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# Design, Development and Evaluation of Subsoiler-Cum-Organic Manure and Soil Amendments Applicator

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**Abstract** A tractor drawn 'subsoiler-cum-vermicompost and soil amendments applicator' was designed and developed for application of organic manures either alone or in combination with inorganic fertilizers and other soil amendments at desired depth. The developed machine consisted of two main units, i.e., first subsoiling unit and second fertilizer metering and placement unit. These unit which were mounted on a rectangular frame with depth control wheels and category-II hitch system. The subsoiling unit consisted of single vertical leg and food with chisel share and wings for placement of materials in band underneath the wings. The fertilizer application unit consisted of a gear reduction unit (10:1). The metering device was a screw conveyor of 50 mm (pitch), 62.5 mm (diameter) and 610 mm (length) mounted along central vertical axis of a 200 kg capacity fertilizer box through 72.5 mm circular casing behind the leg of subsoiling unit. This machine could wark upto a depth of 0.5 m. The developed machine was tested in the field to observe its performance on mustard crop. The results showed an increase in yield of 22.56% due to higher plant height, plant girth number of siliquae/plant, root length and volume by 13.58%, 37.41%, 115.50%, 200% and 104.97% respectively as compared to conventional method 100% (inorganic) + Mixing in 100 mm depth (Control).

**Keywords** Subsoil health management, Subsoiling, Vermicompost placement, Fertilizer placement in subsoil, Mustard crop response.

## Introduction

The soils generally found in subsoil are inherently poor in nutrient status. These soils are low in organic matter content and in water holding capacity, and are relatively deficient in available phosphorus and potassium contents due to hard impermeable layer. Subsoil compaction restricts the movement of nutrients as at high level of compaction as almost all of the non-capillary pores are destroyed. The subsoiling in situation where it was needed had increased the fertilizer use efficiency and yields of crops [1, 2].

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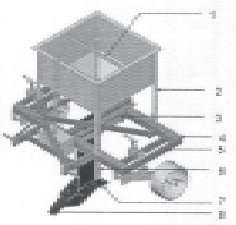
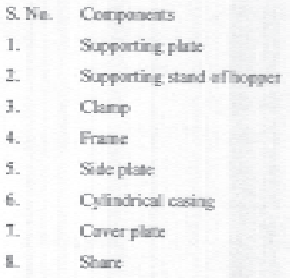




| S. No. | Components |
|---|---|
| 1. | Supporting plate |
| 2. | Supporting stand of hopper |
| 3. | Clamp |
| 4. | Frame |
| 5. | Side plate |
| 6. | Cylindrical casing |
| 7. | Cover plate |
| 8. | Share |

**Fig. 1.** Isometric view of designed. **Fig. 2.** Developed machine machine in Auto CAD.

Subsoiling has given yield increase of over 26% in wheat, 16% in maize and 35% in sugarcane in comparison to conventional method of soil cultivation [3, 4]. In broadcasting of fertilizers, only 40 to 50% of N fertilizers and 20 to 30% of P and K fertilizers are effectively used by the crops, while the remaining get lost. The incorporation of P and K in subsoils has positive results as reported by many researchers.

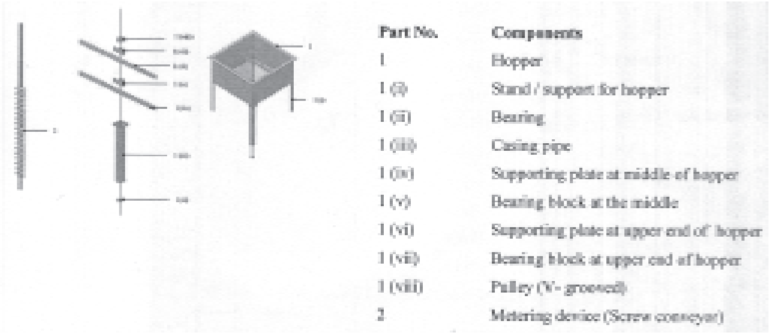
Organic manures such as vermicompost, FYM, pressmud are good sources of different macro and micro-nutrients, and have a significant role to play in nutrient supply. Vermicompost, which is an important and valuable source of plant nutrients, increases the root nodulation, microbial activity in the rhizosphere, soil organic carbon, crop growth and yield attributes, available NPKS and micronutrients, and decreases the bulk density of soil when used either alone or in combination with inorganic fertilizers [5—8]. Soil amendments such as gypsum, pyrites, lime, flyash, coconut pith, rice husk and cement, and organics such as vermicompost, FYM and pressmud either alone or in combination with NPK reduce deleterious effect of acidity and alkalinity of the soil, and improve the uptake of nutrients, water-holding capacity and soil productivity. Presently no suitable technology is available in the context of placement of organic manures in solid states into the subsoil zone except spreading it on the soil surface and then mixing with suitable equipment. Therefore, there is a need to develop equipment for placement of organic manures and inorganic fertilizers as well as soil amendments at required depth upto 500 mm while subsoiling for obtaining their maximum utilization. Thus, keeping the above points in view, present investigation was carried out.

