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Analyzing tractor-implement combinations for improved tractive performance and fuel economy at part loads

Nihal Kumar Pandey, AK Dave, AK Shrivastava and Nisha Verma

Abstract
A field experiment was conducted at dry and wet field conditions of Chhattisgarh. Fuel economy and tractive performance of three different tractors models was determined at part loads with commonly used tillage implements with influence of dry and wet field conditions. A field testing of seven tractor-implement systems for dry field conditions viz. tractor-zero till ferti seed drill, tractor-MB Plough, tractor-disc harrow, tractor-seed drill, tractor-rotavator, tractor-cultivator and tractor-subsoiler and for wet field conditions viz. tractor-rotavator and tractor- cultivator was carried out at eight different throttle positions (0%, 25%, 50%, 60%, 75%, 85%, 90% and 100%). Gear was selected at constant condition at low-IInd. Three tractor models with their power rating 55 hp (T_1), 57 hp (T_2) and 63 hp (T_3) were used for experimentations under actual field conditions. Fuel consumption, field capacity, width and depth of cut of implements were measured at different part loads for different implements. In dry field conditions, the following throttle positions are recommended for optimal performance with various tractor attachments. A Tractor 2nd (57 hp) equipped with a zero till ferti-seed drill attachment should be set to 85% throttle for peak performance. When using a Tractor 2nd (57 hp) with an M.B. plough attachment, it's best to operate it at 50% throttle for ideal results. For a Tractor 1st (55 hp) with a disc harrow attachment, maintaining a throttle position of 50% is recommended for optimal operation. When using a Tractor 1st (55 hp) with a seed drill attachment, it's advisable to set the throttle at 75% for the best performance. Similarly, if you have a Tractor 1st (55 hp) with a rotavator attachment, it should be operated at 50% throttle to achieve the most efficient performance. When using a Tractor 1st (55 hp) with a cultivator attachment, it's recommended to set the throttle at 75% for optimal conditions. Finally, if you're using a Tractor 1st (55 hp) with a subsoiler attachment, operating it at 100% throttle provides the best conditions for field performance in dry soil. In wet field conditions, it is recommended to operate Tractor 3rd (63 hp) with a rotavator attachment at 60% throttle for optimal field performance. Likewise, when using Tractor 3rd (63 hp) with a cultivator attachment, setting the throttle to 75% is advised for achieving the best possible conditions during field operations.

Keywords: Tractor-implement combinations, tractive performance, fuel economy, part loads

Introduction
Agriculture, being the backbone of many economies worldwide, relies heavily on the efficient utilization of farm machinery to increase productivity and reduce labour intensity. Tractors play a vital role in modern agriculture, providing the necessary power to perform various field operations. However, tractors' performance and fuel consumption are influenced by a multitude of factors, and understanding these interactions is crucial for sustainable and economically viable farming practices. In the central Indian state of Chhattisgarh, agriculture forms the backbone of its rural economy. As farming practices evolve and become more mechanized, the role of tractors becomes increasingly significant. The region's diverse topography and varying field conditions demand a comprehensive analysis of tractor performance and fuel consumption at part loads.

The mapping of tractive performance and fuel consumption at part loads involves examining how tractors perform under less-than-maximum load conditions. In real-world farming scenarios, tractors seldom operate at full capacity throughout their work cycles. Understanding how tractors behave at part loads becomes essential to optimize fuel efficiency and minimize operating costs. Several factors come into play when studying tractive performance and fuel consumption at part loads. These factors include soil type, moisture content, crop type, and field topography. Each of these elements can influence the power requirements and energy demands of tractors during various field operations, such as plowing, tilling, planting, and harvesting. The study aims to gather empirical data from field experiments conducted across different regions of Chhattisgarh. By conducting trials under various field conditions and using different tractor models, researchers can collect valuable insights into the relationship between tractive performance, fuel consumption, and part load operations. Advanced telemetry systems and data logging tools will be employed to record and analyze the tractors' performance metrics accurately.

