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# Development of Passive-Passive Combination Tillage Implements Suitable for Mini-Tractor

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***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

Indian agriculture account for nearly 14.2% of the gross domestic product and involves over 58.2% of population. The biggest challenge before the agriculture 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. Since the cultivated area has remained nearly constant (142 Mha) over the years, the only option to increase food production is to increase the productivity of land. The developed combination tillage implement comprises of two passive tillage implement one as front passive tillage implements and other as second passive tillage implement. 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. The developed tillage implements were evaluated under actual field condition at different depth and operating speeds. The tillage performance parameters such as draft force, fuel consumption, wheel

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slip, power requirement was measured. A digital dynamometer was used for measurement of draft force of the tillage implement at different operating depths under field evaluation. The draw bar 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. 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.

*Keywords: Draft; depth; combination tillage implement.*

## 1. INTRODUCTION

Tillage operation is defined as the mechanical manipulation of soil performed to achieve desired seedbed to provide optimum environment of seeding germination and plant growth. Seedbed preparation for sowing, planting of different crops is done through primary and secondary tillage operation. The optimum seed-bed preparation for raising upland crops, involving the following unit operations [1]. 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 [2].

The combination tillage implement comprises passive-passive tillage elements. Some studies on development and performance evaluation of 2WD tractor drawn combination tillage implements have been conducted in India [3,4,5,6,7].

However it was reported that the passive-passive combination tillage implements outperformed the conventional tillage practices in fuel consumption, time requirement and cost of operation [7]. Hence such types of implements are very much required for low kW tractors (8-15 kW).

Sahu and Rehaman [7] developed the draft prediction equation for passive –passive set of combination tillage implements which indicates that the draft requirements of both tillage implements were significantly affected by speed, depth, width of cut and soil cone index while the characteristic lengths of implement (curvature and length for moldboard and tine; and concavity for disk) and soil bulk density were found to be non-significant.

Shinners et al. [8] also tested an experimental active-passive combination tillage implements in the field to investigate the effects of velocity ratio, forward speed and depth ratio and power requirement. It was found that the velocity ratio was most influential in affecting the draft and power requirement of implement than the other operating parameters.

Weise et al. [9] also performed experiments with a combination tillage implement and reported that the speed range between 0.5 and 1.5 m/s, the power demand of the implement varied linearly with forward speed.

Shinners et al. [10] tested a combination tillage implement that combined both active and passive implements in the field and reported that the depth had a greater effect on total power requirement than the width. The depth had an exponential effect on the draft while width had a linear effect.

## 2. MATERIALS AND METHODS

### 2.1 Design Considerations

In most part of a country soil condition is soft so people generally use cultivator as primary tillage implement instead of M.B. plough. Therefore cultivator is selected as front passive set for opening of soil and better cutting action whereas disk harrow and clod crusher was selected as rear passive set for better pulverization. The reason to develop this implement is to reduce the draft force of the implement by decreasing the volume of soil handling capacity, The peg teeth should penetrate in to the soil at uniform depth. The rear passive should roll easily to reduce the positive draft of the implement. The depth of operation of the single-acting disk harrow (rear passive set) was kept same as that of cultivator (front passive set). As there may be undulations in the field so to maintain constant depth of harrow hinge is provided. Because of hinge the harrow will go down by its own weight and maintain a constant depth. As hinge is provided there may be problem in transporting the implement and also will create problem during turning. To overcome these problems a nut-bolt is provided on the support frame to limit the depth of harrow up to certain limit. The rear passive set should cover the tilled soil made by front passive set.

The cutting width of the implements should cover the wheel track of the tractor. The size and weight of the implements should not affect the stability of the tractor. The implements should be capable of operating in light and medium soils under normal tillage conditions without soil clogging. The time, energy and cost for seedbed preparation should be lower than the existing conventional tillage practices. The total power requirement should not exceed the power available from the tractor selected.

