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Laboratory and field evaluation of subsoiler- cum -vermicompost and soil amendments applicator

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■ **ABSTRACT :** A tractor drawn 'subsoiler cum vermicompost and soil amendments applicator' was design and developed to examine the basic concept for placement of organic manures and inorganic fertilizers in subsoil at different depth upto 400mm. The developed machine was evaluated in laboratory for discharge rate and distribution pattern of different organic manures *viz.*, vermicompost, pressmud and FYM at three moisture states and soil amendments *i.e.* gypsum, lime, cement and rice husk. Prior to laboratory testing of the machine, the physical properties of materials were studied. The machine was also tested under field condition on the basis of changes in dry bulk density, specific draft and wheel slippage at 250, 300, 350 and 400 mm depths of operation. The results revealed that the bulk density was uniform throughout the soil profile after operating at 400 mm depth. The bulk density reduced to a maximum of 13.88 per cent. The specific draft for 400 mm depth of operation was found lower by 33.26 per cent than that at 250 mm depth. Whereas, the wheel slippage was found to a maximum of 21.07 per cent at the draft of 12.20 kN for 400 mm depth of operation. The results obtained during performance evaluation of developed machine on response of mustard crop have clearly revealed the advantage of subsoiling and deep placement of organic and inorganic fertilizers in terms of substantial increase in yield parameters.

■ **KEY WORDS :** Field evaluation, Subsoiler- cum -vermicompost, Soil amendments applicator

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The fertilizer application is generally accomplished by manual spreading, broadcasting, placement or mixing in upper soil layer of 20-50 mm only (Chauhan and Kumar, 1972 and Chichester *et al*., 1985). Broadcasting of fertilizers, especially phosphorus (P) and potassium (K), produces fixation problems due to more soil contact, whereas volatilization of nitrogen (N) results in reduction of applied nitrogen content to the soil. Only 40 to 50 per cent of N fertilizers and 20 to 30 per cent of P and K fertilizers are effectively used by the crops, and the remaining get evaporated, volatilized, leached to groundwater or get fixed with soil as per the properties of their contents (Olsen *et al*., 1971 and Rowse and Stone, 1980). The incorporation of P and K in subsoils has positive results as reported by many researchers (Rowse and Stone, 1980; Godwin and Spoor, 1981 and Mandal, 2007). Organic manures such as vermicompost, FYM, pressmud etc. are good sources of different macro and micro-nutrients and have a significant role to play in nutrient supply. In addition to improving soil physico-chemical properties, the supplementary and complementary use of organic manures also improve the efficiency of mineral fertilizers. Many field studies have demonstrated a decrease in soil bulk density and increase in porosity resulting from compost application (Bulluck and Ristaino,2002). 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 (Sharma and Agrawal, 2003; Manjunatha *et al.*, 2006 and Pawar and Patil, 2007).

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 (McKenzie and So, 1989; Gupta *et al.*, 1989 and Chukwu, 2001). The aim of incorporating organic manures and soil amendments in the subsoil is to reduce losses of nutrients and improve soil physical properties and nutrient availability by enhancing aggregate stability which results in improved water holding capacity, aeration and increase in microbial activities besides reducing the application rate of inorganic fertilizers by increasing the fertilizer use efficiency. In most of the cases, fertilizers both inorganic and organic manures and soil amendments are applied at the surface and mixed with the soil which result in poor utilization efficiency. But the placement of fertilizers into the subsoil under Indian condition as well as abroad has revealed very positive response. Packing of FYM in furrows has been found to increase the productivity of rainfed wheat in hill eco-system (Annual Report, 2007-08 of VPKAS, Almora).

