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Evaluate the performance of developed combination tillage implements under varying field and operating conditions

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Abstract

The energy use in field preparation is of great concern for scientists and farmers. Among all field operations, conventional tillage requires highest amount of energy input. It requires several passes of various soil-turning and soil-pulverizing equipments requiring more time, fuel and labor. Moreover, several passes of tractor with tillage implement increase soil compaction. The combination tillage implement comprises combination of either active and passive or passive and passive tillage implements. In case of passive implements, power losses are more at tire-soil interface and also a considerable weight is required on drive wheels of tractor to provide necessary traction that results into detrimental soil compaction. Active tillage implements require considerable power per unit width as they till a greater volume of soil than is required in most field crop systems. Investigations are presently being carried out on combined tillage equipment to the complete the tillage and sowing operation in one pass.

The present study was conducted on the development of active-passive and passive-passive combination of tillage implements suitable for mini tractor. The combination tillage implement such as cultivator- single acting disc harrow(C-DH), cultivator with clod crusher (C-CC) and rotavator with tines (R-T) were developed. The developed tillage implements were evaluated under actual field condition at different depths and operating speeds. The tillage performance parameters such as draft force, fuel consumption wheel slip, soil inversion and fuel efficiency were measured. The drawbar power requirement of the combination tillage implement was calculated. During field evaluation it was observed that the draft force of the cultivator with disc harrow (C-DH) found to vary from 190 to 220 kgf, and that of cultivator with clod crusher(C-CC) found to vary from 86 to 101 kgf and rotavator with tines (R-T) found to vary from 166 to 137 kgf.

The fuel consumption of the (C-DH) found to vary from 2.897 to 3.79 L h^{-1}, (C-CC) found to vary from 2.846 to 3.822 Lh^{-1} and (R-T) found to vary from 2.195 to 3.225 L h^{-1}. The wheel slip of the driving wheels of the tractor with developed implements found to vary from. 5.6 to 7.8 per cent. The field efficiencies of developed tillage implement found to vary from 81.5 per cent to 90.7 per cent as well as the soil inversion of the combination tillage implement vary from 46.1 to 92.35 per cent.

Keywords: Depth, draft, speed of operation, combination tillage implement

1. Introduction

Indian agriculture account for nearly 14.2 per cent of the gross domestic product and involves over 58.2 per cent of workforce (Anon., 2011a) [2]. The biggest challenge before the agricultural sector of India is to meet the growing demands of food for its increasing population from 1.21 billion in the year 2011 to 1.6 billion by the year 2050 (Anon., 2011a) [2]. Since the cultivated area has remained nearly constant (142 Mha; Anon., 2011a) [2] over the years, the only option to increase food grain production is to increase the productivity of land. This can be achieved by increasing cropping intensity and reducing turnaround time through increased mechanization. However, the mechanization level in India is quite low. The application of machines to agricultural production has been one of the outstanding developments in Indian agriculture. The efficient utilization of available resources and timeliness of agricultural operation are the major factors influencing the productivity level of agricultural commodities.

The energy use in field preparation is of great concern for scientists and farmers. Among all field operations, conventional tillage requires highest amount of energy input. It requires several passes of various soil-turning and soil-pulverizing equipments requiring more time, fuel and labour. Moreover, several passes of tractor with tillage implement increase soil compaction. Conventional tillage employs many passes of machinery over a field with various soil-turning and soil-pulverizing equipments *viz.*, mouldboard plough, disk harrow, spike-toothed harrows and cultivators etc. Such conventional tillage operations require expensive machinery and high fuel consumption and contribute to compaction of the soil (Claassen, 1996) [3].

Also, in conventional tillage practices most of the Indian farmers utilizes the available tillage implement with any ranges of tractor power, consequently there is improper matching of tractor and implement combinations resulting in under loading of tractor engine hence, poor efficiency (Alam, 2000) [1].

These difficulties can be overcome by either increasing speed of operation and width of cut of tillage implements or reducing the number of passes required for tillage operations to prepare the seedbed without sacrificing the quality of work. As the land sizes in India are small, the scope for increasing the speed or width of existing implements is less feasible. Hence, reducing the number of passes by combining two or more field operations with the use of combination tillage implements may provide better solution (Sahu and Raheman, 2006) [9]. The combination tillage implements also help in reducing time, labor and fuel costs for seedbed preparation (Downs, 2003) [4].

The combination tillage implement comprises either active-passive or passive-passive tillage elements. Some studies on development and performance evaluation of 2WD tractor drawn combination tillage implements have been conducted in India (Kumar and Manian, 1986; Manian *et al.*, 1999; Kailappan *et al.*, 2001a and b., Sahu, and rahamen 2006) [7, 8, 5-6].

