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RESEARCH PAPERS

Design, Development and Testing of 6-Row Compost Applicator Machine

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ABSTRACT

The study was conducted in the month of January during the year 2022-23 at G. B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India (29° 02′ 60.00″ N, 79° 30′ 59.99″ E). In this machine a screw conveyor metering mechanism was developed for disposed the manure into the subsoil. Hence a mechanism was designed which could mixed the vermicompost properly and then disposed it in correct ratio So a screw flight of pitch 90 mm and a thickness of screw of 3 mm was welded over the solid shaft. The length of the shaft was 1800 mm with a pitch angle of 29^0. The metering mechanism was evaluated for three screw flight outer diameters (96, 106, and 116 mm) were selected and tested in the workshop for performance evaluation of screw mechanism at four different moisture contents (13,21, 31, and 43%) respectively. Therefore, the result pertained that for handling of vermicompost manure at a discharge rate of 10 t ha^{-1}, the screw conveyor flight of outer diameter 116 mm, vermicompost moisture of 43 % (dry basis) and the tractor forward speed was normally maintained between 2.0 to 3.0 km h^{-1} were recommended respectively. In the field evaluation, the average width of operation, row to row spacing, depth of operation, field capacity, and field efficiency were 1.2 m, 0.2 m, 0.1 m, 0.4 ha h^{-1}, 81.17% at 3 km h^{-1}. The developed machine was found suitable for placing the manure in row at certain depth.

HIGHLIGHTS

- Vermicompost manure is considered a high rich organic nitrogen manure which improves soil fertility.
- The study was aimed that to design a 6-row compost applicator machine for easy application of vermicompost manure below the soil surface and reduces the global warming due to ammonia emission from the fertilizer to the atmosphere.
- The study revealed that machine improves the field conditions.
- The developed machine suitable for placing the compost in row at certain depth.

Keywords: Vermicompost, manure, screw conveyor, furrow opener**,** shaft

In India precision firming includes precise nutrient management. India is home to 30% of total organic produces in the world having 2.30 Mha in 2022. The organic firming is gaining the improve in which chemicals, synthetic fertilizer, and growth regulators. The various concepts to ensure soil health like revaluation, manuring, application of compost mulching etc. (Anonymous, 2020). Organic farming significant job to improve the physical properties, expanding soil aggregation, water holding capacity, hydraulic conductivity etc. (Singh and Thomas, 2010). As agriculture is facing the issues of loss of fertility, soil degradation and soil health, vermicompost provides excellent effect on overall plant growth, encourages the

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growth of new shoots leaves-1 and improves the quality and shelf life of the produce. For maximum efficiency of applied fertilizer, it is essential to deliver nutrients to the root zone of plants at a rate which is sufficient for maximum uptake while avoiding fixation with clay particles. The attention should, therefore, be given towards addition of fertilizer in subsoil to increase its nutritive status. In situations where deep loosening was required, the incorporation of fertilizer has been found to be beneficial (Godwin and Spoor, 1981). Hence, it is important to incorporate P fertilizers into the soil especially when using low water-soluble phosphates. By increasing the efficiency, the same level of yield could be obtained with fewer amounts of fertilizer and *vice-versa* (Cooke, 1982). In developing countries, a lot of work has been conducted on deep tillage with results showing substantial increases in crop yields. Earlier experiments (McEwen and Johnston, 1979; Rowse and Stone, 1980; Godwin and Spoor, 1981 and Liu *et al.* 1988) highlighted the potential yield increase for different crops, which could arise from amelioration of compaction and the incorporation of granular phosphate (P) and potassium (K) fertilizers into the subsoil. Therefore, incorporation of granular fertilizers with subsoiling operations for deep loosening and hardpan breaking may be effective and beneficial. Fertilizers may be placed either in continuous or intermittent bands as per the cropping pattern, root density of crops and metering system available. The evenness of placement should be maintained in vertical and horizontal soil profiles. Limited research has been conducted on subsoil delivery of fertilizers and tillage to reduce compaction while improving nutrient uptake. Subsoiling and fertilizer application by making two different passes across a field may not prove to be economical therefore combining into one pass is desired

