Research Article

Effect of Tillage Practices on Soil Properties and Crop Productivity in Wheat-Mungbean-Rice Cropping System under Subtropical Climatic Conditions

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This study was conducted to know cropping cycles required to improve OM status in soil and to investigate the effects of medium-term tillage practices on soil properties and crop yields in Grey Terrace soil of Bangladesh under wheat-mungbean-T. aman cropping system. Four different tillage practices, namely, zero tillage (ZT), minimum tillage (MT), conventional tillage (CT), and deep tillage (DT), were studied in a randomized complete block (RCB) design with four replications. Tillage practices showed positive effects on soil properties and crop yields. After four cropping cycles, the highest OM accumulation, the maximum root mass density (0–15 cm soil depth), and the improved physical and chemical properties were recorded in the conservational tillage practices. Bulk and particle densities were decreased due to tillage practices, having the highest reduction of these properties and the highest increase of porosity and field capacity in zero tillage. The highest total N, P, K, and S in their available forms were recorded in zero tillage. All tillage practices showed similar yield after four years of cropping cycles. Therefore, we conclude that zero tillage with 20% residue retention was found to be suitable for soil health and achieving optimum yield under the cropping system in Grey Terrace soil (Aeric Albaquept).

1. Introduction

Holistic management of arable soil is the key to dealing with the most complex, dynamic, and interrelated soil properties, thereby maintaining sustainable agricultural production systems, the lone foundation of human civilization. Any management practice imposed on soil for altering the heterogeneous body may result in generous or harmful outcomes [1, 2]. Unsuitable management practices cause degradation in soil health (depletion of organic matter and other nutrients) as well as decline in crop productivity [3]. Reducing disturbance of soil by reduced tillage influences several physically [4], chemically [5], and biologically [6, 7] interconnected properties of the natural body.

Soil tillage is among the important factors affecting soil properties and crop yield. Among the crop production factors, tillage contributes up to 20% [8] and affects the sustainable use of soil resources through its influence on soil properties [9]. The judicious use of tillage practices overcomes edaphic constraints, whereas inopportune tillage may cause a variety of undesirable outcomes, for example, soil structure destruction, accelerated erosion, loss of organic matter and fertility, and disruption in cycles of water, organic carbon, and plant nutrient [10]. Reducing tillage positively influences several aspects of the soil whereas excessive and unnecessary tillage operations give rise to opposite phenomena that are harmful to soil. Therefore, currently there is a significant interest and emphasis on the shift from extreme tillage to conservation and no-tillage methods for the purpose of controlling erosion process [11]. Conventional tillage practices cause change in soil structure by modifying soil bulk density and soil moisture content. In addition, repeated
disturbance by conventional tillage gives birth to a finer and
loose-setting soil structure while conservation and no-tillage
methods leave the soil intact [12]. This difference results in a
change of characteristics of the pores network. The number,
size, and distribution of pores again control the ability of soil
to store and diffuse air, water, and agricultural chemicals and,
thus, in turn, regulate erosion, runoff, and crop performance
[13]. Losses of soil organic C (SOC) and deterioration in
other properties exaggerated where conventional tillage was
employed [14]. With time, conservation tillage, on the other
hand, improves soil quality indicators [15] including SOC
storage [16].

During the first 4 years of tillage, Rhoton [17] determined
a 10% loss of initial soil organic matter content with plough
tillage. Mann [18] also estimated the soil organic matter
deposition between 16 and 77% caused by the tillage. In most
instances, increased levels of tillage or increased tillage peri-
ods resulted in reductions of soil carbon. When conventional
tillage is converted to conservation tillage, both CO₂ emis-
sions from soil and N uptake by the crop are reduced. Al-Kaisi
[19] reported that reducing tillage significantly decreases SOC
loss from soils with high organic matter content. Continuous
cultivation for cereal cropping in the major cereal growing
areas of Bangladesh leads to lowering the nutritional status
of soil in most of the areas. Hence, the depletion of SOC and
N concerned has taken place, a problem which needs to be
managed through N fixation by the plant. In this situation,
leguminous crop such as mungbean can fix N in the range of
30–40 kg N ha⁻¹ [20].

Cropping system has an immense effect on physical and
chemical soil properties and thereby on crop productivity
[21]. Soil fertility often changes in response to land use and
cropping systems and land management practices [22]. Inten-
sive 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 soils
of Bangladesh [23]. Use of green manure especially legumes
in a cropping pattern could help restore crop productivity.
The major cereal cropping system of South Asia is rice and
wheat grown on the same field but in different seasons during
one year. Currently, about 12 million hectares of land in
Pakistan, Nepal, India, and Bangladesh use this cropping
pattern, accounting for nearly one-fourth of the region's
cereal production. After rice, wheat has become an impor-
tant component of cropping pattern in Bangladesh which is
cultivated mostly after aman rice (lowland rice grown
in the wet season from June to November in Bangladesh
and east India). Crop production could be increased by
adopting appropriate tillage operation and selecting suitable
crops in the cropping pattern including leguminous crops,
which demands intensive field research [23, 24]. Whether
conservation tillage practice performs better than the long-
practiced traditional tillage practices in terms of improve-
ment of edaphic and yield influencing characters of the
specific and unearthy soil-water-plant ecosystem of the region
is still unknown. As the conservation tillage practices have
been reported to manipulate soil positively, they could also
be a solution of poorly managed soil condition in the region
of rice-wheat cropping system. Effect of medium-term tillage
practices on soil properties in Grey Terrace soil under wheat-
mungbean-T. aman (the tall traditional rice, some of which
is deep water rice) cropping system has not been reported.
The present study, therefore, has been initiated with the
following objectives. The specific objective of the study was to
observe how many cropping cycles would be required to build
up organic matter (OM) in soil and the general objectives
were (1) to evaluate the effects of tillage practices on soil
hydrophysical properties, (2) to study the effect of tillage
practices on the yield performances of wheat-mungbean-T.
aman cropping system, and (3) to study the medium-term
effect of tillage practices on organic matter status of soil.