### 2.2 Development of Combination Implements Using Disk Harrow, Cultivator and Clod Crusher

The overall cutting width of the harrow was kept as1.2 m with a gap of 0.3 m at the center to cover the soil opened by 5x22 cm cultivator. The side forces on the disks in the single-acting disk harrow should balance each other so that the lateral stability of the implement was not affected, six 40 cm sizes of disks were used because small diameter disks penetrate more readily than do large disks, i.e., they require less vertical force to hold them to given depth. The harrow should be kept behind the cultivator with certain gap to avoid clogging. Adequate overlap was provided to minimize the untilled soil. A two-section single action configuration was selected with the disk gangs' end on. This would ensure balance of the lateral forces and reduce the overall length of the implement. A clod breaker behind the soil working tool was provided to break the clods and to develop the seed bed having fine tilth. The clod crusher was developed using GI pipe (with 10 cm diameter and 120 cm length) having four rows of spike tooth with 11 pegs with a length of 10 cm were rigidly fixed to the pipe having sharp pointed edge towards ground surface with an angle of 3° in each row, One end of the peg tooth was welded to the pipe where as the other end was sharpened and bended at the end with an angle of 6° to penetrate and lifts the soil for better pulverization.

A nut- bolt is provided on the support frames of the tillage implements to hold the disc gangs and roller in aligned position to limit the depth of harrow up to certain limit. The rear passive set should cover the tilled soil made by front passive set. A provision made for adjustment of gang angle of rear passive set. A provision was also made to adjust the depth of operation. A frame consisting of horizontal bars having length of 50 cm were attached to the frame of rear passive set using nut and bolt arrangement whereas sixteen number of 0.5 cm diameter vertical bars were welded to the horizontal frame mounted on back side of rear passive set as shown in Fig. 1 to collect weeds, trashes from the ploughed land. The developed crusher was hinged at lower ends of the frame with the help of the suitable links. The center to center distance in a row and inter row distance of pegs is 10 and 6 cm respectively.

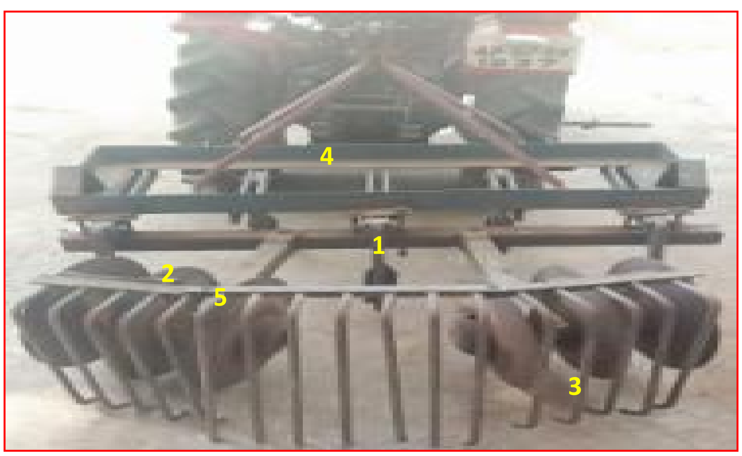


**Fig. 1. Developed passive-passive combination tillage implements C-DH with test tractor**
*1. Supporting frame; 2. Disc harrows; 3. Weed collector; 4. Front passive set; 5. Rear passive set*

