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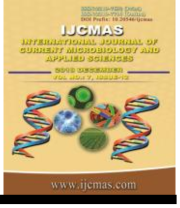

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Studies on Performance Evaluation of Vertical Rotary Plough

Chandrashekar* and Jayant Singh

Department of Farm Machinery and Power Engineering, GBPUAT Pantnagar, Uttarakhand, India

**Corresponding author*

ABSTRACT

The undulating and sloppy geography, small size fields with uneven topography, lack of skilled labour, poor repair and maintenance facilities, low purchasing capacity of farming community and non-availability of improved farm implements and machines are some of the main reasons for low level of mechanization in the hilly region of the state. By keeping in mind the problems faced by the farmers in hilly areas and to promote farm mechanization a new type of rotary plough cum weeder is designed. The designed rotary plough has 4 straight knife edge blades which were attached on circular mounting plate with the help of nuts and bolts. Power from main engine shaft is transmitted to the rotary blades by using bevel (Pinion: 10 teeth and 4 cm diameter, Crown: 40 teeth and 16 cm diameter) and spur gear transmission system. The effect of forward speeds, rotor speed and soil moisture content on actual field capacity, field efficiency, fuel consumption, energy required per unit area and total cost operation were studied. Two soil moisture content (12.5 ± 0.5 and 14.5 ± 0.5 %), three forward speeds (1.5, 1.75 and 2 km h^{-1}) and three rotor speed (350, 450 and 550 rpm) have been chosen. The results showed that, the maximum actual field capacity of vertical rotary plough 0.097 ha h^{-1} was obtained when the rotor speed was 350 rpm, with the forward speed 2 km h^{-1} and the soil moisture content of at 14.5 ± 0.5 %. The highest field efficiency of vertical rotary plough was 88.09 % when the soil moisture content was 14.5 ± 0.5 % with a rotor speed 350 rpm and 2 km h^{-1} forward speed. The minimum fuel consumption of vertical rotary plough was 0.84 l h^{-1} when the rotary plough operated at 350 rpm of rotor speed with 1.5 km h^{-1} forward speed of operation and soil moisture content was 14.5 ± 0.5 %. The maximum energy per unit area of vertical rotary plough 1298.71 MJ ha^{-1} was obtained when the machine is operated at 2 km h^{-1} forward speed, 12.5 ± 0.5 % soil moisture content with 550 rpm of rotor speed. The minimum operation cost per unit area of vertical rotary plough ₹ 1504.22 ha^{-1} was obtained when the soil moisture content 14.5 ± 0.5 % at 1.5 km h^{-1} forward speed and 350 rpm of rotor speed. The maximum weeding efficiency of vertical rotary weeder was 84.44 % with a rotor speed 550 rpm and 2 km h^{-1} forward speed.

Keywords

Rotary speed,
Forward speed,
Rotary plough,
Depth of operation

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Introduction

In Uttarakhand state, about 70 % population is living in rural areas and depends directly or indirectly on agriculture. Uttarakhand (28°43' to 31° 27' N and 77°34' to 81°02' E) is located in the North Western Himalayas and is blessed with the climate favourable for the good production of wide variety of agro-horticultural crops. However, the degree of farm mechanization, mainly in hills is very poor with respect to mechanical power, efficient tools and implements used by the farmers. The undulating and sloppy geography, small size fields with uneven topography, lack of skilled labour, poor repair and maintenance facilities, low purchasing capacity of farming community and unavailability of enhanced farm tools and machines are some of the main reasons for low level of mechanization in the hilly region of the state. There is a need to fulfil the 71 % marginal farmer's requirement by developing the required size of power tiller with matching implements.Agriculture is the mainstay of Indian economy as it provides uninterrupted employment to about 69 % of the working people in India (Mandal *et al*., 2016). Mechanization plays a vital role in agriculture and assures the timely completion of farm operations as well as less expenditure per unit area. About 78 % of the farmers possess an area less than 2 ha with poor resources at their command, especially in the dry-land regions. Tillage is the most significant operation for crop production. The purpose of tillage is to create favourable environment for seed placement and plant development (Jakasania *et al.,* 2017). It has always been one of the larger power consuming operations on a farm. This operation includes breaking the soil surface up to a certain depth and to loosen the soil mass using equipment's like mould board plough, disc plough, disc harrow, cultivators and it requires multiple operations. These multiple operations consist of primary and secondary tillage. Primary tillage results in preparing suitable seed bed and destroy weeds grown on the surface and improves the soil physical condition followed by secondary tillage, which improves soil pulverization, conserves the moisture, cuts the crop residue and mixes vegetative matter with top soil. In case of the sliding action tillage implements, frictional resistance is high, whereas, in rotary tillage implements it is low enough (Jakasania *et al.,* 2017). Vertical rotary plough gives a better quality of soil tilth than horizontal axis rotary plough. Soil resistance in vertical axis rotary plough is less than horizontal axis rotary plough and soil disturbed in vertical axis rotary plough is much more than horizontal. Rotary plough saves 30-35 % of time and 20-25 % operation cost as compared to tillage by cultivator. It gives a better quality of tilth by 25-30 % than the tillage by cultivator. The rotary plough is the most efficient means of transmitting engine power directly to the soil with minimum wheel slip and a major reduction in transmission power loss.

Power tiller termed as walking tractor, garden tractor, hand tractor, or a two-wheel tractor. There is a possibility for these power tillers to be used in hilly areas for seedbed preparation and inter-culture operation. At present-day, most of the power tillers mass-produced in the country are in the series of 6-7.46 kW (Kadu *et al.,* 2015). The power tiller is a versatile hand tractor designed mainly for rotary tilling, puddling and other operation on farms. Unavailability of corresponding equipment for different farm operations limits the versatility of the use of power tillers. Small tractors are the most suitable for small and marginal farmers for in most areas of the country, as the small tractors have the benefit in size, light-weight and good manoeuvrability. Small tractors are fit to the level of mechanical knowledge and management in rural areas. The construction of small tractors is simple and this makes the operation, maintenance and repair easy (Ademiluyi *et al.,* 2007).

Some pull type light weight power tillers are also existing in the country to pull plough, harrows and cultivators (Narang *et al.,* 2005). In Tarai, foot hills and valley region, some farmers have hand tractors/power tillers to field operation. There is a necessity to develop gender friendly small tools and implements for tillage, sowing, intercultural, harvesting and threshing operations, so that the requirement of about 71% marginal farmers could be met. Farmers can execute tillage operation in their personal fields as well as on custom hiring basis (Singh, 2014).