Soil microbes play an important role in the breakdown of organic matter and fertilizers into useable plant nutrients. Organic matter has a strong positive effect on the infiltration rate of water into the soils. This effect is mainly due to decrease in bulk density and improvement in aggregation and structure of soil (MacRae and Mehuys, 1985). Incorporation of organic matter in a compacted soil lowers the bulk density and increases the electric charge, thus, increasing repulsive forces between soil particles which improve soil aggregate strength and enhanced the population and growth of earthworms, which ultimately improved soil physical conditions (Soane, 1990 and Jordan *et al.*, 2000). Limited information is available on deep/subsoil placement of organic and inorganic fertilizers and soil amendments, but the reported literature on these aspects has clearly shown very positive results in terms of deeper root growth, higher root biomass, increased nutrients availability and uptake, higher crop growth parameters and yield. Loss of nutrients along with fertile surface soil due to erosion and volatization have been found to be enormous which could be curtailed significantly by placement into the soil including subsoil. No suitable equipment is presently available in the country for subsoil placement of organic manures and soil amendments suggesting, thereby, the development of suitable technology for subsoil manipulation and its fortification with nutrients for improving crop productivity. 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 0.5 m while subsoiling for obtaining their maximum utilization. Thus, keeping the above points in view, a 'Subsoiler-cum-Vermicompost and Soil Amendments Applicator' was developed, and evaluate its performance under laboratory and field conditions.

■ METHODOLOGY

A 'subsoiler-cum-vermicompost and soil amendments applicator' was designed and developed as shown in Fig. A and B for placement of different materials at varying depths upto 475 mm while performing subsoiling operation. 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/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.

Laboratory evaluation of machine:

The developed machine was evaluated /calibrated in the laboratory with different materials such as vermicompost, FYM, pressmud, rice husk, agricultural lime, gypsum and cement, procured and collected from the market. All the physical properties *i.e.* moisture content, bulk density, angle of repose etc. and chemical properties of different materials were characterized. The application rates of different organic manures at three

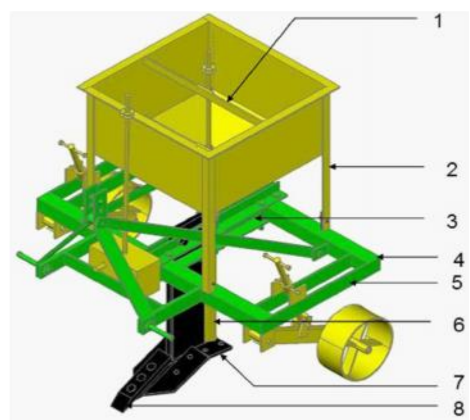

Fig. A : **Isometric view of designed machine in auto CAD**

Fig. B: **Developed subsoiler-cum-vermicompost and soil amendments applicator**

Sr. 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

moisture states and soil amendments were determined at three peripheral speeds *i.e.* 120 (0.63 m/s), 180 (0.94 m/s) and 240 (1.26 m/s) rpm of metering device. The machine was operated with a 40 kW tractor in stationary condition for 5 minutes with each material and the delivered material was collected and weighed. The experiment was repeated three times at each speed setting and the average delivered amount was calculated. The machine was also operated on concrete floor at a speed setting of 2.0 km/h for observing the distribution pattern of materials.

Field evaluation of machine:

The field capacity of developed machine varies between 0.16 and 0.30 ha/h at two operating speeds (2.0 and 2.5 km/h) and spacing intervals of subsoiling (1.0 and 1.5 m). This machine was also evaluated in the field by operating it with a 40 kW tractor at a constant forward speed of 2.0 km/h and four depths of 250, 300, 350 and 400 mm. Various soil parameters *i.e*. bulk density and moisture content, and machine parameters such as draft, soil disturbance, specific draft and wheel slip were measured for each operating depth. The evaluation of developed machine in the laboratory with different organic manures and soil amendments such as vermicompost, FYM, press mud, gypsum, lime, cement and rice husk and in the field in respect of machine parameters was carried out with the help of following parameters.

Moisture content :

Oven dry method was used to determine the moisture content of organic manures and soil amendments as well as experimental field soil. The samples were kept in the hot air oven for 24 h at 105^{0}C and the weight was taken before and after drying to calculate the moisture content using eq. 1 given below:

$$M.C. = \frac{W_1 - W_2}{W_2} x\ 100 \quad ....(1)$$

where,

M.C. = Moisture content, % (d.b.);

W_1= Weight of sample box with sample before drying, g and

W_2= Weight of sample box with sample after drying, g.

Bulk density:

The bulk density was determined using a standard volume container filled with known weight of samples. A measuring cylinder of known volume was taken and filled with organic materials and soil amendments. The volume for that sample was noted and the bulk density was calculated using the following eq.

$$\rho_m = \frac{W_m}{V_m} \quad ...(2)$$

where,

ρ_m = Bulk density of material, Mg/m^3;

w_m= Weight of the material, Mg and

V_m = Volume of the material, m^3.

