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Research Article

Estimation of Field Parameters of Rice Transplanter Using RTK GNSS

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Abstract

Farmers and farm managers in Bangladesh encounter difficulties when assessing the field effectiveness of agricultural technology, typically due to the lack of precise data for accurate evaluations. Global Navigation Satellite System (GNSS) and Geographic Information System (GIS) are two of the important technologies of precision agriculture (PA). Using these technologies machine performance can be evaluated precisely. The paper provides a rationale for utilizing Real Time Kinematic Global Navigation Satellite System (RTK GNSS) technology to evaluate different operational attributes (transplanting track, efficiency and turning time loss) of a rice transplanter. Geo-referenced data for rice transplanter operation during the Boro transplanting season (January-May, 2020) were collected by the GNSS receiver from a field located at Dumuria upazila, Khulna, Bangladesh. The field efficiency of rice transplanter calculated from GNSS receiver data was found higher (73.83%) compared to that obtained from manually observed data (50.948%). This is because GNSS measured time loss more precisely than manual method. Geo-referenced machine data can enable farmers and farm managers to plan their farm operation according to their accurate machine performance. The findings of the study are anticipated to provide valuable guidance for decision-making, minimize inefficiencies, and improve the overall performance of agricultural technologies like rice transplanter.

Keywords: Field efficiency, Paddy, RTK GNSS, Rice Transplanter

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1. Introduction

Agricultural mechanization is one of the ways to feed 165.1 million people [1] with our limited agricultural land and resources. To increase the cropping intensity cultivation practices have to be mechanized. Realizing the situation, the government of Bangladesh has taken various initiatives to enhance mechanization by making available of machines and equipment available from the land preparation to the storage facilities through subsidy program. Globally, Rice (Oryza sativa) is the second most important cereal crop in terms of production area and the staple food for nearly half of the population of the world. With a production of 35.3 million tons, Bangladesh is the third largest rice producer in the world [2]. Rice contributes to approximately 93.11% of the national food grain production of Bangladesh [3].

Transplanting, the first and major pre-harvest operation of rice production, is an important part of mechanized agriculture. Traditionally rice is transplanted by hand in Bangladesh, which is labour intensive, time consuming and costly operation. The conventional technique of rice transplanting takes higher time. The time available between the harvest of one crop and transplanting of paddy is short. In these circumstances, to meet up the crisis of labours in transplanting season, to minimize the total production costs of cultivation, to make the operations in time and to increase the production per hector, mechanical rice transplanting is needed.

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Precision agriculture technologies are being adopted by farmers and farm managers around the world to evaluate machine performance and to manage farms. Precision agriculture i.e., the use of GIS, GPS and VRT can lead to increased productivity of farm operations [4-7]. Precision agriculture is a process which involves collecting, interpreting, planning and use of data about a field or crop [8].

GPS technology can be used for soil sampling, farm planning, field mapping, machinery guidance, crop scouting, variable rate applications and yield mapping [9-11]. These technologies also help the farm managers in identifying the causes of inefficiencies, managing them and taking better decisions to increase productivity. GNSS stands for Global Navigation Satellite System, and is an umbrella term that encompasses all global satellite positioning systems. This includes constellations of satellites orbiting over the earth's surface and continuously transmitting signals that enable users to determine their position. The Global Positioning System (GPS) is one component of the Global Navigation Satellite System (GNSS). Specifically, it refers to the NAVSTAR Global Positioning System, a constellation of satellites developed by the United States Department of Defence (DoD). GPS is now the most widely used GNSS in the world, and provides continuous positioning and timing information globally, under any weather conditions.

With the decrease in number of people running the farm operations, it is crucial that the machine capabilities are used to their full potential and operators can obtain the maximum productivity with their machines. If farm managers are going to accurately plan and budget both time and money for the completion of farm operations, they must have access to appropriate machine performance data to determine machinery related costs and machine performance characteristics [12]. Navigation systems help operators to reduce skips and overlaps, especially when using methods that rely on visual estimation of swath distance and counting rows. This technology reduces the chance of misapplication of agrochemicals and overlapping during transplanting. GPS navigation can be used to keep implements in the same traffic pattern year-to-year (controlled traffic), thus minimizing adverse effects of implement traffic.

GPS tools can locate the implements and record important machine data, thus helps in decision making. Uses of GPS tool in agriculture also include finding the exact location of field machinery, yield mapping, planting and fertilizer application, parallel swathing, precision ploughing etc. In this study GNSS tool is used to record and analyze the data generated by a rice transplanter so that effective and lost time of operation, turning and pattern of operation can be understood clearly.

