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# AMA

## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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# AMA

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# EDITORIAL

Some years ago, the report on “the limit of the growth” was published from Rome Club, which makes mention of expanding global population and limited natural resources. It says that at some point in the future social economy will stop growing with a limited supply of natural resources. That recognition drove us to find the solution toward a sustainable society. Also, sustainability has been, more and more, an important concept in the field of agriculture.

Now, in the early 21st century, world population exceeded six billion and is still increasing. The population is predicted to grow up to nine billion in 2050. China, the most highly populated country in the world, has controlled population growth as a national policy. Nevertheless, its population is estimated to be 1.4 billion, although the growth rate has decreased. In the second most populated country, India, the youth population growth rate will cause an even greater total population growth. India is expected to pass China in total population by 2030, and have over 1.5 billion people in 2050.

The Chinese economy has grown remarkably and has achieved almost 10 % annual growth. Average personal annual income has exceeded ten thousand dollars in Guangzhou. If the Chinese economy keeps growing at the present rate, 8 % annually, Chinese national income per capita in 2030 is estimated to be equal that of the 2004 per capita income in the United States. What happens if Chinese people possess three cars per four persons and use them as Americans presently use them? More than 98 million barrels of oil per day will be consumed, only in China, far more than the present total oil production in the world, 84 million barrels a day. What happens if the consumption rate of paper in China is the same as that presently consumed in the United States? Over 3.12 billion tons of paper will be needed, only in China, more than double the present total paper production in the world. All forests will disappear throughout the world at that time. Not only China, but India, and many other developing countries are eager to get a wealthy life.

The figures mentioned above, however, indicate that such economic growth will be impossible. The limited natural resources will not only put the brakes on economic growth but increase international tensions in connection with the struggle for natural resources if science and technology remain at the present level. Scientist and engineers are required to develop the technology which contributes to resources that save economic growth. The Japanese car company, Toyota, developed the hybrid car, “Prius”. Oil consumption will be cut to half if such hybrid cars are used all over the world. Present energy demand in the United States will be supplied only by wind power if wind power plants work sufficiently.

Production of bio-ethanol from corn has raised corn prices in the international market.
This has caused a food shortage not only in developing countries but also in developed countries where food has been over-supplied. The increase of bio-energy production will take the food away in the future, even in developed countries. It is of particular concern in Japan where food self-sufficiency rate is only 39 %, lower than 40 %!

We must develop and spread the technology contributing to sustainable agriculture to produce necessary food on limited farmland without losing the balance of ecological systems. Required mechanization of precision farming is substantial to raise land productivity. Agricultural machines will play an increasingly important role. AMA continues to make an effort to fulfill the task of agricultural engineers.

**Yoshisuke Kishida**
**Chief Editor**

Tokyo, Japan
September, 2007

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# Modification of Power Transmission System to the Stationary Combine Thresher


by

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## Abstract

The experiment was conducted in Atbra town, River Nile State, Sudan, to modify and evaluate the power transmission system to the stationary combine thresher. The modification was designed from a differential unit, a universal joint, shaft assembly for power transmission and power regulating unit.

The evaluation tests were carried out on two crops, sorghum and faba bean and compared with the unmodified thresher. The results indicated that the modification was significantly affected by the time taken for linking the machine to the tractor and also the average effective field capacity at ($p > 0.01$). The time taken for linking the machine was 0.3hr and 0.43hr, and the effective field capacity obtained was 1.43 fd/hr, 0.93 fd/hr for the modified and the unmodified machines respectively.


## Introduction

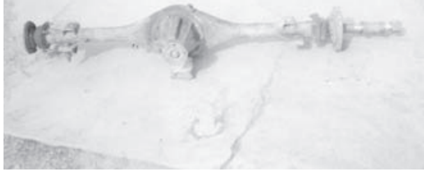
Power source in agriculture is of great importance in determining the level of agricultural mechanization and development. In the farm there are three sources of power for carrying out operations, the human power (about 0.07-0.1 kW) for limited amount of work which seldom exceeds subsistence level, and animal power, which is mainly used for draft work or transport of goods and people (Grossly and Kilgour, 1983). Mechanical power through tractors will continue to be an absolute necessity for agricultural production (Hunt, 1983). This power is required for two kinds of work, dynamic as for pulling or draft of implements and static for operating machines like water pumps or threshers.

Transmitting of power from its

**Plate 1** The chassis

**Plate 2** A combined differential chassis

**Plate 3** The differential



source to the points of use is one of the important variables to the farm equipment designers.

Krutz et al. (1984) cited that the selection of proper power transmission systems on mobile agricultural machinery must take into account the customer requirements, cost constraints, field usage, operator safety and reliability.

The primary function of the transmission member is to affect the change in speed between the two shafts as well as in linking them. It is generally required that the transmission system should have adequate reliability, service life, simple in construction, little resistance to motion, produce little noise, offers substantial resistance to vibration and easy to control.

There are many power transmission systems used, but the most extensively used in agricultural machinery applications are V-belts (Kepner et al., 1982; Krutz et al., 1984). Shigley and Mitchell (1983) stated that, the efficiency of V-belts ranges from 70-95 %. Gears and chains are also widely used for power transmission as linear or rotary motion (Hunt and Garver, 1973; Spotts, 1978; Crouse, 1980; Liljedahl et al., 1984). Other power transmission systems included bearings, shafts and universal joints. Spotts (1978) cited that, bearings are important in almost every kind of machine and device with rotating parts. Rotating shafts are of various lengths, diameters and types and they may be subjected to bending, tension, compression or torsion loads, acting singly or in combination with one another (Shigley and Mitchell, 1983; Hunt and Garver, 1973). Therefore it is important to locate the PTO shaft of the tractor with respect to the draw bar because of the telescoping action of the drive member when the tractor is moving over rough ground and the vibration of the universal joints when the tractor is turning (Liljedahl et al., 1984).

Stationary threshers which are drawn and operated by tractors PTO are now of great important in the Sudan for threshing many crops, but the system of power transmission from the tractor to the machine causes some losses in power use and efficiency of work. That is because power transmission to the machine is from one side, which means unlinking the machine from the tractor in the field and linking again (**Plate 1**).

Therefore, the main objectives of the present research work are to modify the power transmission system to the thresher and evaluate the modification, to improve the machine performance and minimize the operation costs.

## Modification of Power Transmission System of the Machine

The study was carried out in Darmally village, 13 km north of Atbara

**Fig. 1** Chassis

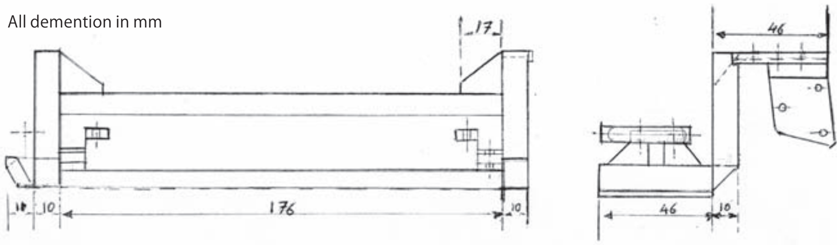



**Fig. 2** Shaft assembly for power transmission

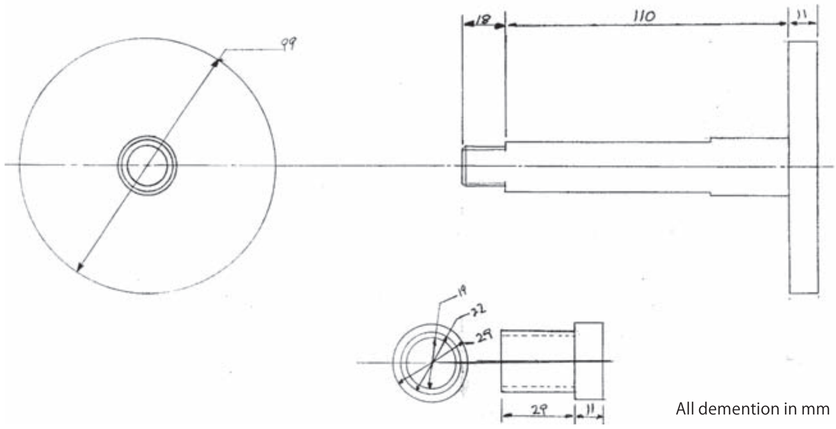
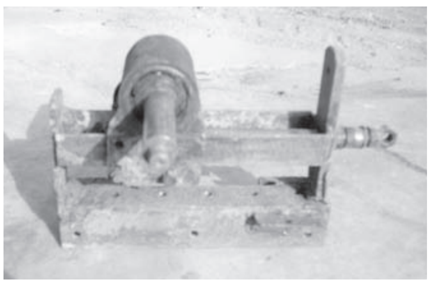



**Plate 4** The modified universal joint

**Plate 5** Shaft assembly for power transmission

**Plate 6** Power regulating unit



city and 325 km north of Khartoum city. A Massey Fergeson (290) tractor of 74.8 hp (maximum PTO) was used as a source of power for operating a stationary thresher with its technical specifications shown in **Table 1**. Other materials and tools used to carryout the modification included, iron sheets, iron angles, iron flanges, fixing bolts, nuts, shims, shafts, pulleys, bearings and other workshop equipment.