Angle of repose:

The angle of repose is the angle with the horizontal at which the material rests when piled-up. Various parameters such as size, shape, moisture content and orientation of particles influence the angle of repose. The angle of repose of materials under study was measured by 'Pouring Method'. The apparatus consisted of a conical hopper mounted on a circular base plate of 300 mm diameter. A scale was attached to the set-up for measuring the height of heap above the base plate. The pointer attached to the scale was moved down to the base plate and reading on the scale was noted. It was then moved upward. A sample of material was poured inside the hopper through the funnel which formed a conical heap on the base plate. It was continued until the base of the plate was completely filled and particles had just started to slide down. The pointer was then moved upto the top of the heap and reading on the scale was noted. The difference in these two readings on the scale gave the height of heap, which was used to determine the angle of repose by using eq. 3 given below:

$$\varphi_x = \tan^{-1}\frac{2h}{D} \qquad \text{...(3)}$$

where,

φ_x = Angle of repose, degree;

h = Height of heap, mm and

D = Diameter of the base plate, mm.

Draft of machine:

The draft of developed machine at different depths of 200, 300 and 400 mm was measured by mounting a direct reading S- type digital strain gauge dynamometer of 2500 kgf capacity in-between the two tractors as shown in Fig.C. The first tractor pulled the second tractor with machine in raised position and the dial reading was noted. Then, a depth of operation was set by adjusting the depth control wheels and the front tractor pulled the second tractor while in neutral position. The reading for that run was noted from dynamometer. The tractor for the test run was operated at the speed of 2 km/h. The draft of the machine was calculated by subtracting no-load readings from with-load readings. The experiment was then repeated for different depths of operation with three replications.

Area of soil disturbed:

A soil profilometer developed by Kumar (2003) was used to determine the area of soil disturbed by the subsoiler. The profilometer was placed on the ground horizontally at the site after removing the loose soil disturbed by subsoiler. A chart/graph paper was fitted on the profilometer board and aluminum rods were allowed to fall down freely to represent the shape of depression made (Fig. D). The upper points of the rods were marked and joined freely to obtain the shape of profile and the squares bound by the curve below the reference line were counted and added to know the area disturbed by the machine.

Fig. C : **Attachment of S-type digital strain gauge dynamometer for measurement of draft**

Fig. D : **Profilometer for the measurement of soil disturbance by the developed machine**

Specific draft :

Specific draft is the draft per unit cross-sectional of disturbed soil. The specific draft for a particular depth was obtained by using the formula given below**:**

$$\text{Specific draft (kgf/m}^2) = \frac{\text{Draft (kgf)}}{\text{Area disturbed (m}^2)} \qquad \text{... (4)}$$

Wheel slippage:

For computing the wheel slippage of tractor, a mark was made on the rear wheel of the tractor and distance covered in 10 revolutions of rear wheel was measured with and without load with the help of a measuring tape. The time taken to travel this distance during each test run was also noted to calculate the forward speed of tractor. The experiment was replicated thrice and repeated for different depths of operation. The wheel slippage was calculated by the following formula:

$$\text{Slip},\% = \frac{\text{Distance travelled without load} - \text{Distance travelled with load}}{\text{Distance travelled without load}} \times 100 \qquad ....(5)$$

■ Results and Discussion

The data obtained on physical properties of different organic manures and soil amendments are presented in Table 1 and the chemical properties of materials are presented in Table 2. The physical properties of organic manures such as vermicompost, FYM and pressmud, and soil amendments *i.e.* gypsum, lime, cement and rice husk govern their delivery which in turn affect the rate of application. The physical properties such as moisture content, bulk density and angle of repose were determined.

Moisture content and bulk density of different materials:

The moisture content of a material is most important parameter that affects its delivery. The data on moisture content of organic manures in its original state presented in Table 1 showed that the moisture content of materials varied as 42.50, 31.42 and 44.68 per cent for vermicompost, pressmud and FYM, and 8.55, 6.00, 7.76 and 6.52 per cent for gypsum, lime, cement and rice husk, respectively.

