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## Effect of Soil Texture on Agricultural Machine Performance in Sylhet, Bangladesh

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### ABSTRACT

Soil texture is one of the primary physical properties of soil that largely affects agricultural machine performance. Before implementing an agricultural machine at the farm level, it is important to test the machine to understand its technical functionality and economic viability to get the best output from it. The research was carried out to assess how soil texture influences the performance of machinery, aiming to determine the effectiveness of agricultural equipment on a particular type of land. Soil samples were collected from nine fields, and their textures were determined using hydrometer analysis. To correlate soil textural classes with machine performance, machinery data—effective field capacity, forward speed, and field efficiency—were calculated by operating a combine harvester on the study areas during the harvesting season of Boro rice. The findings of the study showed that machine efficiency has a positive correlation with sand proportion and a negative correlation with clay and silt fractions. It was observed that soil with loamy sand-type textural classes demonstrated better field efficiency, higher effective field capacity, and higher forward speed compared to sandy loam soil. Small and irregularly shaped fields also caused variation in performance. The study notable significant variation in speed between these two types of soils but no significant effect on effective field capacity or field efficiency at the 5% significance level. The outcomes of this research will help farmers make informed decisions when selecting appropriate machinery for their agricultural operations.

### INTRODUCTION

Farmers in a developing country like Bangladesh still rely on manual crop harvesting, which is both labor-intensive and time-consuming. Recently, manual harvesting is also facing the challenge of a labor shortage during harvesting season as the workers tend to move to cities for high income instead of working in the field (Zhang *et al.*, 2014). But failure to harvest crops in time causes an immense loss to the total yield. Due to a shortage of manpower and natural calamities, crop loss is observed annually (Noby *et al.*, 2018). To address this problem, along with maximizing profit and minimizing energy consumption and production costs, implementing agricultural machinery is imperative. Therefore, to overcome the rising concern as well as facilitate farm management work, combine harvesters have been introduced in Bangladesh, which can perform different harvesting operations at a time on varieties of crops.

Before implementing the machine at the farm level, testing the machine is very important to understand its technical and economic performance. Assessment of agricultural machinery performance involves evaluating the speed and quality of task execution (Hunt, 2013). The major agricultural performance includes the effective field capacity, field efficiency, theoretical field capacity, forward speed of the machine, etc. Various factors influence performance of the combine harvester including the field dimensions, field to field distance, weather, soil conditions, machine accessibility, crop types,

management techniques as well as financial conditions (Islam *et al.*, 2016; Bhuiyan *et al.*, 2020).

The physical attributes of soil that impact both crop productivity and the demands of tillage include the dimensions, configuration, and distribution of solid particles and empty spaces, as well as the forces pertinent to these soil characteristics. According to John *et al.* (1987), effective machine performance on any land largely depends on the soil composition. Different soil types exert different magnitudes of resistive force, making this a major consideration in selecting appropriate machinery. Machine performance is mainly influenced by soil conditions such as terrain, vegetation cover, and physical properties such as soil texture, structure, moisture content—specifically porosity—and bulk density. So, to improve the effective performance of the machine, the interaction between soil and machine must be studied. Machine performance concerning the soil texture describes how the machine behaves when it is operated on the fields of various soil textures. Soil texture controls the driving force for selecting appropriate machinery as it also influences different soil conditions like water-holding capacity, permeability, soil workability, bulk density, particle density, soil compaction, energy consumption, soil moisture content, soil plasticity and cohesion, the surface area of soil, chemical soil properties, etc. For instance, Kepner *et al.* (1972) found that clay soil requires more breakup energy compared to sandy loamy soils. Shebi *et al.* (1988) observed that the energy requirements

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for a particular soil rise with its bulk density. According to Belel & Dahab (1987), compared to loose soil, agricultural machines exhibited better efficiency in firm soil conditions. Moreover, Yohanna & Ifem (2004) noted that machine performance varies depending on soil type, operational practices, and overall management systems. Machines are assessed on their ability to meet certain design criteria, but the performance of a machine may vary from soil to soil. An in-depth understanding of the functions of the machine, its operational requirements, and its limitations is necessary to get the most output from the machine. To select the appropriate machine for a specific type of soil, it is very important to demonstrate the relationship between machinery and soil texture and evaluate the effectiveness of the machine for that land.