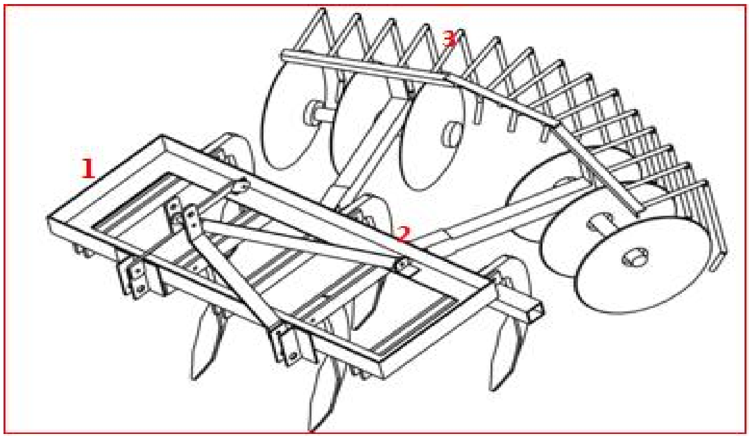


**Fig. 2. Schematic diagram of cultivator with single-acting disk harrow**
*1. Front passive set; 2. Rear passive set; 3. Weed/trash collector*

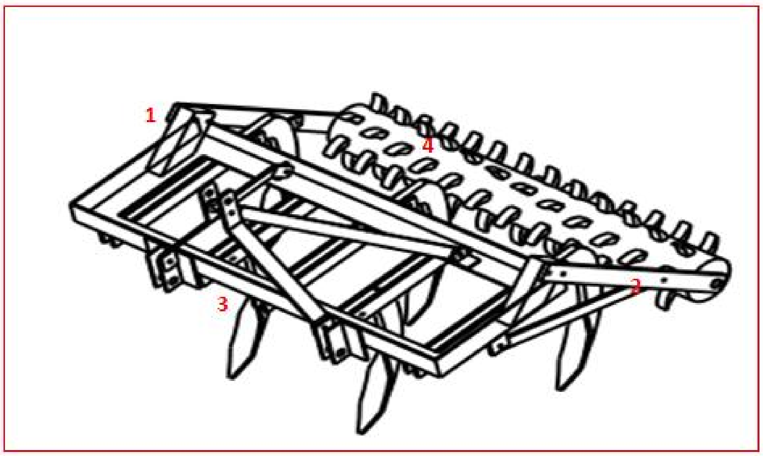


**Fig. 3. Schematic diagram of cultivator with clod crusher**
*1. Frame; 2.Arms ; 3. Cultivator; 4. Clod crusher*

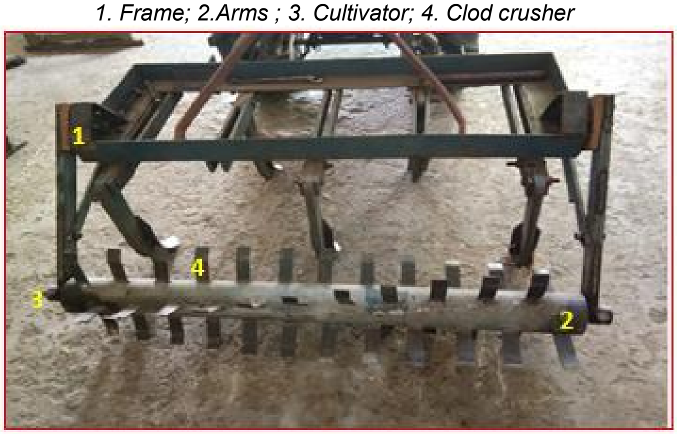


**Fig. 4. Developed combination tillage implement with cultivator and clod crusher**
*1. Supporting frame; 2. GI pipe; 3. Shaft; 4. Spike/Pegs*

The developed roller with pegs was connected to the frame of front passive set i.e. cultivator with the help of two side arms to overcome the problem during transportation and turning in operation. The CAD views and the developed combination tillage implements using cultivator with disc harrow cultivator and clod crusher is shown in Figs. 2 to 4.

## 2.3 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. The time required for each operation was each combination tillage implement were recorded. The fuel consumption for each operation was also measured. The draft force requirement of the each implement was calculated by using ASABE empirical equation according to ASAE standard 1997 D497.3 [11]. The research plan for the field tests to be conducted has been presented in Table 1.