2. Materials and Methods

2.1. Study Area. The field experiment was conducted at the
Bangladesh Agricultural Research Institute (BARI), Gazipur,
Bangladesh, for the four consecutive years from 2008 to 2012.
The physical characteristics and chemical status of the initial
soil are shown in Tables 2 and 3, respectively. The experimen-
tal site is located at the centre of the agroecological zone of
Madhupur tract (AEZ-28) at about 24° 23' north latitude and
90° 08' east longitude having a mean elevation of 8.4 m above
mean sea level. The soil belongs to the Chhiata series of the
Grey Terrace soils (Aeric Albaquert) under the order Incepti-
sols in the USDA Soil Taxonomy [24, 25]. The morphological
and taxonomical characteristics of the experimental site are
shown in Table 1. The textural class was clay loam having
soil pH 5.7 and the land type is medium high. Geographical
position of Gazipur district is presented in Figure 1.

The climate of the experimental area was subtropical, wet,
and humid. Heavy rainfall occurs in the monsoon and is
scarce in other times. The climatic data of the study area
for the period from 2008 to 2012 indicates that the mean
annual rainfall is above 1600 mm of which 72.2% is received
during the main growing season (Kharif: one of the three
seasons in Bengali crop calendar starting from mid-March.
Table 1: Morphological and taxonomical characteristics of the experimental site.

| Mammological characteristics | Value |
|------------------------------|-------|
| Locality                     | BARI, Gazipur, Bangladesh |
| Geographic Position          | 24°0'N latitude, 90°25'E longitude, 8.40 m height above the sea level |
| AEZ                          | Madhupur tract (AEZ 28) |
| General Soil Type             | Near neutral soil pH, Grey Terrace soils (Aeric Albaqupt) |

| Taxonomic Soil Classification | Value |
|-------------------------------|-------|
| Order                         | Inceptisol |
| Suborder                      | Aquept |
| Subgroup                      | Aeric Albaqupt |
| Soil Series                   | Chhiata |
| Physiographic Unit            | Madhupur tract |
| Drainage                      | Moderate |
| Flood Level                   | Above flood level |
| Vegetation                    | Clean cultivation and maintaining cropping pattern |
| Topography                    | Medium high land, 8.40 m height above the sea level |

Table 2: Physical characteristics of the initial soil of the experimental plot.

| Particle size distribution | Value |
|---------------------------|-------|
| Sand (%)                  | 35.30 |
| Silt (%)                  | 37.29 |
| Clay (%)                  | 27.41 |
| Textural class            | Clay loam |
| Bulk density (g cm⁻³)     | 1.60 |
| Particle density (g cm⁻³) | 2.58 |
| Total porosity (%)        | 37.98 |
| Moisture content at field capacity (%) | 24.00 |

And stretching to mid-October, that is, from the middle of March 2009 to the middle of October 2009. July and August alone contributed more than 50% to the annual rainfall (Figure 2). From late October to mid-March, the minimum and maximum temperatures were in the lowest range whereas from mid-March onward up to mid-October temperature was in the maximum range. However, the highest maximum temperature was recorded in May (Figure 3(a)).

The periods from October to May are virtually dry. The relative humidity (%) varied between day and night of which at day time relative humidity (%) was about 90 (%) and at night it fluctuated to a wide range from 43 to 85% in February and March, respectively (Figure 3(b)).

2.2. Cropping Season. There are three major cropping seasons in Bangladesh, namely, Rabi, Kharif-I, and Kharif-II. Rabi season stretches from the middle of October to the middle of March, Kharif-I season stretches from the middle of March to the end of June, and Kharif-II season stretches from early July to the middle of October. In this experiment, wheat was grown in Rabi season, whereas mungbean and T. aman were in the Kharif-I and Kharif-II, respectively.

2.3. The Test Crop. The first crop of the cropping system was wheat (Triticum aestivum L.) cv. Sourav which was collected from the Wheat Research Centre (WRC) of BARI, Gazipur. It is a semidwarf, early maturing variety having large white grain and is suitable for cultivation in both irrigated and rain-fed conditions. The seeds of mungbean (Vigna radiata L. Wilczek) cv. BARI Mung 5 were collected from the Pulse Research Centre of BARI, Gazipur, while seeds of T. aman rice (Oryza sativa L.) cv. BRRI dhan39 were collected from the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh.

2.4. Experimental Design. The experiment was laid out in a randomized complete block design with four replications. The experimental design was performed as follows: zero tillage (ZT: a single slot is opened for seed sowing or transplanting), minimum tillage (MT: ploughed by power tiller maintaining depth by depth control lever up to 6–8 cm), conventional tillage (CT: similar to MT up to 14–16 cm depth), and deep tillage (DT: tillage by chisel plough up to 24–26 cm depth). The unit plot size was 5 m × 4 m.