The implications of this study can be far-reaching. Farmers and policymakers can use the findings to make informed decisions about tractor selection, proper matching of machinery to specific field conditions, and optimal utilization of resources. Moreover, this research can contribute to the development of precision agriculture techniques, allowing farmers to enhance their productivity while minimizing environmental impact. In conclusion, mapping the tractive performance and fuel consumption of tractors at part loads under different field conditions in Chhattisgarh is a significant endeavour with broad implications for the agricultural sector. The study's findings have the potential to transform the way farmers in the region approach their mechanized farming practices, promoting sustainability, efficiency, and economic viability in agriculture while contributing to the overall growth of the state's rural economy.

Operational management should take care of various factors like soil variables, tractor condition implement used and knowledge and skill of tractor condition implement used and knowledge and skill of tractor operator to adjust the throttle settings in accordance to the part load to avoid tractors to become fuel guzzlers. Smith and fornstorm (1980) [7] studied the energy requirement of selected dry land wheat cropping systems and found that the mean specific fuel consumption for S-cultivator (3.5m) was 6.3 l/ha at the forward speed 4.8 km/h and for mould board plough (three bottom 35.6 cm bottom) at the forward speed 4.0 km/h was 34 l/ha which was about 6.5 times more than S- cultivator. Kamble and Panwar (1987) [2] reported an average fuel consumption of 0.104 l/h to 0.140 l/h for 35 hp tractors in different field operations on a 35-acre mechanized farm. It would be further useful to study the performance of different tractor models popular on farmer's field to know their economy and capacities at different part load settings. As in sandy loam soil fuel consumption at 2/3rd engine speed for different model tractors with cultivator was 8-20% more than that for disc harrow due to higher depth of operation.

Materials and Methods

A field testing of seven tractor-implement systems for dry field conditions viz. tractor-zero till ferti seed drill, tractor-MB Plough, tractor-disc harrow, tractor-seed drill, tractor-rotavator, tractor-cultivator and tractor-subsoiler and for wet field conditions viz. tractor-rotavator and tractor- cultivator was carried out at eight different throttle positions (0%, 25%, 50%, 60%, 75%, 85%, 90% and 100%). Gear was selected at constant condition at low-IInd. The study concludes three different tractors as horsepower ranging as 55 hp, 57 hp and 63 hp. The seven selected implements (M_1, M_2, M_3, M_4, M_5, M_6 & M_7) is used in this study. As the result and discussion concludes, the reported results of conventional and modern tractor implement system which usually affects the parameters like system which affects the parameters like fuel consumption, drawbar performance, power at rated speed and wheel slippage, which must vary with different tractor models. During the test run of the study, the measurement of fuel consumption was done using top-up method for each operation at different set of variables. The tests were conducted on three tractor models i.e., T_1 (55 hp), T_2 (57 hp) and T_3 (63 hp) for all the seven selected implements at eight different throttle settings. For evaluating field capacity and field efficiency at part loads, all the selected implements were operated in both dry and wet field conditions as per usual operational methods and normal depth of cut. Observations were taken on actual useful time, and different time losses. All the tests were replicated thrice to avoid experimental errors. The average value of both dependent and independent variables was calculated. Data was presented to establish the patterns of variations in fuel consumption and field capacity with part loads.

Table 1: Plan of experiment for performance test of tractor-implement system

Independent variables	Levels	Dependent variables
1. Type of implement	• M_1- Zero till ferti seed drill (1.6 m) • M_2- M B plough (4 bottom) • M_3- Disc harrow (8+8 disc) • M_4- Seed drill (2.19 m) • M_5- Rotavator (2.12 m) • M_6- Cultivator (11 tynes) • M_7- Subsoiler (1 tyne)	1. Effective Field Capacity (ha/h) 2. Theoretical Field Capacity (ha/h) 3. Field efficiency (%) 4. Bulk density (kg/cm^3) 5. Soil moisture content (%) 6. Drawbar power (hp) 7. Fuel efficiency (%) 8. Vehicle efficiency (%) 9. Speed of travel (km/h) 10. Slip (%) 11. Draft (kgf) 12. Rolling resistance (kgf) 13. Soil pulverization (mm) 14. Soil Inversion (%) 15. Cone index (kPa) 16. Tractive Efficiency (%)
2. Tractors used (hp)	• T_1 - 55 hp • T_2- 57 hp • T_3- 63 hp	
3. Throttle positions	• At 0% Throttle (No load) • At 25% Throttle • At 50% Throttle • At 60% Throttle • At 75% Throttle • At 85% Throttle • At 90% Throttle • At 100% Throttle (Full load)	
4. Type of field	• F_1-Dry • F_2-Wet	