The quantity of nutrients of organic manure required by the plants varies depending on plant characteristics (like crop, yield level, variety, planting rate), environmental conditions (like moisture and temperature), soil characteristics (soil properties, fertility), and soil and crop management. Although these interacting factors affect plant nutrient uptake and recovery of applied nutrients, nutrient accumulation during the growing season generally follows plant growth. Since nutrients of soils are absorbed by roots. The roots must fully ability to exploit soil nutrients and water for optimum productivity. The present study was aimed that to design and developed a machine to subsurface placement of vermicompost manure below the soil in the root zone of seed with accurate rate. Therefore, a tractor drawn subsurface manure applicator was designed in the G.B.P.U.A&T Pantnagar University Uttarakhand, India in 2022-2023 at farm machinery and power engineering department of GBPUA&T Pantnagar University to place the manure below the root zone of the seed so that the roots can uptake adequate amount of nutrients for growing stage. In India manure is applied using manual broadcasting method and bullocks' carts resulting in increasing labor cost, more time consumption per unit area and loss of nutrients with poor application uniformity and wide variation in the application rate. In view of the above, suitable technological mediation was needed for mechanization of manure application below the soil surface uniformly and in less time, therefore tractor drawn manure applicator was developed

MATERIALS AND METHODS

The research was carried out at the experimental orchard of the Department of Farm Machinery and Powering Engineering, G.B. Pant University of Agriculture and Technology, Uttarakhand, India (29° 02′ 60.00″ N, 79° 30′ 59.99″ E), in the *rabi* (January- June, 2022) season, aiming to design and developed a tractor operated compost applicator machine. The following criteria were considered in designing of the subsurface manure and seed applicator (Fig. 1**)** were (a) simplicity of fabrication (b) portability and (c) cost of manure applicator.

Design consideration

1. Constructional descriptions of the subsurface manure applicator

The design of the subsurface manure and seed applicator (Fig.2) is so simple that it can be fabricated with locally available materials like mild steel sheet, mild steel beam (square section), angle iron (L-shape), roller chain, mild steel sprocket and nut bolt. The different functional parts of the machine were made with these materials: vermicompost and seed hopper, hub, ground wheel,