2.5. Fertilizer Application and Other Intercultural Operations. The fertilizer doses for wheat (Sourav), mungbean, and T. aman rice were N₁₂₀ P₃₅ K₇₅ Zn₂, N₂₀ P₁₀ K₃₅ S₅, and N₉₀ P₁₈ K₄₈ S₇₅ kg ha⁻¹ along with cow dung (CD) 5 ha⁻¹, respectively, based on higher yield goal [25]. The fertilizer requirements were calculated on soil test basis. In the case of first crop (wheat) one third urea, whole amount of triple superphosphate (TSP) and cow dung were applied during final land preparation. The rest of the urea, MoP, gypsum, and ZnSO₄ were applied in two equal splits at 3rd and 5th weeks after seed sowing. For second crop (mungbean), whole amount of fertilizers was applied during final land preparation. For the third crop (T. aman rice), one third of urea...
Table 3: Chemical status of the initial soil of the experimental plot.

| Depth (cm) | pH  | OM (%) | Total N (%) | P (mg kg\(^{-1}\)) | S (mg kg\(^{-1}\)) | B (mg kg\(^{-1}\)) | Cu (mg kg\(^{-1}\)) | Fe (mg kg\(^{-1}\)) | Mn (mg kg\(^{-1}\)) | Zn (mg kg\(^{-1}\)) | K (mg kg\(^{-1}\)) | Ca (mg kg\(^{-1}\)) | Mg (mg kg\(^{-1}\)) |
|-----------|-----|--------|-------------|-------------------|------------------|---------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 0–25      | 5.7 | 1.30   | 0.085       | 13.1             | 12.1            | 0.15          | 7.34           | 590.0          | 17.63          | 2.12           | 70.0           | 1202.0        | 240.0         |
| Critical level | —   | 14   | 14          | 0.20             | 1.0             | 10.0          | 5.00           | 2.00            | 78.0           | 400.0         | 96.0           | 400.0         | 100.0         |

Figure 3: Temperature (a) and relative humidity (b) of the experimental site.

2.6. Seed Sowing/Transplanting. Wheat (cv. shatabdi) seeds were sown on the last week of November for all the years of experimentation while the first subsequent crop, mungbean (cv. BARI mung 5), was broadcasted by hands on the second week of April and the second subsequent crop, T. aman (cv. BRRI dhan 39), was transplanted on the first week of July. After picking pods twice, the total biomass of mungbean was incorporated into soil. The spacing maintained for BRRI dhan 39 and wheat was 25 × 15 cm and 15 × 5 cm, respectively. The experimental plots were kept fixed during the entire growth periods.

2.7. Sampling Procedures. In all the cropping years, the wheat was harvested in the first week of April whereas the mungbean harvesting was started in the first week of June and continued up to the third week of June. Likewise, T. aman rice was harvested in the first week of November at full maturity. Data of wheat, mungbean, and T. aman were recorded from one-square-meter area from each plot and then converted into yield per hectare. All the crops were cut at the ground level. Threshing, cleaning, and drying of grain were done separately plotwise. The weights of grain and straw were recorded plotwise. About twenty percent (20%) residue was retained in experimental field in case of wheat and rice crops. Soil samples were collected at 0–25 cm depth from each plot before sowing/planting and at the end of each cropping cycle in every year.

2.8. Soil Analyses. Soil samples were then analyzed for pH, OM, N, P, K, and Zn following standard procedures [5]. Soil pH was measured using a glass electrode pH meter (WTW pH 522) at a soil-water ratio of 1:2.5 as described by Ghosh [27], soil organic C was measured by Walkley and Black’s wet oxidation method as described by Jackson et al. [28], total N was measured by micro-Kjeldahl method [5]; available P was determined following the Olsen method [28], exchangeable K was determined using NH\(_4\)OAC extraction method [26], S was determined by turbidimetric method with the help of a spectrophotometer using a wave length of 420 nm [5], Ca was determined by complexometric method of titration using Na\(_2\)TA as a complexing agent [5], Mg was determined by using NH\(_4\)OAC extraction method [26], and available Zn, Cu, Fe, and Mn were determined by using diethylenetriamine pentaacetic acid (DTPA) extraction method [29]. Particle size distribution was done by hydrometer method [26] 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 [30]. The soil porosity was computed from the relationship between bulk
density and particle density using (1). Soil field capacity and permanent wilting point were measured using pressure plate apparatus, while available water content was calculated using (2) [26]. Consider
\[
\text{Porosity} \, (\%) = \left( 1 - \frac{\text{BD}}{\text{PD}} \right) \times 100, \quad (1)
\]

where BD is bulk density (g cm\(^{-3}\)), PD is particle density (g cm\(^{-3}\)), and
\[
d = \frac{\text{FC} - \text{PWP}}{100} \times \text{BD} \times \text{Soil depth}, \quad (2)
\]

where \(d\) is available water content (cm) at 60 cm depth, FC is field capacity (%), and PWP is permanent wilting point (%).

The double ring infiltrometer method was used to determine the water infiltration and was computed as cumulative infiltration and rate of infiltration in mm h\(^{-1}\).

2.9. Roots Analyses. The root mass density was measured at maximum vegetative stage in three different soil depths (0–15, 15–30, and 30–45 cm) with auger-like root sampler 15 cm (6 inch) in diameter and 22.5 cm (9 inch) in length using (3) [31]. Consider
\[
\text{Root mass density} = \frac{\text{Mass of root}}{\text{Total volume of soil}} \, \text{mg cm}^{-3}. \quad (3)
\]

2.10. Statistical Analysis. The analysis of variance for various crop yields and soil physical and chemical properties was performed following ANOVA technique and the mean values were adjudged by Duncan’s multiple range test (DMRT) method [32]. Computation and preparation of graphs were done using Microsoft Excel 2003 Program.

3. Results

3.1. Changes of Soil Physical Properties

3.1.1. Bulk Density, Particle Density, Porosity, Field Capacity, and Permanent Wilting Point. Bulk density (BD), particle density (PD), porosity, field capacity, and permanent wilting point were influenced by the different tillage practices. Soil bulk density varied considerably \((P \leq 0.05)\) among tillage practices. After four years, bulk density was decreased due to tillage practices. The highest BD reduction (6.41%) was found in ZT followed by MT (3.95%), while DT showed the lowest reduction (Figure 4(a)). The soil particle density was decreased after four years of study. The highest decrease was noted in ZT and the minimum was in DT (Figure 4(b)). After four years of cropping cycles, porosity was increased from the initial value (6.2, 2.9, and 0.69% increase in ZT, MT, and CT, resp.) (Figure 5(a)). The field capacity (FC) was also increased due to different tillage practices. The highest FC increase (14.65%) was found in ZT followed by MT (8.52%). CT showed the lowest increase of field capacity from the first year value (Figure 5(b)). Permanent wilting point (PWP) was also influenced by the different tillage practices. After four years, the permanent wilting point was decreased due to tillage practices (Figure 6(c)). The highest reduction (11.91%) was found in ZT followed by CT (8.32%) and the lowest reduction (1.13%) in DT.