In case of terraces having high vertical interval, lightweight power tiller (80-100 kg) with appropriate corresponding equipment can be used widely for doing various agricultural operations and can be lifted with the assistance of 2-3 men from one terrace to another terrace (Mandal *et al*., 2016). So it is felt necessary to develop a lightweight power tiller fitted with 5-10 hp engine with a gearbox having a minimum two forward speeds.

Weed is any plant other than crop grown in the field. The existence of weeds in the field, consume the applied fertilizer and reduce the total yield and productivity. Therefore, the weeding is one of the utmost important operation in crop production to obtain maximum yield. Weeding operation consumes 25% of the whole labour requirement (900-1200 man-h ha^{-1}) in crop production (Yadav *et al*.,2007). Most of the time in India, the weeding operation is carried out by manually with the assistance of khurpi, but it consumes very high manpower, takes more time, increases the operative cost and also drudgery as compared to chemical and mechanical operation.

Materials and Methods

The development work was carried at dept. of FMPE workshop, College of Technology and the field trials were carried crop research field centre GBPUAT Pantnagar. The parts of developed rotary plough are described as below.

Design parameters

Design of power transmission

Selection of gears plays an important role in transmission of power from one shaft to additional shaft. The successfully transmit of motion from one shaft to additional shaft accomplished by successively engaging the teeth of gears. There is no middle link or connector between gears and the motion will be transmitted by direct contact. The gears having only two possible motion either rolling or sliding motion by tangentially contact from engine to PTO shaft, PTO shaft to Bevel gear, from bevel gear to another bevel gear which was mounted on vertical shaft

Design of rotor shaft

The extreme peripheral force plays a significant role for designing the rotor shaft. The extreme peripheral force takes place at the minimum of blades peripheral speed and it was determined by the subsequent formula (Bernaki *et al*., 1972).

$$K_S = \frac{C_S N_C \eta_C \eta_Z}{U}$$

Where,

K_s = Maximum tangential force (N)
C_s = Reliability factor (1.5 for non-rocky soils and 2 for rocky soils)
N_c = Power of engine (kW)
η_c = Traction efficiency as (0.9)
η_z = Coefficient of reservation of engine power (0.7-0.8)
U = Minimum tangential speed of blades (m s^{-1})

The maximum moment on the rotor shaft (M) is calculated through the following:

$$M = K_S \times R$$

Where,
R = Radius of rotor shaft (mm)

The yield stress of rotor shaft made from tempered steel was 520 MPa. The permissible stress on the rotor (τ_{all}) was deliberate by the following equation (Mott and Kaveh, 1985):

$$\tau_{all} = \frac{.577 \times K \times \sigma_Y}{FOS}$$

Where,
τ = Allowable stress on rotor shaft (M Pa)
k = Coefficient of stress concentration (0.75)
FoS = Factor of safety (1.5)
σ_y = Yield stress (520 M Pa**)**

Rotor shaft diameter was calculated as:

$$D = \sqrt[3]{\frac{16M}{\tau_{aLL}\pi}}$$

Design of mounting plate

The mounting plate which is used for the attaching the rotary blades on it. The total two number of mounting plates are used in this design, with diameter and thickness of 260 and 10 mm respectively. The two number of mounting plates gives 550 mm width of cut, which is sufficient width for the operation.

Design of soil cutting blade

Blades are the only part of the rotary plough which directly contact with the soil and have to face impact force during the ploughing operation. The high strength material is used for the manufacturing the blades. The life of blade depends on the kind of materials. The cutting blades was designed and developed by following the standard procedure. The finished geometry diminishes the power required as well as declines the cost of manufacturing.

The various parameters considered like cutting width, disc thickness, blade peripheral velocity on which blades are mounted and length of blade. The standard handbook of machine design (Shigley *et al.,* 1986) and agriculture machine (Bernaki *et al.,* 1972) were consulted to designing the safe strength and bending stresses. Assumptions were made as i) number of blades in one working set = 2 ii) length of blade = 200 mm iii) width of blade = 30 mm iv)thickness of blade = 5 mm v) revolution per minute of rotor shaft (N) = 400 rpm and vi)radius of rotor (R) = 130 mm were considered.

For a designing the blade, the cutting width and thickness are important parameters. The blades would be subject to shearing as well as bending stresses during operation. The total employed width of the plough was 550 mm. The total number of 4 blades was used in operation. The soil force acting on blade (K_e) was calculated by using the following equation (Bernaki *et al.,* 1972).

$$K_e = \frac{Ks \times Cp}{i \times Ze \times Ne}$$

Where,
K_s = Maximum tangential force (N)
C_p = Coefficient of tangential force (0.8)
i = No. of mounting plates.
Z_e = No. of blades on each side of the mounting plate.
N_e = No. of blades which act jointly on the soil by a total number of blades.

Construction details of vertical rotary plough

The frame was made of (50 × 50 × 5 mm) mild steel angle iron section of 600 mm length and 200 mm width to accommodate the gearbox and cutting unit and flats of mild steel was also used for the supporting the main frame. Plates of mild steel have dimensions of

500 × 190 mm were used for fitting the gearbox.In this experiment the straight knife blades were used for ploughing operation. The high carbon steel was used for making the blades. The blades are attached to the rotary shaft by means of nuts and bolts. The length, width and thickness of blade was 200 mm, 30 mm, and 5 mm respectively. The blade is having 10 mm diameter of holes for attachment to the rotor shaft with the nut, bolts and washer. In this experiment the single cylinder, four stroke diesel engine, recoil start of 325 cc (3.73 kW) with side valve and the air-cooled engine was used as a prime mover for the rotary plough. The hand operated throttle lever was provided for regulatory the speed of the machine during tillage operation and was attached to right-hand side of the handle. A gauge wheel which is connected to the back side of the frame for the adjustment of depth of operation which is having diameter of 152.4 mm was utilized for the ploughing operation. The gauge wheel was connected to the frame with the support of nuts and bolts. The depth of operation can be adjusted by raising and lowering gauge wheel on the frame. The gear-box connected horizontally to the engine through the help of flat frame. The power, which is produced in the engine, was transmitted to the rotor with the help of the bevel gear arrangement. The rotary wheels were rotated through the help of power transmission from the engine (Table 1 and 2).

