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Development of Active - Passive Combination of Tillage Implement Suitable for Mini Tractor

T. Mahesh Babu [a++*], A. Ashok Kumar [b#],
K.V.S Rami Reddy [a†] and H.V. Hema Kumar [c‡]

[a] Department of Farm Machinery and Power Engineering, Dr. NTR, College of Agricultural Engineering, Bapatla, India.
[b] AICRP on FIM, Dr. NTR College of Agricultural Engineering, Bapatla, India.
[c] Department of Soil and Water Conservation Engineering, Dr. NTR College of Agricultural Engineering, Bapatla, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An experimental tillage tool, which integrates active - passive implements (cultivator tines in the front and a rotavator in the rear), was evaluated in the field. The forward-rotating active elements produced a negative draft, significantly reducing the overall draft requirements of the tool. When

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[++] *Post Graduate Student;*
[#] *Principal Investigator;*
[†] *Associate Professor;*
[‡] *Professor;*
**Corresponding author: E-mail: maheshbabutumati7@gmail.com;*

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compared to a tool with four passive elements, a combination machine equipped with two active and two passive elements experienced an 87 per cent less draft and draft power, despite having similar total power. According to estimates of power transmission efficiency, a combination machine would use 34 per cent less energy than a similar passive tillage tool. The tillage performance parameters, including draft force, fuel consumption, wheel slip, and power requirement, were measured using a digital dynamometer at different operating depths. The drawbar power needed for the combination tillage implement was determined. During field test, the draft force of the rotavator with tines was observed to be 0.46 kw, 1.7 kw, and 3.5 kw at forward speeds of 1.5, 2.5, and 3.5 km h^{-1}, respectively.

Keywords: Depth; draft; combination tillage implement.

1. INTRODUCTION

Energy consumption during filed preparation is a major concern for scientists as well as farmers. Including all agricultural field operations, conventional tillage demands the highest energy input. This process necessitates multiple passes through the soil-turning and soil-pulverizing equipment, leading to increased time, fuel, and labour requirements. Additionally, repeated tractor passes with tillage implements contribute to increased soil compaction [1]. To control the above obstructions, Minimizing the number of passes needed to prepare the seedbed is crucial while maintaining high-quality results. According to Sahu and Raheman [2], this can be accomplished by combined tillage implements to work simultaneously. Both active-passive tillage implements are included in the combination tillage implement. Passive implements experience significant power losses through the tire-soil interface and require substantial weight on the tractors drive wheels to provide the necessary traction, leading to detrimental soil compaction. On the other hand, active tillage implements demand substantial power per unit width due to their ability to till a larger amount of soil than typically needed in most field crop systems. According to Srivastava et al. [3], a rotovator creates forward thrust that generates negative draft, possibly requiring extra energy inputs to manage tractor steering and the three-point hitch, potentially impacting the tractors drive train. To mitigate this adverse forward thrust, integrating both active and passive elements can offer the following potential advantages.

The transmission of power for soil tilling can be more efficient through a mechanical power train compared to tire-soil interface. Hendrick [4] evaluate that PTO-powered active tillage elements achieved an average power transmission efficiency of 82 per cent, while drawbar-powered passive tillage elements achieved 49 per cent. Negative draft of active implements can be utilized to generate full or partial draft for passive implements, reducing overall draft of tillage implements [5-8]. Consequently, it reduces wheel slip, enhances field productivity, and enables use of lighter tractors, thereby mitigating soil compaction. Furthermore, decreased draft allows operations to be carried out in more demanding traction conditions without need additional ballast, dual tires, or assistance from front wheels [9].

