

Original Research Article

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Use of Different Tillage Tools for Minimizing Number of Passes in Secondary Tillage Operations

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ABSTRACT

Soil tillage is one of the most important operations in the crop production system and consumes a large amount of energy and time than any other operation. The cost, energy and time requirement during the tillage operation mainly depends on the soil condition, power source and the tool used during the operation. The cost and the timeliness of operation assume critical importance while deciding the type of tillage tools. In this paper, an attempt has been made to overview the effect of the different tillage tools on reducing the number of passes in the secondary tillage operations. The combined tillage tool with the combination of a disk harrow and a Cambridge roller has been developed in Iran. Three treatments were namely disk harrow once; disk harrow twice and combined machine were applied after moldboard ploughing. Findings showed that increasing rotational speed from 130 to 165 rpm, decreased the mean weight diameter and instability index. A methodology for the prediction of draft requirements under the combination of tillage implements in the different soil and operating conditions have also been developed. Combination tillage implement comprising cultivator and a single-acting disk harrow in sequence (C-DH) with a total cutting width of 2.1m had draft found to be within 7.4 to 11.1 kN with an associated slip of 10.5 to 22.4 %. The overall performance index was found to be higher for combination tillage implement as compared to that of individual tillage implements indicating the better efficiency of the tractor-implement combinations. It can be concluded that new combined machine would be a substitute for several disking and allows the operation to complete in one pass.

Keywords

Combination tillage, Instability index, Moldboard ploughing, Secondary tillage operations, Tillage tools.

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Introduction

Tillage consumes a large part of the energy in mechanized agriculture. Tillage or soil preparation has been an integral part of traditional agricultural crop production practice (Gill and Vandenberg, 1968; Kumar and Chopra, 2016). Tillage breaks the soil, enhances the release of soil nutrients for crop growth, destroys weeds and enhances the circulation of water and air within the soil

(Reicosky and Allmaras, 2003; Kumar and Chopra, 2013). Combined tillage is the act of using two or more different types of tillage implements or tools at the same time to manipulate control or reduce the number of operations in the field (Al-janobi and Al-suhaibani, 1998). Manian and Kathirvel (2001) reported that combined machines are more complex than passive tilling implements

or rotary machines, but these machines can unite the advantages of active and passive machines and they can create lower resistance than the passive machines and, at the same time, they can ensure lower specific work than the active, rotary machines. Javadi and Hajiahmad (2006) reported that draft and clod mean weight diameter (MWD) significantly decreased when combined tillage operation is done compared to single operation with many passes.

Above reviews show the importance of combined tillage operation in a single pass to save time, money, fuel in land preparation. Sahu and Raheman (2006) stated that operations simultaneously utilizing two or more different types of tillage tools or implements to simplify, control or reduce the number of operations over a field are called combined tillage. The combination that enables the task to be completed in the shortest time with minimum operating cost and energy requirement is usually selected (Onwualu and Watts, 1998). Combined machines are complex than passive tilling implements or rotary machines, but these machines can unite the advantages of the active and passive machine and they can create lower resistance than the passive machines and at the same time they can ensure lower specific work (Kepner *et al.*, 1972).

Most of the primary tillage operation is for unsettling the compression of soil and root growth. In this regard, Ruci and Vilde (2006) reported that ploughing is one of the most power-consuming and expensive processes in agricultural production. Craciun *et al.*, (2004) reported some advantages about combined machines for seedbed preparation and sowing in terms of the draft. Therefore, the present investigation was conducted for the use of different tillage tools for minimizing number of passes in secondary tillage operations

Materials and Methods

A conventional offset disk harrow with 140 cm working width and 53 cm disk diameter was used. A Cambridge roller was selected, which was more efficient for clod breaking. An extended chassis was added on disc chassis to attach roller behind the disk. Divisions of roller were attached to each other enabling to cover disk harrow width. The attachment was done in such a way to put the pulling centre of disk and roller in direction with pulling a line of the tractor. The combined machine was then evaluated in the field and its effect on the soil physical and mechanical properties was determined. Completely Randomized Block Design with three replications was adopted as follows after ploughing for the three selected treatments viz., 1) Disk harrow once 2) Disk harrow twice 3) Combined machine (disk harrow + Cambridge roller). Bulk density on a dry basis was determined before and after the operation.