Although rice transplanter is much more time and labour efficient than manual transplanting, most of the time the efficiency reduced due to inefficient operation goes un-noticed. The analysis of lost time due to machine idling, traveling without operation, turning and seedling loading gives a precise view of machine performance. GNSS tool can be used not only to determine the ineffective time during transplanting but also to determine the loss of fuel and labour associated with this time loss. When time loss can be measured effectively, productivity loss in terms of fuel and labour loss can be determined. Machine performance can be evaluated from GNSS tool recorded data; hence it is possible to increase machine efficiency. With the above problems and prospects, the study aimed to collect real time field data of rice transplanter using RTK GNSS to estimate field parameters and performance of rice transplanter based on RTK GNSS data and compare with manually collected data and estimation.

2. Materials and Methods

2.1 Location of the Study

The experiment was conducted on a land of Dumuria upazila, Khulna, Bangladesh on February 5, 2020, during the transplanting operation of Boro paddy (January-May). The paddy variety in the field was BRRI Dhan29. Data was collected for a rice transplanter (ACI Daedong DP 480) during transplanting in order to evaluate some important machine parameters and the effectiveness of a GNSS device. The location of the experimental site is shown on map in Figure 1.

2.2 Field Conditions

Field conditions affect the overall field performance and efficiency of machine operation. So, field conditions were observed before starting the transplanting operation. Two days before transplanting, the experimental plot was ploughed by a two-wheel tractor (2WT) to have puddled soil condition. Finally, irrigation was applied in the field for creating a muddy state condition for transplanting.

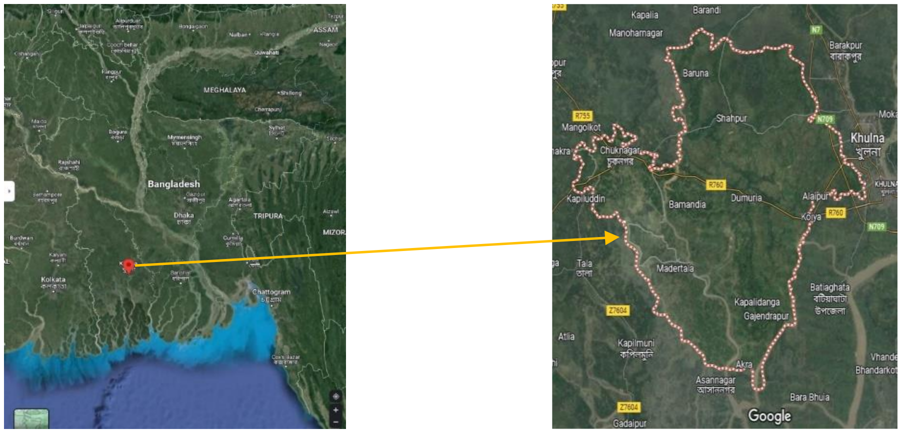

Figure 1. Location of the study

2.3 Crop Parameters

For optimum performance of the rice transplanter, some crop parameters such as seedlings height, depth of mud were needed to be within the required range of the rice transplanter. Crop parameters related observations are presented in Table 1.

Table 1. Crop parameters.

Parameters	Observations
Paddy variety	BRRI Dhan29
Seedlings height	19 cm
Soil type	silt loam with an average sand
Depth of mud	10-12cm

2.4 Transplanting Pattern

Substantial improvements in field efficiency can be made by analyzing and varying the pattern of field operation. “The Straight Alternation Pattern” was used to transplant the rice seedlings in the field. The visual presentation of the pattern is shown in Figure 2.

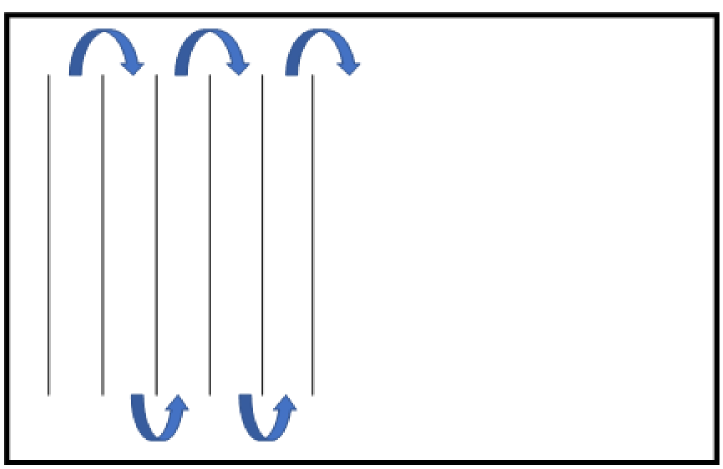

Figure 2. Transplanting pattern

2.5 Farm Equipment

During the experiment, a rice transplanter was used to perform the transplanting operation. After considering the availability of local distributors and repair services, the ACI Deadong DP480 rice transplanter was chosen for the experiment (Figure 3).

