Journal of Scientific & Industrial Research
Vol. 81, June 2022, pp. 683-694

Design of an Innovative Tractor-Operated Seeder for Mat Type Paddy Nursery

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Received 06 December 2021; revised 12 May 2022; accepted 13 May 2022

This study contains the design approach, development details, and field evaluation of an innovative tractor-operated seeder for sowing mat type paddy nursery. In order to design and select the various components of mat type nursery seeder, the fundamentals of farm machinery design were taken into due consideration. The machine comprises of soil cutting unit, inclined conveyor unit, screw type conveyor auger, sieving unit, compaction roller, polythene sheet laying unit, soil metering and seed metering unit. The basic criteria for design were to prepare a soil bed with a width of 1000 mm and width of cut of channel 240 mm on both sides of the bed to irrigate the prepared soil bed. The soil cutting unit and conveyor unit were designed based upon amount of soil required on soil bed to have 20–30 mm soil mat bed thickness and seed metering unit was designed to deliver 2–3 seeds·cm^{-2} on the bed. The machine was fabricated based on design calculations and then evaluated in laboratory as well as actual field conditions. During field evaluation of this machine, it was found that the coefficient of uniformity for seed spread was 7.33%, coefficient of uniformity for soil spread 5.67%, fuel consumption 39.6 l.ha^{-1} and actual field capacity 0.11 ha·h^{-1} with 1.7 km·h^{-1} forward speed of machine. Labour saving using the designed tractor-operated seeder was observed to be 86.4% as compared to the manual method of sowing mat type nursery using steel frames.

Keywords: Farm machinery, Farm mechanization, Mat type nursery, Nursery seeder

Introduction

In India, paddy cultivation has excessive underground water exploitation. As a result, looming underground water crisis in Punjab made the government to pass legislation not to transplant paddy crop before June 10. So, due to shortened duration for paddy transplanting around 20 days, farmers confront difficulties in timely transplanting of paddy crop either due to want of labour or due to high rates being demanded by the labour. The delayed paddy transplanting through early July every year, results in reduction in the yield.[1] Labour scarcity is a major problem in Punjab. Paddy crop is mainly transplanted by the migrated labours from Bihar, Chhattisgarh, Orissa and Uttar Pradesh. It has been observed that in the past 4–5 years, cost of production in paddy crop has increased and profitability decreased due to rise in wages. To overcome this difficulty of farmers, State Government in collaboration with the Department of Agriculture, Punjab and Punjab Agricultural University introduced paddy transplanters in Punjab. In recent years about 760 paddy transplanters were procured by farmers, custom hiring centers as well as cooperative societies on subsidy.

All mechanical paddy transplanters use mat type nursery for transplanting paddy seedlings. This mat type nursery is raised either in plastic trays or on the open field. In an open field method, two persons can plant mat type nursery for two hectares in one day. Manual method for raising mat type nursery requires a number of operations. A well-prepared seedbed is used for sowing mat type nursery. A plastic sheet of 50–60 gauge thick with one-meter width is spread on the well-prepared field and steel frames made of rectangular hollow steel pipes having two-centimeter height are placed on this plastic sheet in line. Soil from the sides of frame is filled in the compartments of frame with the help of spade and pre-germinated seeds are spread manually in each compartment to obtain a uniform density of 2–3 seedlings·cm^{-2}.[2] The seeds are protected by a thin layer of soil over it and water is sprinkled by hand sprayer for appropriate setting of soil and then frames are uplifted. Some attempts to mechanize this sowing procedure have been done in the past, however performing multiple operations at a time is a considerable bottleneck for nursery mechanization. A manually operated mat type nursery sowing machine was devised to raise paddy seedlings in 420 mat frames with 25–30 kg seeds, although it requires 2–4 passes which may be suitable

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for transplanting one-hectare area.[3] Similarly, a manually operated device with soil spreading and seed spreading units was developed to sow paddy seedlings on soil-filled frames; further satisfactory results were obtained when the device passed three times.[4] Similar operations are performed for sowing nursery in trays. A mat type nursery raising machine was designed for filling the soil and distributing the seeds on the nursery tray.[5] In another study, paddy seedlings were raised in a plastic tray filled with sandy loam soil and fertilizer, and seeds were sown before loose soil was spread over the tray.[6] Currently, electrical machines are being developed to achieve uniform placement of soil and seed in a tray, however, there is a necessity for manual placement of soil, seed, and water in the respective hoppers. Further, a hand-operated stationary paddy seeding device was developed for swing mat type nursery in a perforated tray. It performed satisfactorily with desired seed density (100–120 g·mat^{-1}) but required two passes.[7] The only difference is that in this method, soil is filled in tray instead of frames placed on polythene sheet.[8] Therefore, to accomplish all the operations in one go, faster, easy, simple and cost-effective, there is a need to design and develop a seeder intended for raising mat type nursery of paddy crop.

In line with this, some efforts were carried out and developed a prototype of nursery seeder machine (mounted type) but it could not deliver the desired results.[9] Moreover, the research on the development of a mechanized approach for sowing mat-type nursery instantly in the open agricultural field is limited in India and overseas except stationary method as deliberated above. Thus, the mechanization in sowing mat type nursery is need of the hour to boost mechanical paddy transplanting.[10] To address this issue of human drudgery and high energy requirements involved in growing in conventional mat type nursery, there was necessity to design, and develop a cost-effective machine with simple mechanism i.e. tractor-operated seeder for sowing mat type nursey of paddy crop.[2,9,10] This developed machine could be an innovative mechanical intervention which fulfills the objective of timely infield nursery sowing with complete automized nursery soil bed preparation and subsequent sowing of seeds uniformly without minimal human intervention in growing of mat type nursery for mechanized paddy cultivation. Hence, keeping aforementioned facts in mind, the specific objective of the study was to design and fabricate a tractor-operated machine for sowing of mat type paddy nursery.

Materials and Methods

Conceptual Design

The conceptual design of an innovative tractor-operated seeder intended for mat type paddy nursery was based on functional requirements of mat nursery seeder: (i) The soil surface of 1000 mm width (within the tractor tyres) has to be compacted enough to obtain the firm and compacted soil surface to lay the polythene sheet. (ii) Arrangement for laying the polythene sheet on the compacted surface of soil. (iii) Arrangement for cutting, conveying, sieving, and metering the sufficient soil to make a soil mat of desired thickness (20–30 mm).[2–4] (iv) Seed metering system to meter the seed in a uniform manner to have 2–3 seeds·cm^{-2}.[(2–4)] (v) Accomplish simultaneously all operations of sowing mat type nursery in one go.