Bulk density of soil

The bulk density of soil was determined by using core cutter method. For determining the bulk density of the soil, the soil samples were taken randomly from the experimental plot with the help of core sampler having 12.7 and 9.7 cm height and diameter respectively. The core sampler was inserted into the soil with the help of hammer and then dug out the core sampler along with soil and separate the soil sample from the core sampler and weight soil sample. The bulk density was determined previously and afterward operation of rotary plough according to procedure mentioned in IS: 2720 (P: 29): 1975.

$$\text{Bulk density} = \frac{\text{Dry weight of soil}}{\text{Volume of core sampler}}$$

$$\rho = \frac{M}{V}$$

Where,

ρ = Bulk density (g cm^{-3})

M = Dry weight of the soil (g)

V = Volume of core sampler (cm^3)

Moisture content of soil

The soil moisture content was determined by hot air oven method. For determining the moisture content of the soil, collected the soil sample randomly from experimental plot and the known weight of soil sample was kept in the hot air oven at a temperature of 105^0 C for 24 hours. The water content of soil sample was calculated according to procedure mention in IS: 2720 (P 2) 1973.

$$\text{Moisture content, } W = \frac{Ww - Wd}{Wd}$$

Where,

W = Moisture content (% db)

W_w = Wet mass of soil (g)

W_d = Dry mass of soil (g)

Cone index

Cone index is an indication of soil strength and is expressed as force per square centimetre required for penetrating into the soil. Cone index was measured with the assistance of cone penetrometer for a different depth of 3 to 10 cm range. The cone index was determined by following equation:

$$CI = 0.025Y + 0.099$$

Where,
CI = Cone index (kg cm^{-2})
Y = Gauge deflection (divisions)

Theoretical field capacity

It is the amount of field coverage that would be obtained if the machine were performing its function 100 % of the time at the rated forward speed and always covered 100 % of its rated width. The theoretical field capacity was determined by following equation (Bainer *et al*., 1956).

$$TFC = \frac{S \times W}{10}$$

Where,
TFC = Theoretical field capacity (ha h^{-1})
W = Width of cut (m)
S = Speed of operation (km h^{-1})

Actual field capacity

It is the actual average rate of covered by the machine, based upon the total field operation time. The actual field capacity is function of percentage rated width of machine, operational speed and field time lost while operation**.** Effective field capacity usually expressed as (ha h^{-1}) (Bainer *et al*., 1956).

$$AFC = \frac{A}{Tp + T_i}$$

Where,
AFC = Actual field capacity (ha h^{-1})
A = Actual area covered (ha)
T_p = Productive time (h)
T_i = Non-productive time (h)

Field efficiency

It is the ratio of actual field capacity to the theoretical field capacity, expressed as percentage.

$$\eta = \frac{AFC}{TFC} \times 100$$

Where,
η= Field efficiency (%)
AFC = Actual field capacity (ha h^{-1})
TFC = Theoretical field capacity (ha h^{-1})

Fuel consumption

The fuel consumption indicates the requirement of fuel per unit time of operation for the machine and it was measured by top fill method. The fuel tank was filled to full capacity before the testing at levelled surface. After completion of test operation, the actual fuel consumption was noted. The fuel consumption was expressed in (l h^{-1}).

Wheel slip

It is the relative movement of the wheel in the path of travel for a given distance under load and at no load condition. It can be deliberate by the formula (Sahay and Satapathy, 1999).

$$\text{Wheel slip (\%)} = \frac{N_1 - N_2}{N_1} \times 100$$

Where,
N_1= No. of revolution of wheel at load condition
N_2 = No. of revolution of wheel at no load condition

Weeding efficiency

Weeding efficiency is quantitatively expressed as the percentage of number or weight of weeds or stubbles of last crop left on soil surface after operation to that before it. A square frame having sides 100 cm is convenient for counting weed or the stubble. It was determined by using formula.

$$WE = \frac{Wp - We}{Wp} \times 100$$

Where,

WE = Weeding efficiency (%)

Wp = Wt. of weeds before operation for unit area.

We = Wt. of weeds exposed on the after the operation

Clod mean weight diameter

The clod mean weight diameter, the soil sample was allowed to permit through a set of sieves which is collected from the field. Clod mean weight diameters (CMWD) were determined by using formula.

$$\mathrm{CMWD} = \sum_{i=1}^{n} \frac{\mathrm{Xi} \times \mathrm{Wi}}{\mathrm{W}}$$

Where,

CMWD = Clod mean weight diameter (mm)

X_i = Mean diameter of each size class (mm)

W_i = Proportion of each size class to the total sample (g)

W = Total weight of sample (g)

Energy requirement

The energy essential per unit agriculture area was determined with help of fuel consumption of engine and actual field capacity**.** It was expressed in MJ ha^{-1}.The energy requirement for human considered as 1.96 MJ man-h^{-1} for male worker and 1.57 MJ man-h^{-1} for female worker. Only one person is required for this operation hence, hence total human energy consumed was 1.96 MJ man-h^{-1}.

The machine energy was calculated by using formula as given below:

$$M_e = \frac{\mathrm{Wmc} \times \mathrm{Tr} \times 60}{\mathrm{AWH} \times \mathrm{L}}$$

Where,

M_e = Machine energy (MJ ha^{-1})

W_{mc} = Weight of machine (kg)

T_r = Time required (h ha^{-1})

AWH = Annual working hours (h)

L = Life (years)

The fuel energy was calculated by using formula as given below

$$\text{Fuel Energy} = \text{Fuel consumption} \times \text{Energy equilent of fuel}$$

Measurement of noise level

The noise level was measured by using Gesa Electronic Enterprise make digital sound level meter having a range 30-130 dB and a least count of 0.1 dB. The noise level was measured at different rotor speed of 350, 450 and 550 rpm respectively.

Measurement of vibration

The vibration level was measured by using Monitran Electronic Enterprise make digital vibration meter having a range 2-200 m s^{-2}.The vibration level was measured at different rotor speed of 350, 450 and 550 rpm respectively.