## 2.4 Parameters Measured During Field Experiments

### 2.4.1 Draft force measurement

Draft force of the developed combination tillage implements were measured using a digital drawbar dynamometer using a dummy tractor. The developed implements were mounted to the test tractor using 3-point linkage of hydraulic system. A load cell based digital dynamometer was kept in between two tractors using specially fabricated iron rod to measure the subjected draft during operation.

Initially, the implement was lifted and the test tractor was placed in neutral gear and it then pulled by an auxiliary tractor up to 20 m. The force required to pull the implement was recorded. Similarly, the implement was engaged in to the soil and again the test tractor was pulled using an auxiliary tractor up to 20 m. The force required for pulling the tractor was recorded. The difference between initial and final draft force values obtained from the draft requirement of the implement was considered as draft force. The draft was measured at different depths. Measurement of draft force of the developed tillage implement under actual field conditions is shown in Fig. 5.

### 2.4.2 Soil sample analysis

The soil samples were collected from the selected research farm of Dr. NTR College of Agricultural Engineering, Bapatla. The samples were collected before and after operation of the combination tillage implements. The collected soil samples were dried under shade for about 2-3 days, then pounding with wooden hammer was carried out and past thorugh a sieve of 2mm for particle size analysis (textured) by buycous hydrometer method. The percent of clay, silt and sand were determined by the following formulae. The results obtained during the soil sample analysisy is presented in Table 2.

% Clay = corrected hydrometer reading at 6 hrs, 52 min x 100/wt. of sample.

% Silt = corrected hydrometer reading at 40 sec x 100/wt of sample - % clay

% Sand = 100% - %silt -%clay

### 2.4.3 Power requirement

The drawbar power of the tractor i.e. power requirement to pulling of implement is calculated using following formula

Power (hp) = (draft (kgf) x speed (m/sec))/75

### 2.4.4 Measurement of speed of operation

The time taken to travel 25 m distance was measured with a mechanical stopwatch and the speed of operation was calculated by

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

Where $V_a$ = speed of operation, km/h, t = time, s

**Table 1. Research plan for field tests**

| Independent variables | | Dependent variables |
|---|---|---|
| Tillage Implement | Cultivator, Disc harrow and Combination tillage | Draft force |
| Speed of operation | In the range of 1.5 to 3.5 km/h | Wheel slip |
| Depth of operation | In the range of 5.7 to 15.1 cm as depth was measured | Width of cut |
| | | Fuel consumption |


**Fig. 5. Draft force measurement of developed combination tillage implements**
*1. Test tractor with implement; 2. Auxilary tractor; 3. Load cell; 4. Digital indicator; a. cultivator-disc harrow; b. cultivator-clod crusher*

**Table 2. Particle size diameter of soil samples after tillage operation in microns**

| Soil samples | Before operation of the tillage implements | | After operation of the tillage implements | |
|---|---|---|---|---|
| | C-DH | C-CC | C-DH | C-CC |
| Sample 1 | 2 | 2 | 0.71 | 0.5 |
| Sample 2 | 2 | 2 | 0.7 | 0.51 |
| Sample 3 | 2 | 2 | 0.72 | 0.53 |

### 2.4.5 Measurement of Wheel Slip of tractor

The measurement of wheel slip was based on the fixed number of rear wheel revolution. The distance covered in ten wheel revolutions was recorded with and without load and the values were used to calculate slip using the following expression.

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

Where S = Slip %

$d_t$ = distance covered in 10 revolutions of drive wheel at no load in field
$d_a$ = distance covered in 10 revolutions of drive wheel with load in field

### 2.4.6 Width of cut

The width of cut of tillage implement was measured by measuring the width of furrow with a measuring tape at an interval of 3 m along the length of furrow. The average of five reading was taken to determine the width of cut of a tillage implement.