Some research has been carried out in recent times to evaluate the performance of combine harvesters in order to enhance machine efficiency, reduce operational costs, ensure timely farm operations and reduce manual labor. Despite soil plays a major role in machine performance, it is often overlooked by researchers. Even to the authors' best knowledge, no studies have yet been conducted in Bangladesh, particularly in the Sylhet region, regarding the relation between soil type and agricultural machine performance. To address the research gap, the authors of the paper aimed to study the performance of agricultural machinery in the field by analyzing machine behavior with soil texture. This will illustrate how soil texture affects the machine performance.

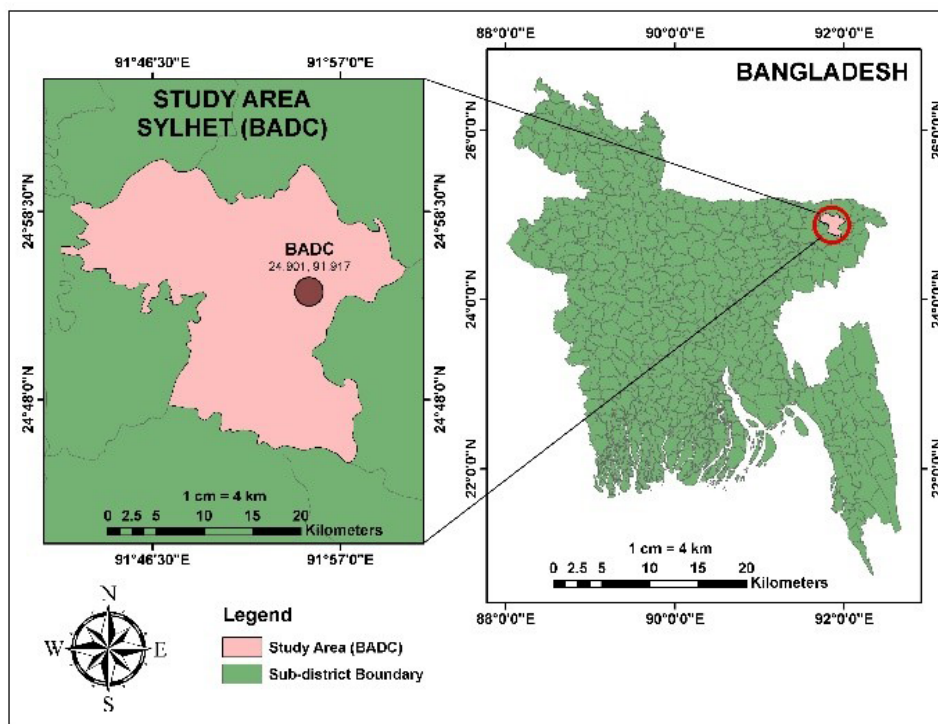


Figure 1: Study Area (BADC, Sylhet)

## MATERIALS AND METHODS

### Study Area

This study was conducted in the paddy field of Bangladesh



Figure 2: Field operation of combine harvester

Agricultural Research Corporation (BADC) in Sylhet district, Bangladesh (Figure 1). BADC is located at 24° 54' 3.6" N, 91° 55' 1.2" E and 18.2 m above sea level. The soil characteristics of this district are mainly formed in combination with the Surma Kushiyara floodplain ridges and the sub-recent Piedmont basin.

### Soil Sample Collection

A total of 54 soil samples were collected from 9 separate plots, with 6 samples taken from each plot with the help of an auger. The auger was driven to a depth of 15 cm to collect the soil samples. These individual samples were then combined to create composite soil samples, ensuring that each composite sample represents the soil characteristics of its respective plot.