Results and Discussion

Performance evaluation of vertical rotary plough was done at 2 moisture content *i.e* 12.5 ± 0.5 and 14.5 ± 0.5 %, 3 forward speed *i.e* 1.5, 1.75 and 2 km h^{-1} and 3 rotor speed *i.e* 350, 450 and 550 rpm. In these condition the following parameters were measured *i.e* bulk density, cone index, actual field capacity, field efficiency, fuel consumption, wheel slip, weeding efficiency, clod mean weight diameter and energy requirement (Fig. 1–14).

Bulk density

The average the bulk density of soil before operation was 1.38 g cc^{-1}. It was observed that, the bulk density of soil after the operation varied from 1.13 to 1.31 g $cc^{-1}$with different forward speed, rotor speed and moisture content. The maximum bulk density of soil after operation 1.31 g $cc^{-1}$was recorded at a forwarded speed 1.5 km $h^{-1}$with rotor speed

350 rpm at 12.5 ± 0.5 % moisture content while minimum bulk density of soil after operation 1.13 g cc^{-1} was recorded at a forward speed of 2 km h^{-1} with rotor speed 550 rpm and 14.5 ± 0.5 % moisture content respectively. The results indicates decreasing in value as compared to Chertkiattipol *et al.*, (2008) when conducted tests were in a dry-land field of clay loam soil with moisture content of 16.04 % (db) and dry bulk density of 1.51 g cc^{-1} at different rotational speeds of 300, 350, and 400 rpm at one and two tilling passes.

Cone index

The average cone index of soil before the operation was 1.53 kg cm^{-2}.It was observed that, the cone index of soil after operation varied from 1.22 to 1.42 kg cm^{-2} was recorded with different forward speed, rotor speed and moisture content. The maximum cone index of soil after operation was 1.42kg cm^{-2} was recorded at forward speed 1.5 km h^{-1} with rotor speed 350 rpm at 12.5 ± 0.5 % moisture content while minimum cone index of soil after operation 1.22 kg cm^{-2} was recorded at a forward speed 2 km h^{-1} with rotor speed 550 rpm and 14.5 ± 0.5 % moisture content respectively. The results shows slightly similar trend as compared to Bist (2017) measured the cone index value at 12.73 and 14.46 % moisture content was 1.38 and 1.23 kg cm^{-2} respectively.

Actual field capacity

The actual field capacity of the rotary plough was varied from 0.053 to 0.096 ha h^{-1} with different forward speeds, rotor speeds and moisture contents. The maximum actual field capacity 0.096 ha h^{-1} was recorded at a forward speed 2 km h^{-1} with rotor speed 350 rpm at 14.5 ± 0.5 % moisture content while minimum actual field capacity 0.053 ha h^{-1} was recorded at a forward speed 1.5 km h^{-1} with rotor speed 550 rpm and 12.5 ± 0.5 % moisture content respectively. It was observed that, the actual field capacity decreased from 0.096 to 0.053 ha h^{-1} as the rotor speed increases from 350 to 550 rpm for both 12.5 ± 0.5 and 14.5 ± 0.5 % of moisture content, from figure 4 and 5, due to increases in depth of operation as the rotor speed of operation increases, this is the main reasons for decreasing the actual field capacity. The above data relatively higher as compared to Pradhan *et al.*, (2000) when evaluated performance of light weight power tiller of diesel operated 3.6 kW power tiller were found as 70% respectively.

Field efficiency

The field efficiency of rotary plough was varied from 64.72 to 88.09 % with different forward speed, rotor speed and moisture content.

The maximum field efficiency of rotary plough 88.09 % was recorded at forward speed 2 km h^{-1} with 350 rpm of rotor speed and 14.5 ± 0.5 % moisture content while minimum field efficiency 64.72 % was recorded at forward speed 1.5 km h^{-1} with 550 rpm of rotor speed and 12.5 ± 0.5 % of moisture content respectively.

It was observed that, the actual field capacity decreased from 88.09 to 64.72 % as the rotor speed increases from 350 to 550 rpm due to increases in depth of operation from 5.1 to 9.5 cm with 12.5 ± 0.5 % and 14.5 ± 0.5 % respectively. Even though, slightly higher field efficiencies were recorded in case of 14.5 ± 0.5 % of moisture content when compared with 12.5 ± 0.5 % of moisture content. The field efficiency of rotary plough shows increasing trend as compared to Pradhan *et al.*, (2000) when evaluated performance of light weight power tiller of diesel operated 3.6 kW power tiller were found as 70 % respectively.

Fuel consumption

The average fuel consumption of rotary plough varied from 0.84 to 1.4 l h^{-1} with different forward speed, rotor speed and moisture content. The maximum fuel consumption of rotary plough 1.4 l h^{-1} was observed at 2 km h^{-1} forward speed with 550 rpm of rotor speed and 12.5 ± 0.5 % of moisture content while minimum fuel consumption of rotary plough 0.84 l h^{-1} was recorded at 1.5 km h^{-1} forward speed with 350 rpm of rotor speed and 14.5 ± 0.5 % of moisture content respectively. The results of fuel consumption for rotary plough shows decreasing trend when compared to Mandal and Maity (2011) when developed a lightweight power tiller was powered with 2.25 kW engine and working width of the power tiller was 450 mm and fuel consumption was 1 l h^{-1}.

Wheel slip

The average wheel slip of rotary plough was varied from 7.25 to 11.50 % with different forward speed, rotor speed and moisture content. The maximum wheel slip of rotary plough 11.50 % was recorded at a forward speed 2 km h^{-1} with rotor speed 550 rpm at 14.5 ± 0.5 % moisture content while minimum wheel slip of rotary plough 7.25 % was recorded at a forward speed 1.5 km h^{-1} with rotor speed 350 rpm at 12.5 ± 0.5 % moisture content respectively. The results indicates that the slightly increasing trend when compared to Kumar *et al.*, (2014) when the wheel slip of power tiller at forward speed of 1.67 km h^{-1} in the field having 18 % soil moisture content was 8 %.

Weeding efficiency

The average weeding efficiency of the weeder was varied from 51.07 % to 84.44 % with different rotor speeds and at different forward speeds. A maximum weeding efficiency of 84.44 % was recorded at a forward speed of 2 km h^{-1} with rotary speed of 550 rpm while was minimum 51.07% at forward speed of 1.5 km h^{-1} with rotary speed of 350 rpm.

