Original Research Article

Development and evaluation of multifunctional tillage implement

Abstract

To improve the mechanization level in India, a low-cost tractor that can be afforded by a normal farmer and also suitable for Indian land size is very much required. One way to reduce the cost of mechanization is optimum utilization of the tractor power for any agricultural operation. For these matching, implements are required for the developed tractor which can use the tractor rated power optimally. To further reduce the cost of operation, two tillage operations can be combined by combining two implements. Hence, a combined Cultivator and Disk Harrow (C-DH) was developed and tested in the Research Farm of College of Agricultural Engineering, Madakasira. The tests were carried out with two speeds and three different depths in each speed. The plots of 50×25m size were selected for the test parameters such as the speed of operation. The time required to travel 25m test length, turning time, depth of operation, the width of operation were recorded. Quality of work was judged by the Mass Median Diameter (MMD) of soil aggregates collected before and after operating C-DH implement in the plot and conducting sieve analysis. From the test results, the average field capacity of the C-DH implement was found to be 0.30 and 0.61 ha/h at 1.8 and 3.4 km/h respectively. The overall performance was expressed in term of Performance Index and was found to be 548.54 at the depth of 13 cm and a speed of 3.4 km/h.

Keywords – *Combination implement, Mini Tractor, Tractive force, Soil parameters.*

1. Introduction

Indian agriculture accounts for nearly 14.2% of the gross domestic product and involves over 58.2% of the population (Anon., 2011a). The biggest challenge before the agricultural sector of India is to meet the growing demands of food for her increasing population from 1.21 billion in the year 2011 to 1.6 billion by the year 2050 (Anon., 2011a). Since the cultivated area has remained nearly constant (142 Mha) (Anon, 2011b) over the years, the only option to increase food production is to increase the productivity of the 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 (Singh, 2005). The application of machines to agricultural production has been one of the outstanding developments in Indian agriculture (Singh et al., 2014). The efficient utilization of available resources and timeliness of agricultural operation are the major factors influencing the productivity level of agricultural commodities.

Conventional tillage employs many passes over a field with various soil-turning and soil-pulverizing equipment (Boydaş & Turgut, 2007) likemouldboard 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). Also, in conventional tillage practises most of the Indian farmer utilizes the available tillage implement with any ranges of tractor power, consequently, there is the improper matching of a tractor and implement combinations resulting in under loading of tractor engine hence, poor efficiency (Alam, 2000). 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 a better solution (Sahu and Raheman, 2006). The combination tillage implements also help in reducing time, labour and fuel costs for seedbed preparation (Downs, 2003).

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, 2006).

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 the tractor (Wismer et al., 1968). 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). Hence such types of implements are very much required for low kW tractors (8-15 kW).

In India cultivator can be used as versatile implement i.e. it can be used as secondary as well as primary tillage tool in case of soft soil condition and it requires relatively low power per meter of width, (Kepner et.al., 1987). Disk harrow is the most common equipment used for clod breaking rather than weed control or residue mixing (Hajiahmad, 2006). Hence a combination of these two passive-passive tillage implements may be tried for low power tractors.

In the context of the above knowledge, there is a strong need for development and evaluation of passive-passive tillage implements for effective utilization of tractor power thereby to get maximum tractive efficiency and to reduce the input sources. This project was, therefore, undertaken with the following objectives:

(i) To develop a passive - passive combination tillage implement (Cultivator and Harrow)

(ii) To evaluate the performance of the developed implement under actual field condition.

The performance of different tillage implements was evaluated based on clod size distribution, fuel consumption, drawbar power, time requirement and cost of tillage operation. Some major findings in this regard are reviewed below:

The idea of using a sequence of tillage implements in combination is fairly old. Spoor and Godwin (1978) conducted field tests with tandem tool configurations (two chisel ploughs followed by a deeper winged subsoiler) in clay soil. The results showed that the draft of tandem tool configurations at different spacing and depths of chisel ploughs was less than the draft of the winged subsoiler alone due to loosening of the top layer of soil by the chisel ploughs.

Bukhari *et al.*, (1982) reported that there was no need for other operations for refining the seedbed due to proper shattering of the soil when the furrow slice of moldboard plough was subjected to operation of any secondary tillage implement (CH-clod buster, IH-coil tine harrow, Broy hill tilling tool, PLH-20 coil tine harrow, pressure-Matic harrow and spike tooth harrow).