3.1.2. Soil Water Content. After four years of experimentation, the result showed no significant variation in available water content (AWC) due to different tillage treatments whereas AWCs were significant after completion of the first and second cropping cycles. In the end of the study, maximum available water content (AWC) was found in the deep tillage (16.50 cm) and the minimum AWC (14.30 cm) in ZT (Figure 6(a)).
Figure 5: Change in soil porosity (a) and field capacity (b) as influenced by different tillage practices (year most recent first). Notes: ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage. Means ± SE are shown in error bar (P ≤ 0.05).

Figure 6: Effect of tillage practice on available water content of soils (a), cumulative infiltration (b), and permanent wilting point (c) (most recent year first). Notes: ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage. Means ± SE are shown in error bar (P ≤ 0.05).
3.1.3. Infiltration. Infiltration of water into soil was influenced by different tillage practices. The infiltration rate was found to be increased after every cropping cycle. After four years, the highest increase (18.44%) was found in ZT followed by MT (7.35%) whereas CT and DT showed decreasing trend after two years (Figure 6(b)). The maximum reduction (3.31%) was observed in DT and the minimum was in CT. The highest intercept was found in DT \((K = 5.203)\) followed by CT \((K = 3.92)\) which explains that deep tillage has higher initial infiltration (Figure 7).

3.1.4. Organic Matter Status of Postharvest Soil. The organic matter content in the initial soil was 1.3% but changed due to different tillage practices after wheat-mungbean-T. *amam* cropping cycles. Organic matter ranged from 1.3 to 1.5% in 2009 and from 1.2 to 1.7% in 2010 (Figure 8(a)) of which the highest OM content of the range (1.7%) was found in ZT and the lowest (1.2%) in DT in both years. In 2011 and 2012, the maximum organic matter content (1.9 and 2.0% in 2011 and 2012, resp.) was recorded in ZT, which was followed by MT (1.8% in 2011 and 2012). DT showed the
minimum organic matter (1.1%) (Figure 8(a)). In 2012, the SOM content in ZT was 34.48%, 31.03%, and 25.86% higher than the SOM in 2009, 2010, and 2011, respectively. After four years of experimentation, the SOM content in ZT was 54.76%, 32.00%, and 13.79% greater than the DT, CT, and MT, respectively (Figure 8(a)). It was found that SOM content gradually increased in ZT with increasing time but the reverse is true in the case of DT. After four years, SOM increased by 50% in ZT compared to initial status whereas MT and CT showed comparatively less increment (Figure 8(a)).

3.2. The Nutrient Status in Postharvest Soil after Every Cropping Cycle. The nutrient concentrations were significantly variable ($P \leq 0.05$) among different tillage practices (Table 8 and Figure 8). The total N (%) content ranged from 0.063 to 0.076% in 2009 and from 0.057 to 0.082% in 2010. In 2010, the maximum total N content (0.082%) was found in ZT while MT showed the highest total N (0.076%) in 2009. The minimum total N content (0.063 and 0.057% for 2009 and 2010, resp.) was noted in DT (Figure 8(b)). In 2011 and 2012, ZT showed the highest total N (%) content (0.094 and 0.099% for 2011 and 2012, resp.) followed by MT and the lowest (0.056 and 0.057% for 2011 and 2012, resp.) was in DT. After four years, the total N content was 73.68, 32.0, and 13.79% higher in ZT than the DT, CT, and MT, respectively (Figure 8(b)). It was observed that the total N (%) content gradually increased in ZT and MT with progressing time (Figure 8(b)).

Phosphorus content was also significantly influenced ($P \leq 0.05$) by the different tillage practices (Table 8). In 2011 and 2012, the highest phosphorus content (18.54 and 20.32 mg kg$^{-1}$ for 2011 and 2012, resp.) was found in ZT which was significantly higher than the other tillage practices. The lowest phosphorus content (13.76 and 14.32 mg kg$^{-1}$) was recorded in DT. The P content was not significantly varied ($P \geq 0.05$) among different tillage practices in 2009 and 2010. However, it ranged from 12.65 to 13.99 mg kg$^{-1}$ and from 13.21 to 14.96 mg kg$^{-1}$ in 2009 and 2010, respectively. The maximum P content (13.99 and 14.86 ppm for 2009 and 2010, resp.) was detected in ZT and the minimum (12.05 and 13.21 ppm for 2009 and 2010, resp.) was in DT. After four years, the available P was 41.90, 36.74, and 9.66% higher in ZT than the DT, CT, and MT, respectively (Table 8).

Sulphur content was significantly varied ($P \leq 0.05$) among different tillage practices in all the years. In 2009 and 2010, the highest sulphur (14.00 and 16.12 for 2009 and 2010, resp.) content was found in ZT followed by MT. The lowest S content (12.52 and 13.52 ppm for 2009 and 2010, resp.) was noted in DT (Table 8). In 2011 and 2012, ZT also showed the maximum S content (17.23 and 18.89 ppm for 2011 and 2012, resp.) which was significantly higher than the other tillage practices followed by MT (15.21 and 15.89 ppm for 2011 and 2012, resp.). The lowest S content (12.05 and 13.21 ppm for 2011 and 2012, resp.) was also in DT (Table 8). After four years of experimentation, available S content was 34.45, 30.73, and 18.88% higher in ZT than the DT, CT, and MT, respectively.