## Materials and Methods

Subsoiler-cum-vermicompost and soil amendments applicator as shown in Figures 1 and 2 was designed and developed by using Auto-CAD software for ease

**Table 1.** Yield attributes of mustard crop in field experiment.

| | Yield attributes | | | | |
|---|---|---|---|---|---|
| Treatments | Seed yield (t/ha) | Stover yield (t/ha) | Harvest index (%) | Oil content (%) | Oil yield (t/ha) |
| $T_1$ | 1.720 | 5.638 | 23.494 | 40.12 | 0.690 |
| $T_2$ | 1.751 | 6.105 | 22.402 | 40.35 | 0.707 |
| $T_3$ | 1.738 | 6.346 | 21.630 | 40.23 | 0.699 |
| $T_4$ | 1.783 | 6.598 | 21.297 | 39.75 | 0.709 |
| $T_5$ | 1.911 | 6.780 | 22.002 | 39.64 | 0.758 |
| $T_6$ | 1.936 | 6.923 | 21.850 | 39.59 | 0.766 |
| $T_7$ | 1.108 | 7.693 | 21.498 | 39.75 | 0.838 |
| SEm± | 0.06 | 0.32 | 0.77 | 0.22 | 0.26 |
| CD at 5% | 0.10 | 0.99 | NS | NS | 0.078 |



| Part No. | Components |
|---|---|
| 1 | Hopper |
| 1 (i) | Stand / support for hopper |
| 1 (ii) | Bearing |
| 1 (iii) | Casing pipe |
| 1 (iv) | Supporting plate at middle of hopper |
| 1 (v) | Bearing block at the middle |
| 1 (vi) | Supporting plate at upper end of hopper |
| 1 (vii) | Bearing block at upper end of hopper |
| 1 (viii) | Pulley (V- grooved) |
| 2 | Metering device (Screw conveyor) |

**Fig. 2.** SE-Isometric view of different components of hopper and metering.

of understanding and fabrication. Developed machine consisted of two main units: (i) a subsoiling unit and (ii) a fertilizer metering and placement unit which were mounted on a rectangular frame with depth control wheels and category-II hitch system. The subsoiling unit consisted of single vertical leg foot with share and wings for placement of material in band underneath the wings. The fertilizer application unit consisted of a gear reduction unit with one end mounted with tractor PTO shaft and the other end transmits power vertically to a belt and pulley arrangement for obtaining desired speed of the metering device, a ground drive wheel for power transmission and its accessories.

### Soil cutting mechanisms

There are two types of soil failure mechanism, first is an upper failure zone, where the soil is displaced forward, sideways and upward, is known as 'crescent failure' and second is a lower zone, where the soil is displaced forward and sidewise, and is known as 'lateral failure'. This type of failure occurs when the tool is operating below its critical depth. The soil above the critical depth fails in brittle manner during crescent failure. The models suggested for crescent soil failure make three assumptions such as: yielding of soil in shear obeys the Mohr-Coulombs failure criterion and a distinct rupture surface is formed in front of the tine, bounding a volume of soil in a state of plastic equilibrium and rate effects on the relevant soil parameters are negligible. The magnitude of the resultant passive force (P) acting at an angle, $\delta$ with the normal to interface can be calculated from the equation as follows:

$$P = [\gamma z^2 N\gamma + c\ z\ N_c + c_a\ z\ N_a + q\ z\ Nq\ ]\ w \qquad ...\ (1)$$