2. MATERIALS AND METHODS

2.1 Development of Active - Passive Combination Tillage Implement

A rotavator provided with test tractor was used for the present study. The purpose of developing implement is to harness negative draft force generated by rotavator. While developing implement, it was kept in mind that, the tines must be placed at front of the rotavator to utilize the negative draft force. Four tines having 39 cm length with shovel length of 20 cm was used in the present study. The width and thickness of the tines are 4 and 2 cm respectively. These tines are specially fabricated with suitable dimensions for mounting on the rotavator to act as front passive set. The developed tines are fitted on an angular bar having length of 120 cm using ‘U’ clamps and nut and bolt system at an equal interval of 30 cm and bar was connected to the rotavator using two supporting arms mounted on both sides of rotavator (Fig. 1). A provision was made in such a way that the tine length could be increased as well as decrease based on the depth requirement, also tines were fitted to the frame of rotavator at an angle of 250 to penetrate in to the soil engage with less draft force. The developed active-passive combination tillage implements under laboratory as shown in Fig. 1. and the developed implement with test tractor as shown in Fig. 2. The CAD view of developed front passive set as shown in Fig. 3.

2.2 Dynamic Simulation of Developed Tine

A dynamic simulation has been carried out to know the load bearing capacity of the mounted tines to the rotavator using Ansy's software. A maximum load of 10000 N was applied on each tine in opposite to the face of the cultivator. It was observed that, the von misses are found to vary from 7.74 × 10^1 to 2.33 × 10^7 N/m^2, where as the yield strength of the develop tine is 4.6 × 10^{-8}. The dynamic simulation of the developed tine as shown in Fig. 4.

Fig. 1. Developed active - passive combination tillage implement
1. Supporting frame; 2. Supporting arms; 3. Tines

Fig. 2. Developed active - passive combination tillage implement with test tractor

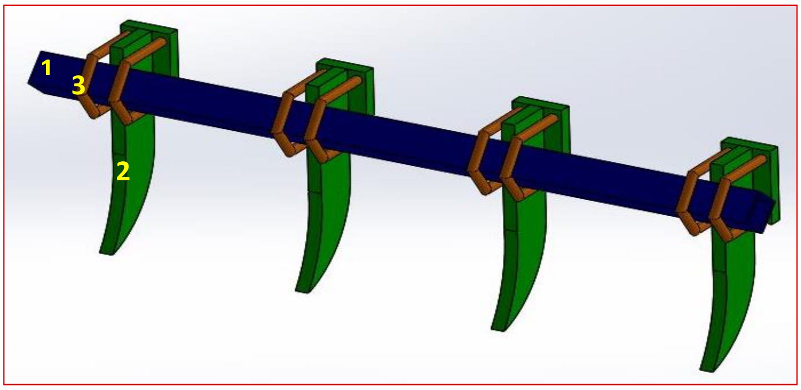

Fig. 3. CAD view of developed front passive set
1. Frame; 2. Tines; 3. U clamps

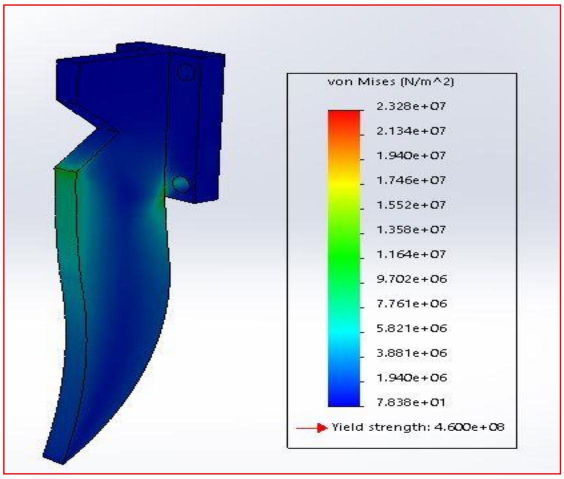

Fig. 4. Dynamic simulation of developed tine

2.3 Analysis of Dynamic Forces in Tractor - Mounted Implement Combination

Fig. 5. diagram illustrates a side view of tractor-mounted moldboard plough combination. Analysis applies similarly to other mounted implements such as cultivators, disk harrows, and so forth. The following key assumptions were taken into account when formulating the dynamic equations for the tractor-implement combination.