Table 2: Design of experiments for dry field conditions

Implement	Tractor 1	Tractor 2	Tractor 3
1. M_1- Zero till ferti seed drill (1.6 m)	At 0% Throttle (No load)	At 0% Throttle (No load)	At 0% Throttle (No load)
2. M_2- M B plough (4 bottom)	At 25% Throttle	At 25% Throttle	At 25% Throttle
3. M_3- Disc harrow (8+8 disc)	At 50% Throttle	At 50% Throttle	At 50% Throttle
4. M_4-Seed drill (2.19 m)	At 60% Throttle	At 60% Throttle	At 60% Throttle
5. M_5- Rotavator (2.12 m)	At 75% Throttle	At 75% Throttle	At 75% Throttle
6. M_6-Cultivator (11 tynes)	At 85% Throttle	At 85% Throttle	At 85% Throttle
7. M_7-Subsoiler (1 tyne)	At 90% Throttle	At 90% Throttle	At 90% Throttle
	At 100% Throttle (Full load)	At 100%Throttle (Full load)	At 100%Throttle (Full load)

Table 3: Design of experiments for wet field conditions

Implement	Tractor 1	Tractor 2	Tractor 3
1. M_5- Rotavator (2.12 m)	At 0% Throttle (No load)	At 0% Throttle (No load)	At 0% Throttle (No load)
2. M_6-Cultivator (11 tynes)	At 25% Throttle	At 25% Throttle	At 25% Throttle
	At 50% Throttle	At 50% Throttle	At 50% Throttle
	At 60% Throttle	At 60% Throttle	At 60% Throttle
	At 75% Throttle	At 75% Throttle	At 75% Throttle
	At 85% Throttle	At 85% Throttle	At 85% Throttle
	At 90% Throttle	At 90% Throttle	At 90% Throttle
	At 100% Throttle (Full load)	At 100%Throttle (Full load)	At 100% Throttle (Full load)

Tractive Efficiency (TE)

The tractive efficiency of a tractor implement system refers to the effectiveness with which the tractors power is transferred to the ground through the implement. It is a measure of how effectively the implement utilizes the tractors power to perform the desired task, such as ploughing, tilling or hauling. The pull, torque and slip characteristics of a driving wheel define both the magnitude and efficiency of tractive performance. The pull-to-weight ratio is the accepted term for defining magnitude level of performance. Similarly, the term tractive efficiency has been adopted to define efficiency.

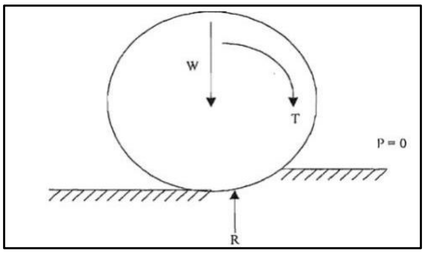

Fig: Free body diagram of self- propelled wheel

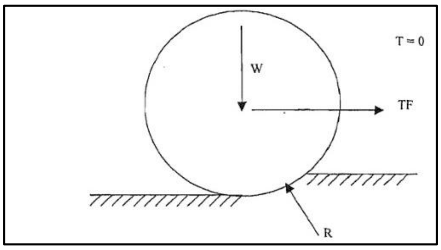

Fig: Free body diagram of a driven wheel

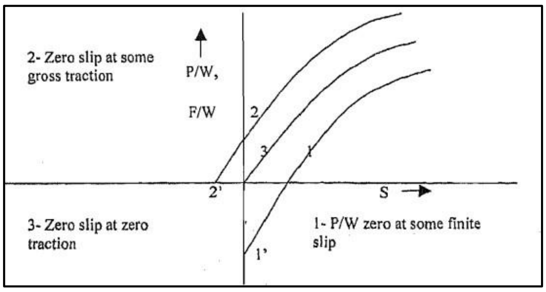

Fig: Slippage-traction curves

$$TE = \frac{P}{(P+R)}(1-s) \times 100$$

Where,
TE = Tractive efficiency, %;
P = Pull, kg;
R = Rolling resistance, kgf; and
s = Slip, %.