Clod mean weight diameter

The clod mean weight diameter of soil was varied from 4.1 to 5.6 mm with different forward speed, rotor speed and moisture content. The maximum clod mean weight diameter of soil 5.6 mm was recorded at a forward speed 1.5 km h^{-1} with rotor speed 350 rpm at 12.5 ± 0.5 % moisture content while minimum clod mean weight diameter of soil 4.1 mm was recorded at a forward speed 2 km h^{-1} with rotor speed 550 rpm at 14.5 ± 0.5 % moisture respectively. The above data was relatively high when compare to Makange (2015)when evaluated the vertical and horizontal axis rotavators with clod mean diameter of 4.00 and 4.72 mm respectively.

Energy requirement

The total energy requirement of rotary plough was varied from 612.5 to 1298.71 MJ ha^{-1} at different forward speed, rotor speed and moisture content. A maximum energy requirement of rotary plough 1298.71 MJ ha^{-1} was observed at 2 km h^{-1} forward speed with 550 rpm of rotor speed and 12.5 ± 0.5 % of moisture content while minimum energy requirement of rotary plough 612.5 MJ ha^{-1} was observed at 1.5 km h^{-1} forward speed with 350 rpm of rotor speed and 14.5 ± 0.5 % of moisture content respectively.

The results shows increasing trend as compared to Bist (2017) when evaluate the energy requirement for 3.6 kW diesel engine power tiller operated at 3600 rated rpm was 348.62 and 181.47 MJ ha^{-1} at 12.73 and 14.46 % moisture content with forward speed of 2 and 1.5 km h^{-1} respectively.

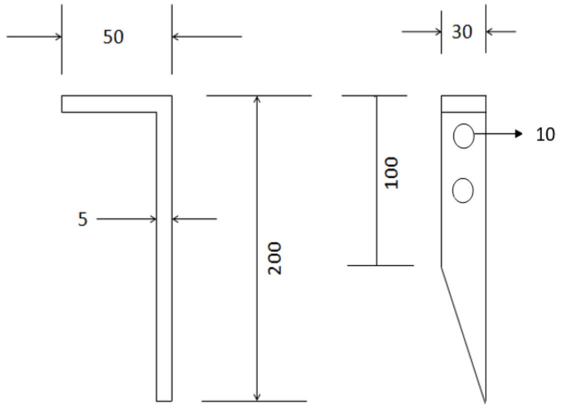
Table.1 Specification of engine

Sl. No.	*Particular*	*Specification*
1	Make	Greaves
2	Model	1520
3	Type	4-Stroke, single cylinder.
4	Serial number	ALS0952697
5	Country of origin	Indian
6	Specification	365 × 427 × 476
7	Rated speed	3600 rpm
8	Displacement	325 cc
9	Rated power	3.73 kW(5 hp)
10	Max net torque	14.51 N-m
11	Engine oil capacity	1 litre
12	Cooling system	Natural air cooling system
13	Ignition system	Transistorized magneto
14	PTO shaft rotation	Clockwise
15	Fuel	Diesel
16	Fuel tank capacity	4.5 l

Table.2 Specification of vertical rotary plough

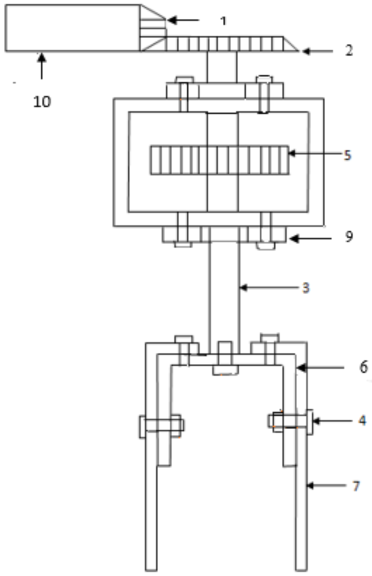
S. No	Specification	Value
1	Working width	550 mm
2	No. of blades	2 per rotor
3	Depth of ploughing	9 cm
4	Rotor speed	300-900 rpm
5	Power transmission	Sliding mesh gearbox
6	Material of blade	High carbon steel
7	Total weight	120 kg
8	No. of rotor	2

Fig.1 Specification of blade



All dimensions are in mm

Fig.2 Side view of transmission system of rotary plough



Description		
S. N0	Parts Name	Specification
1	Bevel pinion	Teeth = 10
2	Bevel crown	Teeth = 40
3	Shaft	Dia = 25 mm
4	Bolt	Dia = 10 mm
5	Spur gear	Teeth = 39
6	Flange	Dia = 260mm
7	Blade	200*30*5mm
8	Gearbox	180*100 mm
9	Bearing block	10 mm
10	Main shaft	Dia = 40