Potassium content also followed the same trend as N, P, and S. Potassium content was significantly influenced ($P \leq 0.05$) due to different tillage practices only in 2012. It ranged from 78.0 to 93.61 ppm in 2011 and from 74.1 to 105.3 ppm in 2012. ZT showed the highest concentration of K in all the years and the minimum was in DT (Table 8). After four years of cropping cycles, available K in ZT was 42.11, 35.0, and 17.39% higher than the DT, CT, and MT, respectively (Table 8).

3.3. Effect of Tillage on Root Mass Density of Wheat. The root mass density of wheat was measured at three soil depths and variations among ($P \leq 0.05$) tillage practices at different depths (Table 4) were found. The highest root mass density was found in 0–15 cm depth followed by 15–30 cm depth. The lowest root mass density was noted in 30–45 cm depth (Table 4). In surface soil, ZT showed the maximum root mass density (9.99 mg cm$^{-3}$) followed by MT (9.92 mg cm$^{-3}$). The
Table 4: Effect of tillage practice on root mass density of wheat and rice.

| Treatments | Wheat | Rice |
|------------|-------|------|
|            | 0–15 cm | 15–30 cm | 30–45 cm | Total | 0–15 cm | 15–30 cm | 30–45 cm | Total |
| ZT         | 9.99   | 1.98   | 0.87b   | 12.84 | 5.40a   | 0.98b   | 0.49b   | 6.87 |
| MT         | 9.92   | 2.26b  | 0.93b   | 13.11 | 4.90b   | 1.26b   | 0.63b   | 6.79 |
| CT         | 8.72   | 2.87ab | 1.21b   | 12.80 | 4.75b   | 1.87a   | 0.81a   | 7.43 |
| DT         | 7.21   | 2.96a  | 1.54a   | 11.71 | 4.64b   | 1.96a   | 0.94a   | 7.54 |
| SE (±)     | 0.89   | 0.19   | 0.07    | —     | 0.09    | 0.18    | 0.06    | —    |

Figures in a column having common letter(s) do not differ significantly at 5% level of DMRT.

ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage.

Table 5: The yield of wheat as influenced by different tillage practices.

| Treatment | Grain yield (t ha⁻¹) | Straw yield (t ha⁻¹) |
|-----------|----------------------|----------------------|
|           | 2009 | 2010 | 2011 | 2012 | 2009 | 2010 | 2011 | 2012 |
| ZT        | 2.76b | 3.00b | 3.53 | 3.69 | 4.45c | 3.99 | 4.22 | 4.38 |
| MT        | 3.89a | 3.88a | 3.71 | 3.78 | 5.10bc | 4.60 | 4.80 | 4.60 |
| CT        | 4.22a | 4.00a | 3.88 | 3.95 | 5.50ab | 5.80 | 4.91 | 5.00 |
| DT        | 4.50a | 4.46a | 4.13 | 4.11 | 6.00a  | 5.92 | 5.31 | 5.34 |
| SE (±)    | 0.19  | 0.20  | 0.39 | 0.25 | 0.25   | 0.60 | 0.41 | 0.51 |

Figures in a column having common letter(s) do not differ significantly at 5% level of DMRT.

ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage.

minimum density was recorded in DT (Table 4). In 30–45 cm depth, the highest root mass density (1.54 mg cm⁻³) was found in DT and the lowest (0.87 mg cm⁻³) was in ZT. As root mass density was highest in the surface soil, tillage effects on the surface would be more important than the deeper layer.

3.4. Effect of Tillage on Root Mass Density of Rice. The root mass density of rice was also significantly (P ≤ 0.05) influenced by the tillage practices (Table 4). In the surface soil, the root mass density was significantly varied among tillage treatments. The maximum root mass density of 5.40 mg cm⁻³ was recorded in zero tillage. The deep tillage showed the highest root mass density (0.94 mg cm⁻³) in the deeper layer and the lowest (0.49 mg cm⁻³) was in ZT. Among the depths, surface soil showed the maximum root mass density followed by subsurface and the minimum density was noted in the deeper layer. Though the DT showed the highest root mass density in deeper layer, this layer contains very small amount of roots, whereas the maximum root mass density was found in ZT at surface soil where maximum amount of roots was recorded compared to deep layer (Table 4).

3.5. Effect of Tillage on the Yield of Wheat. The wheat yield was significantly influenced (P ≤ 0.05) by the different tillage practices from 2009 to 2010. The highest grain yield (4.50 and 4.46 t ha⁻¹ for 2009 and 2010, resp.) was found in deep tillage followed by CT (4.22 and 4.00 t ha⁻¹ for 2009 and 2010, resp.). The lowest grain yield (2.76 and 3.00 t ha⁻¹ for 2009 and 2010, resp.) was obtained in ZT (Table 5). The deep tillage also showed the highest straw yield (6.00 and 5.92 t ha⁻¹ for 2009 and 2010, resp.) followed by CT (5.50 and 5.80 t ha⁻¹ for 2009 and 2010, resp.) and MT (5.10 and 4.60 t ha⁻¹ for 2009 and 2010, resp.). The minimum straw was also obtained in ZT. In 2011 and 2012, the wheat grain yield was not significantly varied (P ≥ 0.05) among tillage practices. The wheat grain yield ranged from 3.53 to 4.13 t ha⁻¹ in 2011 and from 3.69 to 4.11 t ha⁻¹ in 2012. After four years, the yield gap was very minimal (negligible) among different tillage practices, though the deep tillage showed the highest yield. In the case of straw yields, a similar trend was found.