Figure 3. ACI Daedong DP480 rice transplanter

The DP 480 rice transplanter, imported by ACI Private Limited is a four row walk behind type rice transplanter. Table 2 shows the specification of the rice transplanter.

Table 2. Specifications of ACI Deadong DP480 rice transplanter.

Dimensions	Length × width × height (mm)	2385×1530×870
	Overall weight (kg)	160
Engine	Type	4-stroke, air-cooled, gasoline
	Maximum output kW and rpm	3 and 180
Traveling Section	Gearshift: Forward and Reverse	2 speeds and 1 speed
Transplanting Section	Number of rows	4
	Row to row distance (mm)	300
	Plant to plant distance (mm)	110, 130, 150
	Transplanting speed, m/s	0.6 to 1.0

2.6 Data collection device and its installation

An RTK GNSS device mounted on the rice transplanter collects and records data generated by the rice transplanter during transplanting operation. The model name of the RTK GNSS device is TERSUS BX305. The BX305 is a compact GNSS RTK receiver which offers real-time, centimeter-level positioning capability as well as flexible interfaces for several applications, such as precision navigation, precision agriculture, surveying, and UAVs. The BX305 can be integrated into other host devices or can serve as an independent positioning system that is dedicated to delivering high-precision, reliable position information. To operate BX305 the following arrangements are essential: Interface board, or enclosure and cables, Power supply, Data communications equipment and GNSS antenna with Low Noise Amplifier (LNA). BX305 OEM board inside consist of a Radio Frequency (RF) section and a digital section. The receiver obtains filtered, amplified GNSS signals from the antenna. The RF section down converts the incoming RF signals to Intermediate Frequency (IF) signals which are processed by the digital section. The RF section also supplies power to the active antenna LNA through the coaxial cable. The RF section has been designed to reject common sources of interference. The core of the digital section is the base band, which is realized with a FPGA chip. The digital section digitizes and processes the base band signals to obtain a PVT (Position, Velocity and Time) solution. If RTK corrections from the base are received, the receiver will output cm-level position. The digital section also processes the system I/O, shown in Figure 4.

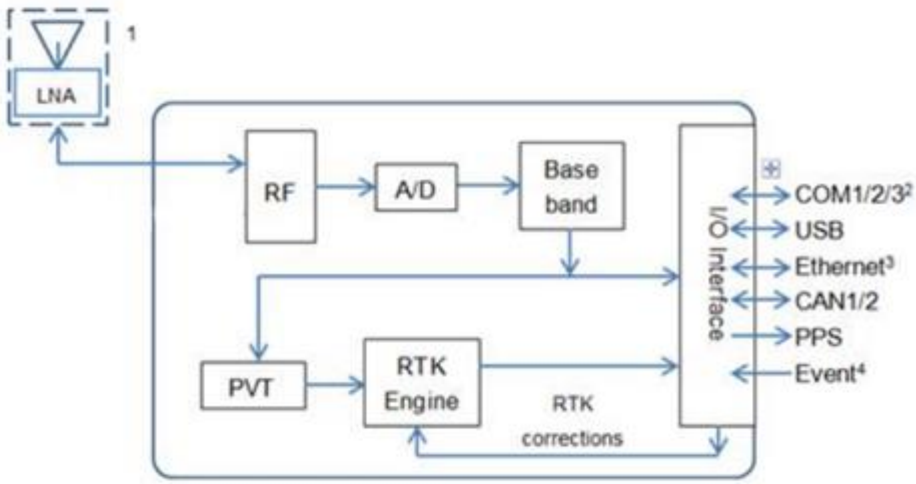

Figure 4. System Overview of BX305

An enclosure is necessary to protect the OEM BX305 board from environmental extremes and high levels RF interference, and it brings convenience for the customers to use the receivers. The pictorial overview of enclosure (Figure 5a) and panel of enclosure (Figure 5b) are shown in Figure 5.

(a) (b)

Figure 5. (a) Overview of Enclosure; (b) Enclosure Panel.

The antenna converts electromagnetic signals transmitted by GNSS satellites into electrical signals that can be used by the receiver. An active GNSS antenna is required for optimal receiver performance. Tersus is providing active GNSS antennas with precise phase centres and robust enclosures. The image of antenna is shown in Figure 6.