Fig.3.Isometric view of vertical rotary plough

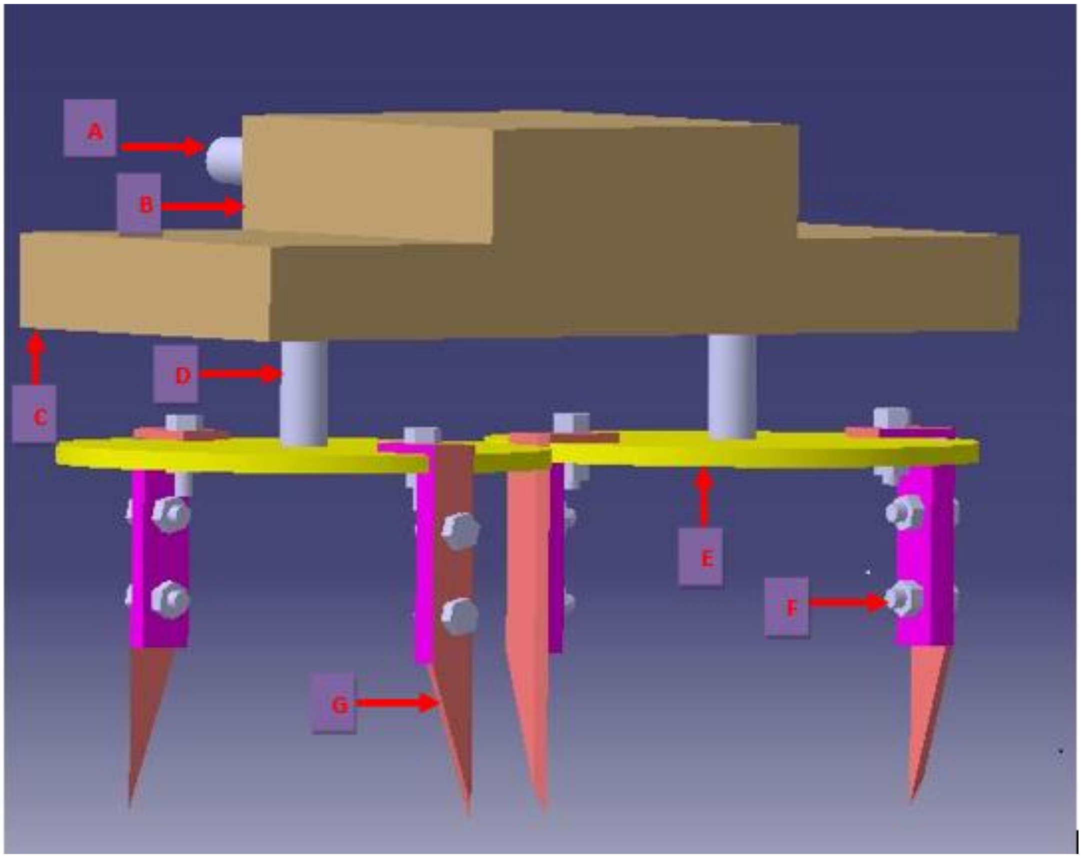


Fig.4 Side view of developed rotary plough

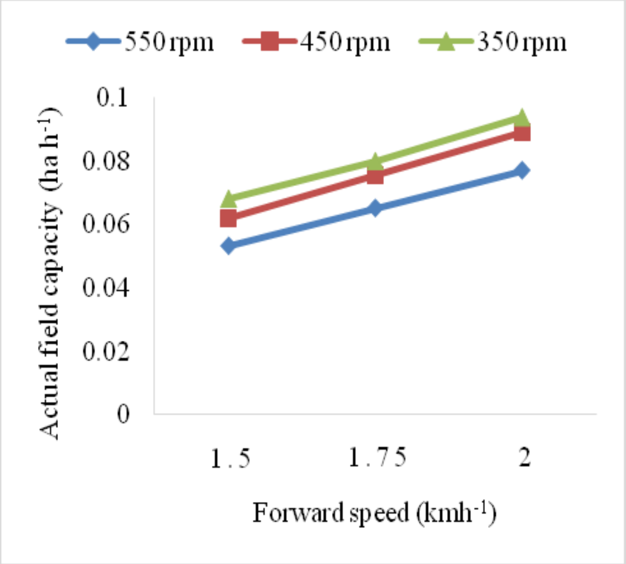


Fig.5 Effect of forward and rotor speed on actual field capacity at 12.5 ± 0.5%moisture content

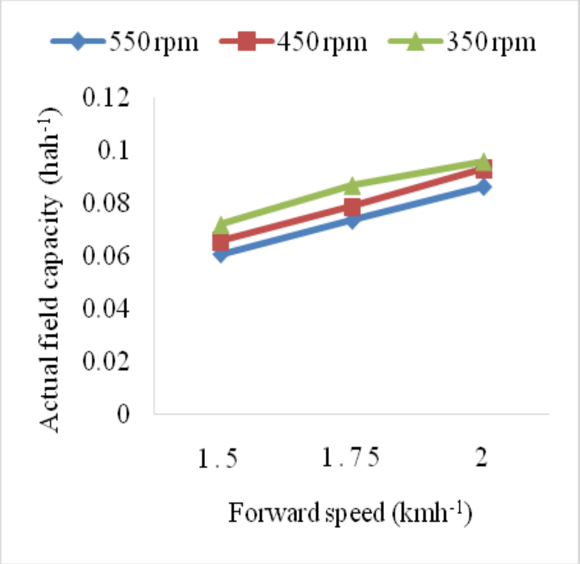
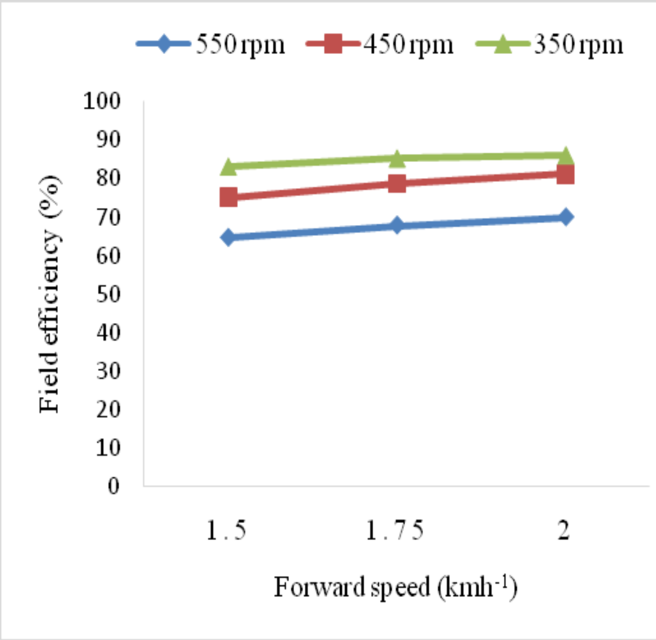


Fig.6 Effect of forward and rotor speed on actual field capacity at 14.5 ± 0.5% moisture content