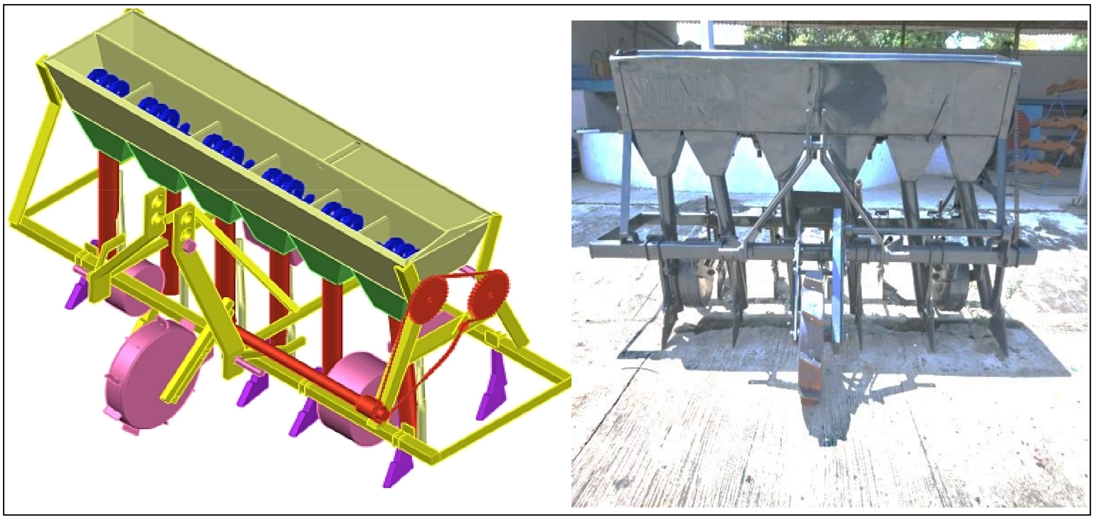

Fig. 1: Isometric view of developed prototype subsurface manure applicator

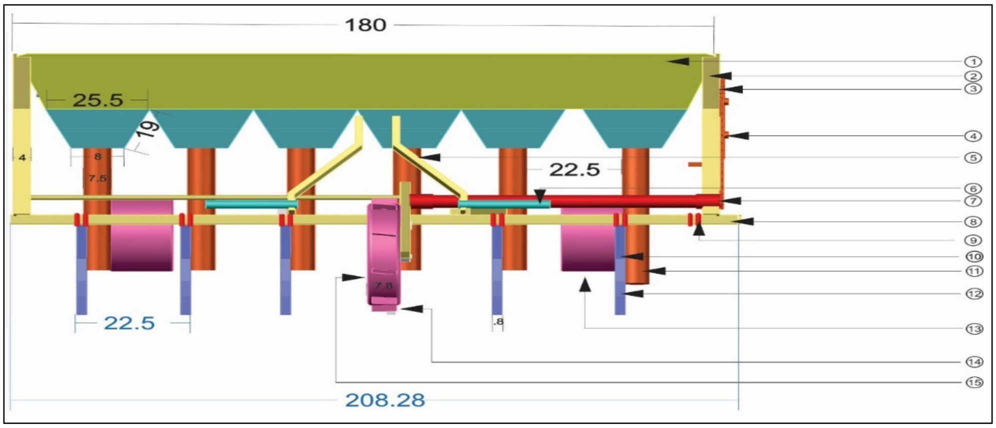

Fig. 2: Front view of developed prototype of subsurface manure applicator

(1) *vermicompost hopper;* **(2)** *hopper supporting stand;* **(3)** *roller chain;* **(4)** *sprocket;* **(5)** *three point hitching system,* **(6)** *hitch pin;* **(7)** *intermediate shaft;* **(8)** *frame;* **(9)** *U clamp,* **(10)** *standard;* **(11)** *vermicompost delivery tube;* **(12)** *furrow opener;* **(13)** *depth control side wheel;* **(14)** *lugs;* **(15)** *ground wheel*

main frame, furrow opener, shaft and supporting frame respectively and major specifications of developed machine are shown in Table 1.

Table 1: Major specifications of the seed drill

Sl. No.	Parameters	Values
1	Type	Tractor mounted
2	Length	2080 mm
3	Width	600 mm
4a	Height	1670 mm
4.b	Row spacing	200 mm
5	Depth of placing	100 mm
6	Total weights	250 kg
7	Numbers of rows	6
8	Capacity of seed box-cum vermicompost	50 kg
9	Application rate	2 to 10 t ha^{-1}
10	Speed of operation	2 to 6 km h^{-1}
11	Field capacity	0.7 ha h^{-1}
12	Power sources	Tractor power (25.36 kW)

Design of screw conveyor metering mechanism

1. Design of conveyor shaft

The shaft was considered to be subjected both bending and torsion moment. According (Gope. P.C, 2019) the failure of the shaft due to be in shear stress and the design considered this fact. Therefore, the solid shaft was selected made of plain carbon steel material AISI 1020 steel. The length and weight of the shaft were 1800 mm and 0.147 kN. The shaft was suspended between two bearings. The diameter of the shaft was determined by according to maximum shear stress theory by the equation 3. The pulling force required to pull the machine was 136.91 N and the shaft was rotated at mean rotational velocity of 35 rpm when the forward speed of tractor was 4 km h^{-1}. Therefore, power transmitted by the rotating shaft at 35 rpm was determined 0.152 kW by the equation given below:

$$P = F.V \qquad \ldots(1)$$

$$T = \frac{9550 \times kW}{rev/min} \qquad \ldots(2)$$

According to maximum shear stress theory;

$$d = \left(\frac{32 \times N}{\pi \sigma_y} \sqrt{4M^2 + 3T^2}\right)^{\frac{1}{3}} = 24.6 \text{ mm} \qquad \ldots(3)$$