**Data Collection**

In the study, a crawler-type combine harvester (Figure 2) was used as agricultural machinery to evaluate its performance on various types of soils. The study was conducted during the harvesting season of Boro rice. The specification of the employed combine harvester is shown in Table 1.

**Table 1:** Technical Specifications of the Combine Harvester

Items	Specification
Type	Crawler-type Combine Harvester
Model	Lovol RF40
Usage	Grain Harvester
Total weight, kg	4070
Dimension (L*W*H), mm	5850×3220×3200
Rated cutting width, mm	2880

The parameters used to assess the machine performance were machine forward speed, machine effective field capacity, machine theoretical field capacity, and field efficiency. The descriptions of these properties with their respective mathematical equations are as follows:

**Machine Forward Speed**

Speed was calculated using the following formula (Hunt, 2013)

$$\text{Forward Speed (km/hr.)}, S = (3.6 D) / t \quad (1)$$

D = distance covered by combine harvester (m)

t = time taken to cover that distance (s)

**Machine Effective Field Capacity**

The calculation for effective field capacity was derived from the formula proposed by Hunt (2013)

$$\text{Effective field capacity (ha/hr.)}, C = S w e / c \quad (2)$$

C = effective field capacity, ha/hr.;

S = speed, km/hr.;

w = rated width of implement, m;

e = field efficiency as a decimal;

c = constant, 10.

**Machine Theoretical Field Capacity**

Theoretical field capacity was calculated by reorganizing the formula proposed by Gbadamosi & Magaji (2003) for field efficiency, resulting in a new equation for theoretical field capacity

$$\text{Field efficiency}, \eta = C_e / C_t \quad (3)$$

$$\text{Theoretical field capacity}, C = C_e / \eta \quad (4)$$

C<sub>t</sub> = theoretical field capacity, ha/hr.;

C<sub>e</sub> = effective field capacity, ha/hr.;

η = field efficiency, decimal.

**Field Efficiency**

Field efficiency was calculated using the formula proposed by Kepner et al. (1972)

$$\text{Field efficiency (\%)}, \eta = (100 T) / T_t \quad (5)$$

$$\text{Total working time (hr.)}, T_t = (T_e + T_d) \quad (6)$$

η = field efficiency, %;

T<sub>e</sub> = actual working (productive) time, hr.;

T<sub>d</sub> = delay or idle time;

**Soil Texture Determination (Hydrometer method)**

Soil texture was determined quantitatively using the Bouyoucos Hydrometer Method (Bouyoucos, 1927) (ASTM no. 152 H, with Bouyoucos scale in g/L and calibrated to read 1.000 in distilled water at 20° C) based on Stoke's law. 5% Sodium Hexametaphosphate (NaHMP) was used as a dispersing agent (Bouyoucos, 1962). The use of chemicals disperses small aggregated clay groups and keeps the particles in a dispersed condition by deflocculation. The mixture of dispersed soil particles in water is called a soil suspension (Khakural & Sharma, 1984). For study purposes, a sample of 50 grams of oven-dried soil mass passed through a 75-micron sieve was taken. The hydrometer was calibrated properly to avoid environmental effects on its value (Robinson, 2017). The 40s and 2 hrs. readings of the hydrometer and temperature were considered for the textural analysis.

The hydrometer readings were adjusted using temperature and meniscus corrections. The corrected hydrometer reading R<sub>c</sub> after applying all the corrections can be given as,

$$R_c = R + C_m \pm C_t \quad (7)$$

Where R, C<sub>m</sub>, and C<sub>t</sub> are the raw hydrometer reading, meniscus correction, and temperature correction, respectively.

**Sand, Silt, Clay Proportions Calculation**

The hydrometer readings (g/L) give the amount of soil in the cylinder as the volume in the cylinder is one liter. According to (Bouyoucos, 1962). According to Bouyoucos (1962), the 2-hour reading indicates the amount of clay (g) in the cylinder.

