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Development of Subsoiler Suitable for Chhattisgarh Plain

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ABSTRACT

Compacted soil hard-pans restrict crop growth by limiting root access to nutrient and moisture in the subsoil. Soil can become deeply compacted in areas tracked by heavy agricultural machineries for primary as well as secondary tillage operation and land management practices. The increased adoption of rotavator among state's farmer results the hardpan formation. Compacted layer typically developed 15-30 cm below the surface where conventional cultivators can't reach. These layer require special equipment called subsoiler and similar chisel/mole plough to fracture them. The objective of this study was to develop an effective subsoiler suitable for Chhattisgarh region that minimized soil disturbance and energy requirements. A subsoiler of 7 cm wide share and operated by 35 hp tractor was developed. The field performance result of subsoiler indicates that it is suitable for operating at 4 km/h forward speed. For achieving 45 cm depth of subsoiling it requires 2.86 meter distance to travel. The subsoiler is suitable for dry and moist soil as the wheel slip was within acceptable limit i.e. around 15 %, field efficiency was more than 80 % and fuel consumption wasless than 4 lit/h. However it was not suitable for wet soil as it results wheel slip of more than 25 %, field efficiency only 66.6 % and fuel consumption 4.70 lit/h. The operating cost of subsoiler was calculated as 427 Rs/ha.

Key words: *Subsoiler, Solonetzic soil, Hard Pan, Deep ploughing, Sub-surface.*

INTRODUCTION

Solonetzic soils, often called burnout or gumbo soils, are characterized by a tough, impermeable hardpan that may vary from 5 to 30 cm or more below the surface[1]. The water infiltration into soil, crop emergence, root penetration and crop nutrient and water uptake is restricted by these hard pan which result in depressed crop yield. Variation in the hardpan causes crops to have a wavy growth pattern during periods of moisture stress. Human-induced compaction of agricultural soil can be the result of using tillage equipment during soil cultivation or result from the heavy weight of field equipment. Deep ploughing and subsoiling are some methods for improving some of these soils[2].

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Subsoiling fractures compacted soil without adversely disturbing plant life, topsoil and surface residue. Fracturing compacted soil promotes root penetration by reducing soil density and strength, improving moisture infiltration and retention, and increasing air space in the soil. How effectively compacted layers are fractured depends on the soil moisture, structure, texture, type, composition, porosity, density and clay content. Success depends on the type of equipment selected, its configuration and the speed with which it is pulled on the ground. No one piece of equipment or configuration works best for all situation and soil condition, making it difficult to define exact specification for subsoiling equipment and operation[3]. Adjustment requires according to field condition.

Modem tractors and machinery are partly responsible for soil compaction and soil pans. Subsoilers are used to break compacted soil, allowing free passage of air and water. For conducting this important operation in crop production, suitable Subsoiler is needed. However without proper land preparation, higher yield of crop production by applying other input cannot be expected. Therefore fields should be subsoiled time to time at right angles to the intended direction of ploughing. Sometimes fanners use expensive, un-tested, imported Ploughs for this purpose. The commercial ploughs used in many developed countries, are beyond the financial capabilities of local farmers. Properly designed subsoiler are usually mounted on the tractor and consist of a strong frame with one or more legs. Each leg has a replaceable point. Working depth is normally from 30 to 50 cm and spacing between passes is from 0.5 to 2m [4]. Subsoiling is best carried out after the cereal harvest when the soil is dry. Considering the above facts, a low cost suitable Subsoiler was developed.

MATERIAL AND METHODS

The strength, durability, operation and economy which depend largely upon quality of material of fabrication were considered in the designing of subsoiler. Keeping in view the physical properties of *Alfisols* and the subsoiling requirements for fracturing of the compacted layer the design of subsoiler was initiated. The choice of material as per availability was made on the basis of cost, ease of handling & processing, suitability to satisfy the requirements and reliability while in operation.