The depth ranging from 0 - 10 and 10 - 20 cm were selected as working depth for all the treatments. For this test un-disturbed samples were taken from the plots by core sampler and dried for 24 h at 105°C in an oven. Clod mean mass diameter was determined using different sieve sizes before and after operations in three replications. Penetration resistance was measured by 10 insertions in each plot before and after operations. A penetrometer (SP 1000) was used with 12.83 mm cone diameter and 30-degree angle based on ASAE standard. Soil moisture content was also determined during cone index recording. Soil surface profile measurement was developed to compare surface uniformity left after each treatment. The device consisted series of Aluminum rods that could be placed on plough furrow. The loose rods were tightened by bolts after placement. By transferring and measuring the movement of each rod and

calculating standard deviation, the uniformity was determined (Javadi and Hajiahmad, 2006).

Tillage equipment

A combo plough has four essential parts which include a chassis, a disk plough, a set of rotary blades and a transmission system. The combo plough is attached to a tractor three-point linkage system and driven by the tractor power take-off shaft (PTO). Power is transferred from the PTO to the gearbox. The drive direction is changed by 90° at the horizontal shaft to the rotary blade shaft. A clutch safety system is placed between the universal joint and the gearbox to prevent overload. The disk implement consists of a standard disk having 61 cm diameter. The position of the rotary blade was determined according to the upward soil movement at the end of the disk (Ahmad and Amran, 2004). The rotary shaft has three kinds of blades: straight (S), C-shaped and L-type. The soil penetration resistance in each experimental plot was determined using a penetrometer (80 mm long and 10 mm cone diameter) at a depth of 0 to 80 mm.

Test procedure

The test was performed based on 2 × 3 factorial treatment in following the same pattern: Completely randomized block design (CRBD) with three replications. Block dimensions were 25 × 27 m². Clod mean weight diameter was determined using different sieve sizes (8, 4.75, 2.8, 2, 0.5, and 0.3 mm) in three replications after the operation. The main plots were allocated to rotary speeds (130,147 and 165 rpm) and subplots were allocated to the three types of blades namely, straight blade (S), C-shaped and L-shaped. Aggregate stability or stability index (SI) was measured using a wet-sieving apparatus to determine the mean weight

diameter, wet basis (MMDw) and dry sieving to determine the mean mass diameter, dry basis (MMDd). The method of wet-sieving was adapted from Kemper and Rosenau (1986). The wet-sieving apparatus duration was 10 min and 50 oscillations per minute and SI was calculated using the following formula:

$$\text{Instability Index (II)} = \text{MMDd} - \text{MMDw}$$
$$\text{Stability index (SI)} = 1 \div \text{instability index (II)}$$

Experiments were conducted to determine the influence of various types of blades and rotational speeds on selected soil physical properties. The soil physical characteristics investigated were MMDd, MMDw, to find out the SI, SII and percentage of aggregate size distribution for aggregates between 2 and 8 mm (ASDd₈). Clod mean mass diameter (MMDd₁₀₀) was determined using different sieve sizes (100, 50, 14, 6.3 mm) in three replications after the operation.

The tillage depth for disk plough was 20 cm. The tractor PTO speed of 540 rpm was reduced to 216.5 rpm using a gearbox. The rotary blade speeds of 130,147 and 165 rpm were obtained by changing the adjustable gear sprockets (13:23, 14:22 and 15:21) in the transmission system. The travel speed used for all treatments was 7.2 km/h.

Measurements of soil characteristics

Twenty-seven soil samples were collected from the field during the tillage experiments from each plot at depths of 0 to 15 and 15 to 30 cm. Soil samples were classified by mechanical analysis using the pipette method.

