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RELATIVE PERFORMANCE OF SATELLITE BASED NAVIGATION SYSTEMS FOR IMPROVING TRACTOR PRODUCTIVITY

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ABSTRACT

The development of novel technologies in modern agriculture is predominantly focused on increasing productivity of field operations and reducing manual labour. The tractor operators are required to ensure precise and efficient movement of tractors, along with attached implements to avoid economic losses, which often results in physiological damage to tractor operators' health. In this context, employment of satellite-based navigation systems on tractors to perform different farm operations may be a suitable technology to decrease the probability of skipping and overlapping of areas which in turn increases operator efficiency. The current study endeavours to compare the relative performance of two commercially available navigation systems viz., offset value guidance system (N_1) and LED lightbar guidance system (N_2) installed on tractors for tillage operations with respect to tractor operated without navigator-assistance. The experiments were conducted by two operators (O_1 and O_2). The results of comparative analyses clearly reveal lower percentage of skipped or missed areas (O_1: 4%, O_2: 3.33%) during N_1 navigator-assisted operations and (O_1: 3.7%, O_2: 5.5%) during N_2-navigator-assisted operations, as compared to without navigator assistance (O_1: 17.33%, O_2: 12.7%). Similarly, overlapped areas also showed marked decrease during N_1 (O_1: 2.33%, O_2: 3.5%) and N_2 (O_1: 3.5%, O_2: 3.83%) operations, with respect to 'without navigator assistance' (O_1: 10.17%, O_2: 13.83%) operations. The study further suggests that use of navigators significantly increases the area of soil pulverization due to lesser missing and decreases the fuel wastage by reducing overlapped area. Overall performance can be further improved by increasing the familiarity of operators with navigator instructions.

Keywords: Field capacity, Global positioning system (GPS), Missed area, Overlapped area, Satellite navigation system.

Tractors are the major source of the power available on an agricultural farm. They have been primarily developed to supply power to farm implements and equipment. Tractors are designed to perform various farm operations in unpleasant environment and adverse weather conditions. This vehicle works for both, on-road and off-road operations (Bello, 2012) such as for tillage, planting, harvesting, threshing and haulage (Mehta *et al.*, 2011).

During field operations, agricultural tractors are used to run for long hours which usually require skilled and experienced human operators (Irwin *et al.*, 2019). Continuous field activities such as ploughing and harrowing over durations longer than 2.5 hrs have been shown to cause mild to severe discomfort, pain and injury in human operators, which adversely affects their health (Mehta *et al.*, 2000).

In India, farmers execute most field operations by guiding their tractors through visual observations and judgement (Magar *et al*., 2014). Tractor operators are required to perform several functions simultaneously. Significant intelligence is needed to integrate diverse field operations with audio-visual stimuli and movement-based signals (Noguchi *et al.*, 2001). In order to drive the tractor on a poorly defined trajectory, the operators are supposed to make continuous steering adjustments while ensuring optimum utilization and performance of the specialized implements that are generally not in their direct vision. This constant multi-tasking for long field hours is a highly strenuous exercise for operators (Zhang *et al.*, 1999), which frequently results in increased heart rates (Muzammil *et al.*, 2004) and possible torsion of neck and spine (Mehta *et al.*, 2000). Such physical problems further cause safety issues and decreased operation efficiency, along with reduced consistency in maintaining precision of operation (Huang, 1994; Yadav *et al*., 2017).

The increase in tractor speed, implement size, power, and functions further enhance the constraint faced by operators (Grisso *et al.*, 2009). Moreover, manual operations of tractors are entirely based on conscious estimation, wherein operators rely on their experience to identify unploughed area by simply visualising the field. However, field operations based on visual observations become increasingly complicated

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after repeated rounds of activity. Such obscure reference is often difficult for the operator to interpret, making this approach error-prone. This complexity usually results in overlapping of covered area, or missing of area (Magar *et al.*, 2014), especially during low visibility. The increased pressure on operators may lead to additional errors in function, time, economy and costs, and environmental problems (Grisso *et al.*, 2009). Thus, development and application of technologies that can reduce the need of multi-dimensional manual attention is crucial.