## Design of Modification Parts

### *The Differential*

A metal differential chassis was fixed in the front part of the thresher and used for locating the differential (**Plate 2** and **Fig. 1**). All design criteria were considered when fixing the chassis strongly with fixing bolts. A simple car differential was used for power transmission between two intersecting shafts at right angle (**Plate 3**). The original universal joint was modified to enable the connection between the differential and the cardan shaft. It consisted of a flange of 120 mm in diameter, a squared section shaft and a universal joint (**Plate 4**). Four fasteners were used to maintain the linkage between the modified universal joint and the differential through the flange.

### *Shaft Assembly for Power Transmission*

A shaft with the same specifications of the one used in the original power transmission unit of the thresher was selected. It consisted of a flange (198 mm in diameter), a shaft (255 mm in length) and a key (65 x 8 x 8 mm). This assembly was used for operating the pulley which was fixed with a fixing nut (23 mm in diameter) at the end of the shaft (**Plate 5** and **Fig. 2**). The assembly was firmly linked to the differential with five fixing bolts.

**Fig. 3a** Power regulating unit part 1

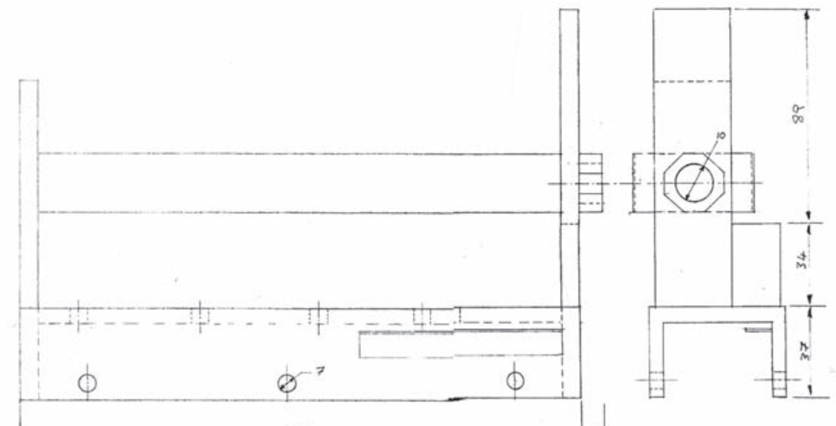
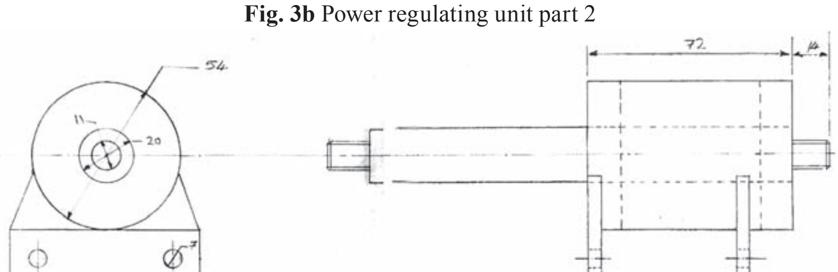



**Fig. 3b** Power regulating unit part 2




### *Power Regulating Unit*

It was designed from a shaft, pulleys and V-belts in order to get an optimum speed (rpm) transmitted from the shaft assembly to the threshing mechanism of the machine (**Plate 6** and **Fig. 3a**, **b**).

## A Modified Removable Draw Bar

A modified removable draw bar was developed and linked at the two points of the lower two linkage of the hydraulic system of the tractor. This helped in raising and lowering the power transmission shaft and the machine easily.

## Speed (rpm) Calculations

The following calculations were made to have an optimum speed (rpm) from the tractor PTO shaft to the threshing mechanism of the thresher through the differential and the regulating unit (**Plate 7**).

## Pulley Selection

In the normal situation, the thresher speed (rpm) ratio may be calculated as follows:

$$\text{Speed ratio} = \frac{PDv_1}{PDv_2} = \frac{SPv_2}{SPv_1},$$

(Krutz et at., 1984),

where

PD = pitch diameter (inch),

SP = shaft speed (rpm),

$V_1$ = driver pulley and

$V_2$ = driven pulley.

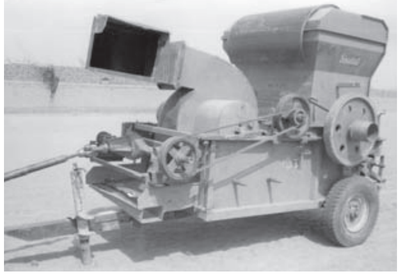
The driver pulley diameter of the thresher = 10 inch.

The driven pulley diameter of the thresher = 5.4 inch.

Speed ratio = 10/5.4 = 1.85

Therefore, the rpm of the threshing mechanism was calculated as

**Plate 7** Steps of power transmission



540 x 1.85 = 999 rpm

For the modified thresher with the added differential,

the differential speed ratio DSR =

$$\frac{\text{No of teeth of the driven gear}}{\text{No of teeth of the driver gear}},$$

(Maitra, 1985),

Driven and driver gear teeth were 39 & 8 and, therefore,

DSR = 39/8 = 4.88

To have the speed 999 rpm at the driven pulley (4) of the threshing unit (5.4 inch diameter), the following steps are taken (**Fig. 4**):

Stopping the right axle of the differential reduced DSR and double the speed coming from the tractor PTO at the first pulley (10 inch diameter) of the thresher (Liljedahl et al., 1984).

Speed (rpm) at pulley (1) =

$$\frac{\text{Tractor PTO (rpm)}}{\text{Differential SR}} = 540/2.44 =$$

221.54 rpm

To give the required speed in the threshing mechanism another pulley was used and its size calculated as follows (**Plate 7** and **Fig. 3**).

The speed at pulley (3) =

$$\frac{\text{Pulley (4)}}{\text{Pulley (3)}} \text{ x Speed (rpm)} =$$

5.4/15.7 x 999 = 343.61 rpm

$$\text{Pulley (2) diameter} = \frac{\text{Speed (1)}}{\text{Speed (2)}} \text{ x}$$

Pulley (1) = 221.54/343.61 x 10 = 6.45 inch

**V-belt Selection**

The center distance between pulley (3) and pulley (4) was 25 inches and this was found to fulfill the equations of Shigley and Mitchell (1983)

C > 3 (d + D),

where

C = center distance,

D = large pulley diameter and

d = small pulley diameter.

Therefore, from **Table 2**, a B-section V- belt was selected.

According to pulleys selected, the maximum rpm at the threshing unit could be obtained as follows:

15.7/5.4 x 540 = 1570 rpm

The pitch length of the belt was calculated as follows:

$$Lp = 2C + 1.57(D + d) + \frac{(D - d)^2}{4C},$$

(Shigley and Mitchell, 1983),

C = center distance,

D = pitch diameter large pulley,

d = pitch diameter small pulley and

Lp = pitch length of belt.

$$Lp = 2 \text{ x } 25 + 1.57 (15.7 + 5.4) + \frac{(15.7 + 5.4)^2}{4 \text{ x } 25} = 87.58 \text{ inch}$$