Draft and depth of operation

The draft requirement of tillage implements and its depth of operation in the field were measured with an instrument attached to the

three-point linkage of a tractor. For measuring draft values, implements were pulled at a different speed and depth for a strip of 25 m length and simultaneously data on pulling force and the angle made by the links were recorded through multi-channel data acquisition system.

Slip

The measurement of wheel slip was based on the fixed number of a 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.

$$S = (d_t - d_a) / d_t \times 100$$

Where S is slip (%), d_t is distance covered in 10 revolutions of drive wheel at no load in the field (m) and d_a is distance covered in 10 revolutions of drive wheel with a load in the field (m).

The volume of soil handled

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

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

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

Mean mass diameter of soil aggregate

The mean mass diameter (MMD) of the soil aggregate was computed as:

$$MMD = \sum W_s M_s / \sum W_s$$

Where W_s is the weight of soil sample retained over S^{th} sieve (g) and M_s is the class of mean size for S^{th} sieve (mm).

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 $F_e = FC \times CV$

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

Overall performance

The overall performance of the tractor implement combination was expressed in terms of tillage performance index (TPI), which is considered to be directly proportional to V_s and S_i and inversely proportional to MWD and fuel energy (F_e).

Mathematically, it could be expressed as:

$$TPI \propto [V_s / (MWD \times F_e)]$$
$$TPI = K \times [V_s / (MWD \times F_e)]$$

Where K is proportionality constant. While comparing the tillage performance of different tillage implements in same soil condition K could be absorbed in the equation

Results and Discussion

The effect of treatments on the bulk density at 0-10 cm depth was non-significant. However, it was noted that combined machine had minimum bulk density. The results showed that bulk density decreased after the operation. This was mainly due to clod breaking and loosening of soil surface layer. There was no difference in bulk density at 10-20 cm depth for all the treatments. The reason was due to working depth of implements, which was mostly in the range of 0 - 10 cm. In cases of similar effect, it is clear that combined machine would be preferable as operation could be done in one pass. Time is also a dominant factor for tillage operation

and the combined machine could save time significantly. Using the disk harrow one time had almost no effect on clod breaking as no change was recognized in mean weight diameter before and after the operation. The combined machine showed the greatest difference followed by twice disking treatment. One-time disking does not significantly affect or break the clods and more disking is often needed. However statistical analysis showed that there was the non-significant difference between treatments after operation with 95% confidence. It can be confirmed that combination of disk harrow with other equipment, which enabled to break the clods and create uniform surface would avoid several disking. Combination of disk harrow and spiked harrows was successfully used in the past. The results showed that combined machine had the maximum effect to decrease penetration resistance, particularly at 10-20 cm depth. There was no significant difference between once and twice disking treatments. Penetration resistance increased in 20 cm depth range, which was due to plough pan in the field. It was reported that field ploughed continuously for more than three years and existing of plough pan was expected. Results revealed that combined equipment created maximum uniformity (minimum non-uniformity) followed by disking twice and once. This result was fairly close to areal condition in the field, where combined machine left more even surface than others.

Tractive performance parameters

Draft

The results obtained are the average of the three replications. The measured draft forces for a cultivator, offset disk harrow and C-DH for 100 and 150 mm depths of operation. From this figure, it can be seen that the draft values for a cultivator, offset disk harrow and

C-DH implements are found to be within 6.8 to 10.3 kN, 4.7 to 7.4 kN and 7.4 to 11.1 kN, respectively for the test range of soil conditions, depths and speeds of operation. The draft values of all tillage implement tested show a polynomial increase with an increase in depth and speed. The draft of C-DH was found to be the highest among the tillage implements tested. This could be due to a higher volume of soil handled per unit width as compared to other tillage implements and also its design and manner of soil handling. The draft values of combination tillage implement as compared to its individual tillage implements were higher by 1.1 to 9.3 %.