1. without considering the operator the center of gravity of tractor is located.
2. Angular motion of the tractor wheels is disregarded.
3. Implement operates at uniform depth.
4. Tire sinkage & deflection are negligible comparison to the rolling radii of the tires and are thus not considered.
5. It is assumed that the implements center of resistance and center of gravity act in same vertical plane.
6. Vertical soil response is 0.3 times the horizontal soil response.
7. Two lower links are equal length and align together when viewed from side, indicating that both lower hitch points at the same height above ground level.
8. The center of resistance is positioned at two-thirds of depth of operation from ground surface.

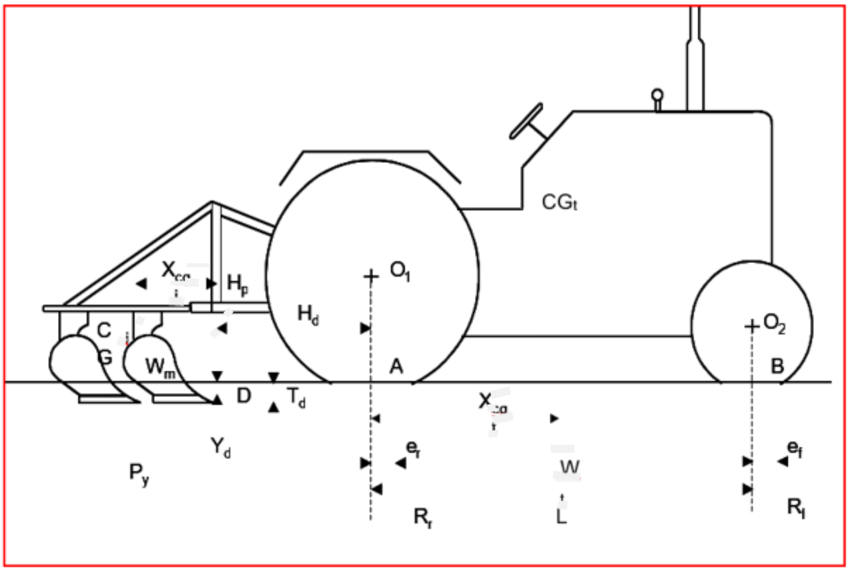

Fig. 5. Free body diagram of tractor-implement combination

$$\sum F_X = 0 \quad \sum F_Y = 0 \quad \sum M = 0$$

$$R_f + R_r = W_t + W_m + P_y$$

By computing the moment of forces around point B, the dynamic weight on the tractors rear axle was determined as follows:

$$R_r (L - e_r + e_f) - W_t (L + e_f - X_{cgt}) - (w_m + P_y)(X_{cgi} + H_d + L + e_f)\, DY_d = 0$$

Or

$$R_r = \frac{W_t (L + e_f - X_{cgt}) + (W_m + P_y)(X_{cgi} + H_d + L + e_f) - DY_d}{L - e_r + e_f} \qquad \text{------} \qquad (1)$$

Or $$R_f = (W_t + W_m + P_y) - R_r \qquad \text{-------} \qquad (2)$$

Where, R_r = rear wheel dynamic weight; R_f = front wheel dynamic weight; *RWS* = rear wheel static weight; FWS = front wheel static weight; W_t = weight of tractor acting at $CG_{t;}$ W_m = weight of implement acting at $CG_{i;}$ X_{cgi} = horizontal distance of CG of implement from tractor lower hitch point $H_{p;}$ H_d = horizontal distance of tractor lower hitch point from the rear axle center; L = wheel base; D = draft; P_y = vertical component of soil force and was assumed 0.3 times the draft; X_{cgt} = horizontal distance of CG of tractor from the rear axle center; $Y_d = \frac{2}{3} T_d$, depth at which draft acted (assumed); T_d = depth of operation; e_r = rear wheel eccentricity = $\rho_r\, r_r$ (Liljedahl et al*.,* 1996); r_r = rolling radius of the rear wheel of tractor; e_f = front wheel eccentricity = $\rho_f\, r_f$ (Liljedahl et al*.,* 1996); r_f = rolling radius of the front wheel of tractor; ρ_r = coefficient of rolling resistance of the rear wheel of tractor; ρ_f = coefficient of rolling resistance of the front wheel of tractor. In present study, above theory was used for measurement dynamic rear wheel reaction with different implements and combination implement.