The inside circumference is calcu-

**Fig. 4** Pulleys 1, 2, 3 and 4

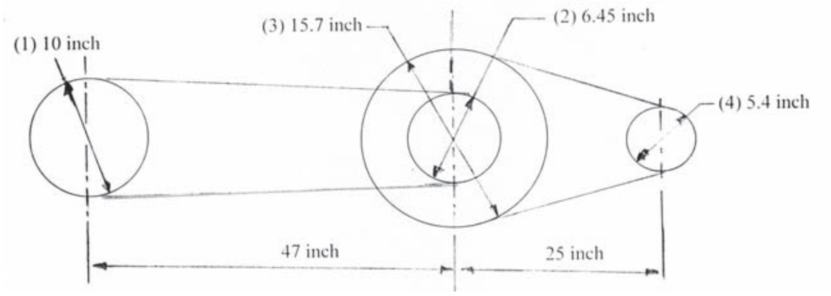



**Fig. 5** Correction factor $k_1$

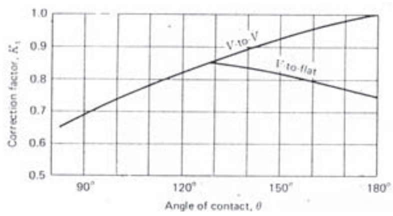



**Table 1** Technical specifications of the stationary combine thresher (Elshams)

| Technical specifications | Elshams |
|---|---|
| Length, m/m | 4,020 |
| Width, m/m | 2,200 |
| Hight, cm | 2,400 |
| Drum type: | Mobile finge |
| Drum length, m/m | 1,200 |
| Drum diameter, m/m | 75/120 |
| Rows of pegs | 4 |
| Numbers of pegs | 44 |
| Output, kg | 2,300 |
| Tire size | 13 x 600 |
| Flywheel diameter, m/m | 732 |
| Flywheel weight, kg | 130 |
| Main bearing inner diameter, m/m | 70 |
| Cardan shaft | Standard |
| Belt tension | Standard |
| Bag filling possibility, seed diameter | All sizes |
| Air flow adjustment | Standard |
| Straw length | Adjustable |

**Table 2** Heavy-duty conversion v-belt section

| Belt designation | Power range per belt hp | Typical standard pulley sizes, inch |
|---|---|---|
| Inch series | | |
| A | 0.2 to 5 | 2.6 up by 0.2 increments |
| B | 0.8 to 10 | 4.6 up by 0.2 increments |
| C | 1 to 21 | 7.0 up by 0.5 increments |

**Table 3** Length conversion quantities for heavy-duty conventional inch series belts

| Belt designation | Size range inch | Conversion quantity |
|---|---|---|
| A | 26 to 128 | 1.3 |
| B | 35 to 240 | 1.8 |
| B | 240 up | 2.1 |
| C | 51 to 210 | 2.9 |
| C | 210 up | 3.8 |
| D | 120 to 210 | 3.3 |
| D | 210 up | 4.1 |
| E | 180 to 240 | 4.5 |
| E | 240 up | 5.5 |

lated using **Table 3**. The conversion quantities shown are in inches and are to be added to the inside circumference to get the pitch length.

Pitch length = Lp - 1.8 = 87.58 - 1.8 = 85.78 inch.

The nearest standard size of V-belt from (**Table 4**) is B-90 V-belt.

The angle of contact of the small pulley Øs was found as follows:

$$Øs = 2 \cos^{-1} \frac{(D - d)}{2c},$$

where

D = pitch diameter for large pulley,

d = pitch diameter for small pulley,

c = center distance and

Øs = contact angle for small pulley.

$$Øs = 2 \cos^{-1} \frac{(15.7 - 5.4)}{2 \times 25} = 156^{o}$$

The rated horsepower (hp) was calculated as follows:

$$hp = (C_1 - \frac{C_2}{d} - C_3(rd)^2 - C_4 \log(rd))(rd) + C_2 r (1- 1/ka),$$

where

r = rpm of high-speed shaft, divided by 1000,

Ka = speed ratio factor (**Table 5**),

d = pitch diameter of small pulley and

$C_1$, $C_2$, $C_3$, $C_4$ = constants (**Table 6**).

The rated horsepower was corrected according to the contact angle by the following equation:

$hp_1 = k_1 k_2 hp$,

where

$hp_1$ = corrected power rating,

$k_1$ = correction factor of angle of contact (**Fig. 5**),

$k_2$ = correction factor for length of belt (**Table 4**) and

hp = rated horsepower.

Since the designed horsepower of the thresher is 35 hp and the calculated hp is 5.02 hp, therefore the number of belts = 35/5.02 = 6.97 (≈ 7.0 belts).

Using seven belts found not to be practical due to some pulleys design difficulties and therefore, four pulleys of B-90 V-belt was used between pulley (3) and (4). The similar above calculation steps were used to select four belts of B-120 V-belt to be used to transmit motion between pulley (1) and (2) (**Fig. 3**).

## The Modified Machine Evaluation and Testing

The modified machine was evaluated by testing in the field and was compared with an unmodified one. The test area was 1.5 fed and was cultivated by two crops, sorghum and fababean. The area was divided into six plots (35 x 30 m). In each plot the crop was cut and collected alone and then threshed separately using the threshers (Modified and unmodified).

Time taken in linking the machine to the tractor and the effective field capacity were measured in all plots.

It was clear that, the time taken in linking the modified machine to the tractor in all plots was less compared to the unmodified thresher. The average time taken was 0.3 hr and 0.43 hr for the modified and unmodified machines respectively. The effective field capacities for the modified and unmodified machine were 1.43 fed/hr and 0.93 fed/hr respectively (**Table 7**). This is mainly due to the time taken and the efficiency in linking and preparing the thresher.

Statistically the difference between the two machines was highly significant at 1 % level.

This modification was found very effective and useful in increasing the efficiency of work and reducing the time and cost of carrying out the threshing operation.

## Conclusions

- The modification helped in

**Table 4** Standard length Ls and length-correction factors $K_2$ for heavy-duty conventional english v-belts

| Ls | A | B | C | D |
|---|---|---|---|---|
| 60 | 0.97 | 0.91 | 0.83 | |
| 68 | 1.00 | 0.94 | 0.85 | |
| 75 | 1.02 | 0.96 | 0.87 | |
| 80 | 1.04 | | | |
| 81 | | 0.98 | 0.89 | |
| 85 | 1.05 | 0.99 | 0.90 | |
| 90 | 1.07 | 1.00 | 0.91 | |
| 96 | 1.08 | | 0.92 | |
| 97 | | 1.02 | | |
| 105 | 1.10 | 1.03 | 0.94 | |
| 112 | 1.12 | 1.05 | 0.95 | |
| 120 | 1.13 | 1.06 | 0.96 | 0.88 |
| 128 | 1.15 | 1.08 | 0.98 | 0.89 |

**Table 5** Speed-ratio factors for use in the power-rating equation

| D/d range | $K_A$ |
|---|---|
| 1.00 to 1.01 | 1.0000 |
| 1.02 to 1.04 | 1.0112 |
| 1.05 to 1.07 | 1.0226 |
| 1.08 to 1.10 | 1.0344 |
| 1.11 to 1.14 | 1.0463 |
| 1.15 to 1.20 | 1.0586 |
| 1.21 to 1.27 | 1.0711 |
| 1.28 to 1.39 | 1.0840 |
| 1.40 to 1.64 | 1.0972 |
| over 1.64 | 1.1106 |

**Table 6** Constants for use in the power-rating equation

| Belt section | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| A | 0.8542 | 1.342 | $2.436(10)^{-4}$ | 0.1703 |
| B | 1.5060 | 3.520 | $4.193(10)^{-4}$ | 0.2931 |
| C | 2.7860 | 9.788 | $7.460(10)^{-4}$ | 0.5214 |
| D | 5.9220 | 34.72 | $1.522(10)^{-4}$ | 1.064 |
| E | 8.6420 | 66.32 | $2.192(10)^{-4}$ | 1.532 |

**Table 7** The average time taken in linking the machine to the tractor and effective field capacity (EFC) of the modified and unmodified threshers

| | Average time, hr | EFC, fed/hr |
|---|---|---|
| Modified thresher | 0.3 | 1.43 |
| Unmodified thresher | 0.43 | 0.93 |

transmitting power from the tractor horizontally to the thresher without unlinking the machine in the field.

- The Field efficiency and effective field capacity of the modified thresher were increased resulting in time and cost saving of the harvesting operation.

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# Performance Evaluation of Tractor Drawn Weeding Cum Earthing-up Equipment for Cotton

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## Abstract

The arduous operation of weeding is usually performed manually with the use of traditional hand tools in an upright bending posture, inducing back pain for a majority of the labour. The situation necessitates the introduction of a suitable machine for weeding operations. The unit developed consists of an inter cultivator cum earthing-up equipment fitted to a standard tractor drawn ridger. Three sweep type blades 45 cm wide are affixed to the ridger frame with 120º approach angle and 15º lift angle for accomplishing the weeding operation between standing rows of crops. Three ridger bottoms fitted behind the sweep blade work on the loosened soil mass and aid in earthing-up by forming ridges and furrows. The unit was evaluated for its performance with the available weeders and the conventional method. Manual weeding with a hand hoe registered the maximum efficiency of 82.56 % (wet basis) and 82.4 % (dry basis). The weeding efficiency of tractor drawn weeding cum earthing-up implement was 60.24 (wet basis) and 61.62 (dry basis). The savings in cost of the weeding operation with bullock drawn junior hoe, self propelled power weeder and tractor drawn weeding cum earthing-up implement when compared to manual weeding was 78.7, 79.8 and 68.7 percent respectively. The savings in time of the weeding operation with bullock drawn junior hoe, self propelled power weeder and tractor drawn weeding cum earthing-up implement when compared to manual weeding was 96.5, 96.6 and 98.9 percent respectively.