$$H_1 = P \sin(\alpha + \delta) \qquad ...\ (2)$$

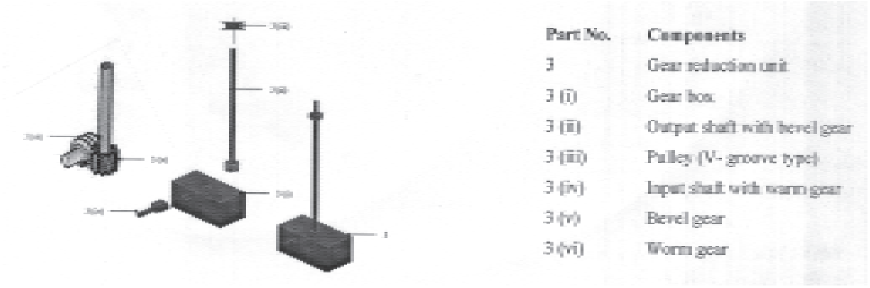
Where,

$\gamma$ = Bulk density of soil, kN/m$^3$
z = Depth of operation, m
c = Soil cohesion, kN/m$^2$
$c_a$ = Soil adhesion, kN/m$^2$
q = Surcharge load, kN/m$^2$
w = Width of tool, m
$H_1$ = Horizontal component of passive force i.e. draft
$\alpha$ = Rake angle of tine, degree
$\delta$ = Angle of soil-metal friction, degree and
$\varphi$ = Angle of internal friction of soil, degree

The N-factors are dimensionless numbers and depend upon the magnitudes of $\alpha$, $\delta$ and $\varphi$.

### Lateral soil failure

The soil below the critical depth fails in two-dimensional manner in a horizontal plane regardless of the rake angle of tines. The resultant stress on the tine



| Part No. | Components |
|---|---|
| 3 | Gear reduction unit |
| 3 (i) | Gear box |
| 3 (ii) | Output shaft with bevel gear |
| 3 (iii) | Pulley (V- groove type) |
| 3 (iv) | Input shaft with worm gear |
| 3 (v) | Bevel gear |
| 3 (vi) | Worm gear |

**Fig. 3.** SE-Isometric view of different components of power transmission system.

can be obtained by solution as:

$$q' = c\ N_c' + P_0\ N_q' \text{ and} \qquad ...(3)$$

$$P_0 = \gamma\ z\ K_0 = \gamma\ z\ [1 - \sin\ \varphi] \qquad ...(40$$

Where,

$K_0$ = Ratio of horizontal to vertical stress on the soil at rest

$= [1 - \sin\ \varphi]$

Therefore, the total force, Q, on the tine face width of 'w' below critical depth, is given by integrating Equation 3 between limits of critical depth ($z_c$) and total working depth (z) by neglecting tine roughness and multiplying by 'w' as:

$$Q = [c\ N_c'\ (x - z_c) + \gamma/2\ K_0\ N_q'\ (z^2 - z_c^2)]\ w \qquad ...(5)$$

Where,

$z_c$ = Critical depth of operation, m

The $N_c'$ and $N_q'$ can be determined from expressions given below:

$$N_c' = \cot\varphi \left[ \left[ \frac{1 + \sin\varphi}{1 - \sin\varphi} \right] e^{2\left(\frac{\pi}{2} + \varphi\ \tan\varphi\right)} - 1 \right] \qquad ...(6)$$

$$N_q' = \left[ \frac{1 + \sin\varphi}{1 - \sin\varphi} \right] e^{2\left(\frac{\pi}{2} + \varphi\right) \tan\varphi} \qquad ...(7)$$