F = force required to pull machine, N

P = Power, kW

V = forward speed of machine, m s^{-1}

T = torque, N.m

d = diameter of shaft, mm

N = factor of safety, 2

σ_y = yield strength, 390 MPa

M = Bending moment, (wl/8), N.m (assume load is uniformly distributed)

w = weight of the shaft, 0.147 kN

Hence, the standard diameter of shaft was selected 30 mm for the design based on availability of material

2. Design of metering system (screw conveyor)

The screw flight pitch and thickness of screw were decided on the basis of type of materials to be delivered. Therefore, a single threaded screw of 3 mm thickness and pitch 150 mm was made on the solid shaft with an included angle of 29^0 (Sahay, K.M *et al.* 1994). The height and pitch diameter of threaded screw were determined as 97.45 mm and 2.57 mm. The conveying capacity for different combination (Sahay, K.M *et al.* 1994). was calculated by using the equation 8 given below;

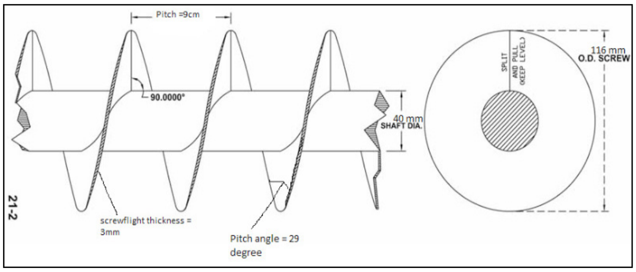

Fig. 2: Single threaded screw conveyor mechanism for vermicompost delivery

$$C_s = 47.2\,(D_s^2 - d_s^2) \times p \times n \qquad \ldots(4)$$

where,

C_s = conveying capacity of screw conveyor, m^3 h^{-1}

D_s = diameter of screw, m

d_s = diameter of shaft, m

p = pitch of screw conveyor, m

n = speed of conveyor, rpm

3. Determination of thickness of seed hopper sheet

The thickness of hopper sheet (t) was designed considering the maximum bending moment (BM_{max}) in the wall by the Rankine's equation 5 as 1904 kg-mm. Sheet thickness was found as 1.77 mm. However, for safer design and ease of availability, 2.5 mm thick MS sheet was selected. The seed hopper was also designed in similar manner.

$$BM_{max} = \frac{\rho h_3^2 b_2^2 \cos\theta}{8} \qquad \ldots(5)$$

$$\sigma_{\max allow} = \frac{BM_{max} I}{y} \qquad \ldots(6)$$

where,

ρ = bulk density of the vermicompost manure, 605 kg m^{-3}

h_3 = maximum height of hopper, 0.37 m

b_2 = maximum width of hopper, 0.51m

BM_{max} = bending moment, kg. m

θ = angle of repose of vermicompost, 45^0

$\sigma_{maxallow}$ = maximum allowable shear stress,9.8 kg mm^{-2}

I = moment of inertia, mm^4

y = distance of the outer stress fiber from the neutral axis, t/2 mm

4. Three-point hitch link

Three-point hitch link was used to connect the machine with the tractor through a three-point hitching system. Mild steel sheet of size 510 mm × 45 mm × 8 mm was used. The overall dimensions length and thickness were 510 mm and 45 mm, respectively. Width varied front and back were 610 mm and 620 mm respectively.