Therefore, the percentage of clay is-

$$\% \text{ Clay} = (\text{corrected 2 hr. reading}) / (\text{mass dry sample}) \times 100 \% \quad (8)$$

The 40-second reading is used to calculate the percentage of silt + clay-

$$\% (\text{Silt} + \text{Clay}) = (\text{corrected 40-sec reading} / \text{mass dry sample}) \times 100 \% \quad (9)$$

Then the silt and sand percentages can be determined by

$$\% \text{ Silt} = (\% \text{ Silt} + \% \text{ Clay}) - \% \text{ Clay} \quad (10)$$

$$\% \text{ Sand} = 100 - (\% \text{ Silt} + \% \text{ Clay}) \quad (11)$$

**Soil Texture Identification**

Soil textures were identified from the USDA soil texture triangle.

**RESULTS AND DISCUSSION**

To evaluate the performance of the combine harvester on the various types of soils, different machinery performance parameters, i.e., operational speed, theoretical field capacity, effective field capacity, and field efficiency, were considered.

### Soil Textural Analysis

The experiment identified two types of soils: loamy sand and sandy loam in BADC fields. The sandy loam soil texture was prevalent (two-thirds of the plots) among the

plots. The descriptive statistics of the soil constituting particles (sand, silt, clay) are presented in Table 2. The average proportion of sand particles was greater than that of clay and silt elements.

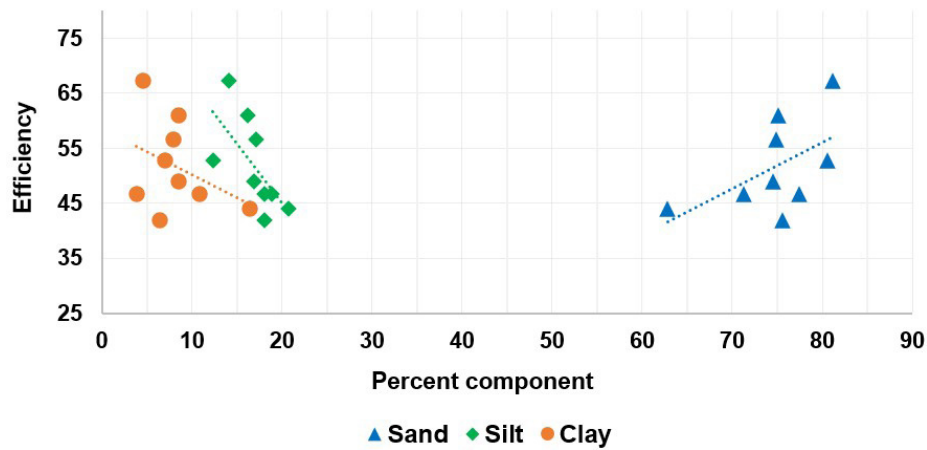
**Table 2:** Analysis of particle size distributions

Statistics	Clay (%)	Silt (%)	Sand (%)
Avg	8.26	16.91	74.83
Max	16.4	20.8	81.2
Min	3.8	12.3	62.8
Std	3.73	2.51	5.47

### Performance of Combine Harvester on Various Soil Constituents

To analyze the combine harvester performance considering the soil particles, a correlation chart is drawn in Figure 3 wherein the x-axis is the percentage values of

constituents and in the y-axis, the efficiency is plotted. Figure 3 shows that the silt fraction and clay fraction have a weak positive correlation with the machine efficiency, while the correlation between sand fraction and machine efficiency is positive..