Based on these functional requirements, the developed machine will cut and lift the soil from both sides and transfer it to sieving system with the help of belt conveyors and auger conveyor. After sieving, the soil will fall in hopper of soil metering system. Before soil metering system a soil compaction roller will be provided in front of the machine to compact the soil surface. One more roller has to be provided on which 50–60 gauge polythene sheet can be wrapped to lay the polythene sheet on this compacted soil surface. Soil metering unit will drop the soil on the laid polythene sheet to form a uniform thickness of soil mat. Simultaneously, seed metering mechanism placed at rear of soil metering system will meter the seeds on the prepared soil bed in a uniform manner. The conceptual design of the proposed machine is shown in Fig. 1.

Design and Selection of Different Components

The following assumptions were taken for the design of mat type nursery seeder: (i) Inclined soil tillage tool should work at slow speed.[11] Thus, the forward travel speed of the machine/tractor (T_s) was taken 0.83 m·s^{-1}. (ii) Width of cut of channel for the irrigation purpose (W_c) = 0.24 m. (iii) Maximum thickness of soil bed (T_m) = 30 mm.

Now, further part of this section is focused on design of various components based on farm machinery approach using different Eqs (1)–(30).

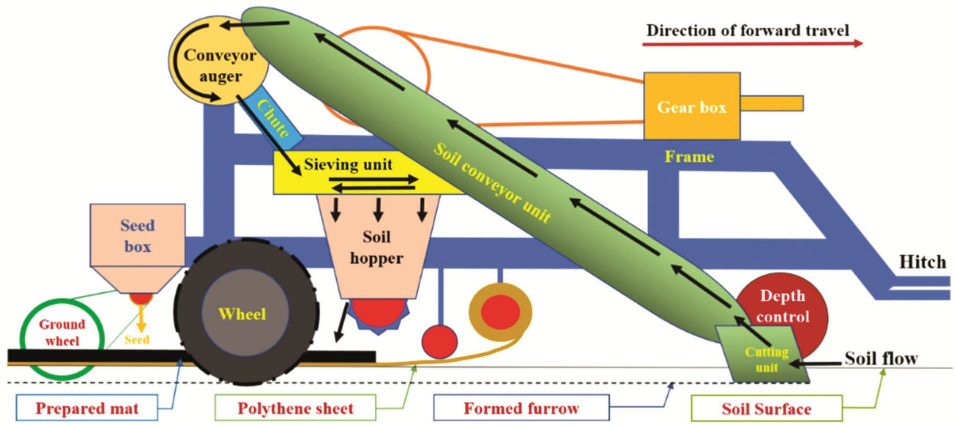

Fig. 1 — The conceptual design of tractor-operated seeder for sowing mat type paddy nursery

Design of Soil Cutting Unit

Amount of Soil Required on Soil Bed

Volume of soil required on soil bed (S_v) for one m^2 area was calculated as follows:

$$S_v = W_b \times L_b \times T_m = 1.0 \times 1.0 \times 0.03 = 0.03\ m^3 \quad \ldots (1)$$

where, W_b = width of soil bed, m; and L_b = length of soil bed, m

Amount of soil required on soil bed (S_a) for one m^2 area

$$S_a = S_v \times \rho_b = 0.03 \times 850 = 25.50\ kg \quad \ldots (2)$$

where, ρ_b = density of soil on sown bed i.e. 850 $kg.m^{-3}$

Adding total losses (determined through replicated experimentation) about 2.0% in conveying, clods etc. and then total amount of soil to be conveyed by both cutting units (S_{tb}) is calculated as:

$$S_{tb} = S_a \times 1.02 = 25.5 \times 1.02 = 26.01\ kg \quad \ldots (3)$$

Hence, soil to be conveyed by one (single) unit (S_{ts}) per meter length is calculated as

$$S_{ts} = S_{tb}/2 = 26.01/2 = 13.0\ kg \quad \ldots (4)$$

Required Depth of Soil Cut

The cross-section of cut by the cutting unit was considered rectangular shape, hence, the depth of cut of cutting tool for required amount of soil was calculated as:

$$V = W_c \times d_c \quad \ldots (5)$$

where, V = volume, m^3; and d_c = depth of soil cut, m

Then, considering 35.0% losses (determined through replicated experimentation) at cutting unit due pushing of soil both sides of the furrow and falling of soil at back of cutting, then actual amount of soil to be cut (S_T) is

$$S_T = S_{ts} \times 1.35 = 13.0 \times 1.35 = 17.55\ kg \quad \ldots (6)$$

$$V_{sc} = S_T / \rho_f = 17.55/1100 = 0.0159\ m^3 \quad \ldots (7)$$

where, ρ_f = density of soil measured on prepared soil (1100 $kg{\cdot}m^{-3}$)

$$d_c = V_{sc}/(W_c \times L_b) = 0.0159/(0.24 \times 1.0) = 0.066\ m = 6.60\ cm = 7.0\ cm \quad \ldots (8)$$

The depth of cut of soil comes out to around 7.0 cm. It can increase or decrease depending upon the bulk density of prepared field which is dependent on type of soil and quality of pulverization and compaction of prepared field. Sufficient soil will be available as depth of cut of rotavator varies from 10–12 cm.

A parabolic shaped soil cutting blade having curved radius of 270 mm was selected to give stability.[12,13] The α is an angle between simple wedge subtending with the horizontal whereas α is rake angle. The cutting blade with rake angle (α = 25°) with upper tapered face was selected taking into account the crushing ability and draft.[14,15] Cutting unit was guarded from both sides to flow the soil on the blade.

Design of Soil Conveyor Unit

To make the machine compact, the length of the conveyor should be less and at the same time has a sufficient height to accommodate other assemblies, which resulted in steeper slope of conveying unit (up to around 40°), which was more than that of the angle of repose of the soil. Hence, a belt of the conveyor was provided cleats or flights fitted on it to reduce the tendency for the conveyed soil to slip. The speed of the conveyor (C_s) should also be at least 25% more (i.e. 1.04 $m \cdot s^{-1}$) than the forward speed of tractor (0.83 $m \cdot s^{-1}$) to avoid chocking and accumulation of soil.