2.4 Draft Measurement

Draft force of the newly developed combined tillage implements was assessed using digital drawbar dynamometer connected to simulated tractor. The implements were attached to a test tractor using a 3-point hydraulic linkage system. To measure the draft force during operation, a digital dynamometer was placed between the two tractors, connected by a specially fabricated iron rod.

Fig. 6. 1. Implement with test tractor; 2. Auxilary tractor; 3. Load cell; 4. Digital dynamometer

Initially, test tractor was set in neutral gear, and the implement was raised. It was towed by an auxiliary tractor over a distance of 20 meters and force needed to pull the implement was identified. Subsequently, implement was inserted into soil, and auxiliary tractor pulled the test tractor for another 20 meters. In order to force required to tow the tractor was noted. Draft force was calculated by determining the variation between initial & final draft forces acquired from implements draft requirements. Draft measurements were conducted at various depths to evaluate the tillage implements performance under real field conditions, as depicted in Fig. 6.

2.5 Parameters Measured During Field Experiments

Field experiments were conducted at Dr. N.T.R. College of Agricultural Engineering, Bapatla. The following performance parameters was measured during the field evaluation of the developed combination tillage implement.

2.5.1 Power requirement

Power needed for the tractor to pull the implement was determined using this equation:

Power (hp) = (draft (kgf) × speed (m s^{-1})) / 75

2.5.2 Speed of operation

The time required to travel a distance of 25 meters was recorded. A mechanical stopwatch was used to compute the speed of operation by using the following formula:

$$Va = 3.6 \times 25/t$$

Where,

V_a = Speed of operation, km h^{-1}, t = time, s

2.5.3 Wheel slip

A fixed number of rear wheel revolutions was noted to calculate the wheel slip. The amount of slip was determined by applying the following expression to the recorded distance travelled in ten-wheel revolutions, both with and without load:

$$S = \frac{d_t - d_a}{d_t} \times 100$$

Where,

S = Slip (per cent)

d_t = distance covered in 10 revolutions of drive wheel at no load

d_a = distance covered in 10 revolutions of drive wheel with load

2.5.4 Width of cut

The width of cut made by the tillage implement was determined using a measuring tape at 3-meter intervals along the furrow's length. The average width was computed from five measurements

2.5.5 Depth of operation

Depth of tillage implement was noted by using a steel rule to measure the distance between furrow sole and ground level along a furrow wall, at intervals of approximately 5 meters along its length. The average of five readings was noted to compute depth of tillage implement.

2.5.6 Turning time

A mechanical stopwatch was placed at each end of the field to record turning time for 180^0 turns of tractor-implement combination during operation. It was calculated by subtracting the time of lifting implement prior to turn from time of engaging it after turn.

2.5.7 Fuel demand

Fuel demand (Fd) was determined using top-fill method. Initially, fuel tank was filled to its maximum capacity prior to testing. After performing soil tillage using the experimental tractor equipped with combination of developed tillage implements, fuel tank was refilled to its maximum capacity again. The amount of fuel refilled was measured using a measuring jar, and fuel demand was calculated using the following equation, expressed in liters per hour.

$$\mathrm{F_c}\,(\mathrm{Lh^{-1}}) = \frac{\mathrm{V}}{\mathrm{t}}$$

Where,

V = Volume of fuel consumed, L

t = total operating time, h

2.5.8 Theoretical field capacity

Theoretical field capacity (TFC) was measured by considering the width of operation and travel speed of the tractor. TFC was expressed in ha h^{-1} and calculated using following equation:

$$\text{TFC (ha h}^{-1}\text{)} = \frac{S \times W}{10}$$

Where,

S = Forward speed, km h^{-1}

W = Width of the implement, m

2.5.9 Effective field capacity

Effective field capacity (EFC) the actual area covered by the implement, based on its total time consumed and its width. The speed of travel, the percentage of rated width used, and the total amount of field time lost while operating. Usually, EFC is expressed in ha h-1. This equation was used to calculate it.