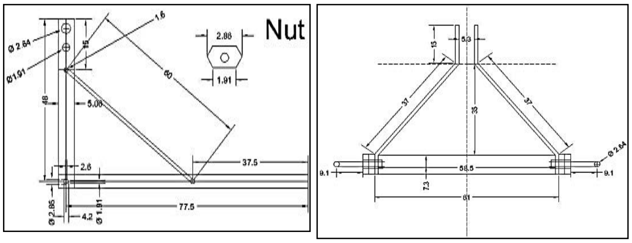

Fig. 3: Side and front view of three-point hitching system

Main frame

1. Design of frame

A rectangular hollow frame of thickness 60 mm, overall length and width as 2080 mm and 600 mm was selected. The frame was designed considering it as a hollow beam with fixed ends and subjected to both bending and twisting moments. Maximum bending moment (M_1) at the center of the beam due to weight of 100 kg of wheat seed and vermicompost manure as shown in (Fig. 5) was filled at a time in the hopper was determined as 441 Nm by using the equation 7.

$$M_1 = R_A \times \frac{L}{2} \qquad \ldots(7)$$

$$M_1 = 490 \times \frac{1.80}{2}$$

$$M_1 = 0.441 \text{ kN m}$$

Where,

M_1= bending moment, N m

R_A= R_B = reaction at ends, 490 N and

L = length of beam, 1.80 m

Considering Fig. 5 and assuming that all the 6 furrow openers are experiencing equal draft force of 1.47 kN, therefore, reaction (R_1 and R_2) at the end of beam would be equal and was determined as:

$$R_1 + R_2 = 6 \times 1.47 \text{ kN} = 8.82 \text{ kN}$$

By symmetry $R_1 = R_2 = 4.41$ kN

Therefore, maximum bending moment (M_2) due to draft force could be determined by taking moment at section x-x, as:

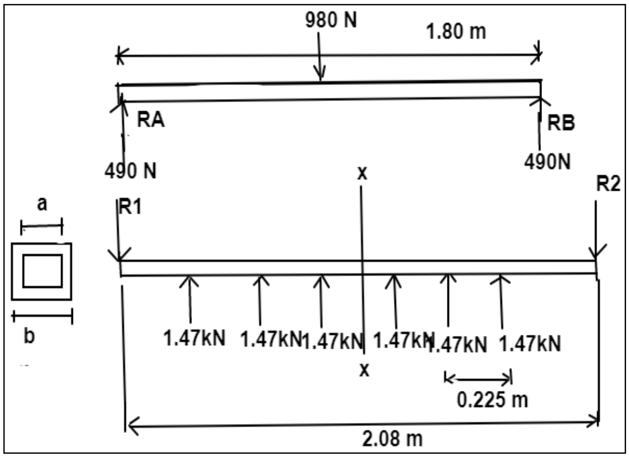

Fig. 5: Weight of wheat seed and vermicompost manure on the frame and draft force acting on forebar of the frame

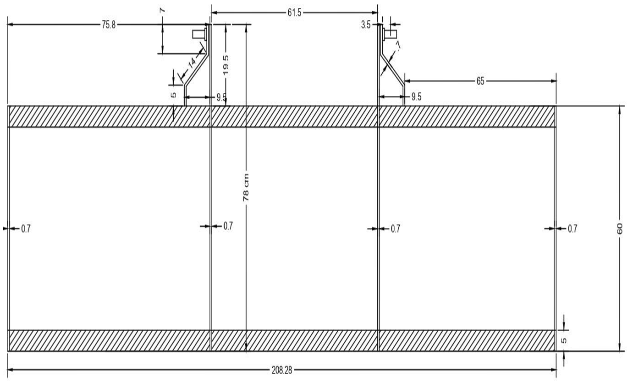

Fig. 6: Top view of the main frame

$$M_2 = R_1 \times (0.90) - 1.47 \times 0.562 - 1.47 \times 0.3375 - 1.47 \times 0.1125 = 2.481 \text{ kN m}$$