Amount of soil to be conveyed by single (one side) conveyor unit$\cdot m^{-2}$ (S_{ts}) was calculated using Eq. (4) as 13.0 kg.

Discharge of soil at the inlet of conveyor (D_{si}) = $S_{ts} \times T_s = 13.0 \times 0.83 = 10.79\ kg \cdot s^{-1}$ … (9)

Volume of soil conveyed by belt conveyor (V_{bc}) = $D_{si}/\rho_f = 10.79/1100 = 0.0098\ m^3 \cdot s^{-1}$ … (10)

Thus, height of cleats on belt (H_c) was calculated as follows

Volume of soil to be conveyed (V_{bc}) = $W_c \times C_s \times H_c$ … (11)

$0.0098 = 0.24 \times 1.04 \times H_c$ … (12)

$H_c = 0.039\ m = 39\ mm \approx 40\ mm$

The length of soil conveying cleats was taken as 210 mm for easy handling and spacing of cleats on belt was 125 mm. The height of sidewall from belt to upside of soil conveyor (belt type) was taken two times more for safe conveying (80 mm) and avoiding loss of soil due to jumping of belt.

Soil Conveyor Auger

Soil discharged from both the belt conveyor was horizontally transmitted to the sieving system with simple auger conveyor (with opposite spiral). The auger was fitted in U shaped trough for the movement of soil with positive action.[16] A partly solid shaft was selected for the auger conveyor.[17] The screw shaft was supported at both ends by bearings. Screw clearance between the screw and the U-shaped trough was kept about 10 mm. In general, the pitch of the screw is equal to screw diameter. Generally, screw conveyors are designed to run at relatively high speed from 200 to 2000 rpm.[16]

According to Woodcock and Mason[16], the radial clearance between the shaft and trough should be 1.75 to 3.00 times the size of the largest clod (lump) in the conveyed product. Maximum soil clods size considered on the field = 20 mm.

Radial clearance between the shaft and trough = maximum size of clod × 3 = 20 × 3 = 60 mm … (13)

Based on clod size 150 mm screw was selected for the course of study.[16] The selected screw conveyor auger was standard flight which has screw diameter equal to screw pitch of the screw. Thus, pitch of screw was taken as 150 mm for the course of study.

Length of the screw conveyor (L_s) was calculated as follows:

$L_s = W_b + (2 \times W_c) = 1.0 + (2 \times 0.24) = 1.48\ m$ … (14)

Allowing some clearance on both sides for the adjustment 15% then, $L_s = 1.702\ m \approx 1.70\ m$

Design of a Soil Metering Unit

Let the soil metering mechanism may be of fluted roller, then volume of soil to be handled by fluted roller in one revolution (V_{soil}) can be calculated as:

$V_{soil} = (S_a \times T_s)/\rho_b = (25.5 \times 0.83)/850 = 0.025\ m^3 \cdot s^{-1} = 1.50\ m^3 \cdot min^{-1}$ … (15)

Generally, seed metering roller has 13 flutes (S_{fn}) thus flutes on soil metering roller were kept same and shape of flute was semicircular to carry soil in a proper manner. Also, revolutions of the roller (N_f) were assumed as 100 rpm. Some clearance was provided between roller and bottom of the hopper for free flow of soil due to agitation due to rotation of fluted roller (approximately 2/3 of total) to smoothen the ruts created by the soil metered by flutes and rest was monitored by the flute volume of fluted roller for uniform spread of soil on the polythene sheet surface. Then the volume of soil carried by the fluted roller in one revolution was calculated from Eq. (15).

$V_{soil} = 0.50\ m^3 \cdot min^{-1} = V_{flute} \times S_{fn} \times N_f$ … (16)

Thus, the volume of an individual flute (V_{flute}) can be calculated from above equation

$0.50 = V_{flute} \times 13 \times 100$ … (17)

$V_{flute} = 0.50 / (13 \times 100) = 0.000384\ m^3 = 384\ cm^3$ … (18)

Also,

$V_{flute} = \frac{\pi \times R_{sf}^2}{2} \times L_r$ … (19)

where, R_{sf} = radius of the flute of soil metering roller, cm; and L_r = length of roller, cm

Putting the values in Eq. (19), the radius of flute comes out

$R_{sf} = \sqrt[2]{\frac{384 \times 2}{\pi \times 100}} = 1.56\ cm = 15.6\ mm$ … (20)

Then, semicircle diameter of flute, $D_{sf} = 31.2$ mm

Let the peripheral spacing (S_{ws}) between two flutes be 12 mm.

Then, diameter of soil fluted roller (D_f) was calculated as:

$$D_f = S_{fn} \times (D_{sf} + S_{ws})/\pi = 13 \times (31.2 + 12)/\pi = 178.7 \text{ mm} = 180 \text{ mm} \quad \ldots (21)$$

Volume of soil received from sieving unit (with density ρ_{ss} of 750 kg.m^{-3}) from both cutting unit (V_{ss}) was calculated as from Eq. (2).

$$V_{ss} = S_a/\rho_{ss} = 25.5/750 = 0.034 \text{ m}^3\cdot\text{s}^{-1} \quad \ldots (22)$$

Soil coming from sieving unit will be highly friable and can easily fall into the soil hopper. Hence, the inlet opening of the soil hopper (top width) should be sufficiently wider to accommodate the soil coming from sieve. Hence, the volume of soil hopper (V_h) was assumed around three times i.e. 0.1 m^3. The soil hopper was kept trapezoidal section. The angle of repose of soil (φ) is 40° thus the design of soil hopper should be such that the φ is more than 40° for better flow of soil. Therefore, for safe design φ was taken as 75°. The length of the hopper (L) was taken 5.0% more than bed width (i.e. 1.05 m) to accommodate soil metering roller and soil coming from sieve. A sectional view of soil hopper with labeling is shown in Fig. 2(a).

$$V_h = \frac{(T + B)}{2} \times H \times L \quad \ldots (23)$$

where, H = height of the hopper, m; B = bottom width of the hopper, m; and T = top width of the hopper, m

Now, putting value of T in Eq. (23), we get

$$V_h = (B + H \cot\varphi) \times H \times L \text{ (as } T = B + 2X \text{ and } X = H \cot\varphi) \quad \ldots (24)$$

Let, B = 0.2 m (as D_f = 0.18 m and taking 10% allowance for soil metering roller accommodation)

Now, putting the values in Eq. (24) we get,

$$0.1 = (0.2 + H \times \cot 75) \times H \times 1.05 \quad \ldots (25)$$

Solving the Eq. (25) and other relations, it yields

$$H = 0.330 \text{ m} = 330 \text{ mm} \quad \ldots (26)$$

$$X = H \times \cot\varphi = 0.33 \times \cot 75° = 0.089 \text{ m} \quad \ldots (27)$$

$$T = 0.2 + 2 \times 0.089 = 0.378 \text{ m} \quad \ldots (28)$$

The top opening width of 378 mm is sufficient for the receiving of soil coming from the sieving unit. Hence, design calculations of the hopper are appropriate for the proper soil transfer and distribution.

