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Effect of operational parameter on tractor-implement system's performance

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Abstract
The main objective of this research was to study the effect of operational parameters like operational speed and tillage depth on performance of tractor-implement system. Three levels of engine RPM (1000, 1500 and 2000), three levels of gear selection (L_3, L_4 and H_1) and three levels of tillage depth (7, 10 and 13 cm) were selected and their effects on draft force and wheel slip were investigated. A full factorial experiment was laid out in a randomized complete block design with three replications. The experiment data were subjected to analysis of variance (ANOVA). The draft force and wheel slip varied from 274.25 to 570.30 kg and from 11.37% to 39.22% respectively in case of 9-tyne cultivator. The developed draft monitoring system were very accurate and validated with calibrated spring balance (R^2 = 0.99). The developed slip monitoring system were very precise (96.64%) with respect to manually measured slip. As the operational speed and tillage depth increases, continuous increase in draft and wheel slip was observed for cultivator, disc harrow and bund former. The statistical analysis of the experiment data indicates that tractor speed and tillage depth significantly (p<0.01) affected the draft force and wheel slip of the tractor-implement combinations.

Keywords: Wheel slip, draft force, performance parameter, operational parameter, tractor-implement system

1. Introduction

In recent years, the demand for food has increased due to the growing population and changing dietary habits. This has put pressure on the agriculture sector to produce more food, more efficiently and with less impact on the environment. Despite the substantial progress made in mechanization of agriculture in the world, the challenges facing agricultural policy makers in the developing countries is how to increase agricultural production more than subsistence production through increase in yield and energy savings (Kabri *et al.*, 2019) [6]. Hunt (1979) [5] reported that proper selection and matching of agricultural machines could reduce the amount of energy required for each implement. There are several operational parameters that can affect the performance of tractor implement system including tractor speed, tractor horsepower, soil type, soil moisture and depth of operation. Field efficiency and capacities are key parameters for evaluating agriculture machinery performance. The first operation farmer has to undertake in growing crop is to use a soil engaging implement to prepare the soil (Kawuyo, 2011) [7]. The draft requirement of tillage tools as a function of operating speed is an important criterion for evaluating of tillage implements (Kushwaha and Linke, 1996) [8]. The existing data on the effect of operating speed on the draft are inadequate and limited for specific location (Majid *et al.*, 2013; Nkakini, 2015; Omofunmi *et al.*, 2016; Abdallah *et al.*, 2017) [9, 11, 12, 1]. This caused improper utilization of available power and result in frequent breakdown. However, most of the previous work that has been done on draft force in the past was focused on specific draft and has concluded to the point that tillage depth is the primary determinant of the amount of force required to pull an implement through soil, with speed having a significant effect (Ehrhardt *et al*., 2001; Collins and Fowler, 1996; Kushwaha and Linke, 1996; Wheeler and Godwin, 1996; McLaughlin and Campbell, 2004) [4, 3, 8, 14, 10]. As operation parameter like tillage depth and operational speed of the implement have the greatest influence on the performance of the tillage implement, this study was conducted to study the effect on draft force and wheel slip of the tractor-implement combinations under varying speed and tillage depth.

2. Material and Methods

2.1 Experimental Site: Experiments were conducted at the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The experimental site was located at latitude of 20.080° N and longitude of 77.154° E and was 228.61 m above the mean sea level. The area of the experimental field was 2 acres.

2.2 Soil Sampling and Analysis: A composite soil sample was collected from different part of the experimental site. The moisture content and dry bulk density was calculated using core cutter method and oven dry method. The soil in the experimental site was clay loam.

2.3 Selection of Tractor: The selection of tractor was based on the power requirement to perform all type of tillage operation. The tractor selected for experiments was New Holland 3630 TX Turbo Super. It has engine power of 50 HP and PTO power of 42.5 HP.

2.4 Selection of Implement: The selection of implement was based on the popularity of implement commonly used among farmers and availability of the implement in the testing facility during field testing. An implement selected for field testing was 9-tyne spring loaded cultivator for ploughing operation, 14 discs offset disc harrow for harrowing operation and bund former.