Therefore, equivalent bending moment (M_b) would be determined as:

$$M_b = \sqrt{(0.441^2) + (2.481^2)} = 2.519 \text{ kN m} \qquad \ldots(8)$$

Maximum torsional force (M_t) transferred on the beam due to draft force would be :

M_t = number of furrow openers × draft on each furrow opener × lever arm

M_t = 6 × 1.47 × 0.58 = 5.116 kN m

Considering maximum shear stress failure theory, the equivalent torsional moment (T_e) was determined as

$$T_e = \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \quad \ldots(9)$$

$$T_e = \sqrt{(2 \times 2.519)^2 + (1.5 \times 5.1156)^2} = 9.17 \text{ kN m}$$

Where

T_e = equivalent torsional moment, kN m

M_b = equivalent bending moment, 2.519 kN m

M_t = equivalent torsional moment, 5.1156 kN m

k_b and k_t = shock and fatigue factors, 2 and 1.5

As the beam is subjected to stresses due to torsional moment, the maximum torsional shear stress was determined by the equation given below;

$$\frac{\tau_{max}}{y} = \frac{T_e}{J} \quad \ldots(10)$$

$$\tau_{max} = \frac{T_e y}{J} = \frac{T_e}{Z} \quad \ldots(11)$$

$$Z = \frac{2}{9}\frac{\{a^4 - b^4\}}{a} = \frac{2}{9}\frac{\{(20+b)^4 - b^4\}}{20+b} \quad \ldots(12)$$

Where,

τ_{max} = N m^{-2}

T_e = equivalent torsional moment, N m

y = distance of edge from the center of the beam, a/2, m

J = polar moment of inertia of the cross section, m^4

Z = polar section modulus of hollow square section, m^3

a = inner length of rectangular section, *m*

b = outer length of rectangular section, *m*

$$\tau_{max} = \frac{S_y}{fos} = \frac{250}{1.2} \quad \ldots(13)$$

= 208.33 MPa

$$\tau_{max} = \frac{T_e y}{J} = \frac{T_e}{Z} \quad \ldots(14)$$

$$208.33 = \frac{T_e}{Z}$$

$$208.33 = \frac{9\ kN - m}{\frac{2}{9}\frac{\{(20+b)^4 - b^4\}}{20+b}}$$

b = 45 mm

and $a = b + 2t$ = 45 + 20 = 65 mm

τ_{max} was determined by equation 14 as 208.33 MPa by considering the allowable yield stress (S_y) for mild steel as 250 MPa and 1.2 as factor of safety (FOS). Now substituting the values in equation 14, the value of outer and inner dimensions (*a* and *b*) of frame were determined as 45.53 and 35.53 mm respectively. However, standard size of hollow square pipe with outer and inner dimensions of 50 and 40 mm, respectively, having 5 mm thickness was selected for fabrication of the frame.

Power transmission system

The power transmission system was such that the power from the ground wheel transmitted equally to both of the metering mechanisms of vermicompost and seed respectively. Power transmission unit consists of a sprocket, roller chain (pitch = 12.5 mm), idler and counter shaft. The ground wheel was fitted with 18 number of teeth sprocket (T1 = 18) and the counter shaft consists of 14 teeth sprockets at both ends (T2 = T3 = 14). The manure shaft consists of 37 teeth sprocket fitted at the end of the manure shaft (T4 = T5 = 37).

(I) The speed reduction was provided in two stages, by chain and sprocket arrangement. Velocity ratios (VR) of the various stages.