### 2.4.7 Depth of operation

The depth of a tillage implement was measured by measuring the depth distance between furrow sole and ground level) using a steel rule along a furrow wall at an interval of about 5 m along the length of furrow. The average of five readings was recorded to determine the depth of operation of tillage implement.

#### 2.4.8 Turning time

The turning time for 180° turn of a tractor-implement system during a tillage operation was measured using a mechanical stopwatch at both ends of the field and was expressed as the difference between the time of engaging the implement after turn and the time of lifting the implement before turn.

#### 2.4.9 Fuel Consumption

Fuel consumption ($F_c$) was measured by top fill method. The fuel tank was filled up to its maximum capacity before testing. After tillage operation using test tractor with developed combination tillage implements the fuel tank was filled up to its maximum capacity. The refilled of fuel was measured using measuring jar. Then the fuel consumption was measured using the following equation.

It was expressed in liter per hour.

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

Where,

V = volume of fuel consumed, lit
t = total operating time, h

#### 2.4.10 Theoretical field capacity

Theoretical field capacity (TFC) is rate of field coverage of the implement based on 100% of time at the rated speed and covering 100 percent of its rated width. For calculating theoretical field capacity, first the speed and width of the implement was measured. The speed was calculated by recording the time required to travel 10 m distance. The TFC was calculated by using the following equation.

$$TFC\left(\frac{ha}{h}\right) = \frac{S \times W}{10}$$

Where,

S = forward speed, km $h^{-1}$
W = width of the implement, m

#### 2.4.11 Effective field capacity

Effective field capacity (EFC) is the actual average rate of coverage by the machine, based upon the total field time. It is a function of the rated width of the machine, the percentage of rated width actually utilized, speed of the travel and the amount of field time lost during the operation. Effective field capacity is usually expressed as hectare per hour. The EFC was calculated by using the following equation.

EFC (ha/h)) = A/(T(p) + T (np))

Where,

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

#### 2.4.12 Field efficiency

Field efficiency ($F_e$) is the ratio of effective field capacity to the theoretical field capacity, expressed as percentage. It was calculated using the following equation.

$$F_e\,(\%) = \frac{EFC}{TFC} \times 100$$

Where,

E.F.C = Effective field capacity, ha $h^{-1}$ and
T.F.C = Theoretical field capacity, ha $h^{-1}$.
$V_s$ = Volume of soil tilled per unit time, $m^3$/h
$T_d$ = depth of operation, m
AFC = Actual field capacity, ha/h

#### 2.4.13 Overall performance

Considering the above mentioned parameters, an index known as performance index (PI) could be used to find out overall performance tillage implements. The PI is considered to be directly proportional to depth, AFC and $S_i$ and inversely proportional to draft. Mathematically, it could be expressed as:

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

Where

PI = Performance index, $T_d$ = depth in cm, AFC = Effective field capacity in hectare per hour, $S_i$ = Soil inversion, D = draft in kgf/$cm^2$

## 3. RESULTS AND DISCUSSION

### 3.1 Development of Combination Tillage Implements

The development of the combination tillage implements was selected, based on the mini tractor specifications which were discussed in the following section. Combination tillage implement, cultivator with single-acting disk harrow (C-DH), cultivator with clod crusher (C-CC) was developed. The ideal specification of the developed implements was given in Table 3.

The speed range of selected tractor considered for operating the developed C-DH, C-CC combination tillage implement was range of 1. 5 to 3.5 km/h.

### 3.2 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 cultivator with disc harrow found to vary from 1863 to 2157 N and 843 to 991 N at an average depth of 5.7 cm as change in speed of operation from 1.5 to 3.5 km/h. Similarly, the draft force requirement of the passive-passive combination tillage implements cultivator with clod crusher found to vary from 2256 to 2550 kg, 1255 to 1530 N, and 1295to 1520 N 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.

It was observed that the draft force requirement of combination tillage implements have 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. 6.

