed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978), B by $CaCl_2$ extraction method (Jeffrey and McCallum, 1988), S by $CaH_2(PO_4)_2.H_2O$ extraction followed by turbedimetric method with $BaCl_2$. Particle size distribution was analyzed by hydrometer method (Black, 1965) and the textural class was determined using the USDA textural triangle. Bulk density and particle density of the soil samples were determined by core sampler method and pycnometer method, respectively (Karim et al., 1988). Moisture content was determined by gravimetric method. The soil porosity was computed from the relationship between bulk density and particle density using the equation 1. Soil field capacity was measured using pressure plate apparatus (Black, 1965).

Porosity (%) = (1 – BD/PD) x 100 (Eq. 1)

Statistical analysis

Analysis of variance for yields, yield parameters were done using ANOVA test and the mean values were compared by DMRT method ($p \leq 0.05$) (Steel and Torrie, 1960). Computation and preparation of graphs were done using Microsoft Excel 2003 Program.

Conclusions

Green manure crops increased soil organic matter, which has improved soil health and crop growth. *S. aculeata* produced more biomass and superior compared to other two green manure crops. Therefore, it was more beneficial for improving soil physical and chemical properties after its incorporation. Soil densities, porosity, texture, field capacity and soil moisture were influenced by green manure crops and tillage practices. The lowest bulk density and particle density were found in *S. aculeata* and deep tillage practices. The highest porosity and field capacity were also observed in this treatment combination. *S. aculeata* and deep tillage combination also caused the highest yield of T. aman and maize. Thus, *S. aculeata* and deep tillage practices are recommended for Green manure-T. aman-Maize cropping pattern for maintaining soil health and sustainable crop production.

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