Thickness of the soil hopper (t_h), cm is calculated as follows.[18]

$$t_h = \sqrt[3]{\frac{3 \times \rho_b \times B^2 \times H^2}{4 \times B \times b_s}} \quad \ldots (29)$$

where, b_s = bending stress of hopper sheet, 1600 kg·cm^{-2}; H total height of hopper, cm; and B = bottom width of hopper, cm

Then Eq. (29), yields

$$t_h = \sqrt[3]{\frac{3 \times 0.00085 \times 20^2 \times 33^2}{4 \times 20 \times 1600}} = 0.205 \text{ cm} = 2.1 \text{ mm}$$

Design of Seed Metering Unit

Seed metering mechanism consists of a rotary element used to displace the seeds from a stationary

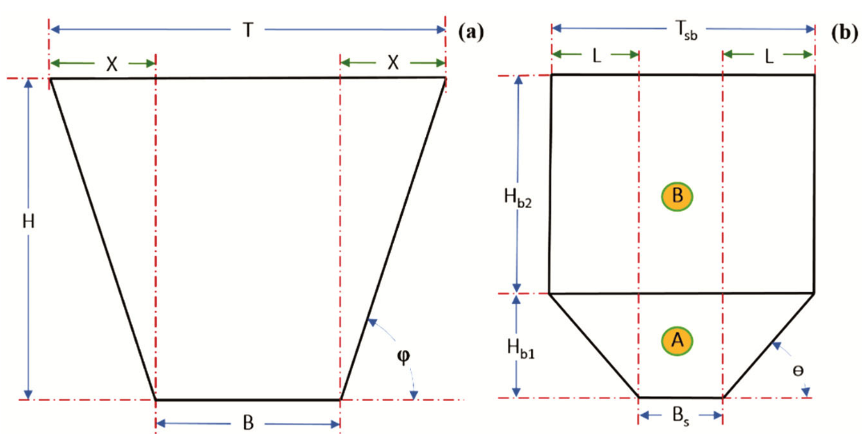

Fig. 2 — A sectional view (a) soil hopper, and (b) seed box

seed-guiding cup and is known as a fluted roller. A roller with semi-circular flute used for manual nursery sowing of paddy was available in the market with dimensions of 14 flutes and 40 mm diameter was used. Seed hopper was designed for sowing nursery length of 50 m to sow nursery of one ha (30.0 kg seed). The design of seed box had two stages: in first stage, trapezoidal shape at the bottom and secondly rectangular shape at the top. The fluted roller was inside the box at the center, parallel to the seed box length. Also, the angle of inclination for both front and rear wall was kept 44° which was greater than the angle of repose of the paddy seed.[19] Although, the length of the seed box was kept same as width of prepared soil bed (fixed 1000 mm). The sectional view of seed box with labeling is shown in Fig. 2(b).

The volume of seed box (V_b), considering 10% freeboard to avoid spillage during operation, would be:

$$V_b = 1.1 \times V_s \qquad \ldots (30)$$

where, V_s = volume of seed, m^3

$$\text{Also, } V_s = W_s / \rho_s \qquad \ldots (31)$$

where, W_s = weight of seed in the box (30 kg); and ρ_s = bulk density of seed (522 $kg \cdot m^{-3}$)[(20)]

Putting these values in Eq. (31) then we get V_s = 30/522 = 0.057 m^3

Thus, from Eq. (30)

$$V_{sb} = 1.1 \times 0.057 = 0.063 \text{ m}^3$$

Hence, the volume of seedbox to hold 30 kg seed with 10% freeboard (V_{sb} = 0.063 m^3) Considering the shape of the box a combination of trapezoidal as well as rectangular cross-section the following formula could be used to determine the size of the seedbox. The ratio of section A to section B was kept as 3:7 for appropriate accommodation of hopper into the frame where the height of hopper was a constraint.

$$V_{sb} = V_A + V_B$$

where, V_A = volume of section —A of box; and V_B = volume of section —B of box

$$V_A = \frac{(B_s + T_{sb})}{2} \times H_{b1} \times L_b \qquad \ldots (32)$$

where, V_A = volume of the seed box, m^3; B_s = bottom width of the seed box (m) which is equal to diameter of seed roller (40 mm); T_{sb} = top width of the seed box, m ($B_s + 2 \times L$); L_b = length of the bottom section of seed box, m (equal to width of mat at end = 1.0 m); and H_b = height of the seed box, m

$$\text{Also, } T_{sb} = B_s + 2 \times L \;\&\; L = H_{b1} \cot\theta \qquad \ldots (33)$$

Then Eq. (32) can be written as

$$V_A = (B_s + H_{b1} \cot\theta) \times H_{b1} \times L_b \qquad \ldots (34)$$

Substituting the value of L_b, θ and V_a (30% of V_{sb} = 0.0189 m^3) Eq. (13) will yield as

$$0.0189 = (0.04 + H_{b1} \cot 44°) \times H_{b1} \times 1.0 \qquad \ldots (35)$$

$$0 = 1.04\, H_{b1}^2 + 0.04\, H_{b1} - 0.0189 \qquad \ldots (36)$$

Solving the above quadratic Eq. (35), and simultaneously other relations it yields

H_{b1} = 117 mm and T_{sb} = 283 mm

Now, the top section i.e. section B was rectangular section where the length was fixed (L_t =1000 mm) thus volume was calculated as:

$$V_B = T_{sb} \times L_t \times H_{b2} \text{ (as } V_B = Vs_b \times 0.7 = 0.0441 \text{ m}^3)$$

Substituting the values, H_{b2} comes out 156 mm, thus total height of hopper is 273 mm.