Figure 6. BX305 GNSS Antenna

The following steps were completed to set up and begin using the BX305 receiver.

a. BX305 was installed in a secure place;

b. GNSS antenna was mounted to a secure, stable structure;

c. GNSS antenna was connected to the receiver with a RF cable;

d. Power was applied to the receiver;

e. The receiver was connected to a computer/laptop or other data communications equipment (Figure 7).

Figure 7. BX305 connected to a laptop

BX305 receiver has serial ports and USB port; hence lots of serial tools can be used to communicate with the receivers. Tersus GNSS Centre is a windows-platform-based serial tool, which is recommended to communicate with the BX receivers. While the Tersus GNSS Centre is run, the following configuration page (Figure 8) is shown and the port as well as baud rate (115200) need to be input.

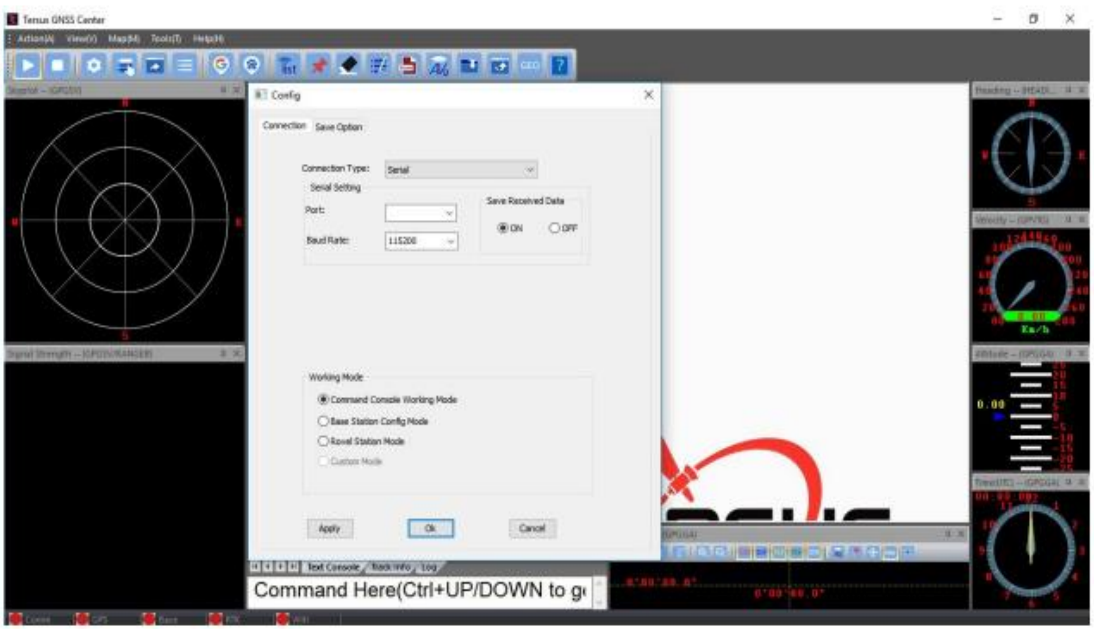

Figure 8. Config Page of Tersus GNSS Centre

Commands can be input in the text console window, an ‘OK’ response is output after a command is input, or the command is not input successfully. The main window of Tersus GNSS Centre is shown in Figure 9.

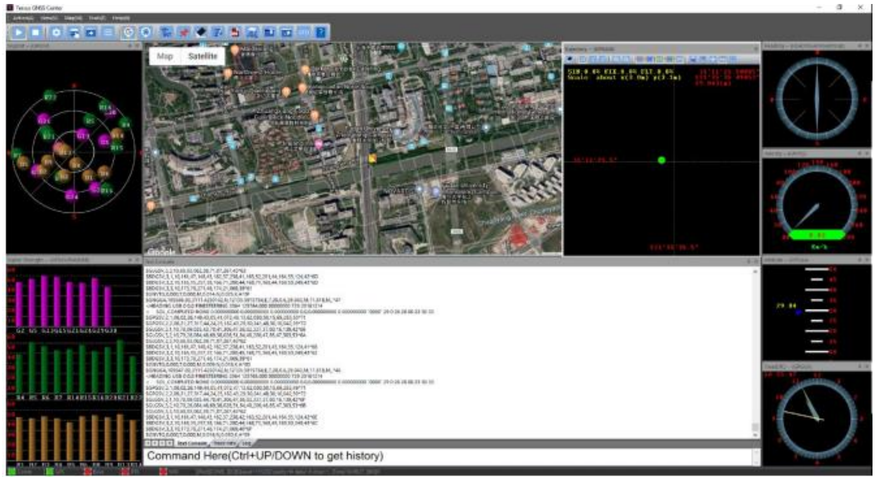

Figure 9. Main Window of Tersus GNSS Centre

The following commands were input for the Base Station Board:

fix position latitude longitude altitude <press “enter”>

log com2 rtcm1074 ontime 1 < press “enter”>

log com2 rtcm1084 ontime 1 < press “enter”>

log com2 rtcm1124 ontime 1 < press “enter”>

log com2 rtcm1005 ontime 10 < press “enter”>

saveconfig < press “enter”>

These commands fixed the coordinate of the base station and configured RTCM message to be transmitted. In the command, the coordinates- latitude and longitude- were expressed in degree and altitude was expressed in meter. After each command was sent, the board would automatically acknowledge a “>OK”, which meant the configuration took effect. The coordinates- latitude and longitude- of a respective place was found using “Google Maps” of any smartphone and altitude was found using any altitude finder website. Different parts of the GNSS device need to be connected properly in order to get appropriate signal from satellite and to make the device ready to go. Figure 10 shows schematic diagram of the required connections.

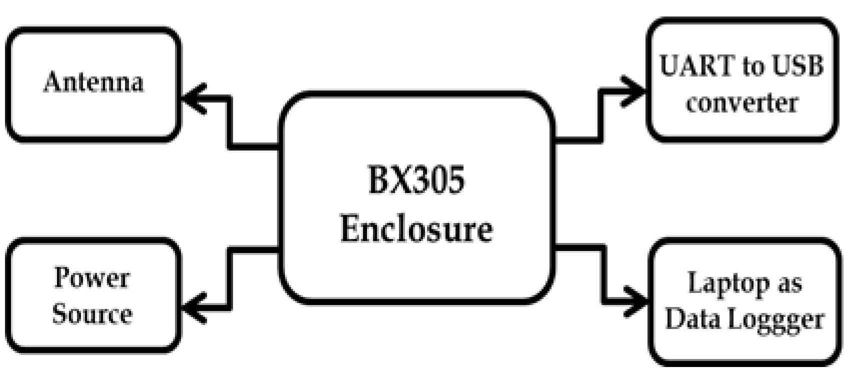

Figure 10. Connection Overview of GNSS Device.

2.7 Data Collection and Processing

Before starting the transplanting operation, several preliminary tasks were performed. Suitable field was chosen for the study. After choosing experimental land, it was measured with measuring tape for obtaining the area of the selected land. As traditional Bangladeshi fields- most of the time- are not perfectly square or rectangular in shape, it was kept in mind during measurement. The measurements were done in more than one time to increase the convenience of future calculation. Standard safety and operation procedures were followed. To record the geo-referenced data generated within the GNSS receiver the GNSS device was positioned on a suitable place of the rice transplanter machine. A stopwatch was used for measuring the effective time, turning time and total operating time during the machine operation. This step was necessary to compare these data with GNSS generated data. Once all the set-up was ready, the rice transplanter machine started its operation with the GNSS receiver on-board. The transplanting operation kept on going until the selected land was completely transplanted shown in Figure 11. After the completion of transplanting operation, the GNSS receiver was uninstalled from the farm equipment.

Figure 11. Transplanting with rice transplanter and data collection with GNSS device

The GNSS receiver recorded the geo-spatial data of rice transplanter operation. The recorded data were then processed and analysed. After the processing and analysis of the data, an observation regarding the study could be obtained. The whole procedure of the study can be illustrated by a flow diagram as shown in Figure 12.