**Fig. 1** Tractor drawn weeding cum earthing-up equipment

## Introduction

Crop intensification, timeliness in farm operations and efficient use of production resources are critical inputs in increasing the productivity of the agricultural sector. A decrease in the availability of agricultural labour is a direct consequence of migration of agricultural labours to the industrial sector due to the development of market economy and rural industries. One third of the cost of cultivation is spent on weeding alone when carried out with manual labour. The arduous operation of weeding is usually performed manually with the use of traditional hand tools in upright bending posture, inducing back pain for a majority of the labours. This situation necessitates the introduction of a suitable machine for weeding operations in cotton cultivation.

## Review of Literature

The yield of cotton was reduced by 41.46 % when the weeds were allowed to grow unchecked. The treatment of weeding alone and interculture and weeding together, however, did not differ significantly. In the row crops of cotton after the 50th day of sowing with or without application of herbicide, the bullock drawn junior hoe was used for inter cultivation. After 2 or 3 times of inter cultivation with the junior hoe, urea or nitrogen was applied to the crop with the help of a ridger. The bullock drawn blade harrow gave better performance when compared to a bullock drawn three tyne cultivator as seen from **Table 1**. The tractor drawn high clearance cultivator with full and half sweeps gave good results. A bullock drawn lister plough may be used at the later stages of plant growth (Bahl et al., 1988).

A ridger should be used between the rows for inter-row cultivation and for collecting soil around the crop rows. Tractor drawn, high-clearance cultivators using full and one-half sweeps has given good results. The bullock-drawn lister plough may be used at later stages of plant growth. A ridger may be used between the rows for inter-row cultivation and for collecting the soil around the crop rows.

## Materials and Methods

**i. Development of Tractor Drawn Weeding Cum Earthing-up Equipment for Cotton**

The unit developed consists of an inter cultivator cum earthing-up equipment fitted to a standard tractor drawn ridger. Three sweep type blades 45 cm wide are affixed to the ridger frame with 120º approach angle and 15º lift angle for accomplishing the weeding operation between standing rows of the cotton crop. The operational view of the unit between the rows of cotton crop is shown in **Fig. 1**. Three ridger bottoms fitted behind the sweep blade work on the loosened soil mass and aid in earthing-up by forming ridges and furrows. The specifications of the unit are shown in **Table 2**.

The salient features of the unit are: weeding and earthing-up operations are simultaneously performed in a single pass; row to row distance between the sweep blades and the ridger bottoms are adjustable (60, 75 and 90 cm); cost of the unit is Rs.12,000; and the capacity is 1.6 ha per day.

**ii. Existing Models of Weeders for Cotton**

The available models of weeders which can be used for weeding in the cotton crop are:

a. Self propelled power weeder (TNAU model)
b. Bullock drawn junior hoe

The description of the above mentioned implements and their specification are furnished below.

***a. Self Propelled Power Weeder (TNAU model)***

The weeder was operated by a 3 hp petrol start kerosene run engine. The engine power was transmitted to ground wheels through a

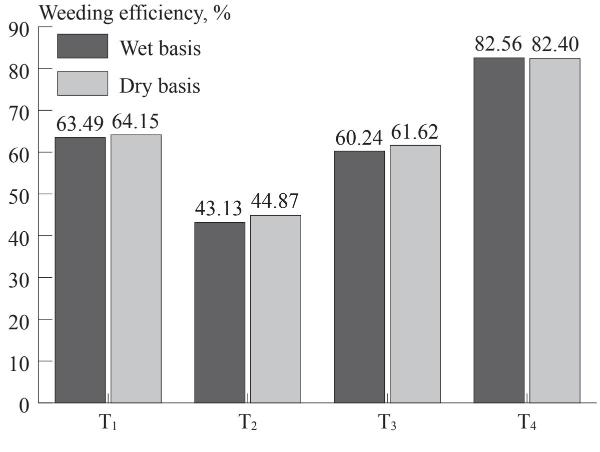
**Table 1** Comparative performance of weeders

| Name of the weeder | Weeding efficiency, % | Plant damage, % | Man-hrs/ha | Cost of weeding Rs./ha |
|---|---|---|---|---|
| Blade harrow | 76.8 | 12.16 | 6.63 | 15.15 |
| Three tyne cultivator | 67.4 | 9.7 | 6.94 | 17.35 |

**Table 2** Specification of weeding cum earthing-up implement

| Details | Value |
|---|---|
| Over all dimensions (L x B x W), mm | 2100 x 630 x 1500 |
| Weight, kg | 242 |
| Number of rows | 3 |
| Number of weeding blades | 3 |
| Number of ridger bottoms | 3 |
| Shape of the weeding blade | V shaped sweep bottom |
| Width of sweep blade, mm | 450 |
| Approach angle, deg | 120 |
| Lift angle | 15 |
| Row spacing, cm | Adjustable (60,75,90 cm) |
| Source of power | 35-45 hp tractor |
| Depth of operation, cm | 15 |

**Fig. 2** Efficiency of weeders evaluated in cotton crop



V belt-pulley and sprocket-chain mechanism. A replaceable sweep blade was fixed at the back of the machine. Sweep blades of different width can be fitted to the machine depending on the row to row spacing of the crop. A tail wheel was provided at the rear to maintain the operating depth. The sweep blade could be raised or lowered so as to have the desired operating depth. A rotary weeding attachment to the power weeder was developed. The rotary tiller consisted of three rows of discs mounted with six curved blades in opposite directions alternatively in each disc. These blades, when rotating, enabled cutting and mulching the soil. The width of coverage of the rotary tiller was 350 mm and the depth of operation could be adjusted to weed and mulch the soil in the cropped field. In addition to the rotary tiller and sweep type blades, the ridger or cultivator could be easily fitted to the unit, in place of the rotary tiller by the operator for field operations. The cost of the machine was Rs. 53,000/- (Rs. 35,000/- excluding the prime mover). The capacity was 0.75 ha per day. Additional features of the unit make it useful for weeding between rows of crops like tapioca, cotton, sugarcane, maize, tomato and pulses whose row spacing was more than 45 cm. The specification of the power weeder are furnished in **Table 3**.

***b. Drawn Junior Hoe***

The bullock junior hoe was an intercultural implement used primarily for weeding between the rows of standing crops. It consisted of reversible shovels with curved tynes attached to the framework with a hinge arrangement. A handle and beam were fixed to the framework for guiding and attaching the unit to the yoke. The spacing between the shovel could be adjusted according to the row spacing of the crop. The cost of the unit was Rs.1500.

**iii. Conventional Method of Weeding**

In the conventional method of weeding the cotton crop, weeding is performed by women with a hand hoe. The hand hoe consists of a triangular shaped mild steel-weeding blade of 75 mm width attached to a short wooden handle of 450 mm length. The weeding operation is carried out in an upright bending posture.

**iv. Treatments Selected for the Investigation**

The treatments selected for the investigation included:

$T_1$: Operation with junior hoe
$T_2$: Operation with self propelled power weeder (TNAU model)
$T_3$: Operation with tractor drawn inter cultivator
$T_4$: Control (Manual with hand hoe)

The developed tractor drawn weeding cum earthing-up implement was evaluated for its performance in terms of weeding efficiency (wet basis and dry basis), depth of operation and percent breakage of cotton plant. The moisture content of the soil during evaluation was 14.48 percent on dry basis.