The advancement in communication and sensors technologies has motivated the use of navigation-based guidance systems in the field of agriculture. Navigation systems are being associated with agricultural vehicles to determine a suitable trajectory for the operators (Yao *et al*., 2005). The major advantage of navigation systems (Global Positioning System and Global Navigation Satellite System) for agricultural vehicles is to provide absolute position measurement along with generation of an ideal reference path. Navigation systems provide direct instructions to the tractor operator regarding the requisite extent and direction of steering wheel movement in order to follow the pre-defined trajectory (Santana-Fernández *et al.*, 2010). In fact, the satellite navigation systems have replaced drill disk markers for making parallel swaths across a field. Consequently, the operators are able to significantly reduce skips and overlaps, which frequently occur while using conventional methods reliant on visual estimation of swath distance and/or counting rows (Grisso *et al*., 2009). Furthermore, navigation system-assisted agricultural vehicles have reduced the requisite amount of effort from the operator, leading to decrease in work arduousness (Thuilot *et al*., 2002) and the probability of fatigue. Besides reduction of labour intensity and enhancement of efficiency, such systems enable the farmers to work during low visibility field conditions such as dust, fog, and darkness, increasing the precision of tasks (Thuilot *et al*., 2002, Grisso *et al*., 2009). To summarize, navigation systems implemented in agricultural practices provide many advantages like saving fuel and operation time, ease of operation, reduction in production losses and saving resources leading to an overall increase in field efficiency (Hamada *et al.*, 2009).

In the current study, the advantages of using navigation-based guidance systems during specific field operations have been analysed for Indian scenario. The study is designed to present a comparative account of two commercially available navigation systems (N_1 and N_2) for improving overall efficiency of implements. The performance of both the satellite navigation systems has been compared for three main parameters i.e., missed area, overlapped area, and field capacity of the implement.

MATERIALS AND METHODS

Selection of navigator systems

Two commercially available imported navigation systems (N_1 and N_2) were used to assist the operator for driving the tractor during the tillage operation (Fig. 1). The N_1 navigator is equipped with offset value type guidance system, GPS, USB slot for data extraction and shows the area covered, missed, overlapped on the screen. On the contrary, N_2 system comprises LED light bar guidance, 5 Hz internal GPS, DGPS and only shows the path that has to be followed. N_1 navigation system guides the operator through navigation map that shows area operated/missed by implement whereas N_2 navigation system provides straight line guidance that shows the diversion of implement from the reference line. There are two available modes of guidance pattern in the navigation systems i.e., one is straight parallel and another is curved parallel. Since, the plots were rectangular in shape; hence, straight parallel guidance pattern was selected for the operation (Fig. 2).

Fig. 1. A view of Navigation Systems (a) Navigation system N_1 and (b) Navigation system N_2

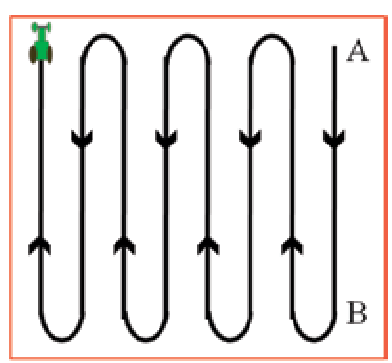


Fig. 2. A view of straight parallel guidance pattern

Installation of navigation systems

Navigation systems mainly consist of navigation monitor, GPS antenna, power supply cable and mounting bracket kit. Both the navigators were mounted in front of the operator without obstructing the view and within easy reach for accessing the functional keys (Fig. 3). The navigators were connected to 12V battery of the tractor. The external GPS antenna was placed at the roof of the tractor via in-built magnet in the GPS that gets attached to the ROPS (Roll over Protective Structure) of the tractor. The accuracy of the system depends on the signal strength received by GPS receiver from GPS satellites orbiting around the earth. Both the navigation systems have the provision to configure and save the details of the attached implements and position of GPS antenna. Also, N_1 navigation system has the provision to save the data of job (operation) performed and provides option to name the saved files. The saved data files were extracted through USB port present at the bottom and analysed on laboratory computer through software provided by the firm. No such provision is available for N_2 navigation system and only monitor display at the time of operation is available.