However, the active element present in active-passive combination tillage implement produces negative draft that may require further energy inputs to control the tractor steering and three-point hitch and is also harmful to the drive train of tractor (Wismer *et al.*, 1968) [10]. It was reported that the passive-passive combination tillage implements outperformed the conventional tillage practices in fuel consumption, time requirement and cost of operation (Sahu and Raheman, 2006) [9]. Hence such types of implements are very much required for low power rated tractors (8-15 kW).

In Andhra Pradesh, small land holdings contribute 27.8 per cent of total cultivated land. In small holdings, medium power rated tractors ranging from 18 to 22 kW are most popular in India than the large tractors and it is the fastest growing segment. But, the cost of tractors in the range of 31-40 kW is more than Rs 5 lakhs. The small and marginal farmers cannot afford these high-cost tractors and machinery though they are inclined towards the mechanization. Apart from lower initial costs, these tractors deliver better fuel efficiency when compared to their higher-powered counterparts, making it viable for small farmers to upgrade from a bullock cart to a tractor. Hence, there is a need to introduce low power rated tractor operated matching combination tillage equipments to improve the socio-economic condition of farming community and to improve the overall efficiency.

2. Materials and Methods

This chapter deals with the research plan, instrumentation, procedure and methodology employed in development and field evaluation of various combination tillage implements. The detailed descriptions are given under the following heads:

a) Research plan for field tests
b) Experimental procedure for field tests

2.1 Research Plan for Field Test

The main aim of the field tests was to evaluate the performance of the developed combination tillage implements. The developed combination tillage implement was tested in the research farm of Dr. NTR College of Agricultural Engineering, Bapatla. A field of one acre land was selected for testing of developed tillage implements with test tractor and sub divided in to 5 plots. The time required for each operation with each combination tillage implement was recorded. The fuel consumption for each operation was also measured. The draft force requirement of each implement was measured by using digital dynamometer. The wheel slip of the test tractor was also measured. The research plan for the field test of developed combination tillage implement is presented in Table 2.1.

Table 2.1: Research plan for field tests

I. Independent variables	
i) Tillage implements	Cultivator, Disc harrow and Combination tillage Implement, Cultivator-clod crusher Cultivator tines with Rotavator Rotavator
ii) Speed of operation	In the range of 1 to 3 km h^{-1}
iii) Depth of operation	In the range of 5.7 to 15.1 cm
II. Dependent variables	
i) Draft Force	
ii) Wheel Slip	
iii) Soil Inversion	
iv) Width of cut	
v) Fuel consumption	
vi) Actual field capacity	

The implement with the test tractor were evaluated at different depths, operating speed and throttle position of tractor. The soil parameters like cone index, bulk density and moisture content of the soil were also measured. The dynamic rear wheel reaction of the test tractor with each implement was measured and weight transfer from the tractor front axle was also measured.

During tillage operation, the time taken to cover a distance of 25 m was noted for 10 times to measure the average speed of operation. The depth and width of tillage operation were measured along the furrow made by the tillage implement. After completion of the tillage operation, the time of completion of tillage operation was noted down. At the end of tillage practice, the soil samples and weeds were collected randomly from five places of the tilled plot to determine soil pulverization and inversion respectively. Testing of developed tillage implements under actual field condition is shown in Fig (2.1).

For comparison of the test results obtained by the active passive combination tillage implement, field tests were conducted only with the rotavor attached to the test tractor. The performance parameters such as depth, width, draft force, soil pulverization was measured.

a. Cultivator with disc harrow (C-DH);

b. Cultivator with clod crusher (C-CC);

c. Tines with rotavator (R-T);

d. Only rotavator

Fig 2.1: Developed combination tillage implements with test tractor

2.2 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.

2.2.1 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

2.2.2 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

2.2.3 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

2.2.4 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

2.2.5 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.

2.2.6 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.

2.2.7 Fuel Consumption
Fuel consumption (Fc) 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.

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

Where,
V = Volume of fuel consumed, L
t = total operating time, h

2.2.8 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:

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

Where,
S = Forward speed, km h^{-1}; W = Width of the implement, m

2.2.9 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.