Weise (1993) performed experiments with a combined tillage implement consisting of wing tines and a rotor with tines. The effect of the distance between the wing tine and the rotor on power consumption was found to be less. Increasing the distance between the wing tine and the rotor reduced the danger of blockage by straw. It was also reported that the rotor tines destroyed mainly the large clods left by the wing tines. Shinners *et al.*, (1990 and 1993) developed two combination tillage machines. The first machine had two active and two passives sets, and the second machine consisted of active rotary-powered tillage set with conventional passive chisel tines.

It was reported that combination machines required less draft and drawbar power than similar machines using purely passive tillage tools although total power consumption was the same. The combination machines were more energy-efficient than similar passive tillage tools. Upadhyaya et al., (2001) developed a one-pass tillage implement called, Incorpramaster and compared its performance with conventional tillage methods (stubble disking and land planning) with a 385 hp 4WD tractor. It was found that the developed machine outperformed the conventional land preparation methods in fuel consumption and time by 19-81 and 67-83% respectively. The mean soil particle size created by the one-pass tillage implement was comparable to that produced by conventional tillage methods.

Loghavi and Hosseinpoor (2002) attached a roller behind a mouldboard plough to combine primary and secondary tillage operation. It was noted that draft and clod mean weight diameter (MWD) significantly decreased compared to separate operation. Moreover, the soil surface was more uniform than using mouldboard plough and disk harrow as a common method. Javadi and Shahidzadeh (2005) developed combined equipment with chisel plough behind of mouldboard plough and indicated that the combined plough enabled to break plough pan during ploughing in one pass and would avoid un-necessary sub-soiling in deep soil layers separately.

Hajiahmad and Javadi (2006) developed a combine machine consisting of disk harrow and Cambridge roller for sufficient clod breaking as well as surface uniformity in one pass and shortest possible time. The results of the test indicated that combine machine improved some physical properties of soil which were important for secondary tillage such as clod breaking and surface uniformity. And no significant difference was noted between combined machines and disking twice in most parameters. In India, few researchers have also developed combination tillage implements for below 40 hp tractors. Nagaiyan (1983) developed and tested a tractor-drawn combination tillage implement consisting of two passive furrows on both sides of the rototiller and leveller in the rear. The results indicated that the cost of operation was reduced by 50% as compared to conventional tillage practice.

Kumar and Manian (1986) reported that by using combination tillage implements, the existing tractor power was better utilized in the field. Due to simultaneous operations of both primary and secondary tillage implements, ten hours of tractor operation was saved per hectare when compared to conventional field operations, viz. moldboard plough plus cultivator plus disk harrow operated separately. It was also reported in the above two studies that only one-third of the total energy input in conventional tillage operations was needed for the combination tillage implements to manipulate the soil for satisfactory seedbed preparation.

Sahay (1991) evaluated the performance of a power tiller operated combined machine for tilling of unsaturated sandy clay loam soil in terms of specific energy, mean weight diameter and inverse performance index. It was reported that the combined machine gave a better performance than the rotary of the power tiller alone in all respects. Manian (1999) reported that there was a reduction in operating cost and energy consumption during seedbed preparation with a combination of tillage-bed furrow-former by 47 and 39% respectively.

Similarly, Manian and Kathirvel (1999) also reported that the energy, time and cost of operation for a combination tillage tool consisting of 16 tine rotary tiller and 2 to 4 chisel plough were reduced by 64.7-71.3, 61.7-69.9 and 62.2-70.3% respectively as compared to the combination of different implements when operated separately to obtain almost the same quality of tilth in black clay loam soil. Kailappan et al., (2001a and 2001b) developed a combination tillage implement to perform both primary and secondary tillage operations in the field simultaneously in a single pass utilizing both tractive and rotor power available in the tractor wheels and PTO shaft respectively. It was found to improve aeration, water holding capacity and pulverization of soil while saving 44-55 and 50-55% in cost and time respectively when compared with different combinations of the moldboard plough, disk plough, cultivator and disk harrow operated separately. Sahu and Raheman (2006) experimented using different combination tillage implement and found that the tillage practices involving combination implements outperformed the tillage practices involving respective individual implements in fuel consumption and time by 14.3 to 47.4 and 30.2 to 59.6% respectively.

2.0 Dynamic Force Analysis of Tractor - Mounted Implement Combination Dynamic rear-wheel reaction ($R_{r`}$)

The dynamic weight on tractor axles is required to study the weight retained on the tractor front axle. Considering force and moments in Fig.1, the dynamic reaction on tractor rear wheel, R_r, and front wheels, R_f can be expressed as follows.