Field trials

The study was carried out at the experimental farm of Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana (Latitude: $30^0$54’38.12” N and Longitude: $75^0$49’05.94” E), Punjab. The field selected was having dimensions 77 m X 26 m (0.2 ha). An eleven tyne spring-loaded type cultivator was used for tillage operation with and without navigator assistance approach. The spacing between two tynes was 225 mm. The swath width of the cultivator was 2.47 m. The speed of tractor during operation varied between 3.0 Km/hr to 3.5 Km/hr. Therefore, in the navigation systems (N_1 and N_2), swath width of 2470 mm was configured and saved as the working width of implement. A John Deere 5310 tractor (with Rollover Protective Structure) of 55 hp 3-cylinder engine having 9 forward and 3 reverse gear was used for tillage operation. A deep tillage was needed for the experimentation as a result of which 55 hp tractor was selected. Trials were conducted without navigator assistance and with navigation systems guidance (N_1 and N_2). Two different operators (O_1 and O_2) having tractor driving experience of more than 10 yrs were selected for the experiments. The operators were oriented to use the navigation assistance for driving the tractor along and over the reference lines displayed on the systems. The operators were instructed to activate and deactivate the implement by pressing “USER” option key of the satellite navigator while entering and leaving the field boundaries.

Field operation without navigation system

The tillage operation was performed through traditional practice without the guidance of the navigator. The operator drives the tractor with his experience and keeps the track in his mind. During the trial, N_1 navigator was attached on the tractor but out of the eyesight of the operator so that the job performed having data of missing and overlapping was automatically saved in it. Later the results obtained without navigation system were compared with assistance methods (Fig. 4a).

Field operation with N_1 navigation system

During N_1 assistance, operator takes guidance from pattern that is continuously being generated on the screen of the navigator. While driving along field border, two marks A & B were set which were helpful for guiding the operator along tracks parallel to this reference. During on-go, the path covered by tractor was displayed in “Light Green” and overlapped area in

(a) (b)

Fig. 3. (a) Installation of satellite navigators (N_1 & N_2) and (b) GPS antenna on tractor

"Dark Green" (Fig. 4b). The missed area was shown in "White" colour.

Field operation with N_2 navigation system

During assistance from N_2 navigator, the operator drove the tractor according to the guided path generated by N_2. A reference straight line (A to B) was fed in the navigator and tractor followed that reference line. As the tractor deviates from the straight-line path, LED light blinks and indicates the driver to keep the tractor inline. Unlike navigator N_1, it lacks storage provision. Therefore, N_1 navigator was also activated and mounted on the tractor but out of the eyesight of the operator in order to store the job performed. Later the results obtained through N_2 assistance were compared with other two methods (Fig. 4c).

Measurement of different parameters

Three parameters were selected to determine the performance of the navigation systems viz., missed area, overlapped area and field capacity of the implement. Firstly, the time taken (hours) to complete the operation was recorded for comparative analysis. Next, missed area (hectares) was documented, which indicates the total area that was left undisturbed by cultivator, i.e. areas where pulverization of the field did not occur. The next parameter was overlapped area (hectares), representing the combined area where the desired operation was performed more than once by the cultivator. The fuel consumed during the experiment trials were recorded using a fuel flow meter mounted in between the tractor fuel supply line. The readings were taken from the same in $ml.s^{-1}$. All treatment operations (Without, N_1 and N_2 assisted) have been performed by both operators (O_1 and O_2) in three replications. All values obtained under each parameter have been presented as mean of three technical replicates, along with the respective standard deviation.

RESULTS AND DISCUSSION

The performance of tillage operations assisted with commercially available navigation systems (N_1 and N_2) have been evaluated over three parameters. The results have been compared without navigation system, wherein the guidance system was not accessible to the operator. The performance analysis of tillage operations with and without navigation systems have been carried out separately for both operators (O_1 and O_2). In case of N_1 and N_2, the respective navigators were visible to the operators. The swath width was consistent in all cases (2470 mm), and the tilled area was also same for all operations and replications (0.2 ha).