Where,

$$\text{Pull (kg)} = \frac{DBHP \times 4500}{\text{Speed(m/min)}}$$

Fuel Efficiency

Fuel efficiency is the measure of how effectively fuel is utilized to perform work. Usually, the work represents, the amount of work or output achieved by the tractor-implement system such as area covered or tasks complete and similarly, the fuel consumption is the amount of fuel consumed by the system during same period and task.

Fuel efficiency of tractor implement system is also defined as standard area covered by an implement for 1 litre of fuel to that of actual area covered by the same amount of fuel.

$$\text{Fuel efficiency} = \frac{\text{Actual area covered by an implement(1L fuel)}}{\text{Standard area covered by an implement (1L fuel)}} \times 100$$

Results and Discussion

Part loads and Engine speed

Tractor-implement system with zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler caused variations in engine rpm at eight different throttle positions as given in table 1. For different tractor models the average observed rpm range were 0, 500-600, 1100, 1300-1400, 1600-1700, 1800-1900, 1900-2000 and 2200 at 0%, 25%, 50%, 60%, 75%, 85%, 90% and 100% throttle positions with operation of zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler in the field. This was due to variations in soil strength and, in turn varying soil resistance developed by the seven implements in two different field conditions dry and wet.

Fuel consumption pattern and fuel efficiency for tractor implement systems at part loads

The tractor implement system with zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was evaluated for fuel consumption at 0%, 25%, 50%, 60%, 75%, 85%, 90% and 100% in 2nd low gear. The fuel consumption for 1 hour run for dry field condition of first tractor T_1 with zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was 1290,4100, 4560,1560,2860,1620 and 4050 ml/h at optimum 75% throttle position respectively. As the fuel consumption for 1 hour run for second tractor T_2 with zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was 1350,4320,4610,2070,3200,1870 and 4190ml/h and for third tractor T_3 with zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was 1540,4650,5080,2520,3500,2300 and 4530ml/h respectively. In general, tractor-implement system the subsoiler, M.B. plough and disc harrow consumed more fuel than that of remaining four implements due to higher depth of operation as they conclude in deep ploughing category.

The fuel consumption for 1 hour run for wet field condition of T_1, T_2 and T_3 with rotavator and cultivator are 3200 and 1940 ml/h, 3520 and 2300 ml/h, 3210 and 2630 ml/h at optimum 75% throttle position respectively. In general tractor implement system, the rotavator consumes more fuel than cultivator. This was primarily due to higher depth of operation and an excessive weight.