Thickness of the seed box (t_s) calculated (when b_s = 1000 $kg.cm^{-2}$) from Eq. (29) as below.[18]

$$t_s = \sqrt[3]{\frac{3 \times 0.000522 \times 4^2 \times 27.3^2}{4 \times 4 \times 1000}} = 0.105 \text{ cm} = 1.1 \text{ mm}$$

The computed and selected values from the design of different parts of the machine have been given in Table 1.

Development and Fabrication

In order to assist the manufacturing, the tractor-operated seeder was developed and fabricated on the

Table 1 — Computed and selected values from design section

Component	Computed value, mm	Selected value, mm
Height of cleat	39.0	40.0
Height of conveyor sidewall	80.0	80.0
Pitch of the screw	150.0	150.0
Diameter of the screw	150.0	150.0
Length of screw conveyor	1700.0	1700.0
Top width of soil hopper	378.0	400.0
Total height of soil hopper	330.0	350.0
Thickness of the soil hopper	2.1	2.5
Diameter of soil fluted roller	178.7	180.0
Top width of seed box	283.0	285.0
Total height of seed box	273.0	300.0
Thickness of the seed box	1.1	2.0

basis of designed parameters. The machine was conceptualized, developed and fabricated at the Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana, India. Different views of 2D drawing of the developed machine are shown in Fig. 3. The suitable size of pulley and belts were selected from the market for power transmission system. A view of power transmission of tractor-operated seeder for mat type paddy nursery is shown in Fig. 4.

The developed parts and assemblies were assembled together on the frame. Initially, wheel assembly was attached at the rear side of the machine frame. The depth control roller was fixed at the front side of the machine. The screw conveyor and trough were assembled on the frame rear side. The trough was covered on top side with MS sheet. A soil conveyor unit was assembled with the help of side wings on both side of the frame. A top edge of the conveyor was placed at the edge of the screw conveyor housing. The nut and bolts were used for the fitting of the conveyor on frame. Sieving system was mounted to the frame so that soil would fall on the sieve tray. Simultaneously, soil metering unit was fixed to the frame using nut and bolts. Polythene sheet roller was attached with the frame with suitable bearings. Two steel polythene sheet rollers were placed subsequently in between the depth control roller and the soil hopper. First roller of diameter 50 mm placed at nearer to the depth control roller which was used to roll or wrap the polythene sheet. A gear box was fixed at the front and exactly on the median plane of the frame. The main drive shaft was fixed at the middle of the frame. The

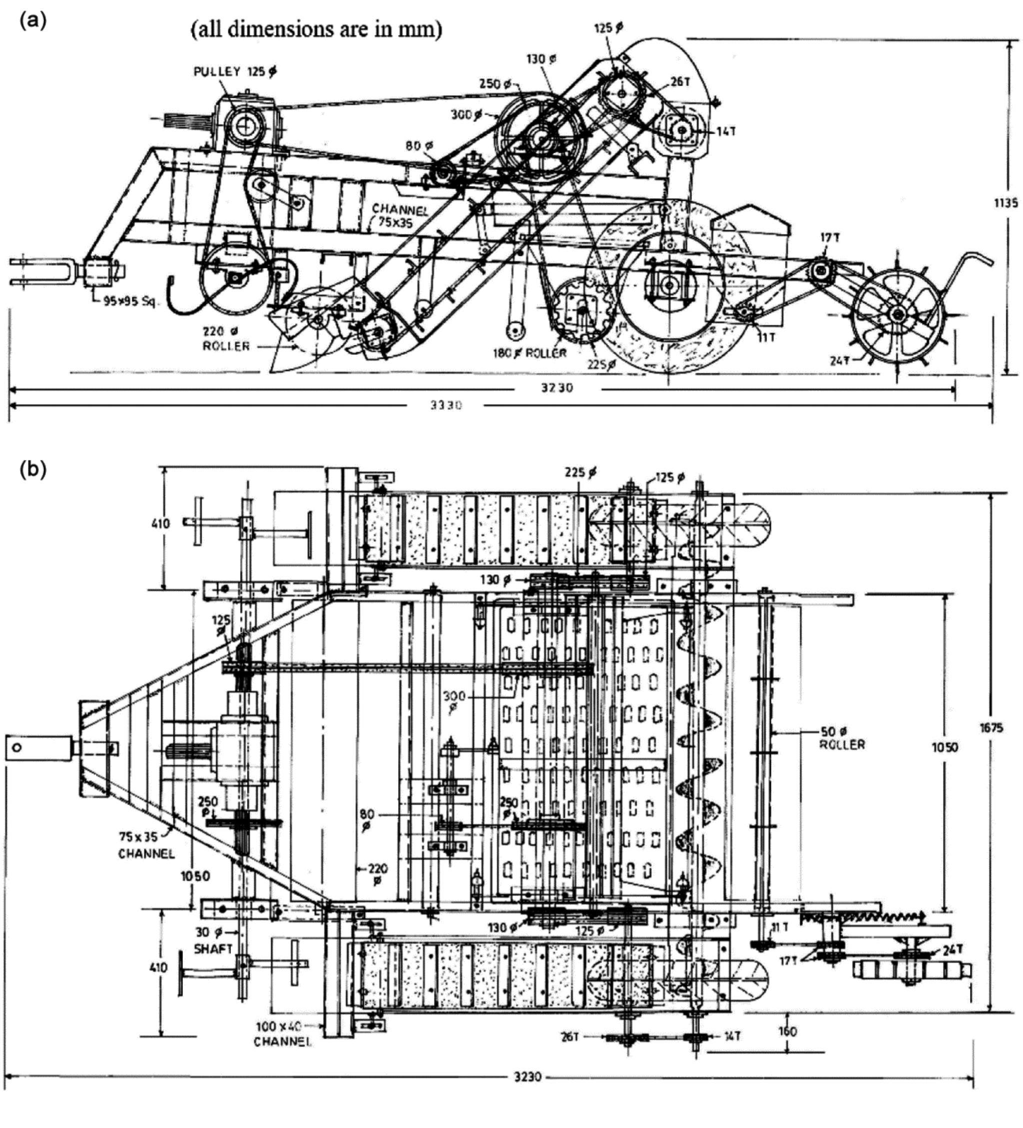

Fig. 3 —Drawing (2D) views of the developed machine (a) side view, and (b) top view