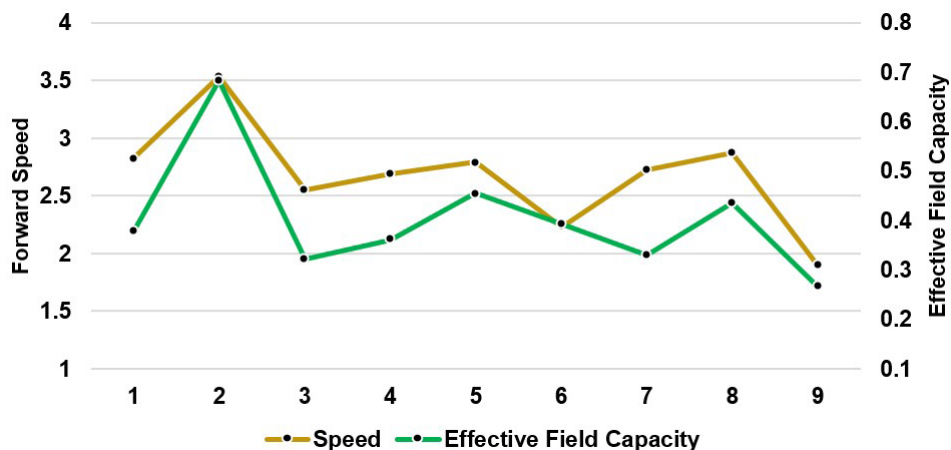


**Figure 3:** Soil constituents vs Field Efficiency

### Theoretical and Effective Field Capacity

This study revealed that the effective field capacity (EFC) of a combine harvester is influenced by its speed. Figure 4 displays the EFC of the combine harvester on various plots with associated speed values. Normally, the EFC of a combine harvester increases with the speed and utilization of the cutting width of the machine. Besides,

the EFC also influences machine efficiency. According to the findings, there is a significant positive relationship between the speed of the combine harvester and the effective field capacity of the machine, Pearson's  $R^2(7) = 0.84$ ,  $P < 0.01$  and also a significant positive relationship exists between effective field capacity and the efficiency of the machine, Pearson's  $R^2(7) = 0.82$ ,  $P < 0.01$ . Plot 2



**Figure 4:** Effective Field Capacity vs Speed

possesses the highest field capacity of 0.683 ha/hr. since the machine's forward speed was the highest. Conversely, plot 9 had the lowest field capacity of 0.266 ha/hr. due to the slowest forward speed. The remaining 7 plots' effective field capacity varies from 0.3 ha/hr. to 0.5 ha/hr. For the soil texture-specific analysis of effective and theoretical field capacity (TFC), a grouped bar chart is plotted in Figure 5. The average EFC (ha/hr.) and TFC (ha/hr.) of the combine harvester for the loamy sand

and sandy loam soils were 0.499, 0.886, 0.354, and 0.714, respectively. The highest theoretical and actual field capacities were 1.018 ha/hr. and 0.683 ha/hr., respectively. Both the highest theoretical field capacity and effective field capacity were observed in Plot 2 with loamy sand-type soil. Similarly, in plot 9, which had sandy loam soil, the lowest theoretical field capacity and effective field capacity were found to be 0.266 ha/hr. and 0.545 ha/hr., respectively.