Measurement of Soil Physical Properties

The physical property of soil plays very vital role for proper operation and safe design of soil working tillage tool. The physical properties viz. moisture content, bulk density and cone index were measured before developing and during the testing of the subsoiler at different depth in the field (fig. 1).The bulk density of soil was determined by core cutter method[5] for which soil samples were taken from three different depth range (0-15, 15-30 and 30-45 cm). The moisture content of above sample was also determined by oven drying method[6]. For determining cone index a cone penetrometer was inserted in field at different locations and at a different profile of soil[7]. Soil cone penetrometer with 30 degree cone apex angle and a flat iron plate of size 70 x 50 mm² was used.

a) b)

Fig. 1: Soil Physical Properties Measurement; a) Core Cutter, b) Cone Index Measurement

Constructional Details of Subsoiler

Frame

The frame of trapezoidal shape was provided for attaching different components of subsoiler. The overall dimension of frame was 680 x 180 x 160 mm which was made from 91x5.5x1 mm MS flat section. The hitch pin on the frame was welded on MS angle iron section to increase strength and reduce overall weight of subsoiler compared to the square/pipe section. The labeled design of frame is shown in fig. 2(a).

Shank

Shank is the part of subsoiler which connects Shoe and share with frame. It was fabricated by profile cutting of MS sheet of 25 mm thickness. The overall dimension of shank was 1050 x160 x 25 mm. Both side on front portion of shank bevel edge of 20 mm was provided. The labeled design of shank is shown in fig. 2(b).

Shoe

The shoe is the part of subsoiler which acts as base for attaching share. It is fixed at the bottom of Shank. The shoe of developed subsoiler was irregular in shape and made of MS flat of 370 mm long 70 mm thick. The lower portion of Shank was sandwiched at one end of shoe having 25 mm cut. Two bolt of 14 mm diameter was provided to fix shank with shoe. Two holes for mounting share with plough bolt of diameter 20 mm was also provided on top face of shoe. The labeled design of shoe is shown in fig. 2(c).

Share

The share is main soil working component of the subsoiler which penetrates into soil. It had the highest wear potential thus was made of high carbon steel. The share tip was fixed at angle of 22º for easy penetration and to minimize draft. Reversible type share was used for better utility.

Design of Share

The power required to operate subsoiler is very high. As per the tractor available in Chhattisgarh the maximum power of tractor which can be available among farmer ranges from 30-40 hp. Thus we have assumed that the available tractor power as 35 hp. Reports from literature indicate that about 20% to 55% of the available tractor energy is wasted at the tractive device-soil interface [8]. The available drawbar power of tractor for subsoiling is taken as 40% of Brake horse power of tractor i.e. 14hp for safe designing of subsoiler. Hence the maximum drawbar pull that can be exerted by tractor is calculated by following formula [9].

$$\text{Pull (kg)} = \frac{\text{Drawbar Power (hp)} \times 4500}{\text{Speed (m/min)}}$$

The speed of 5-6 km/h is recommended to sufficiently break the soil[10]. For efficient and safe operation of subsoiler we have considered speed of operation as 4 km/h. So from above formula the maximum drawbar pull that can be exerted by tractor for safe operation of subsoiler comes to be 945 kg. Now the width of share can be calculated by following formula[11].

$$W_s = \frac{D_i}{n d_p R}$$

Where, W_s= width of share (cm); D_i= draft requirement of implement (kg); n= number of bottoms of subsoiler; d_p= depth of ploughing (cm); R= Specific resistance of soil (kg/cm^2). The draft is horizontal component of pull in the direction of travel. In this design we considered that the line of pull and direction of travel are at zero degree to each other i.e. the draft is equal to pull. The specific soil resistance experienced by subsoiler with conventional straight tine at 40 cm depth is 1.07 kg/cm^2 [12]. The design is for extreme condition so we have considered heavy soil for which specific soil resistance and depth of subsoiling will be 2 kg/cm^2 and 60 cm respectively. So from above equation the width of share comes to be 7.87 cm. Hence for safe design width of share was taken as 7 cm. The overall dimension of share was 310x70x10 mm with both ends beveled up to 60 mm along length. The labeled design of share is shown in fig. 2(d).