2.5 Field Methods: There was recently harvested crop growth and the field was left fallow. Before conducting the experiments, the field was irrigated by using a flood irrigation method. Soil samples were collected using core cutter method from different random location in the experimental field. The samples were weighed during the experiments to determine the soil moisture content. The soil samples were placed in the electric hot air oven, maintained at 110 °C for 48 hours. After 48 hours, the dried soil samples were weighed again and moisture content of the soil was calculated on the dry basis. The bulk density was also calculated from the same sample. Various soil properties of the experimental site are shown in Table 1.

$$M_c(\%) = \frac{W_2 - W_3}{W_3 - W_1} \tag{1}$$

$$Dry\ Bulk\ Density = \frac{W}{V} \tag{2}$$

Where,
W_1 = Weight of the empty container.
W_2 = Weight of the soil sample before drying along with the container.
W_3 = Weight of the soil sample after drying along with the container.
W = Dry weight of the soil sample = $W_3 - W_1$.

$$V = \text{Volume of the core sampler} = \frac{\pi \times r^2 \times h}{4} \tag{3}$$

The field experiment was a full factorial experiment based on randomized complete block design (RCBD) with three replication was used to evaluate the effect of tillage depth and operation speed on draft force of selected implement and wheel slip of the tractor-implement combination. Three levels of tractor engine speed (1000, 1500 and 2000 RPM), three levels of tractor gear selection (L_3, L_4 and H_1) and three levels of tillage depth (7, 10 and 13 cm) were used in combination resulting in a total number of 27 treatments. The treatments were randomly distributed in the field tests.

2.6 Experimental Procedure: An experiment block of 50 m long and 4 m wide was used for each treatment. A small block of 5 m long and 5 m wide at the beginning of each test was not considered in the final data analysis, it was used to enable the tractor-implement combination to reach the required tillage depth and operational speed. Tillage depth was measured as the vertical distance from the top of the undisturbed soil surface to the deepest penetration made by the implement cutting edge. The speed of operation was varied by setting the engine RPM at required level by using hand lever and changing the tractor gear. During field operation, the tractor was operated at the same tillage depth but at different speeds of operation. The draft force of the implement and wheel slip of the tractor was measured, displayed and recorded by the developed ATmega 2560 based data acquisition system fitted near to the tractor operator.

2.7 Data Acquisition System

The data acquisition system consists of a data logger, load cells and Hall sensor. The load cell placed in the developed frame between three-point hitch and implement to measure draft force of the implement. Each load cell was calibrated separately prior to experiments and calibration factor was calculated for each load cell. The same calibration factors were used in the control algorithm to covert the load cell digital output into draft force in kg. the developed three-point hitch dynamometer was also validated by using spring weighing balance and found to be very accurate (R^2 = 0.99). For measurement of wheel slip, Hall effect sensors were placed on the front and rear wheel of the tractor. Hall sensor fitted on the front wheel of the tractor gives actual forward speed of the tractor. While, two separate hall sensors were fitted on each of the rear wheel to calculate the average theoretical speed of the tractor.

$$D = F_{LL} + F_{RL} + F_T \tag{4}$$

Where, D = Total Draft; F_{LL}= Force on left lower link load cell; F_{RL}= Force on right lower link load cell; F_T = Force on top link load cell.

$$Actual\ speed\ of\ operation\ (V_a) = \frac{2\pi r_f N_f}{60} \tag{5}$$

$$Theoretical\ Speed\ of\ left\ real\ wheel\ (V_{tL}) = \frac{2\pi r_{rL} N_{rL}}{60} \tag{6}$$

$$Theoretical\ Speed\ of\ right\ real\ wheel\ (V_{tR}) = \frac{2\pi r_{rR} N_{rR}}{60} \tag{7}$$

$$Theoretical\ speed\ of\ operation\ (V_t) = \frac{(V_{tL} + V_{tR})}{2} \tag{8}$$

$$N = \frac{1 \times 60000}{n \times Time\ taken\ to\ detect\ two\ consecutive\ magnet\ (ms)} \tag{9}$$

$$Slip = \frac{V_t - V_a}{V_t} \tag{10}$$

Where, r_f = Rolling radius of front wheel; N_f = Number of revolutions of front wheel.

r_{rL} = Rolling radius of left rear wheel; N_{rL} = Number of revolutions of left rear wheel.

r_{rR} = Rolling radius of right rear wheel; N_{rR} = Number of revolutions of right rear wheel.