**v. Weeding Efficiency and Percent Breakage**

The weeding efficiency (wet basis) was computed by using the following expression.

$$\eta_{ww}\ \% = \frac{(Wr)_w}{(Wr)_w + (Wr)_w} \times 100$$

Where,

**Table 3** Specification of power weeder (TNAU model)

| Details | Value |
|---|---|
| Over all dimensions (L x B x H), mm | 2400 x 1750 x 1100 |
| Weight, kg | 300 |
| Source of power | 3.5 hp petrol start kerosene engine |
| Number pf blades | Sweep blade: 1, Shovel: 5 |
| Nominal working width, mm | 2,250 (Adjustable depending on row spacing) |
| Depth of operation, mm | 30 (Adjustable) |

**Fig. 3** Depth of operation of weeders and percentage of plant damage in cotton field

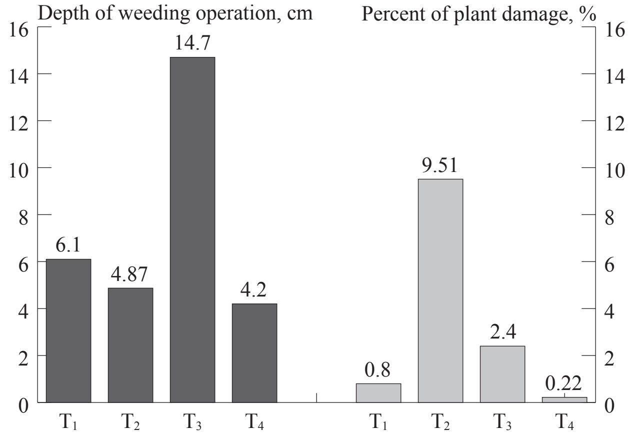
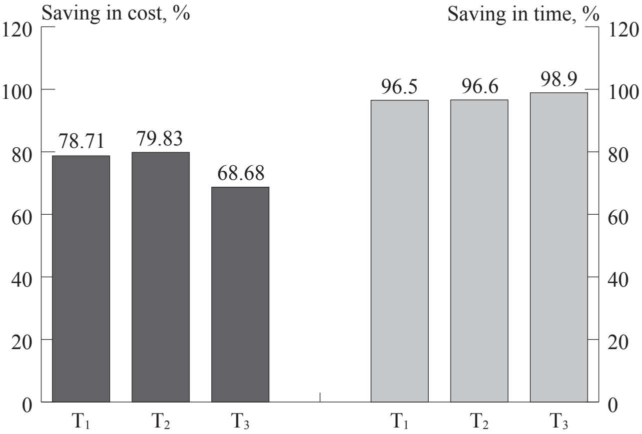



**Fig. 4** Saving in cost and time when compared to conventional method



$\eta_{ww}$: Weeding efficiency (wet basis), per cent

$(Wr)_w$: Wet weight of weeds removed by the implement/m$^2$

$(Wu)_w$: Weight of weeds left in the field after the weeding operation/m$^2$

The weeding efficiency (dry basis) was computed by using the following expression.

$$\eta_{wd}\ \% = \frac{(Wr)_d}{(Wr)_d + (Wr)_d} \times 100$$

Where,

$\eta_{wd}$: Weeding efficiency (dry basis), percent

$(Wr)_d$: Weight of oven dried weeds removed by the implement/m$^2$

$(Wu)_d$: Weight of oven dried weeds left in the field after the weeding/m$^2$

The percent breakage of cotton stalks was computed by using the following expression.

$$\eta_b,\ \% = \frac{P_b}{P_t} \times 100$$

Where,

$P_b$: Number of plants broken in the row

$P_t$: Total number of plants in the row

The cost of weeding with tractor drawn weeding cum earthing-up implement was compared with weeding by power weeder, junior hoe and manual method of weeding. The cost and time saved by the tractor drawn weeding cum earthing-up implement against other methods was compared.

## Results and Discussion

During the field trials, it was observed that the power weeder (TNAU model) could not be operated between the standing rows of the cotton crop. One of the ground wheels has to be necessarily run on the ridge resulting in overturning of the unit. As a result the plants were damaged. Hence, the power weeder was used in the plot sown by a pneumatic planter and cultivator seeder, where there was no ridge between the rows, and the performance was compared.

The performance evaluation of the weeders in the cotton crop is presented in **Table 4**. The weight of the weeds collected in treatment $T_3$ was maximum when compared to $T_1$, $T_2$ and $T_4$. The higher weight of weeds collected was due to complete up rooting of the weeds by the tractor drawn weeding cum earthing-up implement.

The weeding efficiency (wet and dry basis) for all the selected treatments is shown in **Fig. 2**. It was observed that there was no significant variation between the weeding efficiency on wet basis and weeding efficiency on dry basis in all the treatments. Among the treatments, $T_4$ registered the maximum efficiency of 82.56 % (wet basis) and 82.4 % (dry basis). The efficiency of $T_1$ and $T_3$ are comparable. $T_2$ had the lowest efficiency of 43.13 % (wet basis) and 44.5 % (dry basis) among the treatments.

The depth of operation of weeding in all the treatments is shown in **Fig 3**. The depth of operation was the highest in $T_3$. Owing to this maximum depth of operation the weeds were completely uprooted and the weight of the weeds collected per unit area was also maximum in $T_3$ as seen from the observations recorded in **Table 4**.

The depth of operation was the minimum in $T_4$. But the weight of weeds collected per m$^2$ area was more when compared to $T_1$ and $T_2$. This was because some of the weeds were pulled out by hand while manual weeding. The depth of operation was low in $T_1$ and $T_2$, which necessitated additional passes in these two treatments.

The percentage of plant damaged in the trial field during the operation of weeders is shown in **Fig. 3**. The percentage of plant damaged was more in $T_2$ followed by $T_3$. This was because the wheels and the blade caused damage to the plants while passing the irrigation channels and while turning of the weeder at the headland. With sufficient headland and training in the operation of the units between the rows, the percent of plant damage could be minimized. The results of the trial for the weeding operation with the selected treatments are presented in **Table 5**.

**Table 4** Results of the performance evaluation of weeder in cotton crop

| Particulars | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|---|---|---|---|---|
| Wet weight of weeds collected after weeding operation, gm/m$^2$ | 139.3 | 160.0 | 324.9 | 429.9 |
| Wet weight of weeds left in the field after weeding operation, gm/m$^2$ | 80.09 | 211.02 | 214.4 | 91.02 |
| Total wet weight of weeds, gm/m$^2$ | 219.39 | 371.02 | 539.4 | 520.9 |
| Weeding efficiency, % | 63.49 | 43.13 | 60.24 | 82.56 |
| Dry weight of weeds collected after weeding operation, gm/m$^2$ | 72.12 | 68.15 | 148.7 | 245.4 |
| Dry weight of weeds left in the field after weeding operation, gm/m$^2$ | 40.31 | 83.73 | 91.99 | 51.86 |
| Total dry weight of weeds, gm/m$^2$ | 112.3 | 151.88 | 240.7 | 297.2 |
| Weeding efficiency, % | 64.15 | 44.87 | 61.62 | 82.40 |
| No of plants for 30 m length | 162.6 | 150.0 | 167.0 | 155.3 |
| Damaged plants | 1.33 | 14.0 | 4.0 | 0.33 |
| Percentage of damage | 0.80 | 9.51 | 2.40 | 0.22 |
| Depth of operation, cm | 6.1 | 4.87 | 14.7 | - |

The savings in cost and time of weeding operation with the bullock drawn junior hoe, self propelled power weeder and tractor drawn weeding cum earthing-up implement are shown in **Fig. 4**. It is clearly shown from the figure that all the treatments $T_1$, $T_2$ and $T_3$ resulted in savings of cost and time when compared to $T_4$. $T_3$, $T_2$ recorded the highest percent cost saving, followed by $T_1$ and $T_3$. High initial cost of the tractor and weeding unit increased the cost of weeding operation in $T_3$ and hence it was the lowest. There was little difference in time saving among treatments $T_1$, $T_2$ and $T_3$.

## Conclusions

Based on the analysis of the results the following conclusions were drawn.

- An inter cultivator cum earthing-up implement fitted to a standard tractor drawn ridger was developed.
- The developed unit was evaluated for its performance in comparison with the existing models of weeders and conventional method of weeding.
- Manual weeding with hand hoe registered the maximum efficiency of 82.56 % (wet basis) and 82.4 % (dry basis). The weeding efficiency of tractor drawn weeding cum earthing-up implement was 60.24 % (wet basis) and 61.62 % (dry basis).
- The cost saving of the weeding operation with a bullock drawn junior hoe, self propelled power weeder and tractor drawn weeding cum earthing-up implement, when compared to manual weeding, was 78.7, 79.8 and 68.7 percent, respectively.
- The saving in time of weeding operation with bullock drawn junior hoe, self propelled power weeder and tractor drawn weeding cum earthing-up implement, when compared to manual weeding, was 96.5, 96.6 and 98.9 percent, respectively.