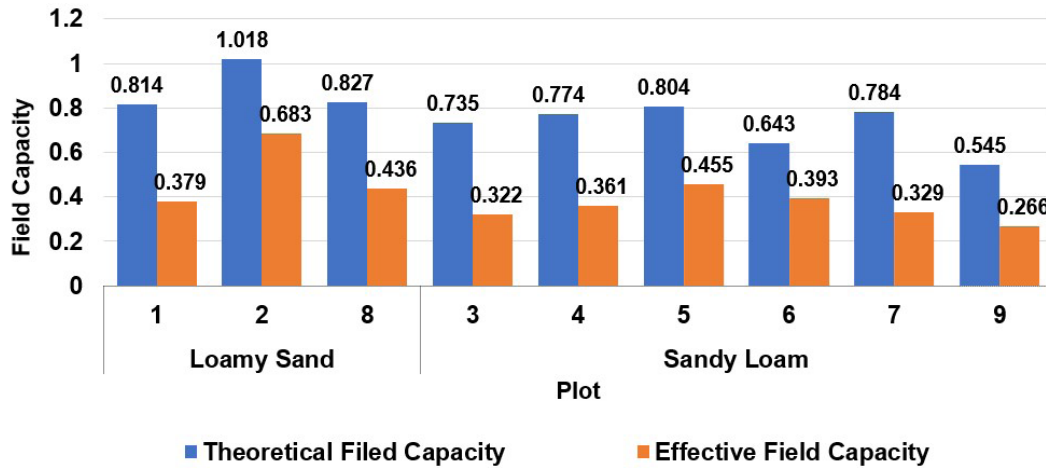


Figure 5: Comparison of Theoretical field capacity and Effective field capacity in various plots

### Speed and Efficiency Analysis

The speed variation and machine efficiency are presented in Figure 6. This figure shows that the operating speed of the combine harvester ranges from 1.5 to 3.6km/hr. The average speed in loamy sand soil and sandy loam soil was 3.08 km/hr. and 2.48 km/hr., respectively. The plot with the loamy sand-type soil had the maximum speed, 3.533 km/hr., while the plot with the sandy loam-type soil had the lowest speed, 1.894 km/hr.

The efficiency of the work process of the combine harvester was observed based on the value of total working time and the value of actual working time on a particular land. The actual working time refers to

how much time was spent during the actual harvesting operation. Meanwhile, total working time was utilized in the actual harvesting operational time, turning time, and additional time (machine unloading time, repairing, idle). From the line plot of Figure 6, it is visible that, plot 7 (sandy loam type soil) had the lowest field efficiency of 42%, whereas plot 2 (loamy sand type soil) had the highest field efficiency of 67.1%. The second highest field efficiency was found at 61.1%, which had loamy sand type soil. It is also noticeable that on loamy sand soil, the field efficiency increases as the speed increases. The correlation coefficient of these two machine parameters for this type of soil is calculated at 0.97.

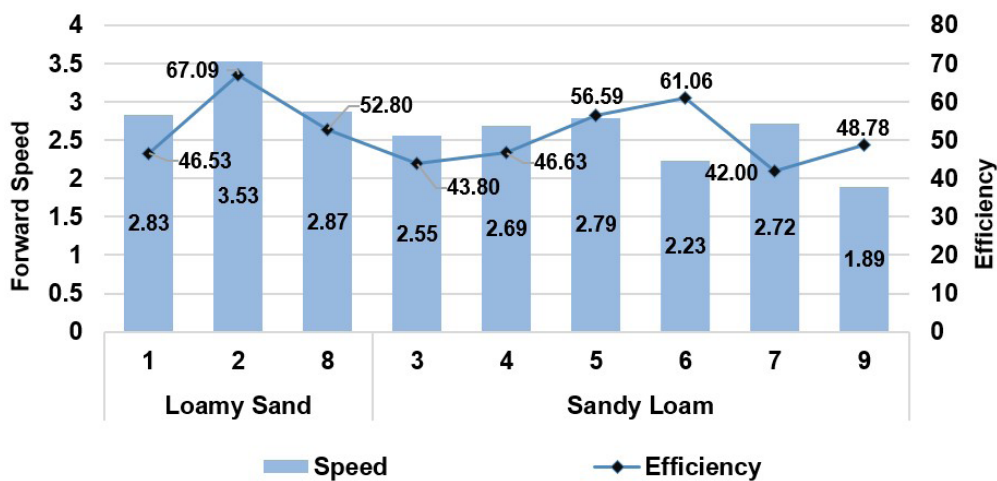


Figure 6: Speed variation and Efficiency analysis among study plots

To further analyze the field efficiency among the different soil textures in the study area, a box plot is presented in Figure 7. Boxplot is a great way to visualize average, maximum, minimum, median, 1st quartile, and 3rd

quartile values in a single plot. This plot demonstrates that loamy sand soil has a greater mean field efficiency (55.47%) than sandy loam soil (49.81%).