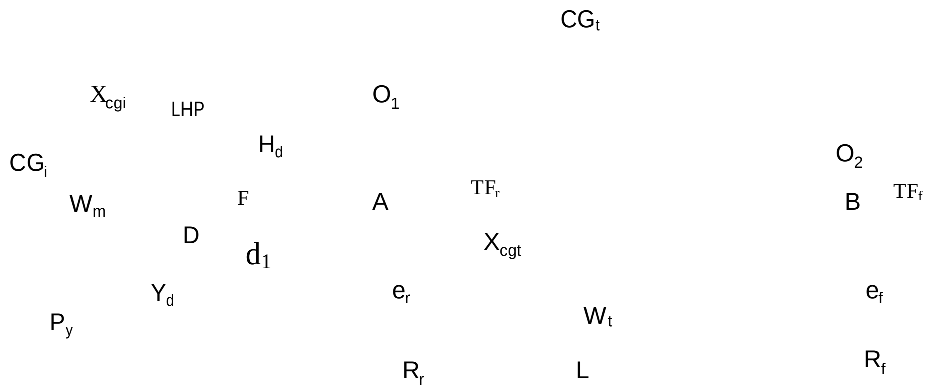

Fig. 1 Forces acting on the tractor- mouldboard plough combination

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

$$R_f = (W_t + W_m + P_y) - R_r$$

In the present investigation, the dynamic wheel reaction was measured by using the empirical equations. The performance of a tractor-implement combination could be evaluated based on the quantity and quality of work done by the implement and fuel energy input to the tractor and are discussed as follows:

2.1 Measurement of Soil Properties

In the present study, the implement was tested in Red soil and considered as medium structured soils hence, based on ASABE standard, the soil specific parameter used for draft force measurement and the cone index of the soil was assumed as 1100 kPa.

2.1.1 Draft Prediction

The horizontal component of the resultant force required to pull a machine in the field is draft. According to ASAE standard 1997 D497.3, it can be calculated by

$$D = F_j\,(A+BV_a+CV_a^{2})*W*d_1 \tag{1}$$

Where: F_j is dimensionless soil texture adjustment parameter (j = 1 for fine, 2 for medium and 3 for coarse-textured soils), and A, B and C are machine-specific parameters, V_a= actual speed of operation, km/h, W = width of operation, m and d_1= Depth of Operation, cm.

2.1.2 Volume of Soil Handled

The volume of soil handled per unit time could be expressed as:

$$V_s = AFC \times T_d \times 10000 \quad (2)$$

Where: V_s is the volume of soil tilled per unit time (m^3/h); T_d is the depth of operation (m); AFC is the actual field capacity (ha/h)

2.1.3 Soil inversion

The inversion of soil (S_i) could be expressed as:

$$S = \frac{W_b - W_a}{W_b} \times 100 \quad (3)$$

Where: Si = soil inversion (%), W_b is the weight of weeds before tillage operation (g), W_a is the weight of weeds after tillage operation (g)

2.1.4 Fuel Energy Input to the Tractor

The fuel (diesel) energy input (F_e) to the tractor to carry out a tillage operation could be expressed as:

$$F_e = FC \times CV \quad (4)$$

Where: F_e is the fuel energy input (MJ/ha),; FC is the fuel consumption (l/ha); CV is the calorific value of diesel (MJ/l)

2.1.5 Overall Performance

Considering the above-mentioned parameters, an index known as Performance Index (PI) could be used to find out overall performance of 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:

$$PI = \frac{T_d \times AFC \times S_i}{D} \quad (5)$$

Where: PI is the performance index, T_d is the depth (cm); AFC is the effective field capacity (hectare per hour); S_i is the soil inversion and D is the draft (kgf per cm^2).

3. Development of Combination Tillage Implement

3.1 Design Considerations

The following design requirements were considered for the proposed combination of tillage implements. In most of a country soil condition is soft, so people generally use cultivator as primary tillage implement instead of M.B. plough. Therefore, the cultivator is selected as a front passive set for opening of soil and better cutting action and disk harrow was selected for better pulverization.

The depth of operation of the single-acting disk harrow (rear passive set) was kept the same as that of cultivator (front passive set). As there may be undulations in the field so to maintain a constant depth of harrow hinge is provided. Because of hinge the harrow will go down by its weight and maintain a constant depth. A hinge is provided there may be a 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 a 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 implements should be the fully mounted type for good manoeuvrability during tillage operation and transport. Combination tillage implement consisted of a 9-tine cultivator and a 6x6 single-acting disk harrow in sequence as shown in Fig. 2.

a) Back view b) Side view

Fig. 2: Cultivator with single-acting disk harrow (C-DH) combination tillage implement.