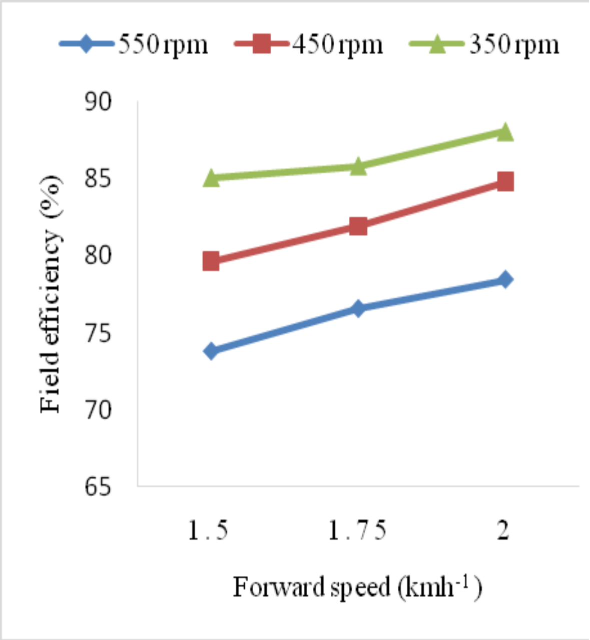
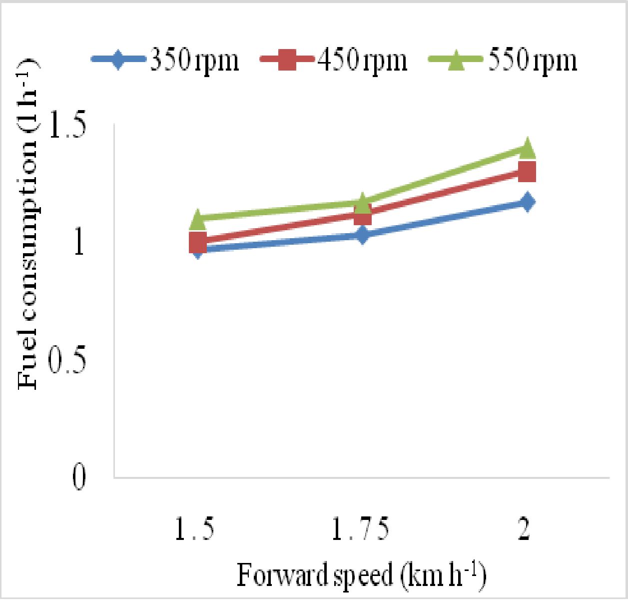


Fig.7 Effect of forward and rotor speed on field efficiency at 12.5 ± 0.5% of moisture content

Fig.8 Effect of forward speed and rotor speed on field efficiency at 14.5 ± 0.5% of moisture content



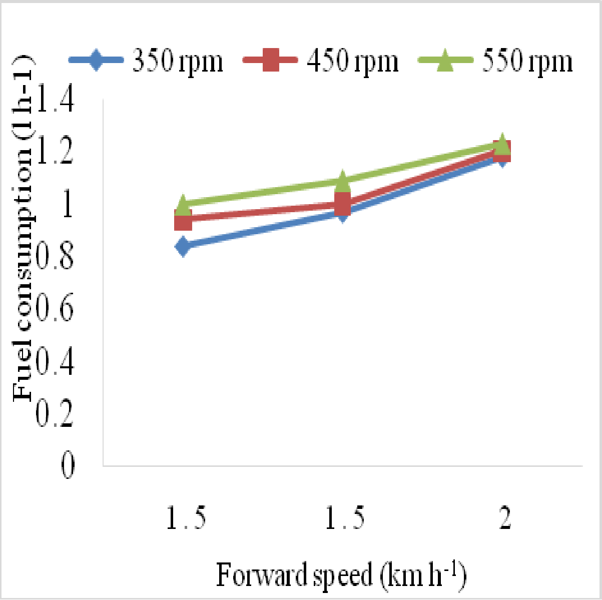


Fig.9 Effect of forward and rotor speed on fuel consumption at 12.5 ± 0.5% of moisture content

Fig.10 Effect of forward and rotor speed on fuel consumption at 14.5 ± 0.5% of moisture content

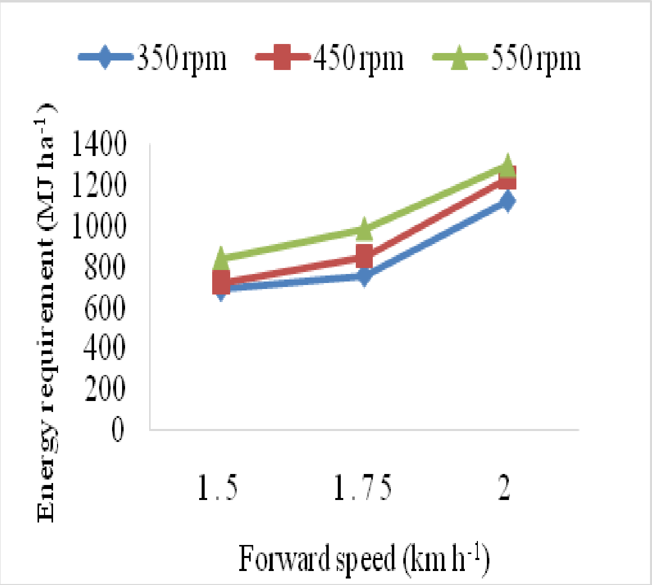


Fig.11 Effect of forward and rotor speed on energy requirement of operation at 12.5 ± 0.5% moisture content

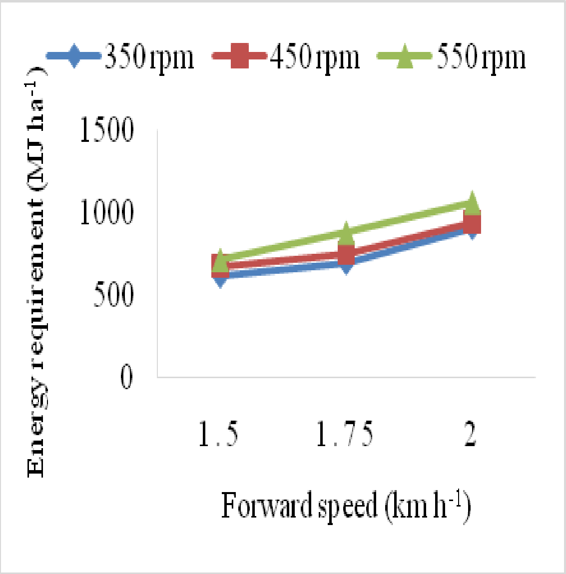


Fig.12 Effect of forward and rotor speed on energy requirement of operation at 14.5 ± 0.5% moisture content