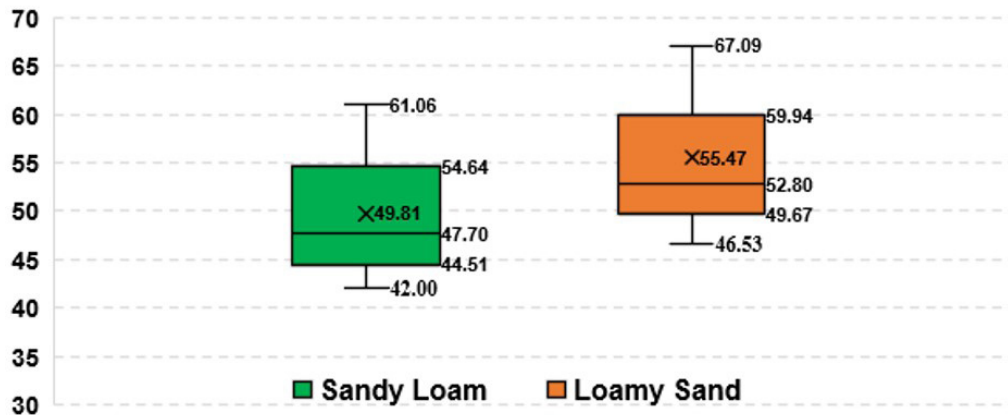


Figure 7: Analysis of Field efficiency

### Statistical Analysis of the Effect of Soil Texture on Combine Harvester Performance

The Mann-Whitney U test, also known as the Wilcoxon rank-sum test, is a non-parametric statistical test designed to assess the variations between two independent samples. This test can be used when the sample size is small and the sample distribution is not normal. The purpose of this test in this study is to evaluate the significance of combine harvester performance measures on the two

types of soil. Table 3 depicts the Mann-Whitney U-Test result for the analysis of combine harvester forward speed on the two types of soil textures, i.e., loamy sand and sandy loam. The null hypothesis,  $H_0$ , for this case, is that there is no significant speed difference between loamy sand and sandy loam-type soil. At a 5% level of significance, the null hypothesis is rejected, which clearly states that there is a significant difference in speed between these two types of soils.

Table 3: Mann-Whitney U-Test for the machine speed analysis considering soil textures

Soil Texture	N	Mean Rank	Sum of Ranks	Mann-Whitney U	U. critical (5%)
Loamy Sand	3	8	24	0	1
Sandy Loam	6	3.5	21		

Mann-Whitney U test was also conducted to analyze the effect of soil texture on the effective field capacity and the field efficiency of the combine harvester, as shown in Table 4 and Table 5. From these tables, it is evident

that there is no significant impact of sandy loam soil and loamy sand soil on the effective field capacity and field efficiency at the 5% level of significance.

Table 4: Mann-Whitney U-Test for the effective field capacity analysis considering soil textures

Soil Texture	N	Mean Rank	Sum of Ranks	Mann-Whitney U	U. critical (5%)
Loamy Sand	3	7	21	3	1
Sandy Loam	6	4	24		

Table 5: Mann-Whitney U-Test for the machine efficiency analysis considering soil textures

Soil Texture	N	Mean Rank	Sum of Ranks	Mann-Whitney U	U. critical (5%)
Loamy Sand	3	6	18	6	1
Sandy Loam	6	4.5	27		

### DISCUSSION

At the plots of BADC in Sylhet, the average proportion of sand particles was higher than that of clay and silt components. The findings of the research indicate that

the silt fraction and clay fraction have a weak positive correlation with machine efficiency. On the other hand, the correlation between sand fraction and machine efficiency is positive.