The total horizontal force component ($H_1$) of P in the direction of travel including interface adhesion above the critical depth is given below:

$$H_1 = P \sin\ (\alpha + \delta) + c_a\ z_c\ w \cot\ \alpha \qquad ...(8)$$

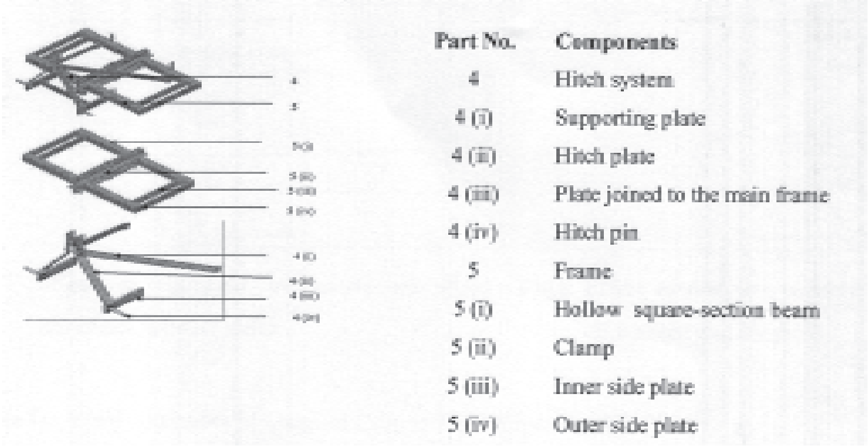
Thus, the total horizontal component i.e. draft force, D in the direction of travel is the sum of Q below critical depth and $H_1$ above it, as given below:

$$D = H_1 + Q$$

$$D = [\gamma z^2\ N\gamma + c\ z\ N_c + c_a\ z\ N_a + q\ z\ N_q]\ w \sin\ (\alpha + \delta) + [c\ N_c'\ (z - z_c) + \gamma/2\ K_0\ N_q'\ (z^2 - z_c^2)]\ w \qquad ...(9)$$

Draft of winged time

When a tool moving passively is less than 10 times as wide as it is deep i.e. z/w >0.1, the accuracy of two-dimensional soil failure approach becomes poor. Hence, for a conventional straight leg subsoiler working at 475 mm depth and having 75 mm share width (aspect ratio, z/w = 6.3), the three-dimensional soil failure approach was adopted. Cohesion and angle of internal friction of soil layer having the maximum density of 17 kN/m$^3$ was taken as 17 kPa and 25$^o$ respectively as determined. The various tool and soil pa-



| Part No. | Components |
|---|---|
| 4 | Hitch system |
| 4 (i) | Supporting plate |
| 4 (ii) | Hitch plate |
| 4 (iii) | Plate joined to the main frame |
| 4 (iv) | Hitch pin |
| 5 | Frame |
| 5 (i) | Hollow square-section beam |
| 5 (ii) | Clamp |
| 5 (iii) | Inner side plate |
| 5 (iv) | Outer side plate |

Fig. 4. Isometric view of frame with hitching system.

rameters adopted to calculate draft in crescent failure zone are given below:

Tool parameters :

| | |
|---|---|
| i. Width of share (w) | = 75 mm |
| ii. Rake angle of share ($\alpha$) | = $22^o$ |
| iii. Depth of operation (z) | = 475 mm |

Soil parameters :

| | |
|---|---|
| i. Cohesion (c) | = 17 kPa |
| ii. Angle of internal friction ($\phi$) | = $25^o$ |
| iii. Soil to metal friction ($\delta$) | = $2/3^{rd}\ \phi = 16.66^o \approx 17^o$ |
| iv. Bulk density of soil ($\gamma$) | = 17 kN/m$^3$ |
| v. Soil adhesion (Ca) | = 0 (Assumed) |

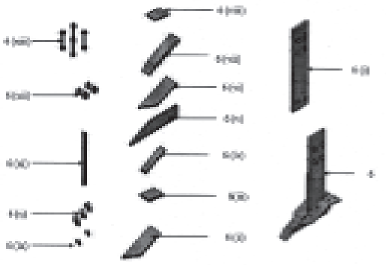
The critical depth ($z_c$) of conventional straight leg subsoiler ranged between aspect ratios of 5 to 7. So, taking $z_c/w = 5$, the critical depth was obtained at 375 mm. For $\alpha = 22^o$, $z_c/w = 5$, $\delta = 17^o$, $\phi = 25^o$, $z = 475$ mm, the values of $N_\gamma$ and $N_c$ were found as 10 and 9 and $N_c' = 40$ and $N_q' = 20$ were found from graphical relation of $\phi$ and N factors. The total draft force (D) was determined as 10.97 kN. However, the draft of winged tine has been reported to be up to 30% higher than conventional straight tine [8]. Therefore, adding 30% additional draft with the calculated draft of conventional tine, the draft of winged subsoiler tine was calculated as 14.26 kN or equal to about 15 kN.