N = Number of revolutions of wheel; n = Number of magnets on the wheel.

The control algorithm was developed and documented for the microcontroller to scan the sensors every 200 milli-second during field operation. Therefore, the number of readings collected in each treatment depended on the operational speed of the tractor and large amount of data can be collected for better understanding. To begin the field tests, the position-control lever of the tractor was marked with respect to different depth of operation, engine speed was set to selected level (1000/1500/2000 RPM) and tractor gear was selected (L_3/L_4/H_1), then the tractor was declutched slowly to the required operational speed and implement was lowered to selected level of depth (7/10/13 cm) before entering the first test block.

Data acquisition system has on/off switch and was activated by pressing the switch as the tractor enters the test block and data acquisition system continued recording of the data up to end of the block. After finishing the first test block, tractor was driven straight towards the second block and same process was repeated for all 27 blocks. The data acquisition system has micro-SD card module to store the load cells data, draft force, operational speed and wheel slip. It has 16×2 LCD display unit to show the numerical value of draft and wheel slip. The developed data acquisition system is shown in Fig. 1 and Fig. 2.

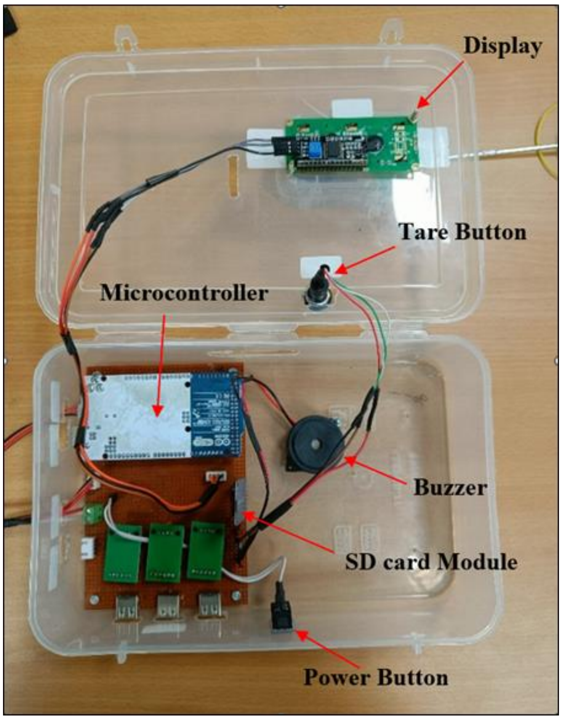


Fig 1: Name of mounted components in a developed data acquisition system