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

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

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

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

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

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

$$V_s = AFC \times T_d \times 10000$$

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}

2.2.12 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:

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

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
This chapter deals with the outcomes and discussions of the findings obtained from different experiments conducted with tractor and developed combination tillage implements and are presented under following headings:
- Development of combination tillage implements
- Performance evaluation of Tractor - Implement Combination

3.1 Development of Combination Tillage Implements
The development of the combination tillage implements was selected, based on the mini tractor specifications which was discussed in the following section. A combination tillage implements, cultivator with single-acting disk harrow (C-DH), cultivator with clod crusher(C-CC) and rotavator with tines (R-T) was developed. The ideal specification of the developed implements was given in Table (3.1).

Table 3.1: Detailed specification of developed combination tillage implement

Implement	Width of the passive sets, m		Overall dimension, m	Implement Weight Kg
	Front	Rear		
C-DH	0.2	0.4	0.2×0.4 ×0.2	175
C-CC	0.2	0.4	0.2×0.4×0.2	130
R-T	0.34	0.35	0.15×0.2×0.34	140

The speed range of selected tractor considered for operating the developed C-DH combination tillage implement was range of 1-3.5 km/h. 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 18 hp, Mitsubishi Shakti MT 180D 2WD tractor and developed combination implement such as cultivator with disc harrow (C-DH), cultivator with clod crusher (C-CC) and Rotavator with tines (R-T) to evaluate the performance of tractor-implement combination on the basis of tractive and performance index parameters. The results obtained as discussed under the following heads.

- Tractive performance parameters
- Performance index parameters.

3.2.1 Tractive Performance
The tractive performance of the tractor-implement combination was evaluated on the basis of the draft and slip parameters

3.2.1.1 Draft Force measurement
During evaluation of the developed combination tillage implements under actual field condition, it was observed that, the draft force requirement of the passive-passive combination tillage implements found to vary from 190 to 220 kg and 86 to 101 kg at an average depth of 5.7 cm as change in speed of operation from 1.5 to 3.5 km h^{-1}, whereas the draft force requirement of active-passive combination tillage implement found to vary from 116 to 137 kg at an average depth of 5.7 cm as change in speed of operation from 1.5 to 3.5. Km h^{-1}.

Similarly, the draft force requirement of the passive-passive combination tillage implements found to vary from 230 to 260 kg, 128 to 156 kg, and 132 to 155 kg at an average depth of 10.8 cm and 15.1 as change in speed of operation from 1.5 to 3.5 km h^{-1}, whereas the draft force requirement of active-passive combination tillage implement found to vary from 121 to 140 and 141 to 166 at an average depth of 10.8 cm and 15.1 as change in speed of operation from 1.5 to 3.5 km h^{-1}.

It was observed that the draft force requirement of combination tillage implements has been increased with increase in speed and depth of operation. It may be due to the acceleration of the soil particles and imparted kinetic energy to the soil. At higher speed resulted in higher shear rate and increased soil metal friction thus leading to higher draft, whereas at higher depths higher volume of soil is handled and the shear strength also increase which leads to higher draft requirement of the implement. The effect of depth of operation on draft force of the implement is shown in Fig. 3.1.

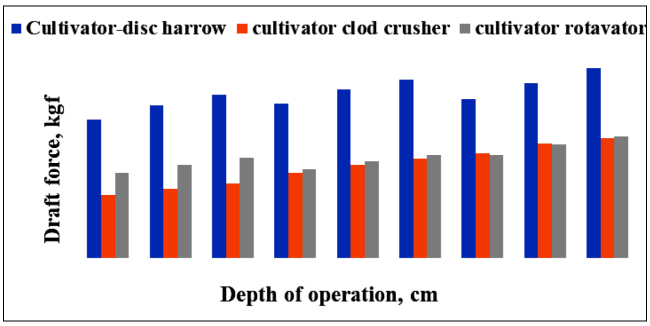

Fig 3.1: Effect of depth of operation on draft force of implements

3.2.1.2 Power requirement of the combination tillage implements
The power requirement of developed combination tillage implements was measured at different forward speeds ranged from 1.5 to 3.5 km h^{-1}. It is very difficult to measure the power requirement of the implement directly; hence it was measured indirectly by measuring the draft force at different depths and forward speeds. The procedure for determination of draft force of combination tillage implements. The power requirement of combination tillage implements such as cultivator with disc harrow(C-DH), cultivator with clod crusher(C-CC) and rotavator with tines (R-C) were observed as, 5.32, 9.866, 18.48 and 2.42, 6.33, 7.7 and 0.46, 1.7, 2.7 kW at forward speed of 1.5,2.5 and 3.5 km h^{-1}, respectively. It was observed that in all three combinations of tillage implements the power requirement is increasing as forward speed increases from 1.5 to 3.5 km h^{-1}. This may be due to the acceleration of the soil particles and imparted kinetic energy to the soil. It was also found that, among these three combinations of tillage implements the power requirement of active-passive combination tillage implement i.e. rotavator with tines comparatively less with the values varied from 0.46 to 2.7 kW this may be due to negative draft force of the rotavator. The effect of the effect of forward speed on power requirement of the developed combination tillage implement is shown in Fig. 3.2.