A detailed description of design considerations and design of various components of combination tillage implements are given in the following sections.

3.2 Design of Components

For combination tillage implement, the front passive set was selected as cultivator because of its popularity for use of primary tillage as an alternative for mouldboard plough. Only the rear passive set with supporting frame was designed. It comprised a single-acting disk harrow and one assembly frame to mount the rear set.

3.2.1 Single-acting Disk Harrow

The following design requirements were considered for single-acting disk harrow.

The overall cutting width of the harrow was kept as 0.85 m with a gap of 0.04 m at the centre to cover the soil opened by 5x17 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. The 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 a given depth. The harrow should be kept behind the cultivator with a 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 the balance of the lateral forces and reduce the overall length of the implement.

3.2.2 Frame Assembly

The frame assembly was designed considering the following requirements: The frame should be able to support the main sub-assembly of a single-acting disk harrow. It should be adequate to withstand bending, torsion and shear forces to be experienced during tillage operation. It should be a simple welded structure having a section modulus with maximum strength and minimum weight.

3.3 Instrumentation for Field Tests

A Mahendra, 2WD tractor (32.8 kW) with the developed tillage implement was used for conducting field experiments. The draft requirements of tillage implement, the fuel consumption of the tractor during field operations were:

3.3.1 Fuel Consumption Measurement System

The study was conducted in the selected plot for fuel consumption of tractor. Before the operation, the fuel tank of the tractor was filled with fuel up to the brim. The tractor was operated with disk harrow and cultivator in the plot. Fuel was filled again in the tank after 18 minutes of operation. The additional fuel which was filled at this time was measured. Thus, fuel consumption was computed in litre per hour.

4. Experimental Procedure for Field Tests

All the field experiments were conducted on a Research farm of College of Agricultural Engineering, Madakasira, India

4.1 **Measurement of Soil Properties**

To quantify the soil condition, bulk density, moisture content and cone index data were obtained in each plot. The bulk density and moisture content were measured with core samples taken for a depth of 150 mm while cone index values were measured with the hand-operated cone penetrometer. These soil data were collected from five different locations for each plot.

4.2 Test procedure and Data Analysis

The test procedure followed during the field tests is explained in two sections. One section is for draft measurement and another section is for performance parameters for combination tillage implements.

5. Results and Discussion

5.1 Performance parameter for combination tillage implement

Before each test, the soil data were collected. This test was carried out in a 50×25 m plot for the tillage practice and was replicated thrice. The tillage performance parameters such as soil pulverization, soil inversion, fuel consumption, actual field capacity, width, depth, speed, turning time for 180° turn of a tractor-implement combination were measured.

The weeds were collected randomly from five places of size 30×30 cm each in the untilled plot. Then, the tillage implement was operated on the given soil condition. 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 the 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.

Fig. 3: Testing of developed combination tillage implement

5.2 Slip

The slip data obtained from the field experiments of C-DH at different depths and speeds were measured. It was observed that the slip of driving wheels of the tractor with C-DH was found to be within the range of 5.6 to 7.8 % for the given set of test conditions. It increased with increase in depth and speed. This behaviour could be due to higher draft requirement of an implement with an increase in depth and speed causing thrust requirement at drive wheels to increase and thus resulting in more slip.

5.3 Performance Index

The performance index of the tractor-implement combination was evaluated based on soil inversion, depth of cut, actual field capacity and unit draft. The overall performance of the tractor implement combination was expressed in terms of the performance index

5.4 Soil Inversion

The soil inversion was determined by weighing the weeds collected from an area of 30×30 cm before and after a tillage operation carried out by the tillage implements tested using Eq. 3. In the combination of cultivator and disk gang pulverization is better so proper inversi on was not possible. As depth has increased the inversion was also increased because the volume of soil handled was increased at higher depth. From Table 1, it can be seen that the soil inversion was less as higher speed because at high speeds the clods were pulverized more rather than getting inverted.

5.5 The volume of soil handled per unit time

The volume of soil handled per unit time during tillage operation was calculated knowing the implement width, speed and depth of operation for each tillage impleme nt tested and was found to be varying from 345.78 to 795.6 to m^3/h as reported. With an increase in either speed of operation or depth, the volume of soil handled increased.