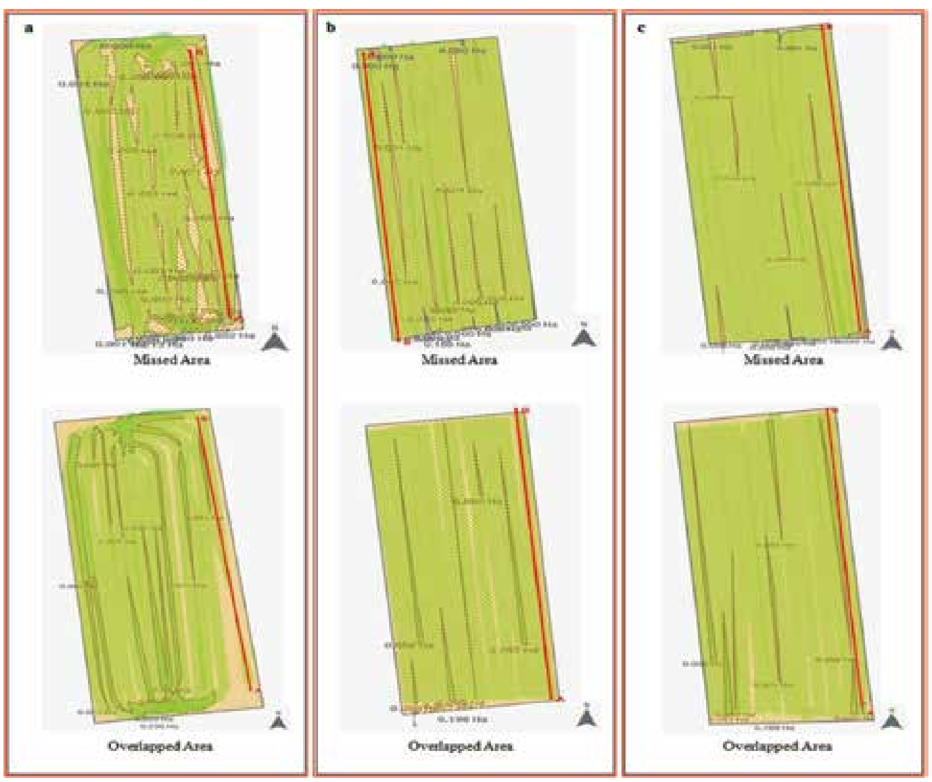


Fig. 4. Representative maps depicting general view of field area after tillage operations using (a) without navigator system, (b) N_1 navigator and (c) N_2 navigator systems obtained from the software symbolizing missed and overlapped areas

Comparative analysis of time taken

In order to ascertain the amount of time saved by using navigation-based systems, the overall time taken to complete the operation was recorded. The mean values of time taken over three replications have been calculated in each case (Table 1). The average time taken to complete the tillage operation without navigator assistance was consistent for O_1 and O_2 (0.236 h and 0.230 h, respectively). In case of using navigation system N_1, while O_1 was able to accomplish the task in average 0.232 h, O_2 completed the same task in 0.241 h on an average. While using N_2 navigation systems, O_1 took 0.261 h to complete the operation, while O_2 accomplished the same task in 0.237 h. No significant reduction in time was observed upon using the navigation systems. This may be due to the reason that as missing and overlapping was reduced by using navigation system, both parameters counteracted in saving of time. These values have been further employed to calculate field capacities. It was further observed that O_1 consumed far less time to complete the task while using N_1 navigation system, as compared to navigation system N_2. On the other hand, O_2 consumed similar amount of time in both cases.

Comparative analysis of missed area

To analyse whether use of navigation-assisted systems affects skipping of areas during tillage operations, the areas missed from overall coverage during 'without navigation assistance', N_1, and N_2 operations by both operators O_1 and O_2 were marked and recorded. The mean values of total missed areas obtained during three replications of all experiments were calculated (Table 1) and compared (Fig. 5a). The percentage missed area observed in case of 'without navigator assistance' operations by O_1 and O_2 operators was 17.3% and 12.7%, respectively. It means no tillage operation was performed by the operator on an average in 15% of the field. In contrast, tillage operations with the use of both N_1 and N_2 navigators displayed sharp decline in missed area average (Fig. 5a). The N_1 navigator-assisted operations resulted in missed areas amounting to 4.0% and 3.3% of total tilled area by O_1 and O_2, respectively. Similarly, the use of N_2 navigator decreased the missed area to 3.7% and 5.5% when operated by O_1 and O_2, respectively (Table 1). On an average, use of navigator improved missing from 15% to 3.75 and 4.5%, respectively for in tillage operations done by the tractor using N_1 and N_2 navigation systems.

Considering the trend of missed areas, it was deduced that the performance of N_1 navigator-assisted operations was marginally better than N_2 (Fig. 5a). Overall, it was noted that use of navigators led to significant reduction in missed areas during tillage operations. The observed decline in missed area may have occurred due to the pre-defined trajectory provided

Table 1. Evaluation of field performance for manual, N_1 and N_2 assisted navigation system