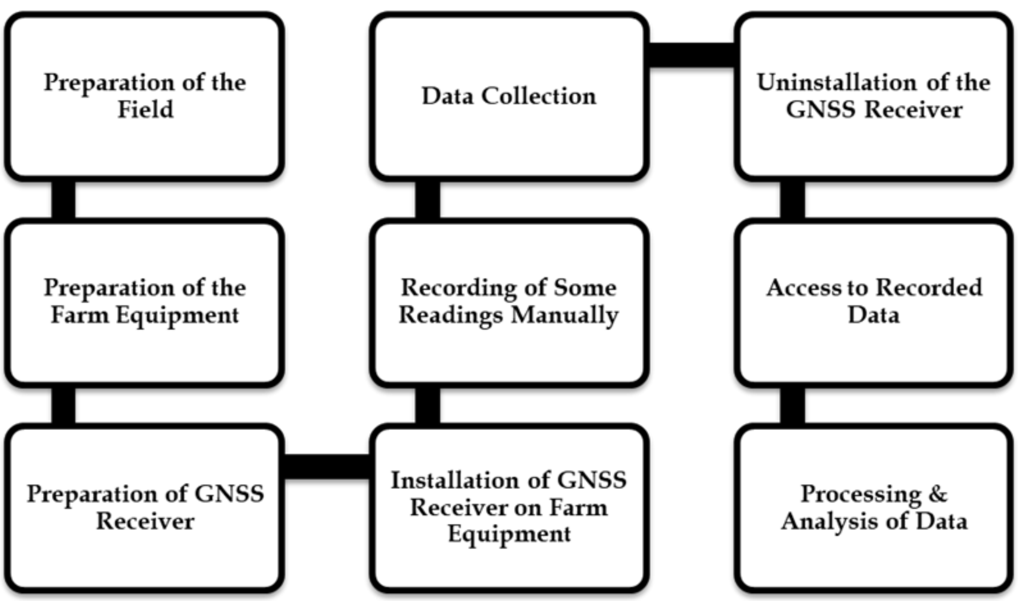

Figure 12. Data flow Diagram

2.8 Field Capacity and Efficiency

Field efficiency of the rice transplanter was determined from its Effective Field Capacity (EFC) and Theoretical Field Capacity (TFC) [13]. The effective field capacity, theoretical field capacity and efficiency have been described in following sub-section.

2.8.1 Effective Field Capacity (EFC)

The effective field capacity of a machine in the field can be easily calculated by dividing the areas completed by the hours of actual field time. In other words, effective field capacity refers to the ratio of area covered during transplanting operation to total field time of transplanting operation and can be calculated following equation number (1).

$$EFC\ (ha/hr) = \frac{Area\ (ha)}{Total\ Field\ Time\ (hr)} \quad (1)$$

Hunt [13] showed that effective field capacity- considering all losses- can be calculated following equation number (2).

$$C = \frac{SwL(E_w)}{(C_1)L + D\,S\,w\,L\,(E_w) + (C_2)ST} \quad (2)$$

Here,

C= effective field capacity (ha/hr)

S= speed (km/hr)

w= rated width (m)

Ew= effective swath coverage, decimal of rated width

D= unproductive time (hr/ha)

L = length of the field (m)

T= turning time (s/turn)

C1= constant (10)

C2= constant (2.7778)

2.8.2 Theoretical Field Capacity (TFC)

The theoretical field capacity of a machine is the rate at which a machine would do a job if there were no interruptions and can be calculated following equation number (3). It depends only on the full operating width of the machine and the average travel speed in the field.

$$TFC\ (ha/hr) = (Rated\ forward\ speed\ (km/h) \times Rated\ width\ (m))/10 \quad (3)$$

2.8.3 Field Efficiency

Effective field capacity is always less than theoretical field capacity due to turns and delays. The ratio of effective field capacity (EFC) to theoretical field capacity (TFC) is called the machine’s field efficiency and can be calculated following equation number (4). Field efficiency is expressed as the percentage of a machine’s TFC actually achieved under real conditions.

$$Field\ efficiency\ (\%) = EFC/TFC \times 100 \quad (4)$$

2.9 Time loss measurement

During transplanting time loss occurs in different phases of the operation. These losses include: - (a) Turning time loss; (b) Seedlings tray loading time loss; (c) Maintenance time loss; and (d) Time loss due to obstacles etc. Turning loss can be measured by using Google Earth’s measuring tool. The GNSS device provide precise location of the transplanter at every second of the operation. From the data map two similar value of longitude can give the location of the transplanter before and after the turn. Because the longitude remains same before and after the turn. Again, from data map file, time difference can be measured for those two similar longitudes. The total number to turns and time to take each turn indicates the total turning time loss.

3. Results and Discussion

3.1 Transplanting path of rice transplanter

Data recorded by the RTK GNSS during the transplanting operation of the rice transplanter were processed to suitable file formats using GPS Visualizer and then was uploaded to Google Earth web application. The GNSS receiver recorded data of every second and assigned the coordinates of the rice transplanter to other parameters like time, speed, heading, latitude, longitude etc. The trajectory of the rice transplanter during the transplanting operation can be observed from the map obtained from the Google Earth web application. The path of the rice transplanter throughout the whole operation was not straight (Figure 13). This happened because of the vibration of the machine. GNSS device mounted on the rice transplanter couldn't absorb the vibration during the transplanting operation. The little up and down movement of the GNSS device was noticed during transplanting. However, RTK GNSS provides very precise data regarding coordinates.

Figure 13. Transplanting path of the rice transplanter.

3.2 Efficiency of Rice Transplanter

The geo-referenced data from the RTK GNSS receiver were used to calculate the efficiency of the rice transplanter. Table 3 shows the field size, total field time, forward speed, rated width, and efficiency for both GNSS receiver's data and manually derived data.