Hitch Unit

The hitch unit developed for subsoiler was pyramid type attachable to three point linkage of CAT-II size. The mast height of hitching unit was 520 mm with 860 mm overall width.

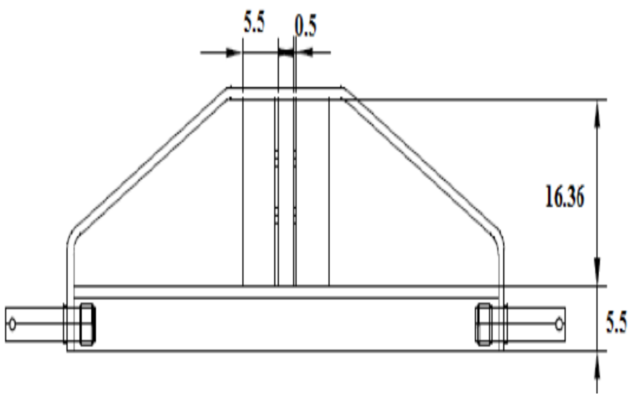
The length and diameter of hitch pin was 90 and 30 mm respectively. The yoke was 55 mm. The labeled design of hitch unit is shown in fig. 2(e).

Material of construction for Subsoiler

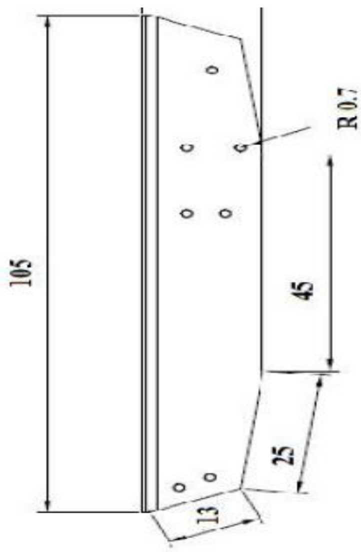
The material used for development of subsoiler was mild steel and carbon steel. The soil working part i.e. share was fabricated from high carbon steel to avoid excessive wearing. The detail of material of construction of different components of subsoiler and their size is depicted in table 1.

Table 1: Materials used for fabrication of subsoiler

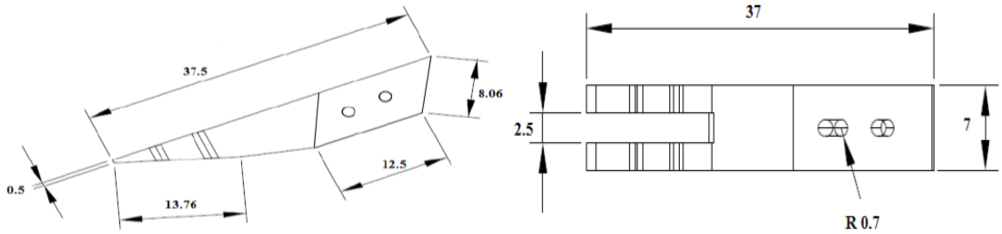
S.No.	Parts	Materials	Size (mm)
1	Frame	MS flat	5.5x1
2	Shank	MS flat	160x25
3	Shoe	MS flat	370x70
4	Share	High carbon steel	310x70x10
5	Hitch unit	MS flat	60x10
6	Hitch pin	Carbon steel	90x30 mm diameter