### 3.3 Power Requirement

The power requirement of developed combination tillage implements were measured at different forward speeds ranged from 1.5 to 3.5 km/h. 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 power requirement of combination tillage implements such as cultivator with disc harrow (C-DH) and cultivator with clod crusher (C-CC) were observed as, 5.32, 9.866, 18.48 and 2.42, 6.33, 7.7 and at forward speed of 1.5, 2.5 and 3.5 km $h^{-1}$, respectively. It was observed that in these two 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.

**Table 3. Detailed specification of developed combination tillage implements**

| Implement | Width of passive sets, m | | Overall dimensions | Implement weight, Kg |
|---|---|---|---|---|
| | Front | Rear | | |
| C-DH | 0.2 | 0.4 | 0.2x0.4x0.2 | 175 |
| C-CC | 0.2 | 0.4 | 0.2x0.4x0.2 | 130 |

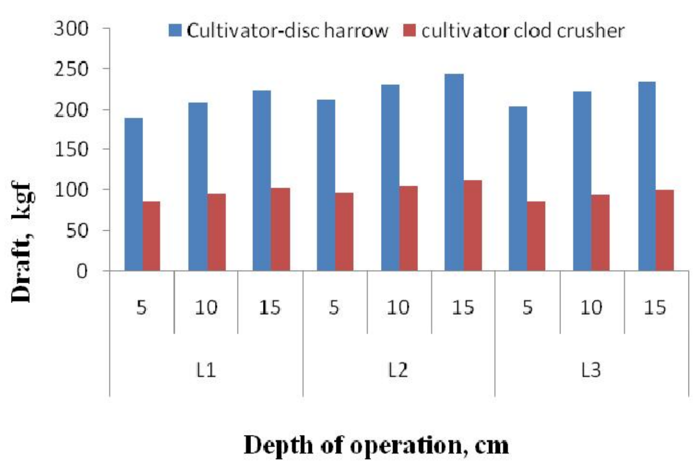


**Fig. 6. Effect of depth of operation on draft forceof the implement**

It was also found that, among these two combination of tillage implements the power requirement of passive–passive combination tillage implement i.e. cultivator with clod crusher comparatively less with the values varied from 2.42 to 7.7 kW. The effect of forward speed on power requirement of the developed combination tillage implement is shown in Fig. 7.

### 3.4 Wheel Slip

The slip of driving wheels of the tractor with developed implements was found to be within the range of 5.6 to 7.8% for the given set of test conditions. 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. 8.

### 3.5 Field Capacity

The theoretical field capacity of developed cultivator with disc harrow found to vary from 0.18 to 0.42 ha/ h where as the effective field capacity found to be vary from 0.15 to 0.35 ha/ h and The theoretical field capacity of developed cultivator with clod crusher found to vary from 0.18 to 0.42 ha/ h. 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. It was observed that, the field capacity of the combination tillage implement with cultivator and disc harrow and cultivator with clod crusher was increased with increase in forward speed from 1.5 to 3.5 km/ h. 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