(II) $N_1 T_1 = N_2 T_2$

RESULTS AND DISCUSSION

Effect of exposure length on application rate of vermicompost

The effect of the forward speed, moisture content and hopper plate opening on the application rate was evaluated during field performance of

Table 2: Effect of exposure length on application rate of vermicompost (manure)

Vermicompost application rate (t ha^{-1})												
		Exposure length of orifice opening					% Variation from mean value					
Moisture content,% (d.b)	Forward speed km/h	1/4th	1/2nd	¾th	Full	Overall mean	1/4th	1/2nd	¾th	Full	SD	CV,%
13	2	6.130	8.510	15.02	20.54	12.54	51.11	32.13	-19.77	-38.94	6.51	51.90
	4	3.160	6.870	13.89	17.67	10.19	68.9	32.58	-36.31	-42.33	6.58	64.57
	6	1.900	5.060	10.66	14.91	8.120	76.60	37.68	-31.28	-45.53	5.80	71.53
21	2	7.354	10.35	16.91	22.63	14.31	48.60	27.67	-18.16	-36.76	6.83	47.74
	4	3.670	7.400	14.75	19.31	11.00	66.63	32.72	-34.09	-43.03	7.05	64.17
	6	2.010	5.610	12.63	16.98	9.310	78.41	39.74	-35.66	-45.17	6.75	72.54
31	2	7.975	11.35	19.60	25.18	16.02	50.21	29.15	-22.34	-36.37	7.81	48.78
	4	4.032	8.560	16.92	20.68	12.55	67.87	31.79	-34.82	-39.31	7.60	60.63
	6	2.460	6.570	12.88	16.98	**9.720**	74.69	32.40	-32.51	-42.76	6.46	66.49

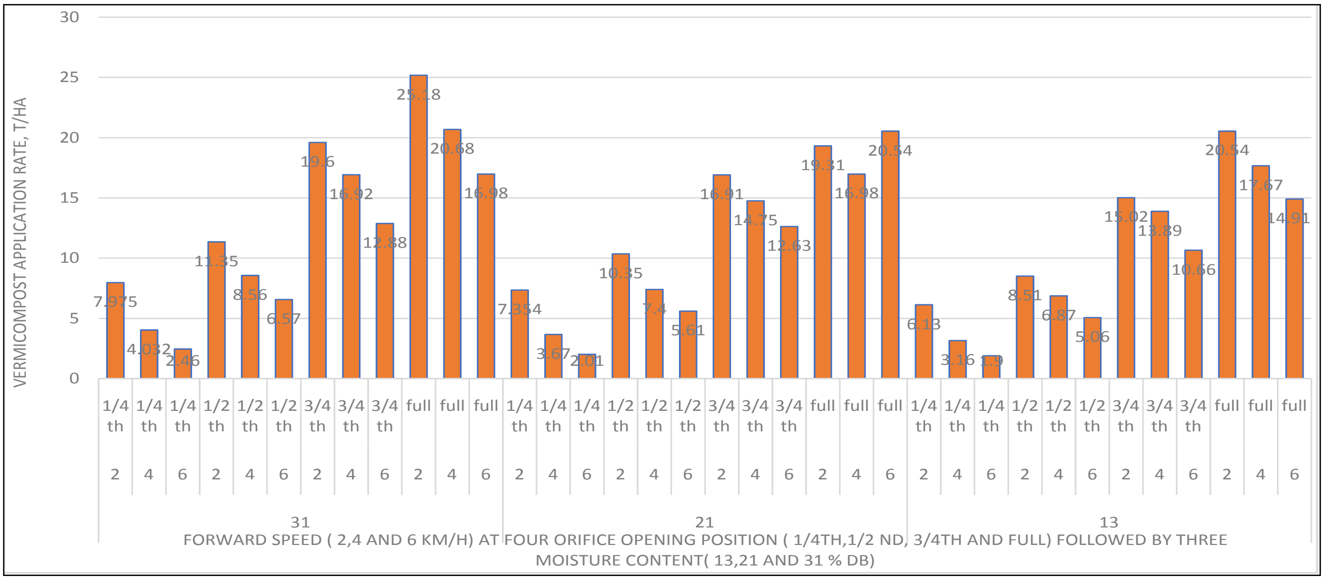

Fig. 7: Forward speed (2,4 and 6 km/h) at four orifice opening position (1/4th, 1/2nd, 3/4th and full) followed by three moisture content (13,21 and 31%db