$$\text{EFC (ha h}^{-1}\text{))} = A/(T(p) + T\ (np))$$

Where,

A = Area of coverage, ha
T_P = Productive time, h
T_{np} = Non-productive time, h

2.5.10 Field efficiency

The ratio of actual field capacity to theoretical field capacity, given as a percentage, this equation was used to calculate it.

$$F_e\ (\text{Per cent}) = \frac{\text{EFC}}{\text{TFC}} \times 100$$

Where,

E.F.C = Effective field capacity, ha h^{-1}

T.F.C = Theoretical field capacity, ha h^{-1}.

2.5.11 Volume of soil handled

Volume of soil handled per unit time can be expressed as:

$$V_s = \text{AFC} \times T_d \times 10000$$

Where,

V_s = Volume of soil tilled per unit time, m^3/h

T_d = depth of operation, cm

AFC = Actual field capacity, ha h^{-1}

2.5.12 Overall performance

Considering the parameters mentioned above, Performance index (PI) can be employed to evaluate the inclusive effectiveness of tillage implements. Performance index is directly proportional to depth, AFC (area covered per unit of time), Si (soil inversion), and inversely proportional to draft. It can be stated mathematically as:

$$\text{PI} = \frac{T_d \times AFC \times S_i}{D}$$

Where,

PI = Performance Index,

T_d = depth in cm,

AFC = Effective field capacity, ha h^{-1},

S_i = Soil inversion,

D = Draft in kgf/cm^2

3. RESULTS AND DISCUSSION

The outcomes and discussions of the findings obtained from different experiments conducted with tractor and developed combination tillage implements are presented under following headings:

i. Development of combination tillage implement

ii. Performance evaluation of tractor - implement combination

3.1 Development of Combined Tillage Implements

The selection of combined tillage implements was based on mini tractor specifications outlined in the following section. A combination tillage implement, cultivator tines with rotavator (R-T) was developed. Speed range of selected tractor was chosen for operating developed cultivator tines with rotavator combination tillage implement was range of 1-3.5 km h^{-1}. The suitable range of tractor was selected on the basis of power utilization, front axle weight lifted tractor where slip of the test tractor.

3.2 Performance Evaluation of Tractor-Implement Combination

Field tests were conducted with a 18hp, MITSUBISHI SHAKTI MT 180$_D$ 2WD tractor and developed combination implement such Rotavator with tines (R-T) to assess the performance of tractor - implement combination on the basis of tractive performance index parameters. The results obtained as discussed under the following heads.

i) Tractive performance parameters

ii) Performance index parameters.

3.2.1 Tractive performance

The tractive performance of the tractor-implement combination was evaluated based on draft and slip parameters.

3.2.2 Draft measurement

During the evaluation of developed combined tillage implements under real field conditions, draft force requirement for the active-passive combined tillage implement ranged from 116 to 137 kgf at an average depth of 5.7 cm. This variation occurred across operational speeds ranging from 1.5 to 3.5 km h^{-1}. Effect of depth of operation on draft force implements as shown in Fig. 7.

3.2.3 Power requirement

Power requirement of the newly developed combined tillage implement was analysed at different forward speeds, ranging from 1.5 to 3.5 km h^{-1}. Since directly measuring the power requirement was challenging, it was determined contingently by recording the draft force at various depths and speeds. For combination tillage implements like the rotavator with tines, the power requirement was observed as 0.46 kW, 1.7 kW, and 2.7 kW at forward speeds of 1.5 km h^{-1}, 2.5 km h^{-1}, and 3.5 km h^{-1} respectively. It was noted that power requirement increased as the forward speed increased from 1.5 to 3.5 km h^{-1}, likely, because of the acceleration of soil particles and kinetic energy imparted to the soil. Interestingly, for the active-passive combination tillage implement (rotavator with tines), the power requirement ranged from 0.46 kw to 2.7 kw, which could be attributed to the negative draft force of the rotavator. Effect of operating speed on power requirement of developed combined tillage implements as illustrated in Fig. 8.