Table 3. Estimation of rice transplanter's efficiency from GNSS and manual data.

Parameter	GNSS Value	Manual Value
Field Area (ha)	0.07001	0.0736
Total Field Time (hr)	0.6417	0.545
Forward Speed (km/hr)	2.1	2.21
Rated Width (m)	1.2	1.2
EFC (ha/hr)	0.1091	0.1351
TFC (ha/hr)	0.252	0.2652
Efficiency (%)	43.296	50.948

The field efficiency for the same field obtained from GNSS receiver data and manually calculated data were found 43.296% and 50.948%, respectively. The lower value of efficiency from GNSS receiver data occurred because the GNSS receiver measured total field time higher compared to manual calculation. Because, the stopwatch was paused when doing maintenance, loading and unloading seedling trays, and dodging obstacles in the field and that results in higher efficiency in manual value. From GNSS data, the theoretical field capacity (TFC) and effective field capacity (EFC) found low compared to manual calculation. This resulted in lower efficiency by GNSS data than manual measurement. Since the data recorded by GNSS receiver is more precise than manual calculation, the efficiency obtained through GNSS data is more accurate. The following Figure 14 demonstrates the comparison between GNSS device collected values and manually collected values.

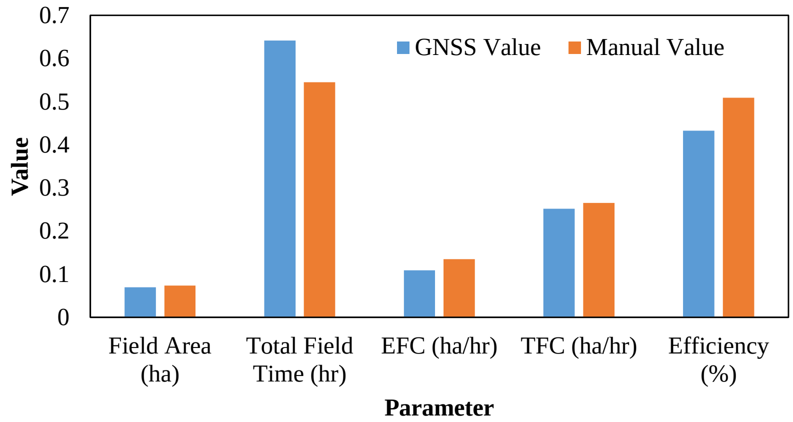

Figure 14. Comparison of GNSS received data and manually measured data.

More precise effective field capacity can be measured by considering the actual time of operation and effective swath coverage. Effective swath coverage is the value of actual width of the transplanter's rated width that works on the field. If there is any overlap of transplantation occurs, effective swath coverage becomes lower than rated width. In this study the effective swath coverage is assumed to be 100% of the rated width. Unproductive time includes seedlings tray loading time, maintenance time and time loss due to obstacles. Length of the field was measured by Google Earth's measure tool. Then the time efficiency was found 0.1860. The table 4 shows the more precise effective field capacity calculations

Table 4. Calculation of precise effective field capacity.

Parameters	Value
S= speed (km/hr)	2.1
w= rated width (m)	1.2
E_w= effective swath coverage, decimal of rated width	1
D= unproductive time (hr/ha)	0.9522
L = length of the field (m)	30.55
T= turning time (s/turn)	6
C_1= constant (10)	10
C_2= constant (2.7778)	2.7778
C= effective field capacity (ha/hr)	0.1860
TFC (ha/hr)	0.252
C= effective field capacity (ha/hr)	0.1860
Efficiency (%)	73.83

The precise field efficiency is the ratio of the effective field capacity to the theoretical field capacity (TFC) measured by GNSS device. The precise efficiency in this study was found to be 73.83%. This value seems higher because, different time losses were considered during time capacity calculation. Again, the constant values of C1 and C2 were considered on the basis of the field condition of foreign country. These values may be different in our country based on our land condition. The Figure 15 demonstrates the comparison among the efficiencies calculated by three different processes. It shows that precise field efficiency estimation reaches the highest value (73.83%) than two other efficiencies.