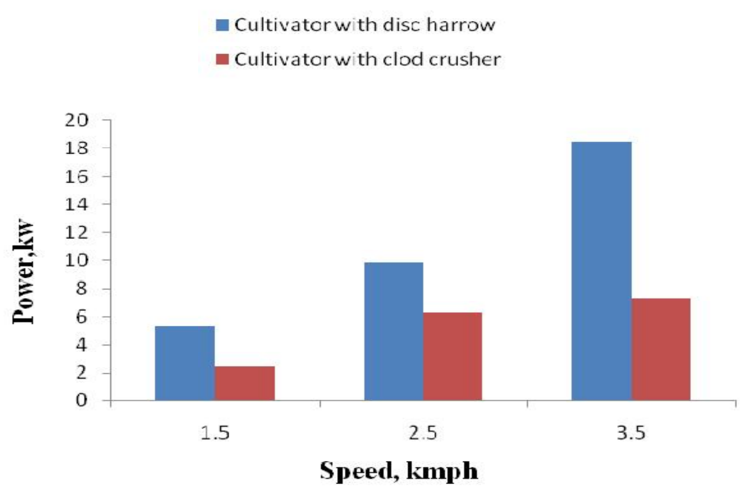


**Fig. 7. Effect of forward speed on power requirement of combination tillage implements**

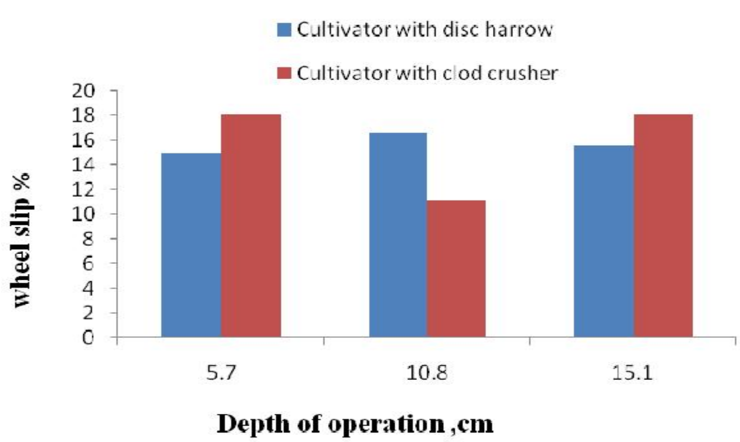


**Fig. 8. Effect of depth of operation on wheel slippage of combination tillage implements**

field capacity of cultivator with disc harrow (C-DH) and cultivator with clod crusher (C-cc) as shown in below.

From the Figs. 9 and 10, it is clearly observed that, among these two combination tillage implements, the effective field capacity of cultivator with clod crusher was comparatively more with the values from 0.1538 to 0.375 ha/ h due to non- productive time demand compared with other two developed combinations.

### 3.6 Fuel Consumption of Combination Tillage Implements

The fuel consumption of developed cultivator with disc harrow found to vary from 2.897 to 3.95 l/h 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 Figs. 11 and 12. Fuel demand of developed cultivator with clod crusher found to vary from 2.846 to 3.822 l/ h 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.

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 two developed implements, the implement cultivator with disc harrow demanded more fuel in all the above operating conditions as compared to the other two implements due to more draft force.