3.2.4 Wheel slip

The slip data acquired from field experiments on the developed combination tillage implements showed that the slip of the tractor's driving wheels ranged from 5.6 to 7.8 per cent under constant speed conditions. This slip increased with both depth and speed of operation. This trend is likely due to the higher draft requirements of the implement at greater depths and speeds, which increases the thrust requirement on the drive wheels and leads to higher slip.

As the depth of operation increased during constant forward speed, the wheel slip also increased as illustrated in Fig. 9. This increase in wheel slip with depth of operation is likely attributed to the higher draft force exerted by the tillage implements. The impact of operating speed on wheel slippage of combination tillage implements as shown in Fig. 9.

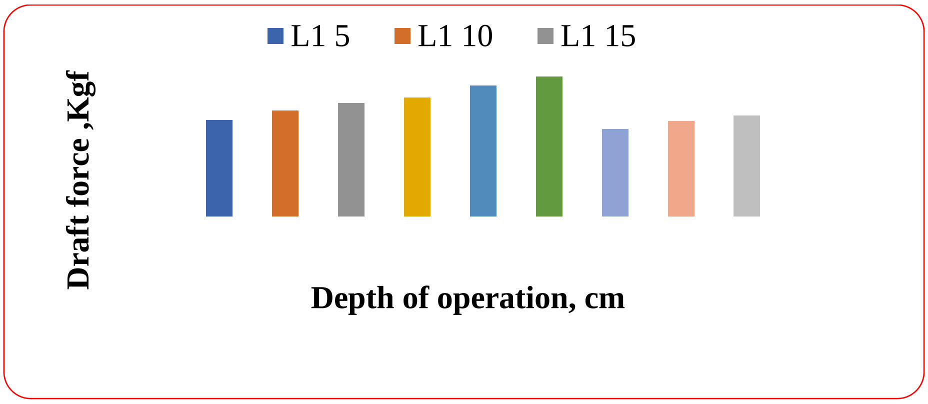

Fig. 7. Effect of depth of operation on draft force of implements

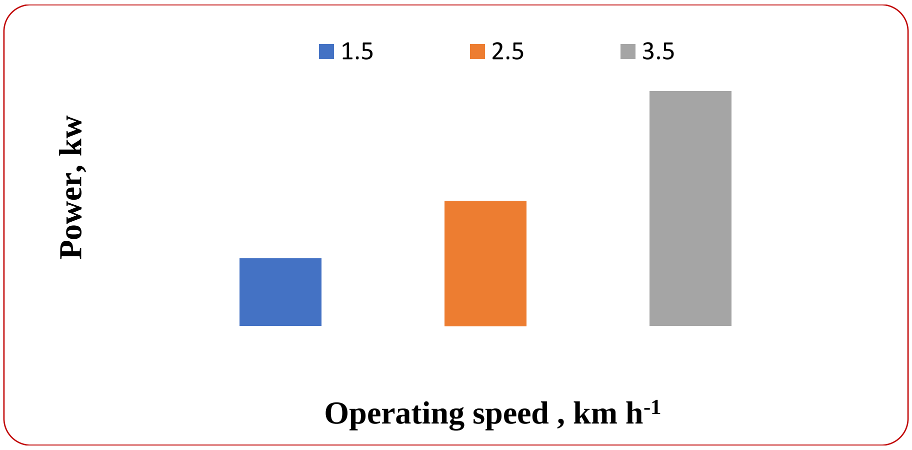

Fig. 8 Effect of operating speed on power requirement of combination tillage implements