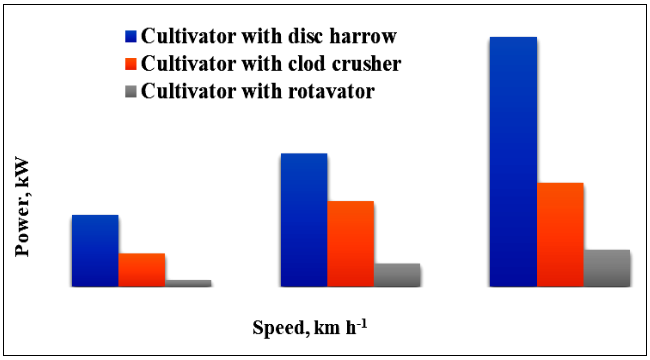

Fig 3.2: Effect of forward speed on power requirement of combination tillage implements

3.2.2 Wheel slip measurement
The slip data obtained from the field experiments of developed combination tillage implements at different depths and constant speed of operation tractor are also presented in Table. 4.2. It can be noticed from the table that the slip of driving wheels of the tractor with developed implements were found to be within the range of 5.6 to 7.8 per cent for the given set of test conditions. It increased with increase in depth and speed. This behavior could be due to higher draft requirement of an implement with increase in depth and speed causing thrust requirement at drive wheels to increase and thus resulting in more slip. It was found that during different depths at constant forward speed of the tractor, the wheel slip was increased while increasing the depth of operation as shown in Fig. 3.3. The reasons for increasing the wheel slip while increasing the depth of operation maybe due to increase in draft force of the tillage implements.

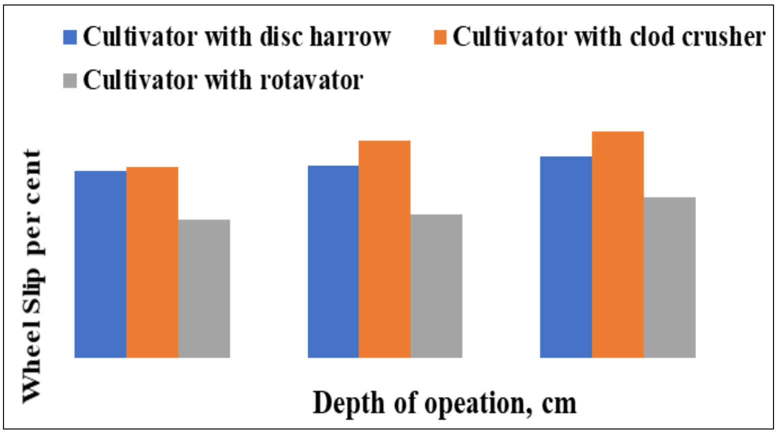

Fig 3.3: Effect of depth of operation on wheel slippage of combination tillage implements

3.2.3 Performance index

The performance index of the developed tractor-implement combination was evaluated on the basis of mean weight diameter (MWD) of soil aggregates, soil inversion, depth of cut, actual field capacity and unit draft. The overall performance of the tractor implement combination was expressed in terms of performance index. The performance index data obtained from the field experiments are presented in Table 3.2 for the three speeds of operation.

Table 3.2: Performance index of implement with different depth and speed of operation of cultivator with disc harrow

Speed, 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	70	0.27	1.73	215.75
	10.8	0.7	62.2	0.16	1.77	680.98
	15.1	0.72	64.8	0.12	1.79	1252.94
2.5	5.7	0.5	54.1	0.30	1.95	245.49
	10.8	0.51	57.3	0.17	2.0	825.57
	15.1	0.53	57.5	0.13	2.1	1523.85
3.5	5.7	0.42	46.1	0.31	2.3	330.62
	10.8	0.4	46.3	0.18	2.4	629.42
	15.1	0.41	46.7	0.14	2.5	1134.13

Table 3.3: Performance index of implement with different depth and speed of operation of cultivator with clod crusher