Parameter	Without navigator assistance		N_1		N_2	
	O_1	O_2	O_1	O_2	O_1	O_2
Swath width (mm)	2470		2470		2470	
Navigator visibility to operator	Not Visible		Visible		Visible	
Total tilled Area (ha)	0.2		0.2		0.2	
Time taken (h)	0.236	0.230	0.232	0.240	0.261	0.237
Total missed area (ha)*	0.035 ± 0.003	0.025 ± 0.009	0.008 ± 0.002	0.007 ± 0.001	0.007 ± 0.003	0.011 ± 0.0026
Total missed area (%)	17.3	12.7	4.0	3.3	3.7	5.5
Avg. missed area (%)	15.0		3.75		4.5	
Total overlapped area (ha)*	0.0200 ± 0.002	0.028 ± 0.009	0.005 ± 0.002	0.007 ± 0.001	0.007 ± 0.002	0.008 ± 0.0015
Total overlapped area (%)	10.2	13.8	2.3	3.5	3.5	3.8
Avg. overlapped area (%)	12.0		3.0		3.75	
Fuel wastage due to overlap (l/0.2ha)	0.071	0.097	0.016	0.025	0.025	0.027
Average fuel wastage due to overlap (l/0.2ha)	0.084		0.021 (25)#		0.026 (30.9)#	
Field capacity (ha/h)*	0.85 ± 0.015	0.873 ± 0.06	0.87 ± 0.065	0.84 ± 0.055	0.774 ± 0.093	0.85 ± 0.081

*Values have been represented as mean ± std. Deviation
#Figures in parentheses denotes percentage of fuel wastage compared with operation without navigation system

by navigation systems which guides the movement of tractors and minimizes the chances of areas being skipped during operations. The increased coverage may also account for similar time being consumed for without and with navigator-assisted operations, as in the latter case more area is being covered. On the other hand, the operators are reliant on visual stimuli, human instincts, and field experience during manual operations to traverse across the entire field, enhancing the probability of missing of regions. Therefore, it could be established that use of navigators increases the coverage of pulverization. It may also be predicted that navigators can ultimately improve the pulverized area, efficiency and overall performance of operations.

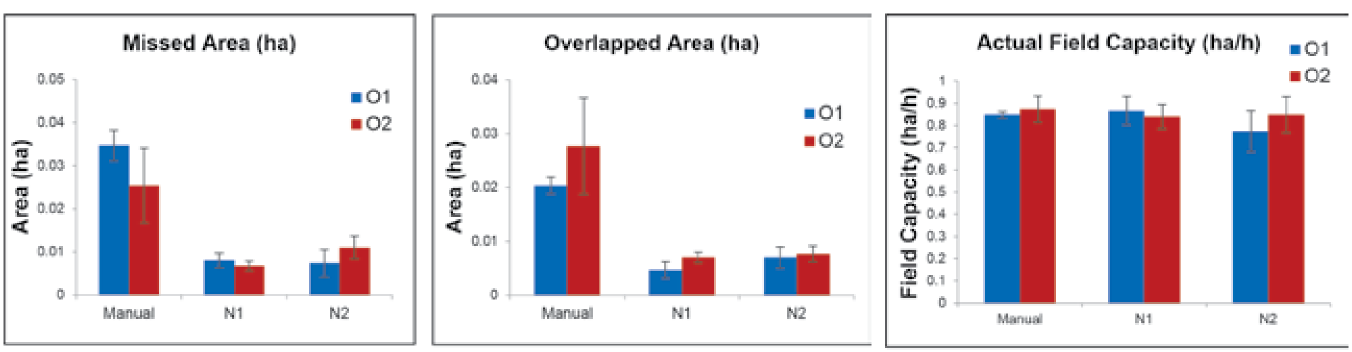
Comparative analysis of overlapped area

To analyse the impact of navigation-assisted field operations on repetitive application of implements, the overlapped areas were marked i.e. areas where operations were performed more than once. The overlapped areas for 'without navigator', using N_1 and N_2 systems during operation carried out by O_1 and O_2 were recorded and compared (Table 1, Fig. 5b). For this purpose, the mean values of overlapped areas obtained from three replications of each experiment were calculated (Fig. 5b). During operations carried out without navigator assistance, the percentage of overlapped area for both O_1 and O_2 operators was relatively higher i.e. 10.2% and 13.83%, respectively than navigator assisted operations. It means overlapping of tillage operation was done on an average in 12% of the tilled area by the operators in absence of navigation system which may have led to fuel wastage (0.084 l/0.2ha). The overlapped area decreased to 3.0% upon use of N_1 navigator, while a marked decrease in overlap was also deduced in N_2 navigator assisted operations conducted by both operators, which revealed 3.75% of overlapped areas on average (Table 1). This also led to reduction in fuel wastage up to 75% (0.021 l/0.2ha) and 69% (0.026 l/0.2ha) in the N_1 and N_2 navigator-based operation, respectively. In case of overlapped areas, operations guided by N_1 navigator showed slightly lesser overlaps than N_2 assisted operations (Fig. 5b). Thus, it was clearly observed that use of navigators reduces the chances of overlapping or reduced fuel wastage, as compared to tillage operations performed without navigators. As explained for missed areas, the decrease in overlapped areas may also be explained on the basis of navigator-assisted coverage of field operations, in contrast to unaided visualisation of field via operators. Overlapping of areas or repetition of activity causes time loss, and may thus lead to reduction of efficiency, productivity and performance.