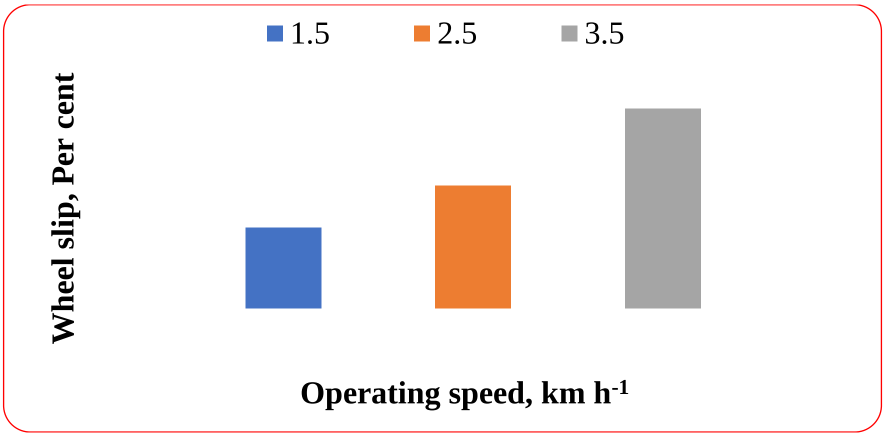

Fig. 9 Impact of operating speed on wheel slippage of combination tillage implements

Table 1. Performance index of implement at different depths and operational speed of tines with rotavator

Speed of Operation, km h^{-1}	Depth of Operation cm	Mean Weight Diameter (MWD), mm	Soil Inversion (S_i), Per Cent	Draft, Kgf/cm^2	Fuel Consumed Per Unit Time (F_u), l h^{-1}	PI
1.5	5.7	0.71	60.0	0.17	1.8	313.83
	10.8	0.7	58.4	0.09	1.82	1093.24
	15.1	0.72	58.0	0.07	1.84	1951.75
2.5	5.7	0.5	54.1	0.17	1.95	480.25
	10.8	0.51	57.3	0.10	2.0	639.92
	15.1	0.53	57.5	0.07	2.2	986.94
3.5	5.7	0.42	46.1	0.20	2.3	499.26
	10.8	0.4	46.3	0.12	2.5	583.46
	15.1	0.41	46.7	0.0.09	2.6	939.13

3.2.5 Performance index

The performance of developed tractor-implement combination was examined using indicators such as mean weight diameter (MWD) of soil aggregates, soil inversion quality, depth of cut, actual field capacity, as well as unit draft. A performance index was employed to quantify the inclusive performance of tractor-implement combination. The data for the performance index