Speed, 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	70	0.13	1.7	469.59
	10.8	0.7	62.2	0..08	1.73	828.75
	15.1	0.72	64.8	0.06	1.76	978.48
2.5	5.7	0.5	54.1	0.30	1.90	270.33
	10.8	0.51	57.3	0.17	1.93	957.38
	15.1	0.53	57.5	0.13	2.0	868.25
3.5	5.7	0.42	46.1	0.31	2.1	317.80
	10.8	0.4	46.3	0.	2.2	1103.02
	15.1	0.41	46.7	0.14	2.3	1391.78

3.2.3.1 Mean Mass diameter (MMD of soil aggregates

The MMD of soil aggregates were determined using the data obtained from the sieve analysis of soil sample collected after completion of the tillage operation. The mass mean diameter of the soil particle after tillage operation with developed implements was found to vary from 0.7 to 0.42 mm. From Table 3.4, it can be seen that the MMD of soil aggregates was increased with the increase in depth, this may be due to that, at higher depth the soil is more compacted and soil particles cannot be separated easily.

Table 3.4: Performance index of implement with different depth and speed of operation of tines with rotavator

Speed, 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

3.2.4 Field Capacity of Combination Tillage Implements

The theoretical field capacity of developed cultivator with disc harrow found to vary from 0.18 to 0.42 ha h^{-1} whereas the effective field capacity varied from 0.15 to 0.35 ha h^{-1} as change in speed of operation 1.5 to 3.5 km h^{-1}. It was observed that, the field capacity of the combination tillage implement with cultivator and disc harrow was increased with increase in forward speed from 1.5 to 3.5 km h^{-1}. This may be due to decrease in rate of time required per unit area with increase in forward speed. The effect of forward speed on field capacity of cultivator with disc harrow(C-DH) is shown in Fig. 3.4.

The theoretical field capacity of developed cultivator with clod crusher found to vary from 0.18 to 0.42 ha h^{-1}. Whereas the effective field capacity varied from 0.1538 to 0.375 ha h^{-1} as change in speed of operation 1.5 to 3.5 km h^{-1}. It was observed that the field capacity of the combination tillage implement with cultivator and clod crusher was increased with increase in forward speed from 1.5 to 3.5 km h^{-1}. This may be due to decrease in rate of time required per unit area with increase in forward speed. The effect of forward speed on field capacity of cultivator with clod crusher (C-cc) is shown in Fig.3.5.

The theoretical field capacity of developed tines with rotavator varied from 0.18 to 0.42 ha h^{-1}. Whereas the effective field capacity varied from 0.1563 to 0.3809 ha h^{-1} as change in speed of operation from of 1.5 to 3.5 km h^{-1}. It was observed that the field capacity of the combination tillage implements with tines and rotavator (R-T) was increased with increase in forward speed from 1.5 to 3.5 km h^{-1}This may be due to decrease in rate of time required unit area with increase in forward speed. The effect of forward speed on field capacity tines with rotavator (R-T) is shown in Fig. 3.6.

From the Figs. 3.4, 3.5 & 3.6, it is clearly observed that, among these three-combination tillage implements, the effective field capacity of rotavator with tines was comparatively more with the values from 0.1562 to 0.3809 ha h^{-1} due to les non- productive time demand compared with other two developed combinations.

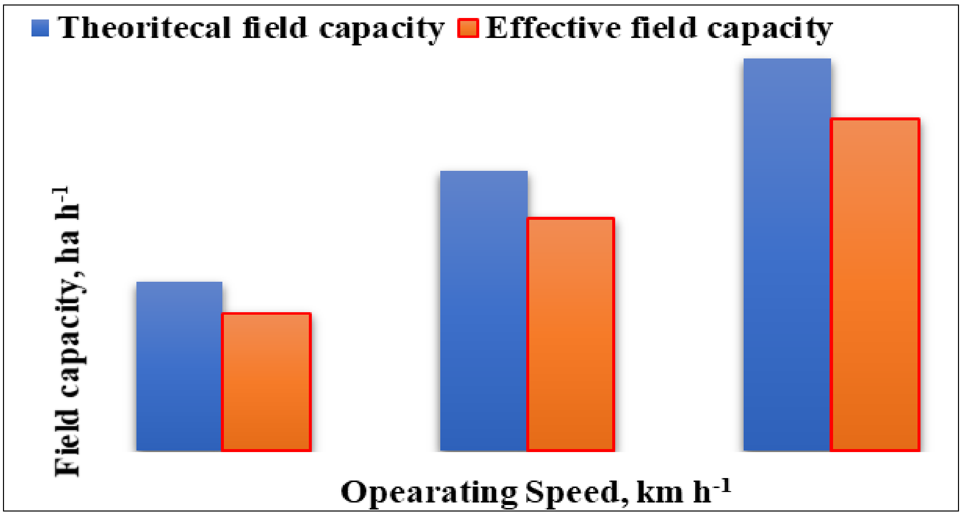

Fig 3.4: Effect of forward speed on field capacity of cultivator with disc harrow