Slip

It can be noticed that the slip of driving wheels of the tractor with cultivator, offset disk harrow and C-DH implements were found to vary from 8.6 to 16.9%, 7.5 to 13.9% and 10.5 to 22.4%, respectively. Further for all implements, it increased with increase in both depth and speed. This behaviour could be due to the higher draft requirement of an implement with an increase in depth, speed and soil strength causing thrust requirement at drive wheels to increase and thus resulting in more slip.

Mean mass diameter of soil aggregates

The MMD of soil aggregates was determined using the data obtained from the sieve analysis of soil sample collected after a single pass of each tillage implement. It was found that the MMD of soil aggregates varied from 17.0 to 25.7 mm for the tillage implements used. The disk harrow produced the lowest MMD of soil aggregates (17.0 mm), while the cultivator produced the highest MMD (25.7 mm). This could be due to both cutting and pulverize actions by disk harrow as compared to only cutting action by cultivator. It can also

be seen that the MMD of soil aggregates produced by C-DH combination tillage implement was lower than the conventional cultivator.

Actual field capacity

The actual field capacity of various tillage implements tested in the field varied from 0.51 to 0.63 ha/h. A maximum of 0.63 ha/h and a minimum of 0.51 ha/h were observed for cultivator and disk harrow, respectively. This could be due to the difference in speed at which they were tested. The actual field capacity of cultivator was found to be 6.35 % higher than that of combination tillage implement. This was due to more time required during turning for combination tillage implement as well as the lesser speed of operation due to higher slip.

The volume of soil handled per unit time

The volume of soil handled per unit time during tillage operation was found to be varying from 637.5 to 945.0 m³/h. As compared to the cultivator, the volume of soil handled per unit time for C-DH implement was 6.35% lesser due to higher slip incurred and losses in time during turning.

Field efficiency

The field efficiency of different tillage implements tested varied from 74.2 to 80.2%. The highest and lowest field efficiencies were found for disk harrow and C-DH combination tillage implement, respectively. This could be due to more time loss during turning of the C-DH implement as compared to disk harrow.

Fuel consumption

The fuel consumption of 31 kW tractors for all the tillage implements tested varied from 3.6 to 4.3 l/h. It was found that C-DH tillage

implement consumed the highest amount of fuel (4.3 l/h), while the lowest (3.6 l/h) was observed for disk harrow. This could be due to more volume of soil handled by C-DH as compared to other tillage implements. However, on the basis of the area covered, the fuel consumption was found to be lowest (6.2 l/h) for cultivator due to its higher actual field capacity.

Tillage performance index

The overall performance of different tillage implements tested during the study was expressed in terms of tillage performance index (TPI). It can be seen that the TPI varied from 0.22 to 0.26 for the tillage implements tested. The highest TPI was found for C-DH tillage implement, while the lowest was found for the cultivator. This could be due to more volume of soil handled and higher pulverization by C-DH as compared to disk harrow and cultivator.

It can be concluded that there were some benefits of using new machine in the secondary tillage operation. Soil uniformity was significantly improved by using the combined machine. In case of similar effect, it can be also recommended that combined machine would be preferable reducing the number of passes, time and costs. The results obtained indicated that no significant differences were noted between types of blades. The blade rotational speeds had highly significant effects on selected parameters (MMD_d, MMD_{wASD_d} and MMD_{d100}). The effects of blade type were similar. The concept of reference tillage tool and reference soil condition could be used successfully to predict the drafts of various combination tillage implements and draft utilization ratio for a rear passive set of the combination tillage implement in field conditions with scale factors related to soil properties and implement geometry. The developed

combination tillage implement could be operated with 31 kW, 2WD tractor in sandy clay loam soil at an average moisture content of 10%, normal depth and speed within the slip range of 15 %. The TPI of combination tillage implements was found to be higher than the TPI of respective individual tillage implements. Thus, the new combined machine would be a substitute for several disking and allows the operation to complete in one pass.

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