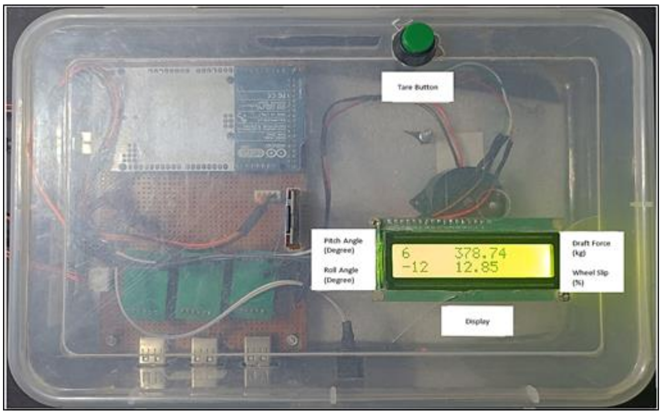


Fig 2: Developed data acquisition system

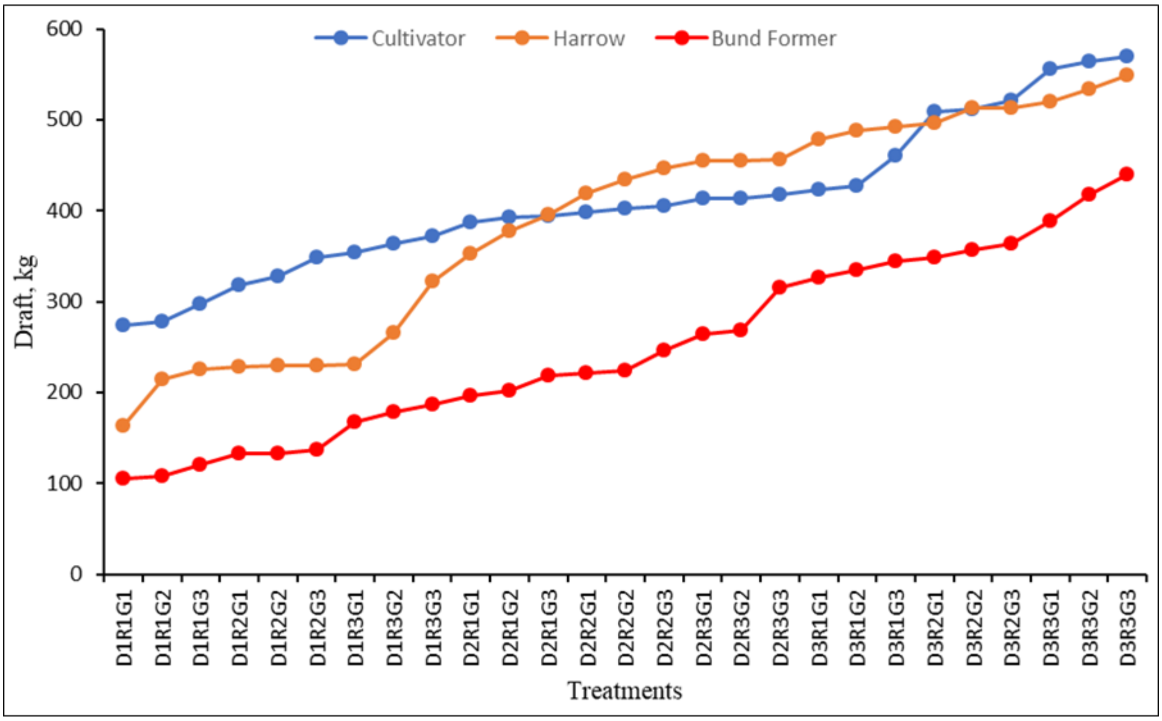
Table 1: Soil properties of the selected field

Field	Soil Condition	Moisture content (DB), %	Dry Bulk Density g/cm^3	Cone Index N/cm^2
Field 1	Medium hard, Moist	14.38 ± 1.42	1.67 ± 0.02	230 ± 10

3. Result and Discussion

3.1 Effect of operational parameters on draft

Fig. 3 shows the results of various experiments conducted with three different implement under varying operational conditions. These results show that the continuous increase in draft with increasing operational speed and tillage depth. The draft force in case of 9-tyne cultivator varied from 274.25 kg to 570.30 kg as of first treatment (Depth = 7 cm, Engine RPM = 1000 and Gear = L_3) to 27th treatment (Depth = 13 cm, Engine RPM = 2000, Gear = H_1). Similarly in case of 14 discs offset disc harrow, draft force varied from 163.10 kg to 548.39 kg as of first treatment to 27th treatment. The draft force for bund forming operation varied from 105.38 kg to 439.43 kg for same treatments. The increase in draft force with increasing depth is due to more penetration of tillage tool result in more soil movement and more resistance it encounters. While increase in draft force with increasing speed is due to more soil acceleration over the tillage tool's surface. Similar observation was reported by other researchers (Ashok Kumar *et al.*, 2016; Majid *et al.*, 2013 and Saleh A. *et al.*, 2021) [2, 9, 13].