## Development of different component of machine

The developed machine consisted of two main units i.e. subsoiling unit, and a fertilizers and soil amendments metering unit. The main components of subsoiling unit are: the frame, hitching system, winged straight leg leg/tine with its various components and depth control device. The fertilizers and soil amendments metering unit consisted of a fertilizer hopper with supportive frame, materials metering device in form of a vertical screw conveyor, gear reduction unit and power transmission system from tractor P.T.O. to the metering device. The various components of the developed machine are described below:

### Fertilizer hopper

The hopper was designed for a capacity of 200 kg vermicompost and illustrated in Figure 2. The hopper box was divided into two sections as top and bottom. The hopper was fabricated from 3.8 mm galvanized iron sheet in two sections i.e. upper square section with cross-section of 750 × 750 mm and the lower trapezoidal section with an inclination angle of $45^o$ from all sides from the vertical. The depth of the hopper was 750 mm with 375 mm in each section. The



| Part No. | Components |
|---|---|
| 6 | Winged tine |
| 6 (i) | Leg |
| 6 (ii) | Gusset plate |
| 6 (iii) | Cover plate |
| 6 (iv) | Base plate |
| 6 (v) | Side plate |
| 6 (vi) | Wing |
| 6 (vii) | Share |
| 6 (viii) | Cover plate |
| 6 (ix) | Counter shank bolts for wings |
| 6 (x) | Counter shank bolts for share |
| 6 (xi) | Shin |
| 6 (xii) | Horizontal clamping bolts |
| 6 (xiii) | Clamping bolts |

**Fig. 5. SE**-Isometric view of different components of winged tine.

bottom of hopper was provided with a circular hole of 72.5 mm diameter for discharging materials in sufficient quantity to the metering device mounted below it. The hopper was welded with four angle iron arms of 50 × 50 × 5 mm size and 750 mm length at its each corner. All the lower ends of arms were bolted with main frame and upper ends were welded with each other by angle irons of 50 × 50 × 5 mm size. The hopper has a capacity of 200 kg of vermicompost in order to have minimum number of refilling during field operation.

### Fertilizers metering device

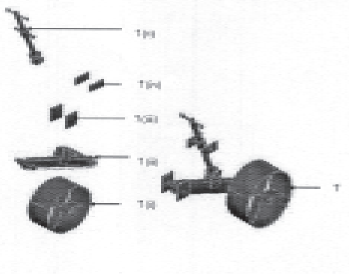
An appropriate size of open casing screw conveyor as shown in Figure 2 was designed and fabricated. The screw conveyor was mounted inside the cylindrical casing of 600 mm (length) × 72.5 mm (diameter) × 14 gauge thickness bolted with the bottom of hopper, and was operated by the belt and pulley power transmission system. The screw conveyor was supported with 750 × 50 × 10 mm size flat welded at the upper and middle sections of hopper with the help of bearing blocks. The lower end was supported on a bearing mounted at the rear of tine. Different fertilizer application rates can be obtained by changing the peripheral speed of the screw conveyor and keeping the forward speed of tractor as constant (2.0 or 2.5 km/h) which is recommended for effective subsoiling.

### Power transmission system

A screw conveyor system as shown in Figure 3 was designed for metering of organic materials such as vermicompost. The power to the screw conveyor was supplied with the help of universal joints from the power take-off shaft (PTO) of the tractor through a gear reduction unit. The power from the gear reduction unit is transmitted upward at 90$^o$ to a V-belt and pulley arrangement between the vertical shaft of 30 mm diameter mounted on the gear reduction unit and screw conveyor. The main driven shaft receives the drive from the PTO at 10:1 ratio and provides drive at 1:1 ratio to the shafts mounted on the fertilizer metering system.