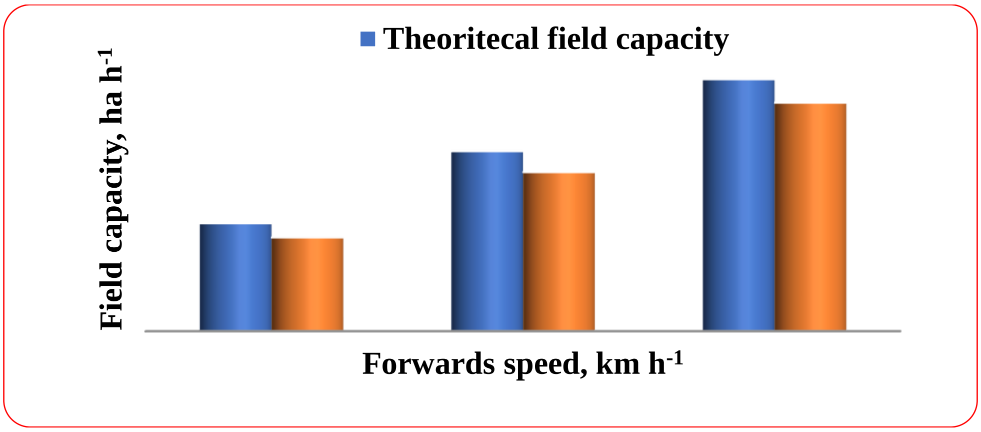

Fig. 10. Effect of forward speed on field capacity of rotavator with tines

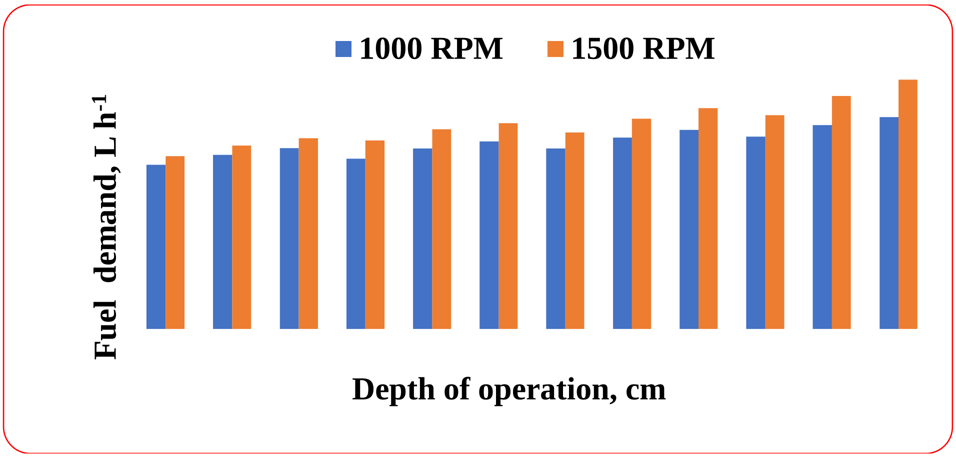

Fig. 11. Effect of depth of operation on fuel demand of test tractor with rotavator and tines

obtained from field experiments are presented in Table 1 for three different speeds of operation.

3.2.6 Field Capacity

Theoretical field capacity of developed tines with rotavator ranged from 0.18 to 0.42 ha h^{-1}. Meanwhile, effective field capacity varied from 0.1563 to 0.3809 ha h^{-1} as the operational speed changed from 1.5 to 3.5 km h^{-1}. It was noticed that field capacity of the combined tillage implements of tines with rotavator (R-T) increased with higher operational speeds ranging from 1.5 to 3.5 km h^{-1}. This improvement is likely attributed to reduced time required per unit area at higher forward speeds. The impact of forward speed on the field capacity of tines with rotavator (R-T) is depicted in Fig.10.

From the figure, it was evident that effective field capacity of the rotavator with tines in the combination tillage implements was relatively higher, ranging from 0.1562 to 0.3809 ha h^{-1}. This is attributed to its lower demand for non-productive time compared to other two developed combinations.

3.2.7 Fuel demand

The fuel demand of the developed tines with the rotavator was observed to range from 2.195 to 3.335 liters per hour, varying with operational depths between 5.7 and 15.1 cm across different tractor gears (L1, L2, L3, and H1). An increase in gear level from L1 to H1 corresponded to a rise in fuel demand. This relationship between depth of operation and fuel consumption at various depths and speeds is illustrated in Fig. 11 [9-11].

4. CONCLUSION

i. Field efficiencies of developed tillage implement varied from 81.5 per cent to 90.7 per cent at forward speeds ranging from 1.5 to 3.5 km h^{-1}. The field efficiencies of the developed implements increased with higher forward speeds due to reduced non-productive time at increased speeds.

ii. It was recorded that, among these developed implements, combination of cultivator tines with rotavator field efficiency comparatively more than other two developed implements with the values varied from 86.83 per cent to 90.07 per cent, because of non-productive time demand of cultivator with rotavator was less than other two combinations.

iii. The comprehensive performance of the newly developed tillage implements was assessed using a performance index. This index takes into account factors like the mean weight diameter (MWD) of soil aggregates, soil inversion, per unit time, and draft. The implement allows for both primary & secondary tillage operations to be carried out simultaneously.

iv. Reducing the number of passes required by draft implement during field preparation can lower cultivation costs. According to literature, decreasing the number of passes is an effective strategy.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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