The bulk density of organic manures and soil amendments were determined by volumetric method and it was found as 0.605, 0.407 and 0.603 Mg/m^3 for vermicompost, pressmud and FYM, and 1.184, 0.616, 1.324 and 0.109 Mg/m^3 for gypsum, lime, cement and rice husk, respectively. In case of organic manures, the highest bulk density was found with FYM followed by vermicompost and the lowest was with pressmud. Similarly, for soil amendments, the highest bulk density was found with cement followed by gypsum and the lowest was for lime in its original state.

Angle of repose:

The angle of repose for vermicompost, pressmud and FYM was 43.31^0, 49.63^0 and 48.51^0, respectively.

Table 1: Physical properties of different organic manures and soil amendments

Materials	Moisture content (d. b.), %				Bulk density, Mg/m^3				Angle of repose, degree			
	R_1	R_2	R_3	Av.	R_1	R_2	R_3	Av.	R_1	R_2	R_3	Av.
Vermi-compost	43.6	42.0	41.9	42.5	605.2	605.4	604.4	605.0	40.9	44.0	45.0	43.3
Pressmud	32.4	31.8	30.0	31.4	405.5	405.5	406.0	406.7	50.1	49.4	49.4	49.6
FYM	45.0	45.1	43.9	44.7	602.1	603.0	602.7	602.6	49.2	48.6	47.7	48.5
Gypsum	7.9	8.8	8.8	8.6	1184.3	1184.8	1183.2	1184.1	43.0	44.0	43.0	43.4
Lime	6.1	6.0	5.9	6.0	617.0	616.5	615.1	616.2	45.9	44.0	43.0	44.3
Cement	7.6	7.8	7.8	7.8	1323.8	1324.9	1323.6	1324.1	45.9	45.9	43.0	44.9
Rice husk	6.4	6.7	6.5	6.5	107.5	109.8	110.3	109.2	55.7	56.9	56.3	56.3

Fig. 1 : Different views while measuring the angle of repose of different organic manures and soil amendments

Table 2: Chemical composition of different organic manures and soil amendments

Sr. No.	Materials	Constituents	Composition (% by weight)	Constituents	Composition (% by weight)
1.	Vermicompost	Nitrogen, %	1.75 -2.40	Total carbon, %	27.20
		Phosphorus, %	1.30-2.20	Mineral, %	52.50
		Potassium, %	0.60-1.8	Soluble carbon,%	0.88
		Organic carbon, %	10-20	C:N ratio	13.60 – 14.30
		Na (%)	0.20	Manganese, ppm	500.00
		Mg (%)	0.60	Copper, ppm	48.00
		pH	7.20	Zink, ppm	100.00
		B (ppm)	22.00		
2.	Pressmud	Nitrogen, %	1.09	Iron, ppm	2570.00
		Phosphorus, %	2.78	Manganese, ppm	1600.00
		Potassium, %	1.86	Copper, ppm	120.00
		Organic carbon, %	32.45	Zink, ppm	265.00
		pH	6.80	Sulphur, %	8.05
		EC at 25 ^{0}C	3.13	CaCO3 equivalent, %	0.18
3.	FYM	Nitrogen, %	0.50-1.40	Soluble carbon,%	1.60
		Phosphorus, %	0.20 -1.80	C:N ratio	20.60
		Potassium, %	0.50 - 0.70	Manganese, ppm	260.00
		Total carbon, %	28.00	Copper, ppm	40.00
		Mineral, %	49.00	Zink, ppm	80.00
4.	Gypsum	Calcium	16.00-19.00	Sulphur	13.00-15.00
5.	Lime	Nitrogen, %	0.01	Iron, %	0.29
		Phosphorus, %	0.06	Manganese, %	0.05
		Potassium, %	0.13	Copper, mg/kg	10.00
		Calcium, %	31.00	Zink, mg/kg	113.00
		Aluminum, %	0.25	Cadmium, mg/kg	0.70
		Magnesium, %	5.10	Chromium , mg/kg	6.00
		Sodium, %	0.07	Lead, mg/kg	55.00
		pH	9.90	Nickel, mg/kg	20.00
6.	Portland cement	Lime (CaO) %	60.00-66.00	Sodium oxide (Na_2O)	0.54
		Silica (SiO_2), %	19.00-25.00	Potassium oxide (K_2O), %	0.64
		Alumina (Al_2O_3), %	3.00-8.00	Dicalcium silicate (2CaO SiO_2),%	32.00
		Ferric oxide (Fe_2O_3),%	1.00-5.00	Tricalcium silicate (3CaO SiO_2),%	50.00
		Magnesia (MgO),%	0-5.00	Tricalcium aluminate	9.00
		Rutile (TiO_2),%	0.24	Tetracalcium aluminofereite	9.00
7.	Rice husk	Cellulose	40.06	Oxygen	40.05
		Lignin	17.02	Nitrogen	0.30
		Pentosan	21.85	Silica	15.70
		Benzene- Alcohol	3.40	Volatile matter	68.50
		Carbon	38.05	Fixed carbon	15.00
		Hydrogen	5.00	Ash	16.50