3.6. Mungbean Yield. Among the four years, mungbean yield was not significantly influenced (P ≥ 0.05) by the different tillage practices except for the yield in 2010 (Table 6). After four years (in 2012), the mungbean grain yield ranged from 792 to 820 kg ha⁻¹. The highest yield (820 kg ha⁻¹) was found in DT followed by ZT (812 kg ha⁻¹). The lowest yield (792 kg ha⁻¹) was noted in MT (Table 6). It was found that the yield difference was negligible among the tillage practices after four-year cropping cycles.

3.7. Effect of Tillage Practices on the Yield of T. aman. In 2009 and 2010, the T. aman yields were significantly influenced (P ≤ 0.05) by the different tillage practices. The grain yield ranged from 2.87 to 4.56 t ha⁻¹ in 2009 and from 3.64 to 4.63 t ha⁻¹ in 2010. The highest grain yield (4.50 and 4.63 t ha⁻¹ for 2009 and 2010, resp.) was found in DT. The minimum grain yield (2.87 and 3.64 for 2009 and 2010,
Tables 6 and 7: Effects of tillage practice on the yield of crops in wheat-mungbean-T. aman cropping system.

Table 6: Effect of tillage practice on the yield of mungbean.

| Treatment | Grain yield (kg ha\(^{-1}\)) 2009 | Biomass yield (t ha\(^{-1}\)) 2009 | Grain yield (kg ha\(^{-1}\)) 2010 | Biomass yield (t ha\(^{-1}\)) 2010 | Grain yield (kg ha\(^{-1}\)) 2011 | Biomass yield (t ha\(^{-1}\)) 2011 | Grain yield (kg ha\(^{-1}\)) 2012 | Biomass yield (t ha\(^{-1}\)) 2012 |
|-----------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| ZT        | 632                              | 6.26                             | 644\(^{a}\)                      | 6.39\(^{b}\)                      | 780                              | 7.26                             | 812                              | 7.56                             |
| MT        | 784                              | 7.12                             | 841\(^{b}\)                      | 7.83\(^{a}\)                      | 785                              | 7.28                             | 792                              | 7.60                             |
| CT        | 837                              | 7.82                             | 1000\(^{a}\)                     | 7.68\(^{a}\)                      | 800                              | 7.62                             | 800                              | 7.87                             |
| DT        | 882                              | 8.15                             | 1100\(^{a}\)                     | 8.29\(^{a}\)                      | 820                              | 8.00                             | 820                              | 8.10                             |
| SE (±)    | 12.56                            | 0.14                             | 10.11                            | 0.12                             | 12.11                            | 0.13                             | 11.57                            | 0.13                             |

Figures in a column having common letter(s) do not differ significantly at 5% level of DMRT.
ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage.

Table 7: The yield of T. aman as influenced by different tillage practices.

| Treatment | Grain yield (t ha\(^{-1}\)) 2009 | Grain yield (t ha\(^{-1}\)) 2010 | Grain yield (t ha\(^{-1}\)) 2011 | Grain yield (t ha\(^{-1}\)) 2012 |
|-----------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| ZT        | 2.87\(^{a}\)                     | 3.64\(^{b}\)                     | 4.18                             | 4.49                             |
| MT        | 3.77\(^{b}\)                     | 3.84\(^{ab}\)                    | 4.24                             | 4.30                             |
| CT        | 4.40\(^{a}\)                     | 4.29\(^{ab}\)                    | 4.29                             | 4.37                             |
| DT        | 4.56\(^{a}\)                     | 4.63\(^{a}\)                     | 4.43                             | 4.51                             |
| SE (±)    | 0.13                             | 0.28                             | 0.17                             | 0.12                             |

Figures in a column having common letter(s) do not differ significantly at 5% level of DMRT.
ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage.

res pers) was recorded in ZT. After two years, rice yield was not significantly variable \((P \geq 0.05)\) among tillage practices (Table 7).

4. Discussion

The experiment was conducted during four years indicating that zero and minimum tillage practices had significant influence on soil physical and chemical properties and yields of crops in wheat-mungbean-T. aman cropping system, compared to conventional and deep tillage practices.

The bulk density \((Bd)\) was decreased by 9.59, 9.59, 10.34, and 11.11% in DT, CT, MT, and ZT, respectively, compared to initial value. Different tillage practices showed more or less similar influence on bulk density. After the completion of four years, it was found that there was no significant \((P \geq 0.05)\) difference among the different tillage practices. This might be due to the deposition of OM in ZT practice. Soil bulk density is the significant indicator of change of soil physical health and water retention capacity under different tillage depths [33]. A similar result was reported by Sarwar et al. [34]. In New South Wales (NSW), Australia, the soil Bd was reduced by 6.7% in no tillage (at 50 cm depth) compared to conventional tillage after 14 years [35]. He et al. [35] reported that the mean bulk density \((0–30\, \text{cm soil layer depth})\) under NT and CT treatments was 1.40 and 1.41 Mg m\(^{-3}\), respectively, and the difference was negligible in the long terms which is in agreement with the findings of our study. In Chinese Loess Plateau, crop stubble retention under no tillage and controlled traffic has been reported to increase soil organic matter and biotic activity, thereby reducing bulk density in the surface soil layer [35, 36]. Soil organic C has a direct impact on the bulk density or inversely on the porosity of soil, since the particle density of organic matter is considerably lower than that of mineral soil and soil organic matter is often associated with increased aggregation and permanent pore development as a result of soil biological activity [37]. The changes in soil bulk density in 0–0.30 m soil layer are consistent with the porosity results. After 8 years of different management, the mean soil bulk density in 2007 was 0.8–1.5% lower in NT than the CT at Daxing and Changping. The reduced bulk density in NT could be attributed to higher organic matter content [38] and better aggregation [39]. Soil particle density \((Pd)\) was varied insignificantly \((P \geq 0.05)\) among tillage practices after four years of experimentation. For an average between 0 and 25 cm depth, particle density was found to be decreasing in ZT with time \((2.56 \, \text{g cm}^{-3})\) as compared to deep tillage \((2.55 \, \text{g cm}^{-3})\) where particle density was stuck at a fairly constant level. The decrease of Pd in ZT \((P \geq 0.05)\) might be due to accumulation of organic matter (OM) with time. A similar result was also observed by Rühlmann et al. [39] where Pd decreased in top soil and it was related to variation in SOC.