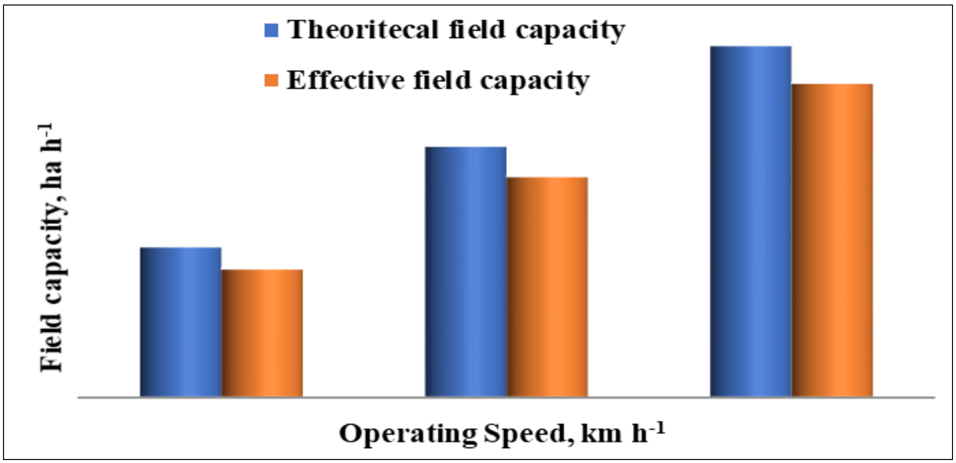

Fig 3.5: Effect of forward speed on field capacity of cultivator with clod crusher

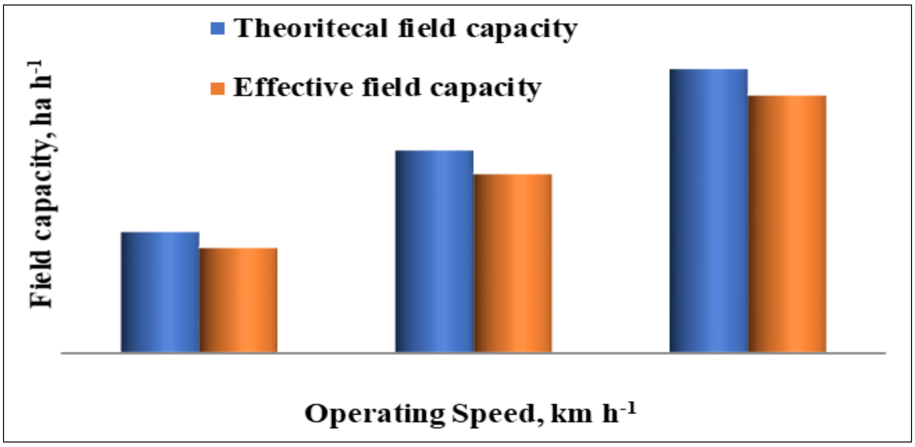

Fig. 3.6: Effect of forward speed on field capacity of rotavator with tines

4.2.5 Field Efficiency on Combination Tillage Implements

The field efficiencies of developed tillage implement found to vary from 81.5 per cent to 90.7 per cent as change in forward speeds from 1.5 to 3.5 km h^{-1}. Field efficiencies of developed implements were found to increase with increase in forward speed, due to decrease in non-productive time as increase in forward speed. Fig 3.7 shows that effect of forward speed on field efficiency of developed combination tillage implements. It was found that, among three developed implements, the combination tillage implement i.e. rotavator with tines indicates more field efficiency ranged from 86.83 per cent to 90.07 per cent with change in speed of operation from 1.5 to 3.5 km h^{-1} compared to the other two developed implements