### Frame and hitch system

The designed frame with different components is shown in Figure 4. The frame was fabricated from two angle irons of 85 × 85 × 10 mm size having 1400 mm length and welded together to form a square hollow beam of 85 × 85 mm cross-section. Similar angle iron beam was positioned parallel to the first beam at a distance of 600 mm and welded together by MS flats of 750 × 100 × 10 mm size to form a rectangular frame with overall dimensions of 1400 mm (length) × 750 mm (width). A winged tine was mounted on the frame with clamps and had provision for adjustment in both hori-



| Part No. | Components |
|---|---|
| 7 | Depth control device |
| 7 (i) | Wheel |
| 7 (ii) | Wheel arm |
| 7 (iii) | Rear attachment |
| 7 (iv) | Front attachment |
| 7 (v) | Depth control screw |

**Fig. 6.** SE-Isometric view of different components of depth control device.

zontal and vertical planes. The hitch system was made of heavy material to withstand high stresses. The hitch points were fabricated by welding two plates with the frame. These plates connected the upper hitch plates and hitch pins together. The lower hitch point was selected for Category-II implements. The mast made from MS flat was attached vertically with the hitching plates with the help of nuts and bolts. In order to distribute load for better balancing of the machine, the top link point was mounted to the rear beam with the help of mild steel flats.

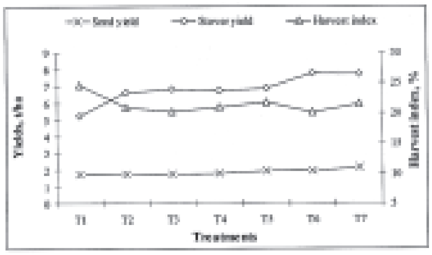
### Winged tine with different component

The different components of winged tine of the machine as shown in Figure 5 are leg and foot, shin, share, wings, gusset plates, side plates and covering plate. The wing lift height of 78.5 mm was selected in order to provide space for mounting wings at rake angle of 22°. The subsoiler leg was fabricated from MS flat of 900 mm (length) × 200 mm (width) × 25 mm (thickness). The lower end of the leg was sandwiched between two side plates of 100 × 15 mm size called ‘foot’ and tapered at 22° for mounting the share. A replaceable shin of high carbon steel of 500 × 25 × 25 mm size and tapered in the front at 90° cone angle was positioned at the front side of the leg. It is the main component of subsoiler which accounts for major portion of draft of the machine. It has highest wear rate and so was made of high carbon steel (EN 31) of 350 × 80 × 30 mm size. The share was hard sirfaced by depositing wear resistant material in the form of a grid to enhance its wear-out life. For easy penetration and minimum draft, the tip of the share was provided with a rake angle of 22°. The share was mounted on the base plate with the help of countersunk bolts. Wings were fabricated from high carbon steel of 600 × 100 × 6 mm size, as these also wear out fast due to cutting action of the soil. The edges of wings were tapered at 40° from the front side for easy penetration and minimum draft while cutting the soil. The wings were mounted on the gusset plates with countersunk nuts and bolts, and are replaceable after wear.

Gusset plates were fabricated from MS flat of 330 × 100 × 10 mm size and tapered on both sides at an angle of 45 degree. The gusset plates had 22° lift angle from the front side in horizontal plane and 12° in vertical plane for proper upheaval of soil. The side plates were fabricated from MS flat of 500 × 100 × 15 mm size and tapered at an angle 25° from the top onto which a base plate made from MS flat of 200 × 55 × 10 mm size was welded to provide a space for mounting of share. The side plates also provide space for attachment of gusset plates onto which the wings are mounted. The covering plate was fabricated from MS flat of 150 × 100 × 6 mm size. It was positioned separately along the side plates for easy movement of soil towards the rear of tine. The covering plate is replaceable after wear.

### Depth control device

Depth control wheels as shown in Figure 6 was made of 326 mm (diameter) × 110 mm (width) × 6 mm (thick-



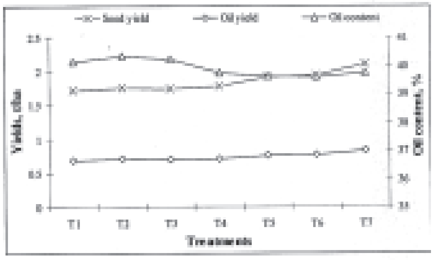


**Fig. 7.** Effect of different treatments on yield attributes, harvest index. **Fig. 8.** Effect of different treatments on seed yield, oil content and oil yield.

ness) MS sheet to support the machine in operation and to provide a uniform depth of operation. It is attached with an arm mounted to the wheel shaft and a bush on the main frame. Depth of the wheel could be varied by rotating the screw and bolt system provided with square threads in either direction. The range of the depth that could be adjusted by this device varies from 150 to 475 mm.