The effects of tillage practices on porosity were smaller but consistently positive over years. After 4 years, porosity was increased in soil from the initial year due to tillage practices. The increase of soil porosity in ZT might be due to the addition of OM and crop residues which was caused by zero and minimum disturbance of soil. Similar results were also reported by He et al. [35]. Many studies have indicated that tillage systems significantly influenced the soil pore size distribution [40]. However, our results were in agreement with the findings of He et al. [35] who reported that total porosity in the 0–15 cm layer was similar under different
treatments and also with that of the work of Zhang and Song et al. [40] where no significant difference in porosity was found at the surface layer. Zhu et al. [41] also reported that no tillage with mulch was found to increase 5.5% of total porosity in 0–30 cm soil layer compared to traditional tillage after 4 years.

Soil moisture retentive characteristics (SWR) were varied by tillage practices. Soil water retention (SWR) at field capacity (−33 kPa) was initially higher in the deep tillage (P ≥ 0.05) but it was gradually increasing in the soil treated with zero tillage with the advancement of experiment. Plant-available water content gave almost similar result (P ≥ 0.05) to soil water retention at FC. Higher difference was also observed in 0–25 cm depth after completion of the first cropping cycle, where AWC was 36.68, 28.18, and 14.78% lower in ZT than the DT, CT, and MT, respectively. After four cropping cycles, the results reflected insignificant AWC among different tillage practices. The increasing trend of water retention in the soil under ZT practices also implied water uptake increase by the crop, resulting in a gradual improvement of crops yield in zero tillage compared to the other tillage practices in the dry season where yields almost remained constant or decreasing in some cases with time. Soils under no-tillage practices have greater water storage capacity than the tilled soils [42]. Fernández-Ugalde [43] conducted an experiment for a medium-term basis and found that the SWR at field capacity was significantly higher in ZT than the CT and reported that these differences were particularly noticeable in the soil surface depth where soil water retention was 23% lower in CT than in NT. In the present study, SWR was found to be increasing in ZT practice with experiment progressing ahead even though the soil water content at field capacity (FC) during the initial year was found to be significantly higher (P ≤ 0.05) with DT. In the long run, SWR and AWC would be found to be significantly higher in zero tillage than the other tillage practices as the experiment showed the evidence of OM build-up and other physical characteristics favourable for this. Besides, infiltration is an important soil feature controlling leaching, runoff, and crop water availability [44].

After the first cropping cycle, the variation in soil water infiltration was higher among different tillage practices than the infiltration variation four years apart which was found to be narrowing down (P ≥ 0.05). ZT practices promote infiltration and water retention year after year. Schwen et al. [44] reported that soils under no-tillage treatment have greater infiltration rates than the tilled soils. With management for less than a few years, water infiltration in NT may be similar or lower than the CT due to initial compaction and lack of sufficient biological activity for development of stable soil structure [45]. Conservation tillage practice with judicious crop residue management improves aggregate stability [46] and leads to reduced soil detachment and improved infiltration rates [47]. Surface OM is also essential for water infiltration and conservation of nutrients [48]. Wang et al. [49] also reported that conservation tillage may delay run-off by 12–16 min in heavy rainfall and improve final infiltration rate by 60.9% in comparison with conventional mouldboard ploughing in Shanxi province.

The root mass density (RMD) of wheat and rice varied (P ≤ 0.05) among the tillage practices and different soil depths. The total RMD of three sampling depths for both crops was found close in range (13.11–11.71 and 7.54–6.87 mg cm⁻³ for wheat and rice, resp.). In 0–15 cm depth, the roots growth was higher in ZT and MT than the CT and DT but the reverse is true in case of subsurface (15–30 cm) and deep soils (30–45 cm). Therefore, ZT plays an important role in root mass density distribution in the soil. The incorporation of biomass from mungbean favoured maximum root growth [50, 51]. The root mass density was drastically reduced downward, which was associated with the increased soil bulk density in deeper zone. Root proliferation or extensibility was obstructed by the dense or compact layer of the soil profile [52]. Similar results were found by Parker and Lear [53] and Alam and Matin [54] in different crops.

It was observed that the OM content (%) was found to be decreased in deep tillage after each cropping cycle of wheat-mungbean-T. aman whereas organic matter was gradually deposited in the soils where no or minimum disturbance occurred throughout the four cropping cycles. A similar result was also found by Chan and Heenan et al. [55] in different tillage practices. Zero tillage along with addition of organic matter and crop residues in the cropping system has been reported to increase soil organic matter significantly in the 0–25 cm soil layer compared to DT after 4 years. Zhu et al. [41] also observed a similar result where ZT had 4.3% SOM in the 0–30 cm soil layer compared to traditional tillage after 4 years. In addition, improvements of crop yields have been documented where conservation tillage was practiced [56, 57]. Ma and Tong [57] reported that the winter wheat yield in conservation tillage was 10–20% higher than

### Table 8: Effect of tillage practice on available P, available K, and available S after wheat-mungbean-T. aman cropping sequence.