Comparative analysis of field capacity

Field capacity is one of the most crucial parameters for evaluation of overall performance and efficiency of operations. In order to accurately predict the difference in overall performance of navigator-assisted and without navigator assisted systems in tillage operations, the field capacity was defined, calculated and compared. The 'Field Capacity' was first computed for all operations and their technical replicates. This entity represents the field capacity of the implement as total area coverage per unit time. As the total tilled area is common (0.2 ha) for all operations, the Field Capacity in each case depends solely on the respective total time taken to complete the operation. The Field Capacity for operation 'without navigation system' was found to be 0.85 ha/h and 0.873 ha/h for O_1 and O_2, respectively (Table 1). The corresponding values of Field Capacity for N_1 were 0.87 ha/h and 0.84 ha/h, and for N_2 were 0.774 ha/h and 0.85 ha/h (O_1 and O_2, respectively). As anticipated, no remarkable differences could be recorded between the field capacities calculated for operation without navigation system, N_1 and N_2 systems (Fig. 5c).

The comparable values obtained for field capacity with and without use of navigation systems were further evaluated for variation among experimental replicates via statistical analysis (Table 2). This analysis revealed



(a) Average missed area (ha) (b) Average overlapped area (ha) (c) Field Capacity (ha/h)

Fig. 5. Comparative analysis of Manual, N_1 and N_2 navigator-assisted operations over selected performance parameters. Error bars represent Standard Deviation about the Mean in all graphs.

that the effect of using navigation systems on field capacity is significantly at par (p = 0.399).

Table 2. Statistical analysis of the parameters

Parameter	P value (0.05)	Mean	Std. error
Total Missed area (ha)	<0.0001	0.016	0.001
Total Overlapped area (ha)	<0.0001	0.012	0.001
Field Capacity (ha/h)	0.3990	0.842	0.016

Therefore, it may be stated that there is no significant difference between field capacity of operations with or without the use of navigation systems N_1 and N_2 when level of significance is 5%. On the other hand, the other two parameters, missed area and overlapped area displayed highly significant variation ($p < 0.0001$ in both cases) between operations performed with and without use of navigation systems at the same level of significance (Table 2). It was thus inferred that minimization of missed area with use of navigation system allowed increased soil pulverization even in previously untouched areas of the field, and significant reduction in overlapped areas caused decrease in fuel wastage and consumption, without affecting the overall field capacity of the implement.

The current study demonstrates the improvement in performance of implements with navigator-assisted tillage operations. The time taken for manual and navigator-assisted operation was almost similar whereas drastic reduction was observed in terms of missed and overlapped area. With use of navigation systems, missed area reduced from 15% to 3.75%, which allowed increased pulverization of soil even in areas which were previously untouched during operations without navigator assistance. This lead to increase in overall germination across the field. Overlapped area reduced from 12% to 3% when navigator systems were used, and thereby a drastic reduction (up to 75% from operations without navigation assistance) in fuel consumption was simultaneously recorded, improving the efficiency of operation. The field capacity of the implement remained unchanged with and without use of navigation systems.

The performance of N_1 navigator system was found to be better than N_2 in terms of all three parameters tested. Additionally, the results suggested that familiarity of operators with navigator instructions is a crucial factor in improving overall performance. Overall, use of navigation systems positively influenced the productivity and efficiency of field operations without affecting the field capacity. This may in turn lead to reduction of operator fatigue, and saving of essential farm resources.

Authors' contribution

Conceptualization and designing of the research work (MS, AP, KS, HG, SS); Execution of field/lab experiments and data collection (KS, HS, SS, AP); Analysis of data and interpretation (KS, AP, MS, HG); Preparation of manuscript (AP, MS, KS, SS).

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