An experiment was laid out in Randomized Block Design with following seven treatments such as: $T_1$ = 100% (inorganic) + Mixing in 100 mm depth (Control), $T_2$ = 50% (inorganic) + 50% (organic) + Mixing (100 mm), $T_3$ = Subsoiling (400 mm) + 100% Iinorganic) + Mixing (100 mm), $T_4$ = Subsoiling (400 mm) + 50% (inorganic) + 50% (organic) + Mixing (100 mm), $T_5$ = 80% (inorganic) placed at 200 mm and 20% (inorganic) placed at 400 mm, $T_6$ = 50% N (inorganic) + 50% N (organic) placed at 200 mm and $T_7$ = 50% N (inorganic) placed at 200 mm + 50% N (organic) placed at 400 mm.

The experimental area was divided into three blocks of seven plots each. The known quantity of fertilizers and vermicompost as per treatment were broadcast manually and mixed in 100 mm depth with two passes of rotavator in treatments $T_1$ (Control) and $T_2$. In treatments $T_3$ and $T_4$, subsoiling operation was performed at a depth of 400 mm by the developed machine i.e. 'Subsoiler-cum-vermicompost and soil amendments applicator' without filling the hopper with vermicompost and a known quantity of fertilizers was broadcast manually and mixed in 100 mm depth with one operation of rotavator. The vermicompost/inorganic fertilizers were applied in all the treatments before seedbed preparation as per treatment.

## Results and Discussion

### Seed and oil yield

The data pertaining to seed yield of mustard in different treatments at harvest during experiment is illustrated in Figures. 7 and 8 and presented in Table 1. The analyzed data revealed that the significantly maximum seed yield (2.108 t/ha) was obtained in treatment ($T_7$) which is at par with $T_6$ (1.936 t/ha) followed by ($T_5$) with the seed yield of 1.911 t/ha. Significantly lowest seed yield of 1.720 t/ha was obtained in $T_1$ (Control). The observations pertaining to stover yield in different treatments at harvest was also revealed that significantly maximum stover yield (7.693 t/ha) was obtained in treatment $T_7$ which was at par with $T_6$ and $T_5$ with the yield of 6.923 and 6.780 t/ha, and followed by $T_4$ (6.598 t/ha) $T_3$ (6.598 t/ha) and $T_2$ (6.105 t/ha). The lowest stover yield of 5.638 t/ha was obtained in $T_1$ (Control). However, the highest harvest index (23.49%) was obtained in treatment ($T_1$).

The observations pertaining to oil content of mustard seeds in different treatments is presented in Table 1 and illustrated in Figure 8. It was found that the maximum oil content (40.35%) was obtained in treatment $T_2$ followed by $T_3$ and $T_1$ with oil content of

40.23% and 40.12%, respectively. The lowest oil content (39.59%) was found in $T_6$. However, the applications of organic and inorganic fertilizers at different depth significantly increased the oil yield. The treatment ($T_7$) recorded significantly the maximum oil yield (0.838 t/ha) which was at par with $T_6$ (0.766 t/ha). Significantly lowest oil yield was recorded in control $T_1$ (0.690 t/ha).

The yield of crop is the final result of combined effect of growth parameters and yield attributes. The seed yield of mustard crop is the function of condition of plants during the growth period, plant height, plant girth, total number of branches and number of siliquae per plant, test weight and oil content. The differences in growth parameters were found significant in different treatments and the parameters were maximum in the treatment in which vermicompost and NPK were placed while subsoiling with the developed machine in comparison to the conventional method of mixing fertilizers in top 100 mm soil. In general, the plant height, plant girth, number of branches and number of siliquae per plant are the main contributing parameters which affect the crop yield. Significant increase in seed yield in treatments with subsoiling and deep fertilizers placement ($T_7$, $T_6$ and $T_5$) is due to higher plant height (13.58, 8.86 and 14.32%), plant girth (37.41, 17.69 and 8.16%), number of siliquae/plant (115.50, 79.10 and 52.61%), root length (200, 135.76 and 137.09%) and root volume (104.97, 55.78 and 52.48%), respectively as compared to Control ($T_1$).

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