(Source: Kumar, 1991 and Jain *et al.*, 1997)

The maximum value of angle of repose was for pressmud followed by FYM and vermicompost. Similarly, in case of soil amendments, the angle of repose was 43.36^0, 44.33^0, 44.97^0 and 56.30^0 for gypsum, lime, cement and rice husk, respectively and its maximum value was found for rice husk with minimum value for gypsum. The visuals of measuring the angle of repose of different materials are shown in Fig. 1.

Laboratory performance of developed machine:

The Laboratory performance test of developed machine on application rates of organic manures and soil amendments was observed. The average values observations on application rates of different organic manures and soil amendments at different peripheral speeds of metering device (screw conveyor) and forward speeds of tractor are illustrated in Fig. 2 and 3, respectively and the visuals of distribution pattern of materials during the laboratory test are shown in Fig. 4. The average values observations are also presented in Table 3. The discharge rates of vermicompost at different states *viz.*, original, adding water (moist) and air dried at different speed of screw conveyor *i.e.* 120 (0.63 m/s), 180 (0.94 m/s) and 240 (1.26 m/s) rpm was found to be 246.48, 369.78, 494.82 kg/h, and 273.90, 422.52, 561.60 kg/h and 261.00, 399.12, 523.20 kg/h, respectively. Similarly, for pressmud, it was found to be 207.42, 307.98, 419.52 kg/h, and 258.78, 387.54, 518.40 kg/h and 165.18, 250.02 and 333.60 kg/h, respectively. For FYM, the discharge rates were 255.60, 378.78, 501.00 kg/h and 254.40, 376.20, 501.60 kg/h and 242.58, 344.40 and 456.00 kg/h, respectively. However, the discharge rates of soil amendments at different speeds *i.e*. 120 (0.63 m/s), 180 (0.94 m/s) and 240 (1.26 m/s) rpm of screw conveyor was found as 492.00, 742.80, 990.60 kg/h and 311.28, 462.90, 610.32 kg/h and 522.00, 763.80, 1010.76 kg/h and 83.70, 121.98 and 161.22 kg/h for gypsum, lime, cement and rice husk, respectively. It is clear from Table 3 as well as Fig. 4 and 5 that the application rate of different organic manures and soil amendments increased linearly with the increase in speed of screw conveyor and reduced with increase in forward speed of tractor at a constant speed of screw conveyor.

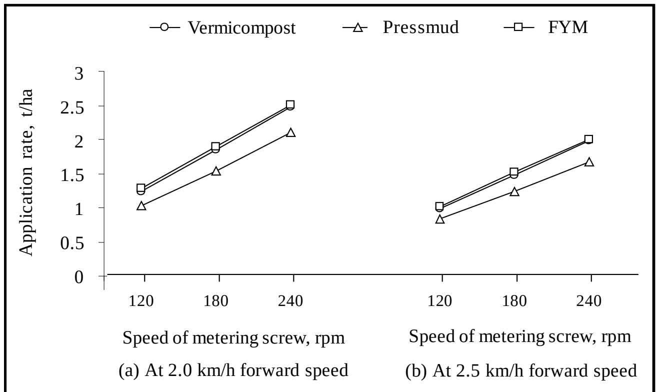

Fig. 2 : Effect of forward speed on application rate of organic manures (original state)