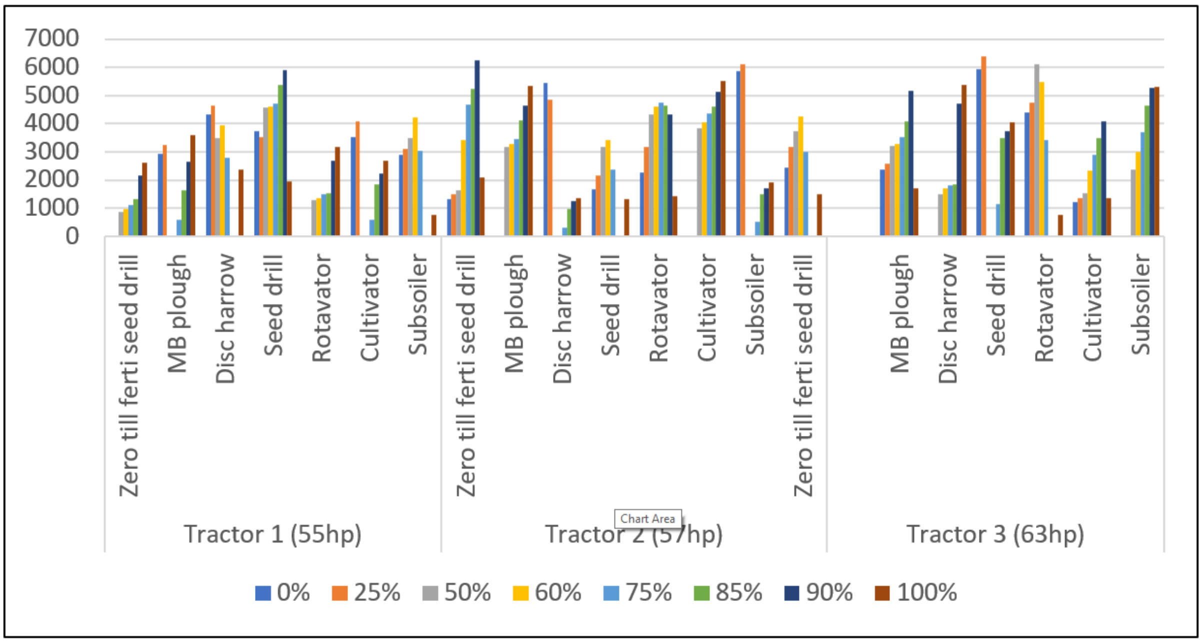

Fig 1: Effect of Interaction between tractor-implement-throttle position in fuel consumption (ml) for dry field conditions

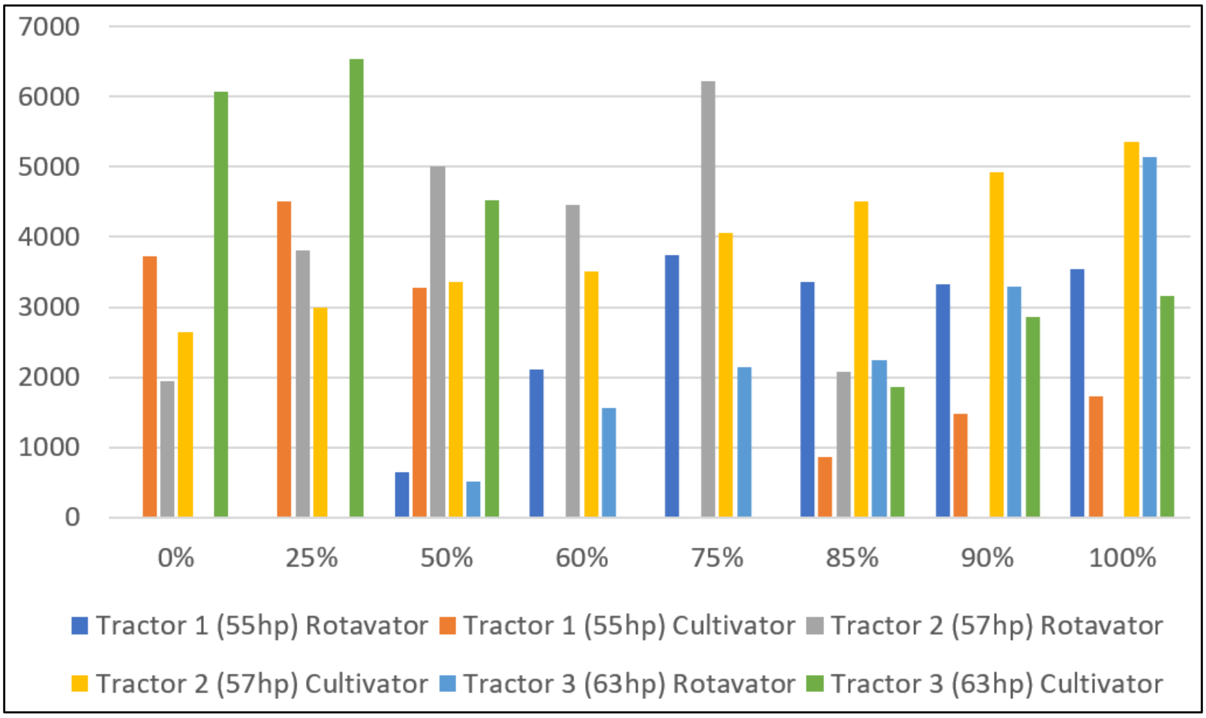

Fig 2: Effect of Interaction between tractor-implement-throttle position in fuel consumption (ml) for wet field conditions

The part load settings of tractor implement system is at favourable position when the fuel efficiency of tractor implement system will tends to be maximum. The maximum fuel efficiency of zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was at M_1T_2 (85%), M_2T_2 (50%), M_3T_1 (50%), M_4T_1 (75%), M_5T_1 (50%), M_6T_1 (75%) and M_7T_2 (50%) for dry field condition and similarly, for wet field condition the maximum fuel efficiency for rotavator and cultivator was at M_5T_2 (50%) and M_6T_3 (75%).