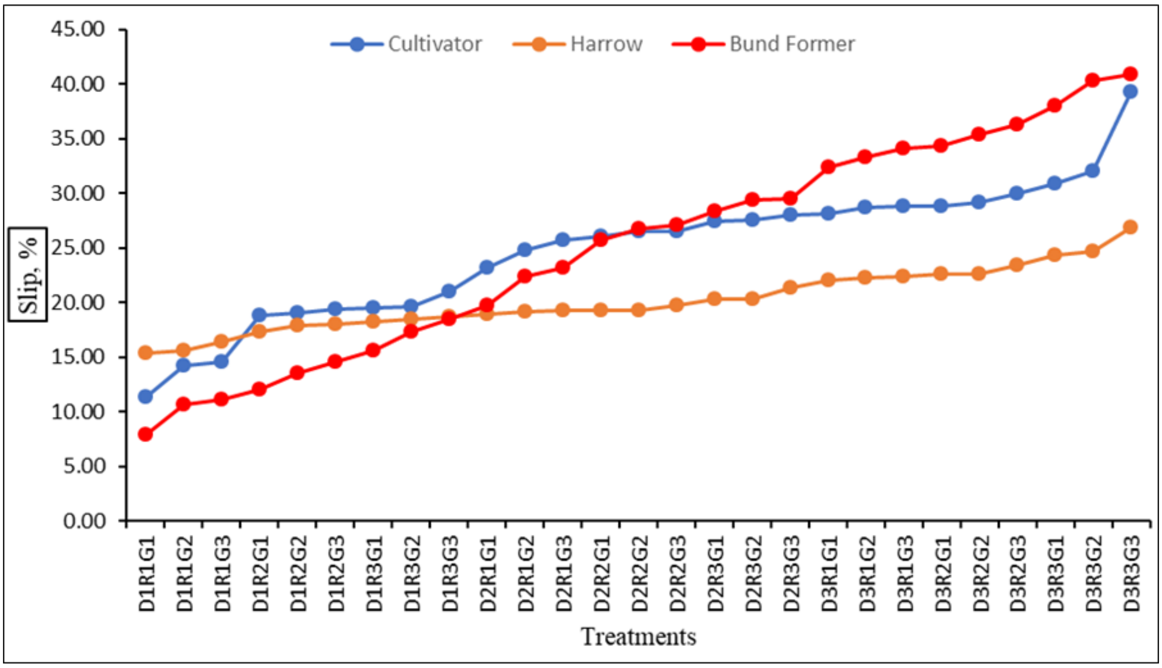


$D_1 = 7$ cm; $D_2 = 10$ cm; $D_3 = 13$ cm; $R_1 = 1000$ RPM; $R_2 = 1500$; $R_3 = 2000$; $G_1 = L_3$ low gear; $G_2 = L_4$ low gear; $G_3 = H_1$ high gear

Fig 3: Effect of tillage depth and operational speed on draft force of implement

3.2 Effect of operational parameters on wheel slip

Fig. 4 shows the effect of operation parameters on wheel slip of the tractor-implement combination. These results show that the continuous increase in wheel slip with increasing operational speed and tillage depth. The average wheel slip in case of 9-tyne cultivator varied from 11.37 % to 39.22 % as of first treatment (Depth = 7 cm, Engine RPM = 1000 and Gear = L_3) to 27th treatment (Depth = 13 cm, Engine RPM = 2000, Gear = H_1). Similarly, in case of 14 discs offset disc harrow, average wheel slip varied from 15.29 % to 26.82 % as of first treatment to 27th treatment. The average slip during bund forming operation varied from 7.84 % to 40.85 % for the same treatments. As the draft force increases with increase in tractor speed and tillage depth, it became more difficult for the tractor to pull the implement results in more slip at higher speed. The same behavioral pattern of the wheel slip was reported by Ashok Kumar *et al.* (2016) [2].



$D_1 = 7$ cm; $D_2 = 10$ cm; $D_3 = 13$ cm; $R_1 = 1000$ RPM; $R_2 = 1500$; $R_3 = 2000$; $G_1 = L_3$ low gear; $G_2 = L_4$ low gear; $G_3 = H_1$ high gear

Fig 4: Effect of tillage depth and operational speed on wheel slip of tractor-implement combination

4. Conclusions

It can be concluded that tillage depth and tractor's operational speed significantly ($p \leq 0.01$) affected the draft force of the cultivator, disc harrow and bund former. Also, with increase in operation speed and depth of operation, draft force of the implement increases simultaneously. In addition, operational speed and tillage depth had the same influence on wheel slip of the tractor-implement combination. The developed data acquisition system was developed to measure and record the draft force and wheel slip. The developed device is very much accurate and very helpful in the research institute.

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