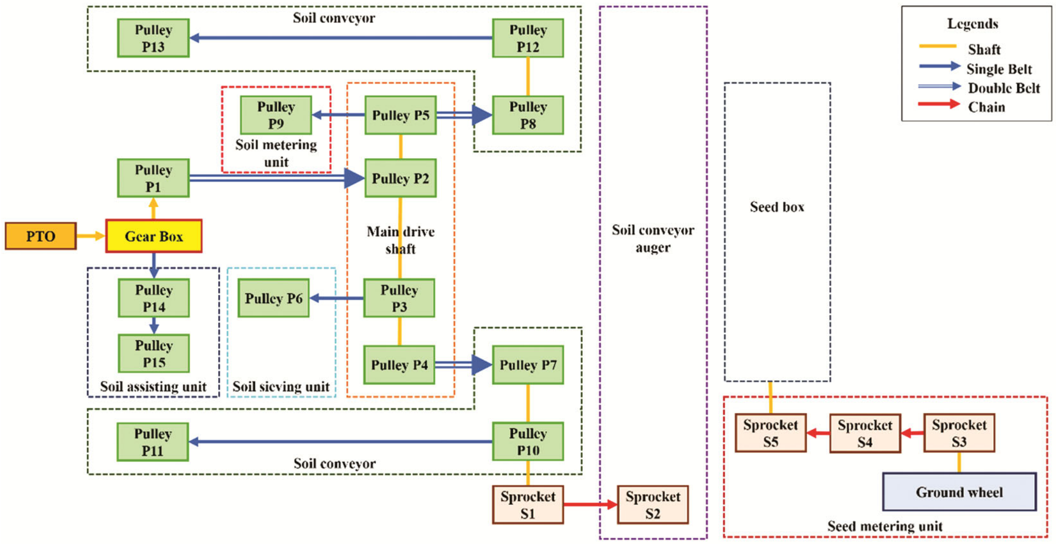

Fig. 4 — A view of power transmission of the designed machine

Table 2 — Specifications of tractor-operated seeder designed for sowing mat type nursery

Machine component	Specification
Source of power, hp	Tractor PTO, ≥ 35
Soil cutting unit	02
Width of cut, mm	240
Soil conveyor unit	02
Angle of inclination from ground, degree	40
Soil conveyor auger	01
Diameter and pitch, mm	150, 150
Sieve unit	01
Sieve dimension (L × B), mm	910 × 560
Soil metering mechanism	Fluted type (13 flutes)
Length and diameter of roller, mm	1000, 180
Seed metering mechanism	Fluted type (14 flutes)
Length and diameter of roller, mm	1000, 40
Soil pressing roller	01
Length and diameter, mm	1000, 220
Polythene wrapping roller	01
Length and diameter, mm	1040, 50
Overall machine dimensions (L × B × H), mm	3330 × 1675 × 1135

seed metering unit was fixed at rear of the frame bottom side. Specifications and stationary view of tractor-operated seeder designed for sowing of mat type nursery is shown in are given in Table 2 and Fig. 5, respectively.

Performance Evaluation

Laboratory (Controlled Field) Evaluation

In the present study, machine evaluation was carried out under controlled field conditions (such as constant moisture content, soil type, field preparation, etc.) that lead to homogeneity which ultimately resembles laboratory experiments. Thus, a factorial completely randomized design was selected at two

Fig. 5 — A stationary view of developed/assembled tractor-operated seeder for mat type nursery

levels of depth of soil cut (40 and 80 mm), three levels of sieve type (round 156 openings with hole diameter of 18 mm, oval 120 openings each having dimensions of 50 × 25 mm and rectangle 225 openings each having dimensions of 25 × 20 mm) and three levels of sieve oscillation (238, 318 and 398 oscillations·min^{-1}) as treatments to evaluate the performance of the developed machine. The effect of these parameters was studied on uniformity coefficient of seed and soil spread. This study was carried out on loam soil and its moisture content ranged between 10.0–14.0% (d.b.). The uniformity of seed spread was measured based on length of bite of cut of transplanter finger. Average length of bite of cut of transplanter finger was taken into consideration for counting number of seeds in grid size (14.11 × 11.70 mm) of 1.65 cm^2 area of a frame (300 × 300 mm). After the operation of seeder, the frame was placed randomly over the seeded bed (middle and sides) and number of seeds was counted in each rectangle at three random locations. Soil mat thickness was measured on the polythene sheet by removing soil with the help of blade. Measurements were taken at 10 random locations on the soil bed with three replications. A view of measurement of seed spread and soil spread in field is shown in Fig. 6(a) and Fig. 6(b), respectively. Uniformity coefficient (C_v) of soil and seed was calculated using the formula given below.

$$C_{v,}\% = \frac{\sigma}{\mu} \times 100$$

where, σ = standard deviation; and μ = mean

Comparative Field Evaluation

Based on the controlled field evaluation, comparative field evaluation was carried out to assess the coefficient of uniformity for seed and soil spread, field capacity, and labour requirement from nursery sowing operations for machine and control (manual method raising of nursery using frames). The developed machine was evaluated for two treatments of forward speed as F1 (1.7 $km{\cdot}h^{-1}$) and F2 (2.2 $km{\cdot}h^{-1}$) based on operational parameters selected from the laboratory evaluation. A view of field evaluation of the developed machine in Fig. 6 (c).

Data Analysis

ANOVA was conducted to evaluate the effects of depth of soil cut, sieve type, and sieve oscillation on the coefficient of uniformity for seed and soil spread during nursery preparation. The dependent parameters of the field study were compared with control using Dunnett test with two treatments. The analysis was done using statistical software SAS 9.3 (SAS Institute Inc., Cary, NC, USA) for Analysis of variance and post hoc test for comparisons of different treatment combinations. Analyses were inferred at 5% level of significance.