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**Table 5** Result of the evaluation trail for weeding operation in cotton crop

| Particulars | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|---|---|---|---|---|
| Width of operation, m | 0.45 | 0.75 | 2.25 | - |
| Length of the field, m | 46.0 | 46.0 | 46.0 | - |
| Time taken to travel, sec | 65.6 | 60.54 | 100.3 | - |
| Forward speed of operation, kph | 2.53 | 2.75 | 1.66 | - |
| Theoretical field capacity, ha/hr | 0.114 | 0.207 | 0.373 | - |
| Size of the field, $m^2$ | 46 x 11.5 = 1,890 $m^2$ | | | |
| Time taken, in 1st pass, min | 27.9 | 29.7 | 16.0 | - |
| Time taken, in 2nd pass, min | 27.0 | 24.6 | - | - |
| Total time taken, min | 54.9 | 51.4 | 16.0 | 450 woman hrs/ha |
| Actural field capacity, ha/hr | 0.058 | 0.06 | 0.198 | - |
| Field efficiency, % | 50.9 | 50.0 | 52.6 | - |
| Cost of operation, Rs/hr | 50 | 55 | 250 | 9.0 |
| Cost of weeding, Rs/hr | 862.07 | 887.1 | 1,268.63 | 4,050.0 |
| Saving in cost when compared to conventional method, % | 78.71 | 79.3 | 68.68 | - |
| Saving in time when compared to conventional method, % | 96.5 | 96.6 | 98.9 | - |

# Studies on Blending of Refined Soybean Oil and Ethanol with Diesel as Hybrid CI Engine Fuel

by

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## Abstract

Blending of ethanol-diesel, ethanol-refined soybean oil, diesel-refined soybean oil and diesel-refined soybean oil- ethanol in different proportions were studied to explore possibility of a hybrid fuel suitable for CI engines. Different proportions were tried and physical observations were studied for a period of three months on the basis of phase separation. It was found that there was a limiting percentage of 20 % for anhydrous ethanol in ethanol-diesel blend. A 15 % of refined soybean oil was limiting in ethanol-refined soybean oil blend. Diesel-refined soybean oil could be mixed in any proportion without phase separation. In case of diesel-refined soybean oil-ethanol blend the results indicated that stable, homogeneous and soluble fuel blends with no sign of phase separation were obtained when the blends had 40-70 percent diesel, 10-40 percent refined soybean oil and 5 to 20 percent anhydrous ethanol.

## Introduction

The petroleum sector plays an important role in the economic development of any country. Energy consumption can be considered as a measure of the vibrancy of any economy. India is the eighth largest consumer of the petroleum oil in the world. Ever since the discovery of this black gold, there has been a consistent increase in its demand. The world oil demand in the year 2001 was around 77.6 mbd (million barrels a day). The demand is further expected to increase to 86 mbd by 2005 and 96 mbd by 2010 at a growth rate of 2 percent. It is interesting to note that 50 percent of future growth will be from India and China (Ram Mohan, 2003). Thus, the search for alternative fuels for internal combustion engines, automobiles and stationary/motive power, has become important. Internal combustion engines continue to be the most important prime movers and they consume more than one third of our crude oil import. Researchers all over the world focus attention on development of various alternative fuels, which may include renewable resources, or blending of renewable with non-renewable fuels.

In the recent past, biogas Ortiz-Canavate et al. (1981), Bhattacharya et al. (1988), compressed natural gas Das and Ghosh (1995), vegetable oils Peterson (1986) and alcohols Gupta (1983) have been found to be promising fuels for compression ignition engines. However, problems of transportability to distant use points of biogas and high viscosity as well as gumming tendency of crude vegetable oils have limited their capabilities to supplement diesel fuel in a large way. On the other hand the physical and thermodynamic characteristics of alcohols do not make them particularly suitable fuels for compression ignition engines, but they offer a means of reducing exhaust emissions of sulphur compounds, smoke, particulates and NOx. The main disadvantage of alcohols is that they have much lower energy content than gasoline or diesel thus requiring more fuel for the unit power produced. However, this effect can be minimized to some extent by modification of engine design such as using higher compression ratio engines (Janius, 1988). The use of alcohols in CI engines also leads to reduced power output and can be compensated by injecting increased amounts of fuel. Other factors requiring consideration are the lower viscosity and lubricity of alcohols which may cause excessive wear in conventional fuel injection equipment. Apart from it, higher volatility of alchols may increase the risk of vapour lock and cavitation.

There are two possible approaches for using ethanol in a diesel engine. The diesel could be injected in the conventional way, along with a carburetor added into the engine's air stream to atomize the ethanol placed in a separate tank. Alternately, the ethanol could be blended with diesel. In order to reduce the inconvenience of engine modification necessary for atomization, ethanol-diesel blends have also been tried. It is convenient, as blended fuel is injected in the normal way without regulating the ethanol input rate separately. The diesel replacement is regulated automatically by the percentage of ethanol in the blend.

Vegetable oils, straight or modified, are known to offer several advantages as engine fuel. These include better self-ignition characteristics, compatibility with fuel injection system of the CI engine, high energy content and safe processing and handling. Moreover, vegetable oils can be processed on the farm itself due to relatively simple and low cost technology of expelling and filtering, which may further save the transport cost. Based on simple calculations, researchers have indicated that one hectare of an oil seed crop can fetch adequate oil to meet the energy needs of an 8 to 10 hectare of agricultural farm Burwer et al. (1980). These fuels can be readily incorporated in to energy pool, should the need arise due to sudden shortage or disruption in the existing petroleum supply system. Also, vegetable oil fuels produce greater thermal efficiency than diesel fuel Goering et al. (1982). However, the use of vegetable oils in direct injection type diesel fuel engines is limited due to higher viscosity. Viscosities of vegetable oils are reported to be 10 to 20 times more than that of diesel fuel and are considered to be lower in total energy and higher in density, carbon residue, and particulate matter (Ali, 1995).

It has been reported that in diesel engines, crude vegetable oils can be used as fuel, straight as well as in blend with the diesel (Shyam, 1984). However, the idea dates back to early part of last century in 1900 when Rudolph Diesel, the inventor of the diesel engine used Peanut oil to fuel the engine (Clevenger et al., 1988). Preliminary studies indicate that over short periods of time total replacement of diesel by vegetable oil fuels perform satisfactorily in unmodified diesel engines. However, the problems associated with their use are difficulty in making a cold start, plugging and gumming of filters, fuel lines and injectors and engine knocking. In long-term uses, the problems may lead to reduced performance or even complete failure of the engine. These include choking of injector nozzles, carbon deposits on the piston and cylinder head, dilution of the crankcase lubricating oil, excess wear on the rings, pistons and cylinder and failure of the engine lubricating oil due to oxidation and polymeriza-

**Table 1** Observations on phase separation of diesel-ethanol blends

| Fuel type | Ethanol proof, ° | Fuel constituents, %, v/v | | Observations |
|---|---|---|---|---|
| | | Diesel | Ethanol | |
| 200º-80-20 | 200 | 80 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-75-25 | 200 | 75 | 25 | Initially homogeneous blend but phase separation observed after 24h |
| 200º-74-26 | 200 | 74 | 26 | Initially homogeneous blend but phase separation observed after 24h |
| 200º-73-27 | 200 | 73 | 27 | Initially homogeneous blend but phase separation observed after 24h |
| 200º-72-28 | 200 | 72 | 28 | Initially homogeneous blend but phase separation observed after 24h |
| 200º-71-29 | 200 | 71 | 29 | Phase separation observed at initial stage of blending |
| 200º-70-30 | 200 | 70 | 30 | Phase separation observed at initial stage of blending |
| 200º-65-35 | 200 | 65 | 35 | Phase separation observed at initial stage of blending |
| 200º-60-40 | 200 | 60 | 40 | Phase separation observed at initial stage of blending |
| 200º-55-45 | 200 | 55 | 45 | Phase separation observed at initial stage of blending |
| 190º-85-15 | 190 | 85 | 15 | Phase separation observed at initial stage of blending |
| 190º-80-20 | 190 | 80 | 20 | Phase separation observed at initial stage of blending |
| 190º-72-28 | 190 | 72 | 28 | Phase separation observed at initial stage of blending |

tion. These problems have been correlated with several basic properties of vegetable oils, such as naturally occurring gums, high viscosity, acid composition, free fatty acid content and moderate cetane rating. It is crucial to understand and anticipate these problems before an attempt is made to use vegetable oils. This problem, combined with the viscosity of vegetable oils, presents the greatest difficulty in using vegetable oils in diesel engines. Therefore, several techniques are being used to reduce the viscosity. These include heating the vegetable oil to sufficient temperature to lower the viscosity to near specification range, diluting the vegetable oil with other less viscous liquid fuels to form blends that have been termed as hybrid fuels, micro emulsifying the vegetable oil and transesterification process, i.e. chemically converting the vegetable oil to simple esters of methyl, ethyl or butyl alcohols. The most popular diesel-vegetable oil fuel combinations have resulted from the blending of the vegetable oils with conventional diesel fuels because they improve fuel properties, give better engine performance than with vegetable oils alone as fuel and reduce the problems encountered because of smaller proportion blends.