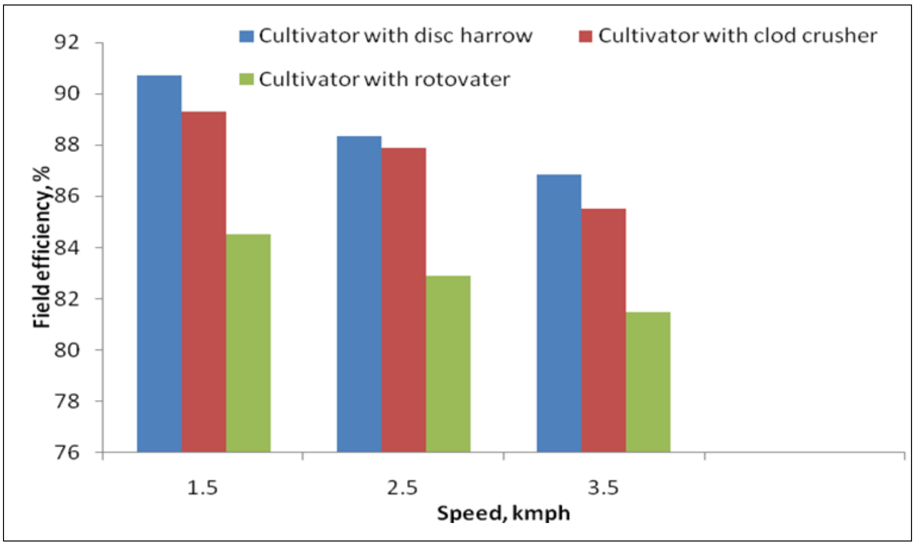

Fig 3.7: Effect of forward speed on field efficiency of developed combination tillage implements

4.2.6 Fuel Consumption of Combination Tillage Implements

The fuel consumption of developed cultivator with disc harrow found to vary from 2.897 to 3.95 lh^{-1} as the depth varied from 5.7 to 15.1 cm at different gears of test tractor such as L1, L2, L3 and H1 at engine speed of 1000 and 1500 rpm. It was observed that the fuel demand of developed cultivator with disc harrow increased as increase in gear level from L1 to H1. The effect of depth of operation on fuel demand of the test tractor at different depths and operating speeds is shown in Fig. 3.8.

Fuel demand of developed cultivator with clod crusher found to vary from 2.846 to 3.822 L h^{-1} as the depth varied from 5.7 to 15.1 cm at different gears of test tractor such as L1, L2, L3 and H1 at engine speed of 1000 to 1500 rpm. It was observed that the fuel demand of developed cultivator with clod crusher increased as increase in gear level from L1 to H1. The effect of depth of operation on fuel demand of the test tractor at different depths and operating speeds is shown in Fig. 3.9.

Fuel demand of developed tines with rotavator found to vary from 2.195 to 3.335 L h^{-1} as the depth varied from 5.7 to 15.1 cm at different gears of test tractor such as L1, L2, L3 and H1 at fuel demand of developed tines with rotavator increased as increase in gear level from L1 to H1. The effect of depth of operation on fuel demand of the test tractor at different depths and operating speeds is shown Fig. 3.10.

It was observed that, for all the developed tillage implements the fuel consumption was increased with increase in operating depths and change in gear level. It was also found that among the three developed implements, the implement cultivator with disc harrow demanded more fuel in all the operating conditions as compared to the other two implements due to more draft force.

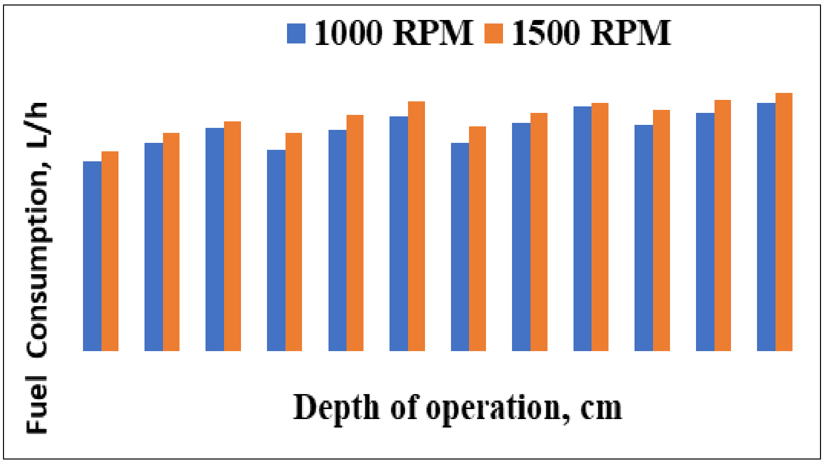

Fig 3.8: Effect of depth of operation on fuel consumption of the test tractor with cultivator and disc harrow