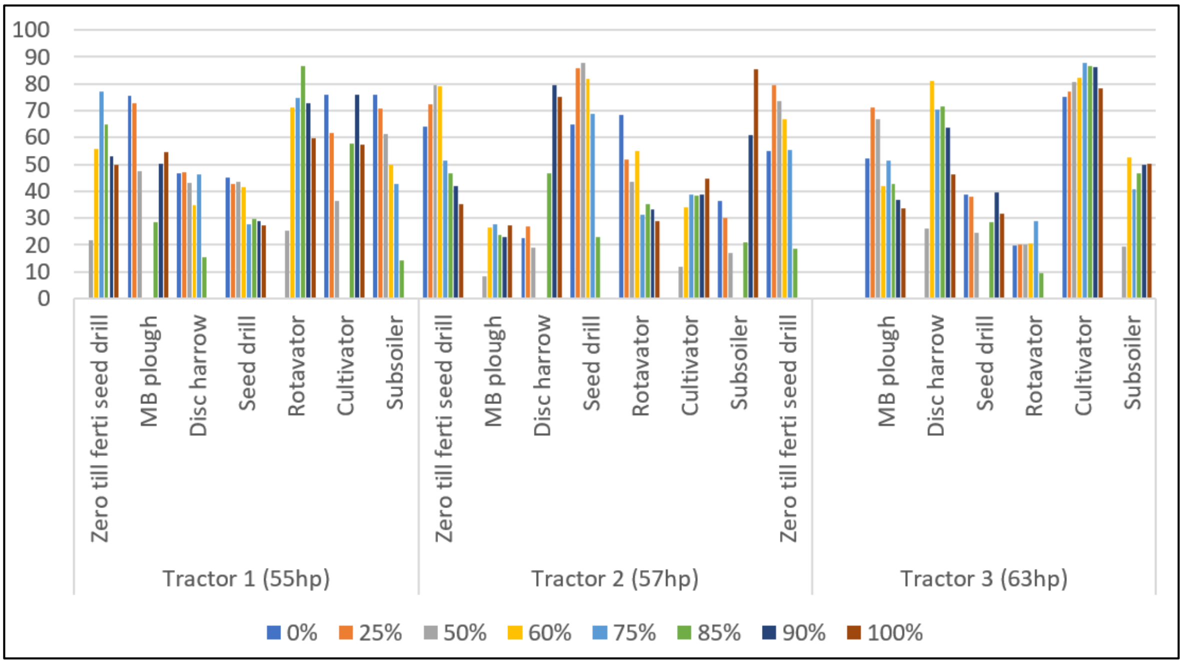

Fig 3: Effect of Interaction between tractor-implement-throttle position in fuel efficiency (%) for dry field conditions