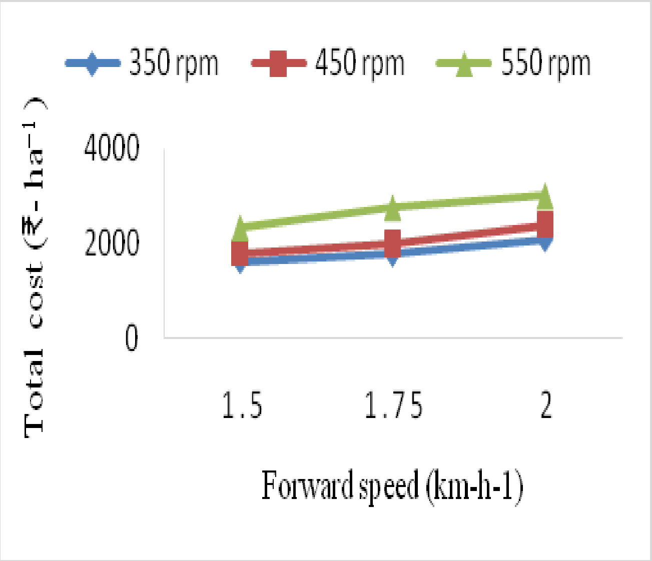


Fig.13 Effect of forward and rotor speed on total cost of operation at 12.5 ± 0.5% moisture content

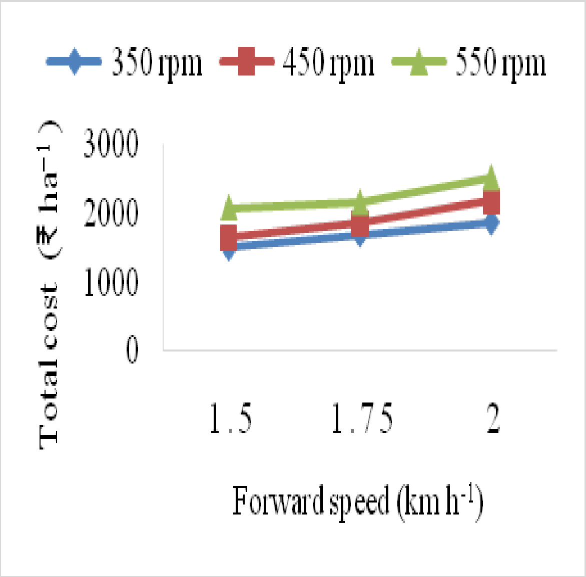


Fig.14 Effect of forward and rotor speed on total cost of operation at 14.5 ± 0.5 % moisture content

Total cost

The total cost of operation of the rotary plough was varied from ₹ 1505.20 ha^{-1} to ₹ 3012.40 ha^{-1} with different rotor speeds and at different forward speeds. A maximum total cost of operation ₹ 3012.40 ha^{-1} was recorded at a forward speed of 2 km h^{-1} with rotor speed of 550 rpm at 12.5 ± 0.5 % of moisture content while minimum ₹ 1505.20 ha^{-1} at forward speed of 1.5 km h^{-1} with rotary speed of 350 rpm at 14.5 ± 0.5 % of moisture content. The results shows deceasing trend as compared to Bist (2017) when evaluate the cost of operation for 3.6 kW diesel engine power tiller operated at 3600 rated rpm was ₹ 5263.00 and 2857.00 per hector at 12.73 and 14.46 % moisture content with forward speed of 2 and 1.5 km h^{-1} respectively.

Noise measurement of vertical rotary plough

The average minimum sound level was 94.1 dB at operator ear level with 350 rpm of rotary speed and the average maximum sound level was 116.25 dB at gear box with 550 rpm of rotary speed. The sound level of the rotary plough was more than the permissible limit of noise level for 8 hour duration per day as recommended by IS: 12239: [P: 3]-1988 and hence require suitable measures to reduce the noise level.

Vibration measurement of vertical rotary plough

The average minimum vibration of rotary plough both horizontal and vertical direction was 0.35 and 0.38 m s^{-2}at gear shift lever with 350 rpm of rotor speed and the average maximum vibration of rotary plough for both horizontal and vertical direction was 2.56 and 2.86 m s^{-2}at top of the fuel tank with the 550 rpm of rotor speed. The vibration of the rotary plough was more than the permissible limit of vibration as recommended by IS: 12239: [P: 3]-1988 and hence require suitable measures to reduce the vibration.

In conclusion, the results shows that, in all field trials as the moisture content increases, the bulk density, cone index, clod mean weight diameter, fuel consumption, energy requirement per unit area and total cost of operation reduces and the actual field capacity, field efficiency, wheel slip, increases with respect to moisture content. It was detected that the mean decreasing the bulk density 7 %, with the moisture content 12.5 ± 0.5 %, after the ploughing operation when compare to density of soil before operation. And it decreases 9 % when soil moisture content was 14.5 ± 0.5 %. The clod mean weight diameter of soil was varied from 4.1 to 5.6 mm with different forward speed, rotor speed and moisture content. The maximum actual field capacity of vertical rotary plough 0.097 ha h^{-1} was obtained when the rotor speed was 550 rpm, with the forward speed 2 km h^{-1} and the soil moisture content of at 14.5 ± 0.5 %. The highest field efficiency of vertical rotary plough was 88.09 % when the soil moisture content was 14.5 ± 0.5 % with a rotor speed 550 rpm and 2 km h^{-1} forward speed. The minimum fuel consumption of vertical rotary plough was 0.84 l h^{-1} when the rotary plough operated at 350 rpm of rotor speed with 1.5 km h^{-1} forward speed of operation and soil moisture content was 14.5 ± 0.5 %. The maximum energy per unit area of vertical rotary plough 1298.71 MJ ha^{-1} was obtained when the machine is operated at 2 km h^{-1} forward speed, 12.5 ± 0.5 % soil moisture content with 550 rpm of rotor speed. The maximum operation cost per unit area of vertical rotary plough ₹ 3012.42 ha^{-1} was obtained when the soil moisture content was 12.5 ± 0.5 % at 2 km h^{-1} forward speed and 550 rpm of rotor speed. The maximum weeding efficiency of vertical rotary weeder was 84.44 % with a rotor speed 550 rpm and 2 km h^{-1} forward speed. The average minimum sound level was 94.1 dB at operator ear level with 350 rpm of rotary speed and the average maximum sound level was 116.25 dB at gear box with 550 rpm of rotary speed in field condition. The average minimum average vibration of rotary plough both horizontal and vertical direction at field was 0.35 and 0.38 m s^{-2}at gear shift lever with 350 rpm of rotor speed and the average maximum vibration of rotary plough for both horizontal and vertical direction was 2.56 and 2.86 m s^{-2} at top of the fuel tank with the 550 rpm of rotor speed.

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