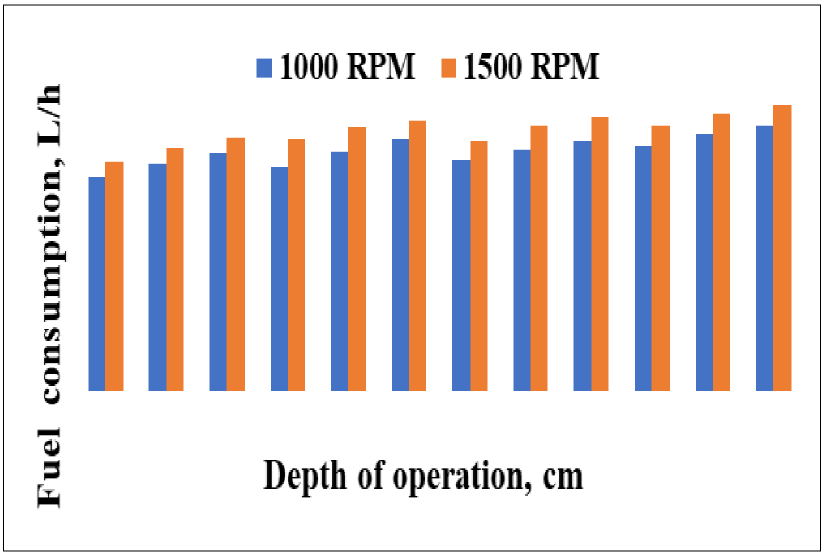

Fig 3.9: Effect of depth of operation on fuel consumption of the test tractor with cultivator and clod crusher

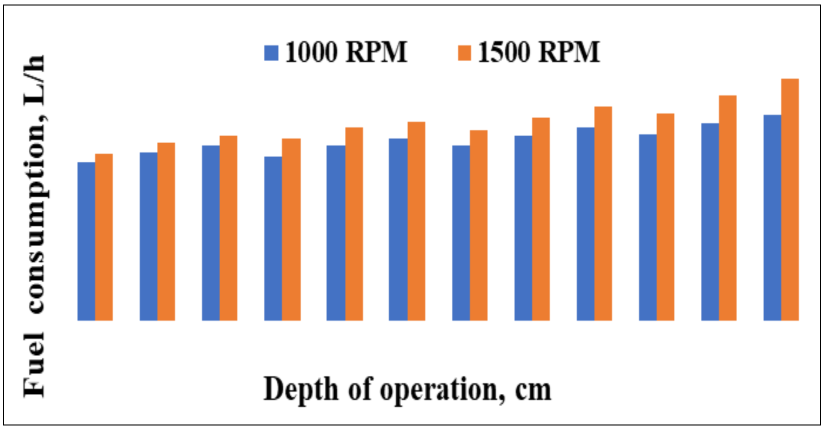

Fig 3.10: Effect of depth of operation on fuel consumption of the test tractor with rotavator and tines

5. Conclusion

Based on the results of this study, the following specific conclusions were drawn:

- The developed C-DH implement can be operated up to the depth of 10 cm and speed of 3.5 km h^{-1}.
- The power requirement of combination tillage implement was observed as, 5.32, 9.866, 18.48 and 2.42, 6.3, 3,7.7 and 0.46, 1.7, 3.5 kW at forward speed of 1.5, 2.5 and 3.5 km h-1, respectively. It was observed that in all three combinations of tillage implements the power requirement is increasing as forward speed increases from 1.5 to 3.5 km h^{-1}. But among these three combinations of tillage implements power requirement of cultivator with rotavator combination comparatively less with the values varied from 0.46 to 2.7 KW.
- The average field capacity of the developed C-DH

implement was found to be 0.306 and 0.612 ha h^{-1} for the speed of 1.5 and 3.5 km h^{-1}, cultivator with clod crusher was varied from 0.1538 to 0.375 ha h^{-1} at forward speed of 1.5, and 3.5 and cultivator with rotavator varied from 0.1563 to 0.3809 ha h^{-1} at forward speed of 1.5 and 1.5.

- Field efficiencies of developed tillage implement found to vary from 81.5 per cent to 90.7 per cent at forward speeds of 1.5 to 3.5 km h^{-1}.Field efficiencies of developed implements was found to increase as increase in forward speed, because of decrease in non-productive time as increase in forward speed.
- It was found that among these developed implements, combination of cultivator 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.
- The overall performance of the developed tillage implements could be expressed in terms of performance index taking into account the MMD of soil aggregates, inversion, volume of soil handled per unit time and draft. By using the implement both the implements such as primary and secondary can be done simultaneously.
- The number of passes of the draft implement can be reduced during the field preparation the observing cost of cultivaton can be saved. By literature by reducing the reducing the number passes

By sing this combination tillage the maximum tractive efficiency of tractor can be reached.

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