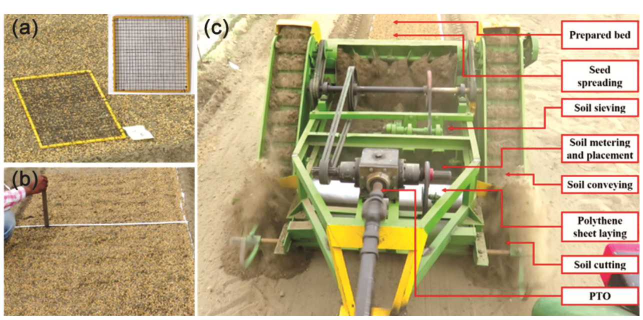

Fig. 6 — A view of dependent parameter measurement and field evaluation of the developed machine (a) seed spread, (b) soil spread, and (c) machine during operation

Results and Discussion

Laboratory (Controlled Field) Evaluation

The preliminary evaluation of the designed prototype of a nursery seeder was carried out in controlled field conditions. During initial preliminary trials, the working of the machine in terms of amount of soil cut, soil conveyed, and soil metered was satisfactory and uniform distribution of soil (mat thickness) was observed.

Coefficient of Uniformity for Seed Spread (U_{sd})

The effect of sieve type, sieve oscillation, and depth of soil cut on coefficient of uniformity for seed spread is shown in Fig.7(a) and Fig. 7(b). Coefficient of uniformity was decreased with increase in level of sieve type, sieve oscillation, and depth of soil cut. The mean lower coefficient of uniformity for seed spread at sieve type-III, sieve oscillations 398 $osc{\cdot}min^{-1}$, and depth of soil cut 80 mm was 9.67%. The effect of sieve type, sieve oscillation, and depth of soil cut was found to be significant ($p < 0.0001$) on coefficient of uniformity for seed spread (Table 3). This might be due to higher sieve oscillation were able to deliver pulverized soil to soil metering unit, sieve type along with optimum sieve opening and higher depth of soil cut formed a better surface quality of soil mat for seed. Sharma and Singh[4] could achieve the desired uniformity for spreading seed but required 4–5 passes of the manual seed spreading device on the same mat.

Coefficient of Uniformity for Soil Spread (U_{sl})

Means of coefficient of uniformity of soil spread corresponding to three levels of sieve type, three levels of sieve oscillation, and two levels of depth of soil cut is given in Fig 7 (c) & Fig 7 (d). Coefficient of uniformity was decreased consistently with increase in levels of sieve type, sieve oscillation, and depth of soil cut. The mean lower coefficient of uniformity for soil spread at sieve type-III (rectangular opening) sieve oscillations of 398 $osc{\cdot}min^{-1}$, and depth of soil cut 80 mm was 9.67%. The effect of sieve type, sieve oscillation, and depth of soil cut on coefficient of uniformity for soil spread was significant ($p < 0.0001$). This may be resulted due to higher soil pulverized at sieve oscillations and again it was sieved from clods and hence had a uniform flow from the soil metering system on the bed. The individual effect of sieve type, sieve

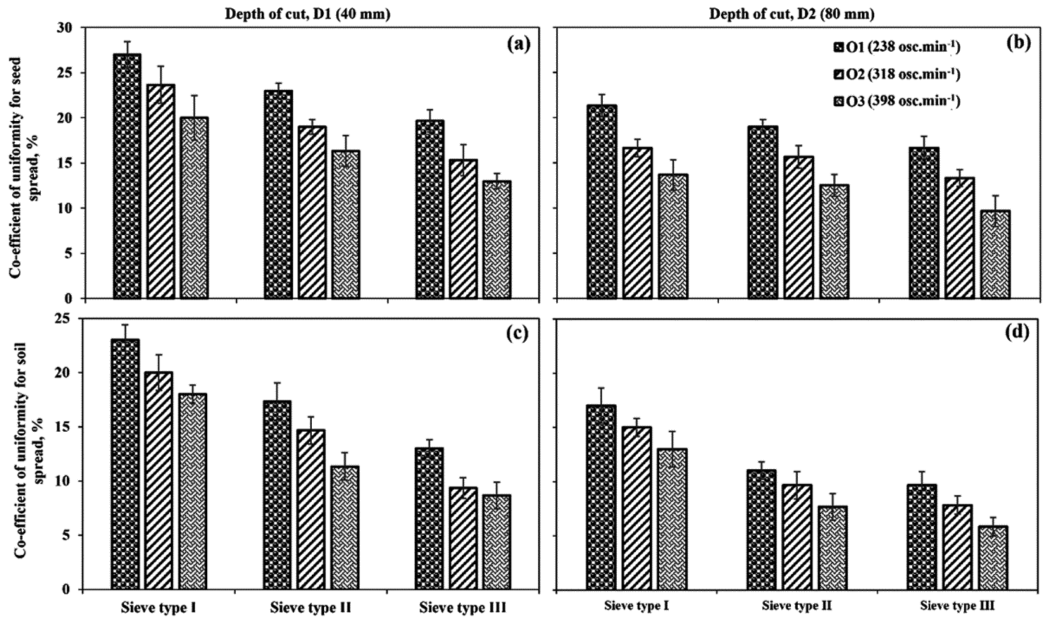

Fig. 7 — Effect of sieve type, sieve oscillation, and depth of soil cut on coefficient of uniformity for seed (a) & (b), and soil spread (c) & (d): depth of soil cut of 40 mm (D1), depth of soil cut of 80 mm (D2), round shape opening (156 openings) of sieve hole having 18 mm diameter (Sieve type I), oval-shaped (120 openings) having dimensions 50 × 25 mm (Sieve type II), rectangular-shaped (225 openings) having dimensions 25 × 20 mm (Sieve type III), 238 sieve oscillation.min^{-1} (O1), 318 sieve oscillation·min^{-1} (O2) and 398 sieve oscillation·min^{-1} (O3), respectively

Table 3 — Statistics of sieve oscillations (S_o, oscillations.min^{-1}), sieve type (S_t), and depth of soil cut (D_c, mm) effects on coefficient of uniformity for seed (U_{sd}, %) and soil spread (U_{sl}, %)

Source	DF	Sum of squares		Mean of squares		F-value		p-value		Significance	
		U_{sd}	U_{sl}	U_{sd}	U_{sl}	U_{sd}	U_{sl}	U_{sd}	U_{sl}	U_{sd}	U_{sl}
S_o	2	432.250	176.083	216.125	88.042	72.150	38.810	<.0001	<.0001	S	S
S_t	2	300.528	691.444	150.264	345.722	50.170	152.400	<.0001	<.0001	S	S
D_c	1	247.042	249.185	247.042	249.185	82.470	109.840	<.0001	<.0001	S	S
$S_o \times S_t$	4	0.889	2.722	0.222	0.681	0.070	0.300	0.9896	0.8760	NS	NS
$S_o \times D_c$	2	0.361	5.787	0.181	2.894	0.060	1.280	0.9416	0.2916	NS	NS
$S_t \times D_c$	2	30.528	20.704	15.264	10.352	5.100	4.560	0.0113	0.0171	S	S
$S_o \times S_t \times D_c$	4	2.778	3.241	0.694	0.810	0.230	0.360	0.9187	0.8374	NS	NS

S: Significant at 5%, NS: Non-significant, DF: Degrees of freedom

oscillation, and depth of soil cut was significantly different ($p < 0.0001$).