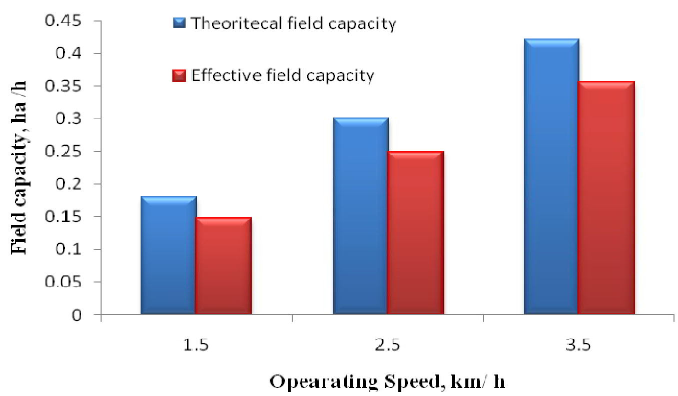


**Fig. 9. Effect of forward speed on field capacity of cultivator with disc harrow**

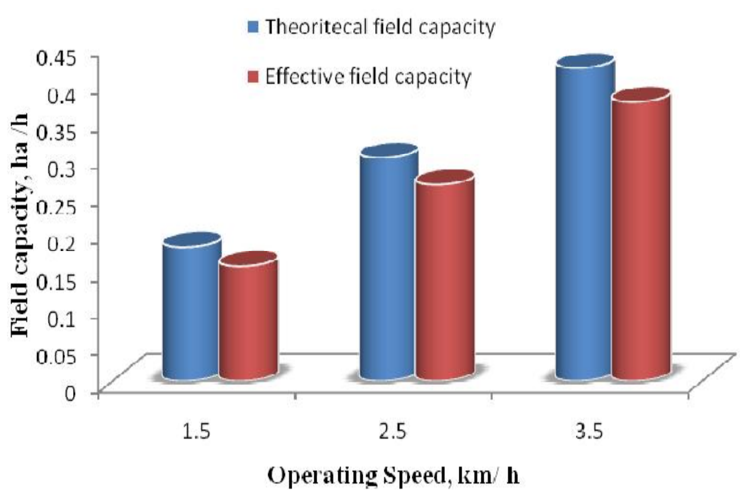


**Fig. 10. Effect of forward speed on field capacity of cultivator with clod crusher**

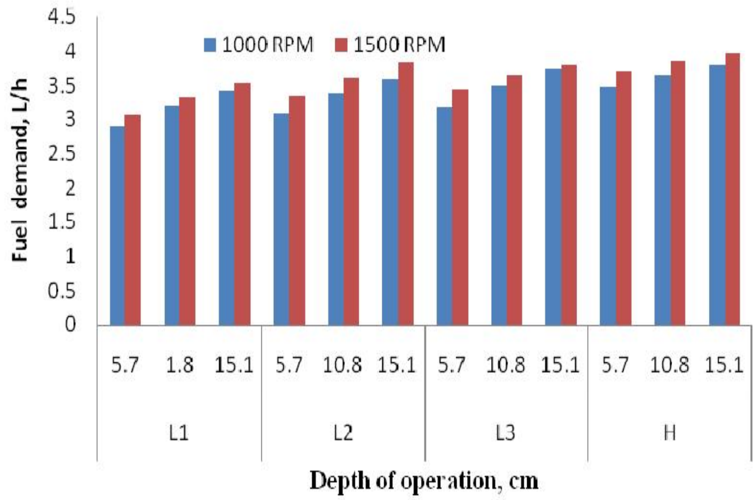


**Fig. 11. Effect of depth of operation on fuel consumption of the test tractor with cultivator and disc harrow**

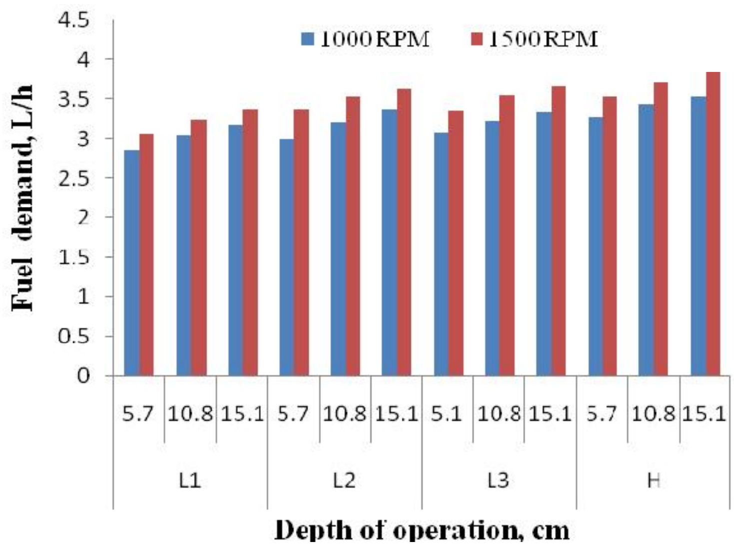


**Fig. 12. Effect of depth of operation on fuel consumption of the test tractor with cultivator and clod crusher**

## 4. CONCLUSION

The overall performance of the developed tillage implements could be expressed in terms of performance index taking into account the mass mean diameter (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 cultivation can be saved. By using this combination tillage the maximum tractive efficiency of tractor can be reached.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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