(a) Frame

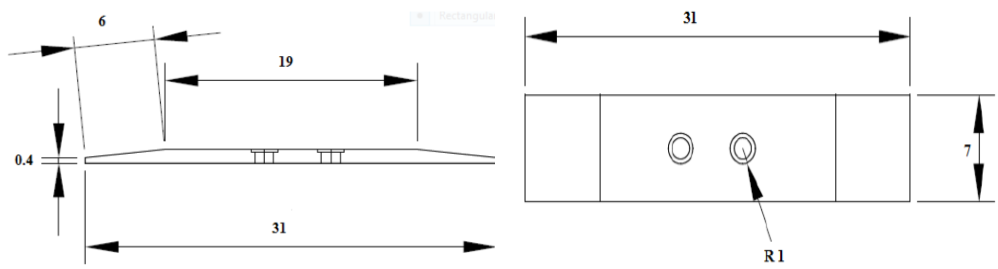


(b) Shank



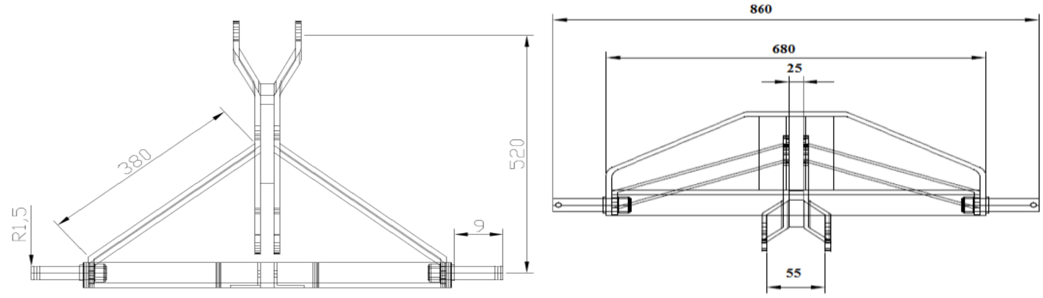
Side View **Top View**

(c) Shoe



Side View **Top View**

(d) Share



Front View **Top View**

(e) Hitch Unit

Fig. 2: Various Components of Subsoiler

a) **b)**

Fig. 3: Developed subsoiler; a) Front view, b) Working Condition

RESULTS AND DISCUSSION

The subsoiler was developed and tested at the Department of Farm Machinery and Power Engineering, Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. After development and fabrication of the prototype of subsoiler by considering the economic approach tested in the field in order to assess the performance.

Soil Physical Properties of Experimental Field

The physical property of field soil at different depth was measured for finalizing the suitable field condition for efficient working of developed subsoiler. The soil condition of field was clay-enriched with relatively high native fertility. Result presented in table 2 shows the experimental observation of bulk density and soil moisture content was conducted in three field condition namely dry, moist and wet. The bulk density of soil in dry, moist and wet field condition for 0-15, 15-30 and 30-45 cm depth was 1.55, 1.62 & 1.70; 1.57, 1.68 & 1.71 and 1.53, 1.65 & 1.70 g/cm^3 respectively. The moisture content of soil in dry, moist and wet field condition for 0-15, 15-30 and 30-45 cm depth was 8.31, 9.40 & 10.08; 12.0, 13.10 & 15.24 and 25.32, 22.26 & 20.36 % respectively.

Table 2: Bulk density and moisture content of experimental field

Field Condition	Soil Parameters	Depth (cm)		
		0-15	15-30	30-45
Dry	Bulk density (g/cm³)	1.55	1.62	1.70
	Moisture content (% wb)	8.31	9.40	10.08
Moist	Bulk density (g/cm³)	1.57	1.68	1.71
	Moisture content (% wb)	12.0	13.10	15.24
Wet	Bulk density (g/cm³)	1.53	1.65	1.70
	Moisture content (% wb)	25.32	22.26	20.36

Field Performance Test of Subsoiler

In order to test the performance of subsoiler for deep tillage of the field, it was operated in the field. The overall performance of the subsoiler was evaluated on the basis of field capacity, field efficiency, labor requirement, cost of operation, energy requirement and quality of work.

Distance required to achieve 45 cm depth

The actual working depth of developed subsoiler ranges from 45-60 cm which can be achieved by operating the subsoiler up to certain distance. Table 3 shows that the subsoiler has to be operated up to 2.86 meter distance for achieving working depth of 45 cm. The drive wheel of tractor needs to complete 3/4 revolution for achieving this depth.

Soil Inversion

Subsoiling operation does not results much soil inversion but brake hard pan in subsurface. The shank of developed subsoiler was 25 mm thick with beveled edge up to 20 mm so it cuts only thin slit and does not create much disturbance in top soil. Table 4 indicates that the developed subsoiler results 13-15 % soil inversion.