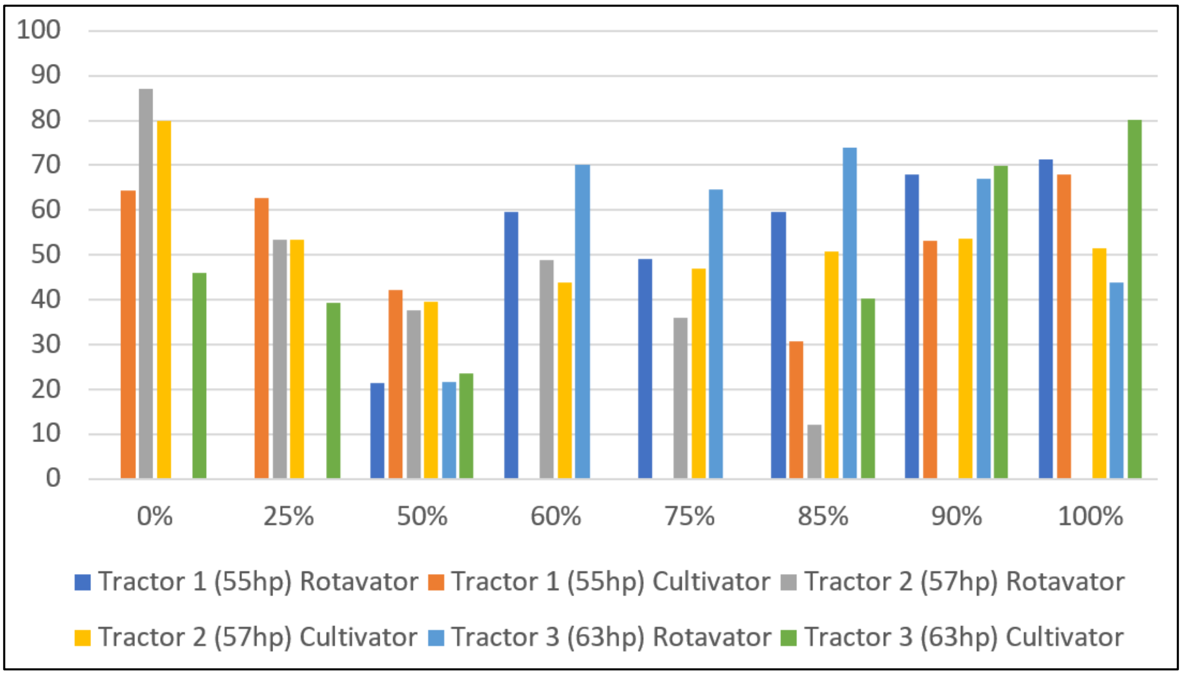

Fig 4: Effect of Interaction between tractor-implement-throttle position in fuel efficiency (%) for wet field conditions

Tractive performance for tractor implement systems at part loads

The basic parameters on which the tractive performance must depends are rolling resistance, draft requirement, pull and wheel slippage. The tractive performance must be concluded by the influence of tractive efficiency of tractor implement system. The part load settings of tractor implement system is at favourable position when the tractive efficiency of tractor implement system will tends to be maximum. The maximum tractive efficiency of zero till ferti seed drill, M.B. plough, disc harrow, seed drill, rotavator, cultivator and subsoiler was M_1T_2 (50%), M_2T_1 (85%), M_3T_3 (100%), M_4T_3 (50%), M_5T_3 (50%), M_6T_1 (60%) and M_7T_1 (85%) for dry field condition and similarly, for wet field condition the maximum tractive efficiency for rotavator and cultivator was at M_5T_1 (60%) and M_6T_1 (100%).

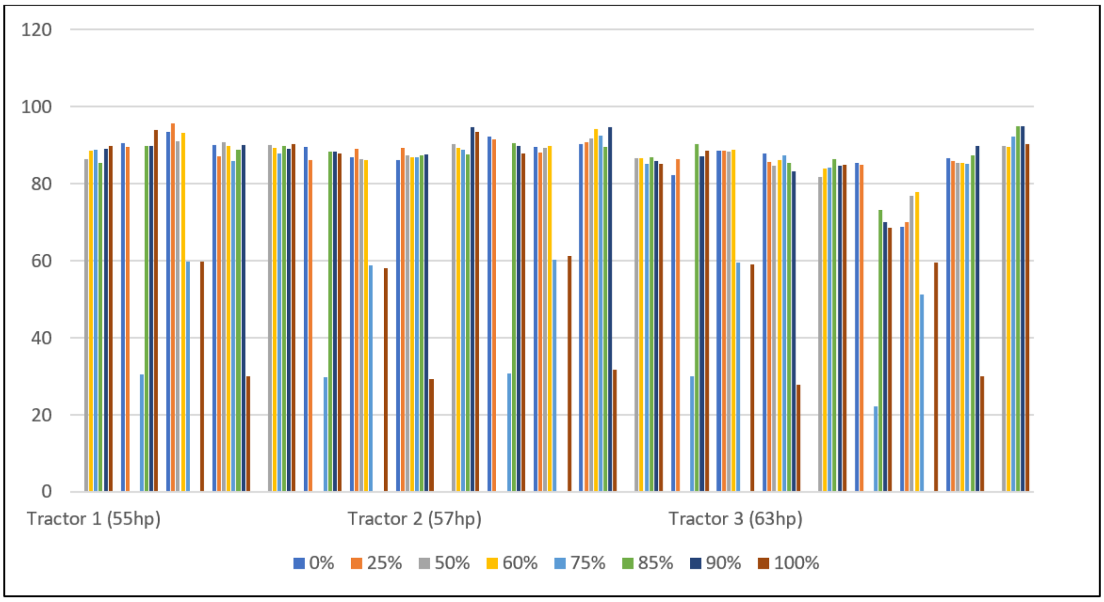

Fig 5: Effect of Interaction between tractor-implement-throttle position for tractive efficiency (%) for dry field condition