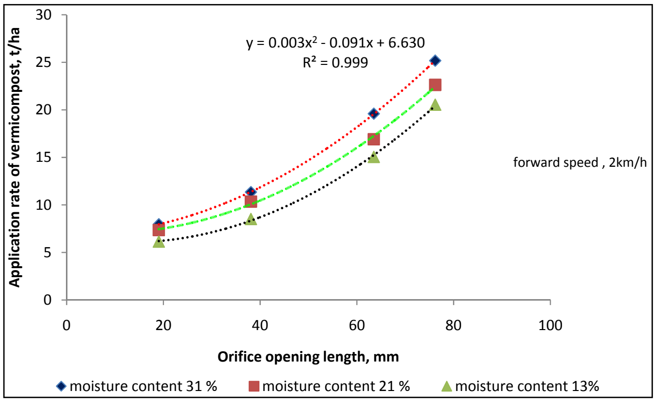

Fig. 8: Effect of forward speed and moisture content on application rate of manure when forward speed is 2 km/h

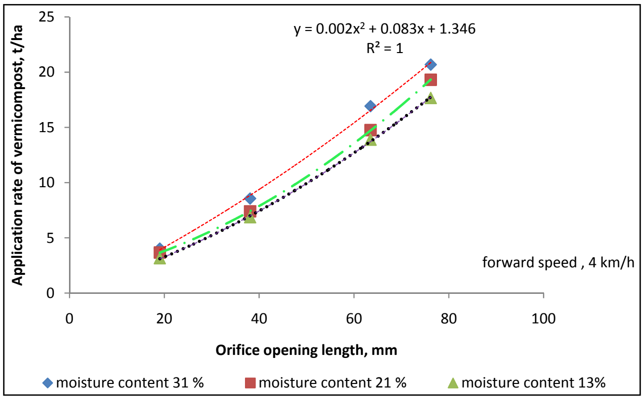

Fig. 9: Effect of forward speed and moisture content on application rate of manure when forward speed is 4km/h^{-1}

the machine. From the graph it was clear that at higher moisture content as the forward speed was increased from 2 to 6 km h^{-1}, the application rate was decreased from 16 to 9.7 t ha^{-1} respectively.

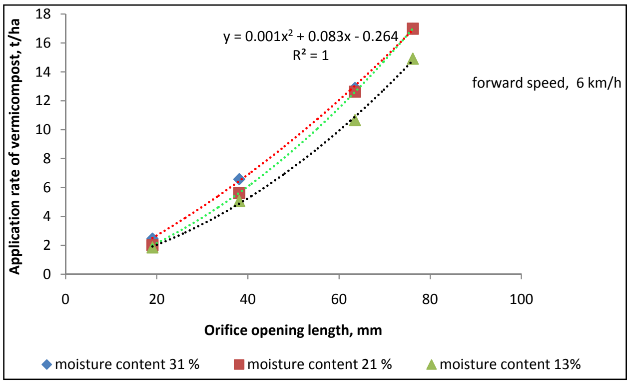

Fig. 10: Effect of forward speed and moisture content on application rate of manure when forward speed is 6 km/h^{-1}

CONCLUSION

The developed subsurface manure and seed applicator was tested under filed condition machine for sowing of wheat and other crops along with the placement of organic manure below the seed was tested by farm machinery and power engineering department Pantnagar Uttarakhand and found to be suitable for placing both the organic manure and seed below the soil at desired depth. The machine worked satisfactory and achieved uniform application rate of vermicompost manure in the field with reduced human power. This machine improves the nutrient uptake of plants by increasing the distribution area of roots into the soil thus increasing the soil fertility and crop productivity and safe the environment and soil with the use of inorganic fertilizer that continuously reduces the strength.

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