Wheel slip

Wheel slip is measure of tractor to suit the developed implement according to power available but here in case of wet condition due to self-weight of tractor subsoiling is not performed satisfactory. For operating tillage implement using drawbar power wheel slip up to 15 % is acceptable [13]. Table 5 shows the wheel slip for dry and moist soil is inacceptable range which is 14.11 and 15.64 % respectively.

Field efficiency and fuel consumption under different field condition

The subsoiler was operated at 1 meter spacing between successive pass and 4 km/h forward speed. The field efficiency and fuel consumption of subsoiler was calculated for different field condition. The maximum field efficiency of the subsoiler was found to be 83.3 % in dry field condition followed by 80.0 and 66.66 % in moist and wet field condition (Table 4). Similarly minimum fuel consumption for operating subsoiler was found to be 3.49 liter per hour in dry field condition followed by 3.98 and 4.70 liter per hour in moist and wet field condition (Table 6).

Table 3: Distance required to achieve 45 cm depth

Field	No of wheel revolution	Distance (m)
1	3/4	2.80
2	3/4	2.90
3	3/4	2.90
Mean	**3/4**	**2.86**

Table 4: Soil Inversion

Field		No of weed before ploughing per m²	No of weed after ploughing per m²	Soil inversion (%)
	1	79	68.33	13.92
	2	135.33	115.33	14.92
	3	153.66	133.66	12.53
Mean		**122.66**	**105.77**	**13.79**

Table 5: Wheel slip under different field condition

Field condition	Distance (m)	Theoretical revolution	Observed revolution	Wheel slip (%)
Dry	20	5.26	6	14.06
	30	7.89	9	14.06
Moist	20	5.26	6.1	15.90
	30	7.89	9.14	15.90
Wet	20	5.26	6.75	28.32
	30	7.89	10	26.74

Table 6: Field efficiency and fuel consumption under different field condition

Field Condition	Area (m²)	Actual area covered (m²)	Field efficiency (%)	Fuel Consumption (ml)	Fuel Consumption (lit/h)
Dry	300	250	83.3	1280	3.49
Moist	300	240	80.0	1660	3.98
Wet	300	200	66.6	2600	4.70

Energy consumption

The energy consumption for operation of subsoiler was calculated using energy conversion coefficient[14].The maximum energy consumption of 2590.72 MJ/ha was recorded in case of dry field followed by 3297.98 and 5147.78 MJ/ha in moist and wet field respectively (Table 7). Wet field condition consumed more energy than the dry and moist field due to low traveling speed, higher fuel consumption and higher time required for operating the same size of field.

Table 7: Energy consumption under different field condition

S.No.	Parameters	Energy Consumption (MJ/ha)		
		Dry field	Moist field	Wet field
1	Diesel Energy	2424.64	3110.69	4898.80
2	Human Energy	24.18	27.20	36.28
3	Implement Energy	15.73	17.69	23.60
4	Tractor Energy	126.80	142.40	189.91
Total		**2590.72**	**3297.98**	**5147.78**

Cost of Operation

Cost of operation by subsoiler with tractor was calculated by straight line method of cost analysis[15]. Total operational cost was found 427 Rs/ha and individually it was 411 Rs/ha and 15.6 Rs/ha for tractor and subsoiler respectively.

CONCLUSIONS

Subsoiling is the main soil tillage practice for conservation systems which should be performed without excessively disturbing the soil surface which fractures compacted soil without adversely disturbing plant life, topsoil and surface residue. A subsoiler was developed to suit the field condition of Chhattisgarh region of the country. The developed subsoiler was tested in field at 4 km/h forward speed using 35 hp tractor. It was operated at 1 meter spacing between successive pass. Its performance was found satisfactory in dry and moist field condition having 10.08 and 15.24 % moisture content at 30-45 cm depth. The cost of operation of subsoiler was Rs 427 per hectare.

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