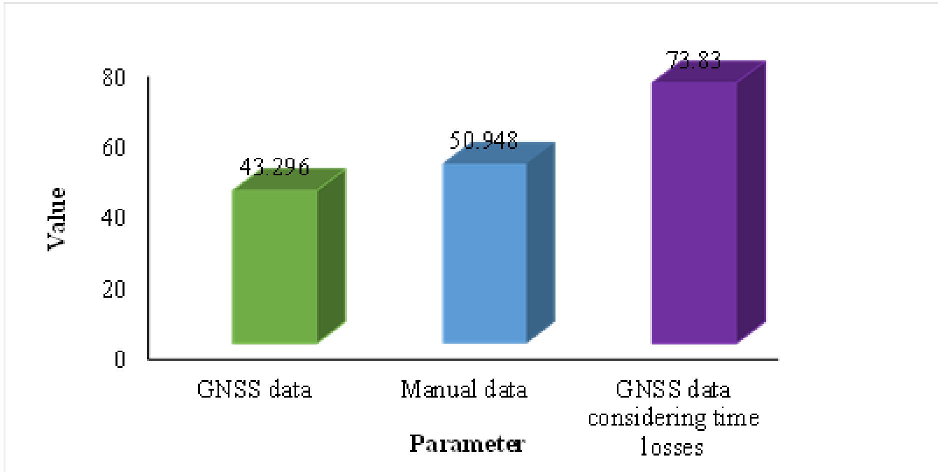

Figure 15. Comparison among the efficiencies

3.3 Time loss during transplanting

During transplanting operation various time loss occurred. These losses are mainly turning loss of rice transplanter, seedlings tray loading time loss, maintenance time loss, time loss due to obstacles in the field, etc (Table 5). These time loss results in lower efficiency.

Table 5. Different time losses during transplanting.

Losses	Time (sec)
Turning loss	108
Seedlings tray loading loss	26
Maintenance loss	74
Time loss due to obstacles	140
Total time loss	**348**

While transplanting, the rice transplanter took 18 turns. Every turn took about 4 to 8 second time each. Total turning time in the field was counted to be 108 sec approximately by Google Earth. As for example, the rice transplanter started turn in the 1st location (latitude 22.82138995, longitude 89.33104361) and finished the turn in 2nd location (latitude 22.82139012, longitude 89.33104361) within 4 sec. Again, in another place in the field the rice transplanter started turn in the 1st location (Latitude 22.82135752, longitude 89.33120408) and finished the turn in 2nd location (latitude 22.82135785, longitude 89.33120408) within 8 seconds. The average turning time was 6 seconds. Though the rice transplanter started operation with full of its seedling tray carrying capacity but needs to stop once in the middle of operation to load the seedlings. Seedlings tray loading took approximately 26 second. For adjustment purpose the rice transplanter took 74 second (maintenance time loss) to make sure that transplanting operation happens perfectly maintaining row to row and hill to hill distance. In the transplanting field there was some bamboo made electric poles that interrupted the continuous operation of the rice transplanter. That caused a time loss of about 140 second. Though time loss due to obstacles (40%) was higher in this study but as it is solely depending on field condition will therefore vary from field to field. However, amongst the rest of the three losses turning time loss (31%) is more significant compared to others (Figure 16) as also agreed by Spekken and de Bruin [14]. This means that more the fragmentation of land the more will be the turning time loss. So, here government can take initiative to consolidate the fragmented land of our country to improve the efficiency of agricultural machineries like rice transplanter.

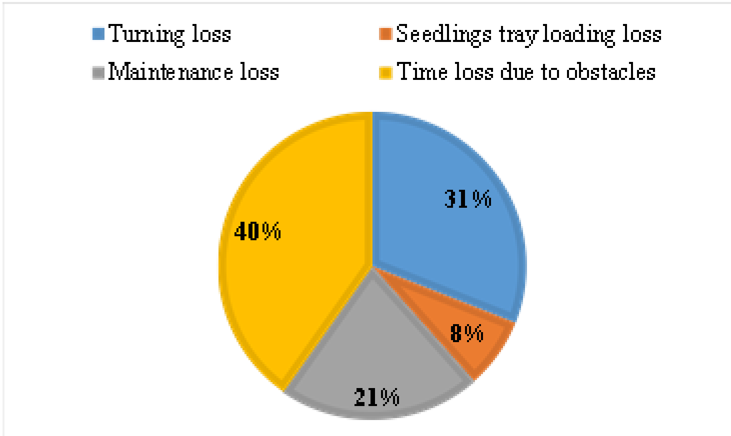

Figure 16. Percentage of different time losses.

4. Conclusions

RTK GNSS technology measured 73.83% field efficiency of rice transplanter which was 22.882% higher than traditional method (50.948%). The reason behind this was the effectiveness of GNSS technology in precise measurement of operational time loss of rice transplanter in field. The operational track data of rice transplanter received from the GNSS receiver can be used to guide the machine in straight operation in the field. In addition, consolidation of fragmented agricultural land is necessary as evident from the study to reduce turning time loss and thereby increasing efficiency of agricultural machinery.

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