Out of 9 plots, 6 had sandy loam soil and 3 had loamy sand soil. In loamy sand-type soil, the forward speed of the machine was comparatively higher than in sandy loamy-type soil. According to Islam & Habib (2020), traditional and medium-sized combine harvesters demonstrate optimal performance when operated at a speed ranging from 3 to 6.5 km/hr. The average operating speed in BADC, Sylhet, was 2.695 km/hr, which is comparatively lower due to the fragmented and smaller field size and age of the machine. The plot with the loamy sand-type soil had the maximum speed, 3.533 km/hr, while the plot with the sandy loam-type soil had the lowest speed, 1.894 km/hr. This experimental result demonstrates that the effective field capacity (EFC) of a combine harvester is influenced by its speed. As the machine's speed increases, the EFC of the combine harvester also increases. There is a significant positive relationship between the speed of the combine harvester and the effective field capacity of the machine, as evidenced by Pearson's correlation coefficient ( $R^2 = 0.84$ ,  $P < 0.01$ ) which agrees with the observation of Jawalekar & Shelare (2020) that the primary factor influencing the combine harvester's performance is its forward speed. Moreover, the EFC impacted the machine's efficiency, with a substantial positive correlation observed between the EFC and machine efficiency, as indicated by Pearson's correlation coefficient ( $R^2 = 0.82$ ,  $P < 0.01$ ). Plot 2 possesses the highest field capacity of 0.683 ha/hr. since the machine's forward speed was the highest. As a result, the plot had the highest field efficiency at 67.09%. Conversely, plot 9 had the lowest field capacity of 0.266 ha/hr. due to the slowest forward speed. These results align with the insights provided by Belel & Dahab (1987), who noted that the field performance of a tractor is influenced by soil type and condition, affecting both the hitched implement and tractor traction. The findings also support the assertion made by Smith (1993) that the plough's performance significantly varies depending on the soil type.

However, some samples exhibited lower machine performance for loamy sand soil because of the variations in field size and shape, machine accessibility, and other factors. Most of the plots were small and of irregular shapes. Islam *et al.* (2021) pointed out that the efficiency of the machine may vary due to multiple factors, including soil physical properties, machine speed, as well as field size and shape. According to Elsoragaby *et al.* (2019), the performance of combine harvesters in the field is primarily affected by a reduction in both the size and shape of the plot area. As per ASAE Standards (2009) irregularly shaped plots can considerably reduce the field performance of the combine harvester.

## CONCLUSIONS

The findings of the study suggests that machine efficiency has a positive correlation with sand proportion and a negative correlation with clay and silt fractions. Machine performance metrics were notably higher in loamy

sand soil than sandy loam soil. A notable difference in speed were observed between the two soil types at a 5% significance level, while at the same significance level, there was no major difference between effective field capacity and field efficiency. Furthermore, the regression analysis demonstrates a strong positive relationship between the speed of the combine harvester and the effective field capacity of the machine ( $P < .01$ ), as well as between the effective field capacity and the efficiency of the machine ( $P < .01$ ). This study will help farmers select suitable machinery for their fields based on the type of soil. Machines can be modified or manufactured based on soil physical properties to ensure the best machine performance. As there is very limited research done on the effect of soil physical properties on agricultural machinery performance, there are many opportunities to perform research in this field. It is recommended to work with other agricultural machinery and gather more representative soil samples and relevant data from different areas for more reliable statistical analysis. Moreover, new and efficient machines should be used because older machinery results in a higher number of errors.

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## Author's Contributions

Nafis Shahid Fahim. planned, designed, and conceptualized the overall design, involved in fieldwork and laboratory work, and was engaged in literature review, manuscript writing, reviewing, editing, and finalizing the manuscript. Bodruzzaman Khan planned, designed, and conceptualized the overall design, participated in fieldwork and conducted data analysis, and was engaged in literature review, manuscript writing, reviewing, editing, and finalizing the manuscript. Mohd. Saifur Rahman was Involved in fieldwork and laboratory work, contributed to data analysis and participated in reviewing, editing, and finalizing the manuscript. Md. Altaf Hossain contributed to reviewing, editing and providing supervision.

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