5.6 Actual field capacity

Actual field capacity is the result of time lost during the field operation for turning, idle travel, operator's skill etc. Depth of operation does not have a greater effect on actual field capacity. Average field capacity for 1.8 and 3.4 km/h was 0.306 and 0.612 ha/h respectively.

5.7 Fuel consumption

The fuel consumption of the tractor during tillage operation with cultivator varied from 1.12 l/h to 1.43 l/h as the depth changes from 8.4 to 14.3 cm. The fuel consumption of the tractor during tillage operation with harrow varied from 1.01 l/h to 1.24 l/h as the depth changes from 8.4 to 14.3 cm. The fuel consumption of the tractor during tillage operation with combination tillage equipment varied from 1.16 l/h to 1.62 l/h as the depth changes from 8.4 to 14.3 cm. The effect of depth of operation on the fuel consumption of the test tractor is shown in Fig. 4.

Fig.4: Effect of depth of operation on fuel consumption

5.8 Operating Time

The time of operation of the tractor during tillage operation with cultivator under L1, L2, L3 gears varies from 1.59 to 2.49 h/ha, 1.5 to 2.40 h/ha, 1.45 to 2.35 h/ha as the depth changes from 8.4 to 14.3 cm. The time of operation of the tractor during tillage operation with harrow under L1, L2, L3 gears varies from 1.46 to 2.36 h/ha, 1.38 to 2.28 h/ha, 1.32 to 2.22 h/ha as the depth changes from 8.4 to 14.3 cm. The time of operation of the tractor during tillage operation with combination tillage implement under L1, L2, L3 gears varies from 1.62 to 2.52 h/ha, 1.58 to 2.48 h/ha, 1.54 to 2.44 h/ha as the depth changes from 8.4 to 14.3 cm. The comparison of time taken for field operations with different implements is presented is shown in Fig. 5

Fig.5: Comparision of time taken for field operations with different implements

5.9 Dynamic wheel reaction

The Dynamic wheel reaction of the tractor during tillage operation with cultivator varied from 1823 to 1840 kg, as the draft changes from 677 to 747 kg. The Dynamic wheel reaction of the tractor during tillage operation with harrow varied from 1598 to 1613 kg, as the draft changes from 553 to 612 kg. The Dynamic wheel reaction of the tractor during tillage operation with cultivator varied from 2350 to 2382 kg, as the draft changes from 1230 to 1359 kg. The effect of draft force on the dynamic rear-wheel reaction of test tractor is shown in Fig. 6

Fig. 6: Effect of draft force on the dynamic rear-wheel reaction of test tractor

5.10 Performance index

The overall performance of different tillage implements tested during the study was expressed in terms of performance index (PI). It was computed using Eq. 5 and the results obtained are presented in Table 1. The highest performance index of 548.54 was observed for the C-DH implement operating at 13 cm depth and 3.4 km/h speed of operation.

Table 1. The performance index of the implement with different depth and speed of operation

Speed, km/h	Depth of operation, cm	Soil inversion (S_i), %	The volume of soil handled per unit time (V_s), m^3/h	Actual field capacity (AFC), ha/h	Draft, kgf/cm^2	Fuel consumed per unit time (F_u), l/h	PI
1.7	11.3	58.09	345.78	0.306	0.15	1.2	330.75
	12.9	62.24	394.74	0.306	0.15	2.2	378.17
	13.2	64.88	403.92	0.306	0.15	2.2	354.99
3.35	11.0	54.17	673.2	0.612	0.20	3.3	446.01
	12.7	57.34	777.24	0.612	0.19	3.3	528.65
	13.0	61.13	795.6	0.612	0.19	3.3	548.54

6. Conclusions

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

i. The developed C-DH implement can be operated up to the depth of 14 cm at a forward speed of 4 km/h.

ii. The average field capacity of the developed C-DH implement was found to be 0.306 and 0.612 ha/h for the speed of 1.8 and 3.4 km/h.

iii. The overall performance of the developed C-DH implement could be expressed in terms of performance index taking into account the MMD of soil aggregates, inversion, the volume of soil handled per unit time and draft. The PI of the developed C-DH implement was found to be 548.54 at 13 cm depth and 3.4 km/h speed of operation.

iv. Time-saving varied from 54.4 % to 60 %

v. Fuel-saving varied from 51.9 % to 53.1 %

vi. Maximum tractor power utilization can be possible.

vii. The traction force of tractor can be increased.

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