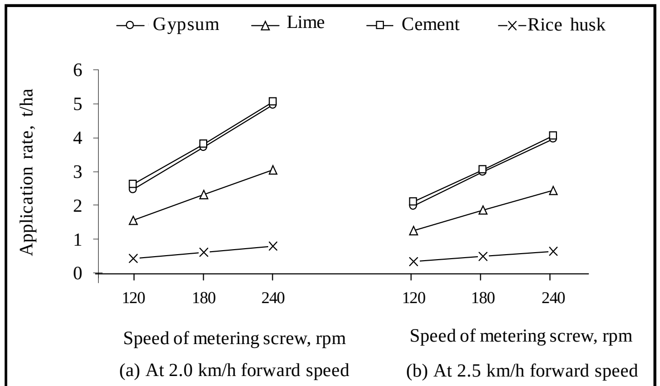

Fig. 3 : Effect of forward speed on application rate of soil amendments

Fig. 4 : Distribution pattern of different materials during laboratory test

Table 3 : Amount of organic manures delivered by metering mechanism at different speed settings and moisture contents

Type of materials	States of materials	Moisture content (w.b.), %	Speed of screw conveyor, rpm (m/s)	Discharge rate, kg/h	Application rate, t/ha	
					At 2.0 km/h	At 2.5 km/h
Vermi-	Original	42.50	120 (0.63)	246.48	1.233	0.986
compost			180 (0.94)	369.78	1.849	1.479
			240 (1.26)	494.82	2.474	1.979
	Adding water	51.10	120 (0.63)	273.90	1.370	1.095
	(Moist)		180 (0.94)	422.52	2.113	1.690
			240 (1.26)	561.60	2.808	2.246
	Air dried	27.50	120 (0.63)	261.00	1.305	1.044
			180 (0.94)	399.12	1.996	1.596
			240 (1.26)	523.20	2.616	2.093
	Original	31.42	120 (0.63)	207.42	1.037	0.830
Pressmud			180 (0.94)	307.98	1.540	1.232
			240 (1.26)	419.52	2.098	1.678
	Adding water	47.50	120 (0.63)	258.78	1.294	1.035
	(Moist)		180 (0.94)	387.54	1.938	1.550
			240 (1.26)	518.40	2.592	2.073
	Air dried	25.80	120 (0.63)	165.18	0.826	0.661
			180 (0.94)	250.02	1.250	1.000
			240 (1.26)	333.60	1.668	1.334
	Original	44.68	120 (0.63)	255.60	1.278	1.022
FYM			180 (0.94)	378.78	1.894	1.515
			240 (1.26)	501.00	2.505	2.004
	Adding water	47.50	120 (0.63)	254.40	1.272	1.017
	(Moist)		180 (0.94)	376.20	1.881	1.505
			240 (1.26)	501.60	2.508	2.006
	Air dried	26.20	120 (0.63)	242.58	1.213	0.970
			180 (0.94)	344.40	1.722	1.377
			240 (1.26)	456.00	2.280	1.824
	Original	8.55	120 (0.63)	492.00	2.460	1.968
Gypsum			180 (0.94)	742.80	3.714	2.971
			240 (1.26)	990.60	4.953	3.962
	Original	6.00	120 (0.63)	311.28	1.557	1.245
Lime			180 (0.94)	462.90	2.315	1.851
			240 (1.26)	610.32	3.052	2.441
	Original	7.76	120 (0.63)	522.00	2.610	2.088
Cement			180 (0.94)	763.80	3.819	3.055
			240 (1.26)	1010.76	5.054	4.043
	Original	6.52	120 (0.63)	83.70	0.419	0.335
Rice husk			180 (0.94)	121.98	0.610	0.488
			240 (1.26)	161.22	0.806	0.645

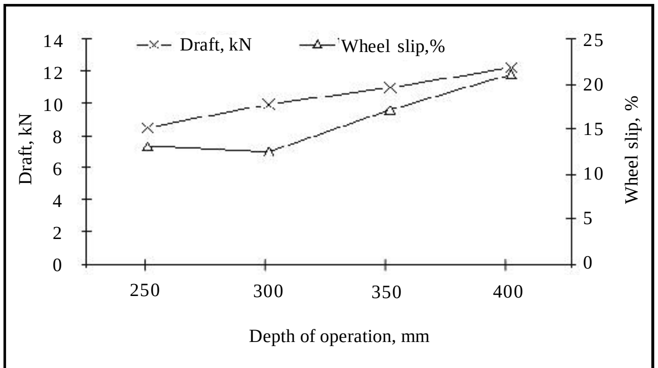

Fig. 5 : Variation in wheel slip of tractor with draft at average forward speed of 2.0 km/h

Effect of developed machine on soil moisture and bulk density:

The moisture content and bulk density of soil collected during the machine performance test in the field at different depths are presented in Table 4. The moisture content before operation was obtained as 14.89, 14.96, 16.34 and 16.88 per cent for 0-100, 100-200, 200-300 and 300-400 mm depths, respectively. It is also clear from the table that bulk density increased with increase in depth, which indicates the presence of compacted soil layers in the subsurface layers. After operation, the bulk density reduced by 5.89, 10.16, 3.57 and zero per cent, 5.70, 10.28, 13.51 and Zero per cent, 5.76, 10.16, 13.45 and 0.76 per cent and 5.70, 10.10, 13.33 and 13.88 per cent for 0-100, 100-200, 200-300 and 300-400 mm profile depth when machine was operated at 250, 300, 350 and 400 mm depth, respectively. When the developed machine was operated at its full depth of 400 mm, the soil bulk density reduced substantially from its original value of 1.715 Mg/m^3 to 1.477 Mg/m^3 in the depth range of 300-400 mm. Also, the bulk density from the ground surface (0-100 mm) to full depth (400 mm) of operation reduced but was in the same order as 1.457, 1.478, 1.482 and 1.477 Mg/m^3 at different depth range which clearly indicated the effectiveness of developed machine for soil structure modification.

Draft of developed machine:

The data noted for different depths are presented in Table 5. The draft force obtained for 250, 300, 350 and 400 mm depths was 8.5, 9.9, 11.0 and 12.2 kN, respectively which shows significant increase in draft with the increase in depth. For 400 mm depth of operation, approximately 43.53, 23.23 and 10.98 per cent higher draft was obtained than that obtained with 250, 300 and 350 mm depths.

Performance of developed machine on soil disturbance:

It is evident from Table 5 that the area of soil disturbed increased significantly with the increase in depth of operation. The soil disturbance for 250, 300, 350 and 400 mm depths of operation was found to be 0.091, 0.151, 0.181 and 0.195 m^2, respectively. At 400 mm depth of

Table 4 : Variation in moisture content and bulk density of soil

Soil profile depth, mm	Initial values		Dry soil bulk density after different depth of operation, Mg/m^3			
	Moisture content (d.b.),%	Dry soil bulk density, Mg/m^3	250	300	350	400
0-100	14.89	1.545	1.454	1.457	1.456	1.457
100-200	14.96	1.644	1.477	1.475	1.477	1.478
200-300	16.34	1.710	1.649	1.479	1.480	1.482
300-400	16.88	1.715	1.715	1.715	1.702	1.477

Table 5: Variations in machine parameters at different depths of operation and a forward speed of 2.0 km/h

Sr. No.	Depths of operation, mm	Draft, kN	Soil disturbance, m^2	Specific draft, kN/m^2	Wheel slip, %
1.	250	8.5	0.091	93.29	13.03
2.	300	9.9	0.151	65.93	12.40
3.	350	11.0	0.181	61.04	17.13
4.	400	12.2	0.195	62.26	21.07
	S.E. ±	0.44	0.002	1.92	0.57
	C.D. (P=0.05)	1.52	0.009	6.64	1.96

operation, the soil disturbance was higher by 114.23, 29.14 and 7.74 per cent than that obtained with 250, 300 and 350 mm depths.

Specific draft of developed machine:

The data presented in Table 5 indicates that the specific draft was found to be 93.29, 65.93, 61.04 and 62.26 kN/m^2 for 250, 300, 350 and 400 mm depths of operation, respectively. The specific draft decreased with the increase in depth of operation because of increase in soil disturbance. However, the specific draft obtained at 300, 350 and 400 mm depths was found statistically at par. This is because of the fact that with the increase in depth of operation of a tillage tool, the area of soil disturbance increases but at a reduced rate because of change in soil failure phenomenon from general shear failure to local or plastic failure of soil.

Performance of machine on wheel slippage:

Tractor wheel slippage at different depths of operation is presented in Table 5 and Fig. 5. The wheel slippage was obtained as 13.03, 12.40, 17.13 and 21.07 per cent for the depths of operation of 250, 300, 350 and 400 mm, respectively. The wheel slippage upto 300 mm depth of operation was well within the acceptable range of 12-15 per cent but for 400 mm depth of operation, the slippage was significantly high as the draft was beyond the pulling capacity of 40 kW tractor used in the study.

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