The use of ethanol in diesel engines has been investigated (Wrage and Goering, 1980 and Boruff et al., 1982) by using blending of diesel with ethanol. It was found that the cetane number of ethanol - diesel fuel blends assumed to increase proportionally with the increase in percentage of diesel in the blend and suggested that the blend of 20 percent ethanol and 80 percent diesel would have a cetane rating equal to the ASTM minimum (Goering et al., 1983). It was further advised to keep alcohol content below 50 percent for minimum adequate cetane rating and heating value of the blend. In light of the above facts, the study was undertaken to ascertain the blending proportion of diesel, ethanol and refined soybean oil for preparation of hybrid fuel for a constant speed CI engines.

## Materials and Methods

The experiments were carried out using high speed diesel (HSD) marketed by Indian oil Corporation in accordance with IS: 1460 - (1974) as as reference fuel for the preparation of blends with ethanol and refined soybean oil.

Anhydrous ethanol was one of the constituent of hybrid fuels prepared for the experiment. Anhydrous ethanol made by Merck ($CH_3CH_2$ OH) was procured from the local market. Basically ethanol can be considered as a biomass based renewable fuel which burns cleaner and has highest octane rating. The application of ethanol as a supplementary engine fuel may reduce environmental pollution such as CO and smoke. The concentration of ethanol is expressed as ethanol proof, which represents twice the ethanol concentration. A 200º proof ethanol is an anhydrous absolute ethanol having 100 percent concentration of ethanol. A 190º proof ethanol having 5 percent water content was prepared from the anhydrous ethanol by adding required quantity of distilled water.

Refined soybean oil was used as another constituent of the hybrid fuel. Better self-ignition characteristics, compatibility with fuel injection system of existing CI engines, high-energy content and high cetane number makes vegetable oils compatible with diesel. However, the viscosity of vegetable oils is 10-12 times more than that of diesel, which must be reduced before supplementing them as an engine fuel.

**Preparation of Hybrid Fuel Blends**

The preparation of fuel blends of selected constituents was carried out as follows:

- Diesel - Anhydrous Ethanol (200º proof) blends
- Diesel - Aqueous Ethanol (190º proof) blends

**Table 2** Observations on phase separation of refined soybean oil-ethanol blends

| Fuel type | Ethanol proof, º | Fuel constituents, %, v/v | | Observations |
|---|---|---|---|---|
| | | Refined soybean oil | Ethanol | |
| 200º-90-10 | 200 | 90 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-85-15 | 200 | 85 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-84-16 | 200 | 84 | 16 | Phase separation observed at initial stage of blending |
| 200º-83-17 | 200 | 83 | 17 | Phase separation observed at initial stage of blending |
| 200º-82-18 | 200 | 82 | 18 | Phase separation observed at initial stage of blending |
| 200º-81-19 | 200 | 81 | 19 | Phase separation observed at initial stage of blending |
| 200º-80-20 | 200 | 80 | 20 | Phase separation observed at initial stage of blending |
| 200º-10-90 | 200 | 10 | 90 | Phase separation observed at initial stage of blending |
| 200º-20-80 | 200 | 20 | 80 | Phase separation observed at initial stage of blending |
| 190º-90-10 | 190 | 90 | 10 | Phase separation observed at initial stage of blending |
| 190º-85-15 | 190 | 85 | 15 | Phase separation observed at initial stage of blending |
| 190º-80-20 | 190 | 80 | 20 | Phase separation observed at initial stage of blending |

Refined Soybean Oil - Anhydrous Ethanol (200º proof) blends
Refined Soybean Oil - Aqueous Ethanol (190º proof) blends
Diesel - Refined Soybean Oil
Diesel - Refined Soybean Oil - Anhydrous Ethanol (200º proof) blends

The anhydrous ethanol - diesel blends were prepared by blending 20-45 % ethanol with diesel. The initial level of 20 % was chosen as past researcher Ajav et al. (1999) had indicated that blending of 20 percent anhydrous ethanol with diesel was found feasible.

The blends of diesel, anhydrous ethanol, aqueous ethanol and refined soybean oil were prepared as per above steps. The level of miscibility of the different fuel constituents with each other was studied by observing phase separation at the initial stage. The details of fuel blends prepared from different fuel constituents are given in **Table 1** to **4**.

The blends that did not show any sign of phase separation at the initial stage were considered as stable. The stability of such blends was further observed at room temperature (10-35 ºC) for a period of three months at an interval of seven days by visualizing phase separation.

## Results and Discussion

The stability and homogeneity studies were conducted on different hybrid fuel blends prepared using diesel, refined soybean oil and various proofs of ethanol.

**Stability of Hybrid Fuel Blends**

The suitability of blending different proofs of ethanol, diesel and refined soybean oil with each other was studied by conducting phase separation studies. The phase separation in blended fuels having different fuel constituents was observed on the basis of homogeneity, solubility and colour of blends which are presented in **Table 1** to **4**.

The observations on blending of diesel and ethanol as shown in Table 1 indicate that a homogeneous blend with no sign of phase separation was obtained when 20 percent anhydrous ethanol and 80 percent diesel was blended. This blend was found stable even after a period of three months. The blending of anhydrous ethanol (200º proof) with diesel in the range of 25 to 30 percent with an increment of 1 percent resulted in a homogeneous soluble fuel blend at the initial stage. However, in these blends the constituents got partially separated after a period of 24 hours. Further, the instant phase separation was observed in a thoroughly mixed anhydrous ethanol - diesel blends containing 35, 40 and 45 percent anhydrous ethanol. The 190º proof ethanol - diesel blends having 15, 20 and 28 percent ethanol were also not found stable because the phase separation in thoroughly mixed blends was observed at the initial stage of preparation. The observations was in line with the findings of (Ecklund et al., 1984) which described that solubility of ethanol with diesel was dependent on diesel fuels hydrocarbon and its wax composition, ambient temperature, water content in ethanol and for practical purposes recommended blending of 20 percent or less anhydrous ethanol with diesel.

The observations on the blends of refined soybean oil and anhydrous ethanol as well as aqueous ethanol (190º proof) are presented **Table 2**. The table indicates that 10 to 20 percent anhydrous ethanol was blended with refined soybean oil. It was observed that a homogeneous, soluble and stable fuel blends of refined soybean oil and anhydrous ethanol with no sign of phase separation were obtained when 10 and 15 percent of anhydrous ethanol was blended. The blending of 16 percent anhydrous ethanol with refined soybean oil resulted in a blend, which initially did not show any sign of phase separation but was found to have partial phase separation after 24 hours. The fuel blends containing refined soybean oil and anhydrous ethanol respectively between 17 to 20 percent were found to be unstable at the initial stage itself. The results also indicated distinct phase separation at the initial stage in the blends having refined soybean oil mixed with 10, 15 and 20 percent aqueous ethanol of 190º proof. Therefore, blending of aqueous ethanol (190º proof) with refined soybean oil may not be feasible.

**Table 3** Observations on phase separation of deisel refined soybean blends

| Fuel type | Fuel constituents, %, v/v | | Observations |
|---|---|---|---|
| | Diesel | Refined soybean oil | |
| 90-10 | 90 | 10 | Homogeneous blend with no sign of phase separation |
| 80-20 | 80 | 20 | Homogeneous blend with no sign of phase separation |
| 70-30 | 70 | 30 | Homogeneous blend with no sign of phase separation |
| 60-40 | 60 | 40 | Homogeneous blend with no sign of phase separation |
| 50-50 | 50 | 50 | Homogeneous blend with no sign of phase separation |
| 40-60 | 40 | 60 | Homogeneous blend with no sign of phase separation |
| 30-70 | 30 | 70 | Homogeneous blend with no sign of phase separation |
| 20-80 | 20 | 80 | Homogeneous blend with no sign of phase separation |
| 10-90 | 10 | 90 | Homogeneous blend with no sign of phase separation |

**Table 3** shows the observations on the blends prepared using diesel and refined soybean oil. It was observed that in this blends 10 to 90 percent refined soybean oil were stable and did not show any sign of phase separation even after a period of three months. However, these blends were found to have a yellowish brown

colour which was different than the colour of diesel and refined soybean oil. It was also observed that the refined soybean oil - diesel blends were thicker than the diesel which was due to high viscosity of refined soybean oil.

The hybrid fuel blends of diesel, refined soybean oil and anhydrous ethanol are presented in **Table 4**. The hybrid fuel blends have been prepared by proportion of diesel between 40 to 70 percent, refined soybean oil between 5 to 55 percent and anhydrous ethanol between 5 to 25 percent. The blends of above composition were prepared to study the feasibility of replacing 30 to 60 percent of diesel by adequate proportion of refined soybean oil and anhydrous ethanol. The results indicated that stable, homogeneous and soluble fuel blends with no sign of phase separation were obtained when the blends had 70 percent diesel, 10 to 25 percent refined soybean oil and 5 to 20 percent anhydrous ethanol. The increase in content of anhydrous ethanol to 25 percent resulted in an unstable blend with distinct sign of phase separation.