Field Evaluation

Comparative field evaluation of the developed tractor-operated seeder was carried out with control on the medium-type soil for sowing of mat type nursery. Dunnett test indicated that three treatments were non-significant ($p > 0.05$) corresponding to coefficient of uniformity for seed (Fig. 8 (a)) and soil spread (Fig. 8 (b)). However, evaluation of the machine indicated that the field capacity (0.11–0.14 ha·h^{-1}) was significantly ($p < 0.05$) different with control (0.001 ha·h^{-1}) for all the treatment combinations (Fig. 8 (c)). Moreover, labour requirement using developed machine (57.4–72.7 man-h·ha^{-1}) was significantly ($p < 0.05$) lower as compare to control (2000.0 man-h·ha^{-1}) as shown in Fig. 8 (d). Thus, it is clear from results that, machine can work at forward speed 1.7 km·h^{-1} (0.11 ha·h^{-1}) and 2.2 km.h^{-1} (0.14 ha·h^{-1}). Optimum performance of the machine was obtained using rectangular sieve type opening with size of 25 × 20 mm, sieve oscillations 398 osc·min^{-1}, and depth of soil cut of 80 mm at 1.7 km·h^{-1} machine forward speed. At these operational parameters, the coefficient of uniformity for seed was 7.33%, coefficient of uniformity for soil spread 5.67%, fuel consumption 39.6 l·ha^{-1} and actual field capacity of 0.11 ha·h^{-1}.

Economic Analysis

The material and fabrication cost for the developed machine was Rs.1 50 000. Calculations indicated that, total of fixed and variable cost of 1211.9 Rs·h^{-1}. Cost

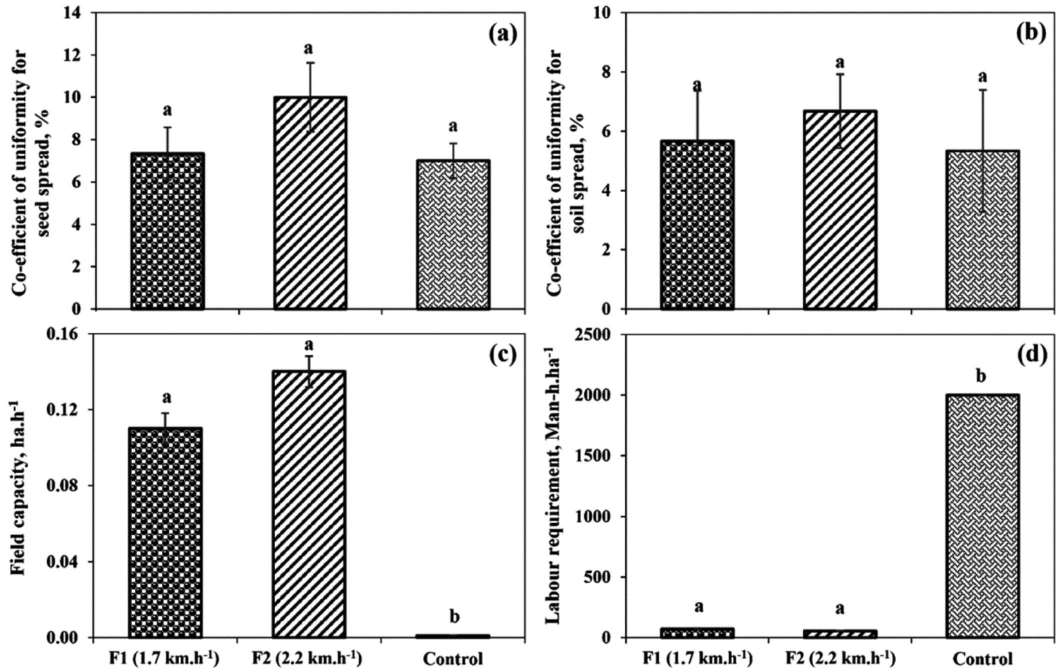

Fig. 8 — Comparison of control with other treatment combinations (a) seed spread, (b) soil spread, (c) field capacity, and (d) labour requirement (means with same letter are not significantly different, $p>0.05$): machine forward speed of 1.7 km.h^{-1} (F1), machine forward speed of 2.2 km.h^{-1} (F2), manual method of sowing mat type nursery with frames (control)

incurred for sowing of nursery using developed machine and manual method was found to be Rs 8656.2 and Rs 81 000.0 ha^{-1}, respectively. Labour saving using tractor-operated seeder for mat type paddy nursery was observed 86.4% as compared to manual method of sowing mat type nursery using MS frames.

Conclusions

Tractor-operated mat nursery seeder was designed, developed/fabricated and its evaluation was carried out. Optimum performance of the machine was obtained using rectangular sieve opening (size of 25 × 20 mm) type, sieve oscillations of 398 osc·min^{-1}, and depth of soil cut 80 mm at 1.7 km·h^{-1} machine forward speed. At these operational parameters, the coefficient of uniformity for seed was 7.33%, coefficient of uniformity for soil spread 5.67%, amount of fuel consumption 39.6 l·ha^{-1} and actual field capacity of 0.11 ha·h^{-1}. Labour saving using the designed tractor-operated seeder for mat type paddy nursery was observed 86.4% as compared to the manual method of sowing mat type nursery using frames in open field.

Acknowledgments

Sufficient funding provided under AICRP on FIM by ICAR and research facilities/infrastructure provided by PAU, Ludhiana for the conduct of research is greatly acknowledged.

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