| Treatment | P (ppm) | K (ppm) | S (ppm) |
|-----------|---------|---------|---------|
|           | 2009    | 2010    | 2011    | 2012    | 2009    | 2010    | 2011    | 2012    | 2009    | 2010    | 2011    | 2012    |
| ZT        | 13.99⁺  | 14.96⁺  | 18.54⁺  | 20.32⁺  | 89.7    | 93.6    | 105.3⁺  | 14.00⁺  | 16.12⁺  | 17.23⁺  | 18.89⁺  |
| MT        | 13.97⁺  | 14.13⁺  | 15.43ᵇ  | 18.53ᵇ  | 89.7    | 85.8    | 89.7ᵇ  | 13.56ᵇ  | 15.27ᵇ  | 15.21ᵇ  | 15.89ᵇ  |
| CT        | 13.21⁺  | 13.92⁺  | 14.90ᵇ  | 14.86⁺  | 85.8    | 81.9    | 78.0ᶜ  | 13.32ᵇ  | 14.23ᵇ  | 14.43ᵇ  | 14.45ᵇ  |
| DT        | 12.65⁺  | 13.21⁺  | 13.76ᵇ  | 14.32⁺  | 85.8    | 78.0    | 74.1ᶜ  | 12.52ᵇ  | 13.52ᶜ  | 14.08ᵇ  | 14.05ᵇ  |
| SE (±)    | 0.95    | 1.09    | 0.61    | 0.27    | 8.08    | 5.69    | 5.39    | 2.06    | 0.36    | 0.43    | 0.44    | 0.65    |

Figures in a column having common letter(s) do not differ significantly at 5% level of DMRT. ZT: zero tillage, MT: minimum tillage, CT: conventional tillage, and DT: deep tillage.
the conventional tillage in Shandong, northern China. Mean wheat yield improvement in no-tillage was estimated to be 4.3% between 2003 and 2004 in the more arid Hexi Corridor area of northwest China [58]. In central Texas, United States, after twenty years in wheat cropping system, soil organic matter and total N were increased by 28 and 33% in no tillage at 0–15 cm soil depth [59]. Conservation tillage was also showed to improve water content and crop yields in many environments [7, 60], whereas Hammel et al. [60] reported negative effects of no-tillage on crop yields in arid areas of the United States. However, frequent and excessive tillage and residue removal in CT and deep tillage practice in the eastern United States. Tillage-induced changes in soil organic N are often directly related to changes in SOC. ZT and MT showed significantly \( P \leq 0.05 \) higher concentrations of available N in the surface soil. Soil available P was also significantly \( P \leq 0.05 \) improved by the MT and ZT, particularly in 0–25 cm soil depth. The accumulation of P at the topsoil in ZT and MT can be explained by the limited downward movement of particle-bound P in no-till and minimum-till soils and the upward movement of nutrients from deeper layers through uptake by roots [62]. Roldan et al. [62] observed that SOM increased by up to 15% through no-tillage and minimum-tillage at 0–50 mm soil depth in Mexico. The significant decreases of available N and P in conservation tillage practices were also consistent with the findings of other researchers [63, 64]. In a study, Reyes et al. [64] reported that soil organic carbon (SOC) was higher in NT (2.77% in 0–15 cm depth) compared to CT (2.22% in 0–15 cm depth). Reicosky et al. [65] also reported that SOM content was increased under conservation tillage practices following the accumulation rate from 0 to 1.15 t C ha\(^{-1}\) yr\(^{-1}\) with the highest values in temperate climatic conditions. Similar data were also observed by Lal et al. [66] where organic carbon accumulation rate ranged from 0.1 to 0.5 t C ha\(^{-1}\) yr\(^{-1}\). This aspect is very important due to the multiple roles played by the organic matter in the soil. It regulates biological, physical, and chemical processes that collectively determine soil health.

After four years of experimentation, it was found that there was no difference in grain yield of rice as influenced by DT and ZT. This might be due to the build-up of organic matter in the zero tillage practice which occurred with the progress of cropping cycles. In the present study, the improved soil chemical and physical properties were probably responsible for the increased crop yields in conservation tillage practices (ZT and MT) in Grey Terrace soil under wheat-mungbean-T. aman cropping system. As reported by Liao et al. [67] and Xue et al. [68], conservation tillage practices have been shown to increase crop yield considerably.

5. Conclusions

After four years, different tillage practices showed that they influenced soil physical and chemical properties along with the improvement of SOM status under wheat-mungbean-T. aman cropping systems. ZT with mungbean biomass and residue incorporation conserved moisture in the soil profile and improved other soil properties, reduced the bulk density, and increased OM, porosity, AWC, and RMD. After four years, the chemical properties were also improved due to ZT and MT practices. The highest total N (\%), P, K, and S in their available forms were found in zero tillage. All tillage practices showed statistically similar yield after four years of cropping cycles. Therefore, zero tillage (minimum soil disturbance) with 20% residue retention was found to be suitable to improve soil conditions and to achieve optimum yield under wheat-mungbean-T. aman cropping system in the Grey Terrace soil (Aeric Albaucept).

### Abbreviations

AEZ: Agroecological zone  
ANOVA: Analysis of variance  
B: Boron  
BARC: Bangladesh Agricultural Research Council  
BD: Bulk density  
BRRI: Bangladesh Rice Research Institute  
CD: Cow dung  
Cu: Copper  
DAS: Days after sowing  
DAT: Days after transplanting  
DMRT: Duncan's multiple range test  
DTPA: Diethylenetriamine pentaacetic acid  
E longitude: East longitude  
FC: Field capacity  
Fe: Iron  
FRG: Fertilizer recommendation guide  
PD: Particle density  
RDF: Recommended dose of fertilizer  
SOC: Soil organic carbon  
S: Sulphur  
T. aman: Transplanted aman  
t: Ton  
TSP: Triple superphosphate  
RMD: Root mass density  
SWR: Soil water retention.

### Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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