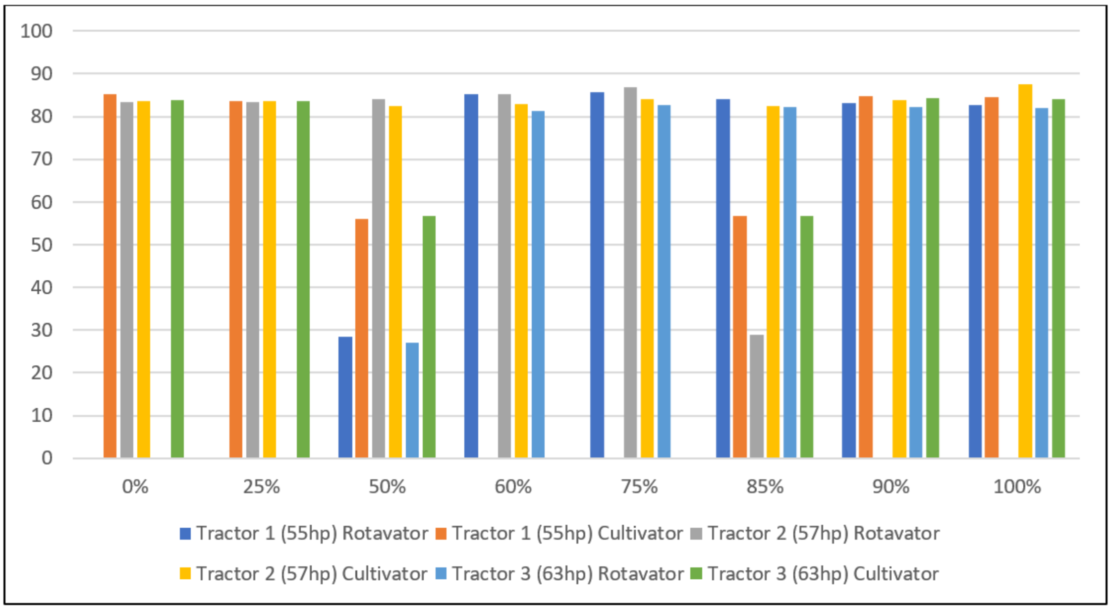

Fig 6: Effect of Interaction between tractor-implement-throttle position on tractive efficiency (%) for wet field conditions

Conclusions

1. In dry field conditions, the following throttle positions are recommended for optimal performance with various tractor attachments. A Tractor 2nd (57 hp) equipped with a zero till ferti-seed drill attachment should be set to 85% throttle for peak performance. When using a Tractor 2nd (57 hp) with an M.B. plough attachment, it's best to operate it at 50% throttle for ideal results. For a Tractor 1st (55 hp) with a disc harrow attachment, maintaining a throttle position of 50% is recommended for optimal operation. When using a Tractor 1st (55 hp) with a seed drill attachment, it's advisable to set the throttle at 75% for the best performance. Similarly, if you have a Tractor 1st (55 hp) with a rotavator attachment, it should be operated at 50% throttle to achieve the most efficient performance. When using a Tractor 1st (55 hp) with a cultivator attachment, it's recommended to set the throttle at 75% for optimal conditions. Finally, if you're using a Tractor 1st (55 hp) with a subsoiler attachment, operating it at 100% throttle provides the best conditions for field performance in dry soil.
2. In wet field conditions, it is recommended to operate Tractor 3rd (63 hp) with a rotavator attachment at 60% throttle for optimal field performance. Likewise, when using Tractor 3rd (63 hp) with a cultivator attachment, setting the throttle to 75% is advised for achieving the best possible conditions during field operations.

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