The study also revealed that the blends with no sign of phase separation replacing 35 percent diesel were obtained, when refined soybean oil and anhydrous ethanol were blended with diesel in the range between 15-30 percent and 5-20 percent respectively. The increase in the level of anhydrous ethanol to 25 percent resulted in formation of an unstable blend.

The blends containing 60 percent diesel showed that stable blends were obtainable when refined soy-

**Table 4** Observations on phase separation of diesel - refined soybean oil - anhydrous ethanol (200º proof) blends

| Fuel type | Fuel constituents, %, v/v | | | Observations |
|---|---|---|---|---|
| | Diesel | Refined soybean oil | Anhydrous ethanol, 200º | |
| 200º-70-25-5 | 70 | 25 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-70-20-10 | 70 | 20 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-70-15-15 | 70 | 15 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-70-10-20 | 70 | 10 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-70-5-25 | 70 | 5 | 25 | Phase separation observed at initial stage of blending |
| 200º-65-30-5 | 65 | 30 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-65-25-10 | 65 | 25 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-65-20-15 | 65 | 20 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-65-15-20 | 65 | 15 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-65-10-25 | 65 | 10 | 25 | Phase separation observed at initial stage of blending |
| 200º-60-35-5 | 60 | 35 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-60-30-10 | 60 | 30 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-60-25-15 | 60 | 25 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-60-20-20 | 60 | 20 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-60-15-25 | 60 | 15 | 25 | Phase separation observed at initial stage of blending |
| 200º-55-40-5 | 55 | 40 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-55-35-10 | 55 | 35 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-55-30-15 | 55 | 30 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-55-25-20 | 55 | 25 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-55-20-25 | 55 | 20 | 25 | Phase separation observed at initial stage of blending |
| 200º-50-45-5 | 50 | 45 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-50-40-10 | 50 | 40 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-50-35-15 | 50 | 35 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-50-30-20 | 50 | 30 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-50-25-25 | 50 | 25 | 25 | Phase separation observed at initial stage of blending |
| 200º-45-50-5 | 45 | 50 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-45-45-10 | 45 | 45 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-45-40-15 | 45 | 40 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-45-35-20 | 45 | 35 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-45-30-25 | 45 | 30 | 25 | Phase separation observed at initial stage of blending |
| 200º-40-55-5 | 40 | 55 | 5 | Homogeneous blend with no sign of phase separation |
| 200º-40-50-10 | 40 | 50 | 10 | Homogeneous blend with no sign of phase separation |
| 200º-40-45-15 | 40 | 45 | 15 | Homogeneous blend with no sign of phase separation |
| 200º-40-40-20 | 40 | 40 | 20 | Homogeneous blend with no sign of phase separation |
| 200º-40-35-25 | 40 | 35 | 25 | Phase separation observed at initial stage of blending |

bean oil and anhydrous ethanol were blended in the range of 20 to 35 percent and 5 to 20 percent respectively. An unstable blend was formed when the level of anhydrous ethanol was increased to 25 percent.

The replacement of 45 percent diesel by forming stable and homogeneous fuel blends of diesel, refined soybean oil and anhydrous ethanol were possible by blending 25 to 40 percent refined soybean oil and 5 to 20 percent anhydrous ethanol and an increase of anhydrous ethanol to 25 percent level resulted in the formation of an unstable blend.

The blends containing 50 percent diesel, 30 to 45 percent refined soybean oil and 5 to 20 percent anhydrous ethanol were also found to be stable with no sign of phase separation. It was also seen that stable blends replacing 55 percent diesel were obtained when 35 to 50 percent refined soybean oil and 5 to 20 percent anhydrous ethanol were blended with diesel. The results also indicated that diesel replacement of 60 percent was obtainable from stable blends with no sign of phase separation when 40 to 55 percent refined soybean oil and 5 to 20 percent anhydrous ethanol were mixed. It is evident from the observations that in hybrid fuels, anhydrous ethanol may be blended up to 20 percent level because an increase to 25 percent level with possible diesel replacement between 30 to 60 percent resulted in the formation of unstable blends with distinct sign of phase separation.

## Engine Performance

The Engine performance of a 3.73 kW constant speed CI engine on three types of hybrid fuel blends was compared with diesel while measuring the brake power, fuel consumption and brake thermal efficiency.

### Effect of Fuel Types on Brake Power

The brake power developed by the engine operating on diesel, diesel - anhydrous ethanol blend (80:20), diesel - refined soybean oil blends mixed in 80:20 proportions and diesel - refined soybean oil - anhydrous ethanol blends mixed in 40:40:20 proportions is presented in **Table 5** at different loads and engine speeds. It is evident that the engine developed brake power of 3.75 kW at 100 percent load on diesel and at 1,499 rpm. The rated power of the engine as specified by manufacturer was 3.73 kW at 1,500 rpm. At 110 percent load, the engine on diesel developed 4.06 kW while corresponding engine speed was 1,486 rpm. The engine was able to develop its rated power at its rated speed (1,500 rpm) as specified by manufacturer at 100 percent load.

**Table 5** shows that the engine was able to develop almost similar power on fuel types at every selected brake load. The engine also developed its rated power on all selected fuel types at 100 percent load and the corresponding engine speed was found to be close to its rated speed. It is, therefore, evident from the observed results that the performance of the engine in terms of brake power on the selected fuel types was all most identical. This could be due to the reason that the volumetric fuel flow rate on hybrid fuels was higher thus contributing energy supply near to diesel.

### Effect of Fuel Types on Fuel Consumption

The fuel consumption (l/h) of the engine on diesel and selected blends of diesel, refined soybean oil, anhydrous ethanol is shown in **Table 6**. It is evident that the fuel consumption of the engine gradually increased with increase in brake load on all fuel types. The fuel consumption of the engine at rated power on

**Table 5** Brake power developed by the Kirloskar AVI engine on different fuels

| Fuel type | Brake load, % | | | | | |
|---|---|---|---|---|---|---|
| | No load | | 25 | | 50 | |
| | engine speed, rpm | Brake power, kw | engine speed, rpm | Brake power, kw | engine speed, rpm | Brake power, kw |
| Diesel | 1,604 | - | 1,532 | 0.95 | 1,535 | 1.91 |
| Diesel - anhydrous ethanol blend (80:20) | 1,541 | - | 1,544 | 0.96 | 1,540 | 1.90 |
| Diesel - refined soybean oil blend (80:20) | 1,593 | - | 1,563 | 0.98 | 1,576 | 1.96 |
| Diesel - refined soybean oil - anhydrous ethanol blend (40:40:20) | 152.3 | - | 1,506 | 0.95 | 1,489 | 1.86 |
| | 75 | | 100 | | 110 | |
| Fuel type | engine speed, rpm | Brake power, kw | engine speed, rpm | Brake power, kw | engine speed, rpm | Brake power, kw |
| Diesel | 1,502 | 2.80 | 1,499 | 3.73 | 1,486 | 4.06 |
| Diesel - anhydrous ethanol blend (80:20) | 1,536 | 2.87 | 1,532 | 3.82 | 1,521 | 4.17 |
| Diesel - refined soybean oil blend (80:20) | 1,551 | 2.90 | 1,533 | 3.81 | 1,515 | 4.14 |
| Diesel - refined soybean oil - anhydrous ethanol blend (40:40:20) | 1,505 | 2.81 | 1,508 | 3.75 | 1,490 | 4.08 |

diesel was 1.336 l/h. The observed fuel consumption at 100 percent load, i.e. when the engine was developing its rated power was higher (1.478 l/h) on the blend containing 80 percent diesel and 20 percent anhydrous ethanol. The observed fuel consumption of the engine also indicates that a decrease in diesel content in the blends resulted in an increase in fuel consumption.

### Effect of Fuel Types on Brake Thermal Efficiency

The observed brake thermal efficiency of the engine on selected fuel types is shown in **Table 7**. The brake thermal efficiency of the engine was found to be highest on all fuel types at 110 percent load. The brake thermal efficiency of the engine on diesel when developing rated power, i.e. at 100 percent load was 24.7 percent. The comparison of observed brake thermal efficiency indicates that when the engine developed its rated power, it was 22.9 percent on diesel - anhydrous ethanol blend mixed in proportion of 80:20 and 24.6 percent on diesel - refined soybean oil blends mixed in 80:20 proportion. The engine under similar conditions had the brake thermal efficiency of 24.5 percent on the diesel - refined soybean oil - anhydrous ethanol blends mixed in 40:40:20 proportions. The observations on brake thermal efficiency of the engine when developing rated power was found almost similar to diesel on the diesel-refined soybean oil blends mixed prepared 80:20 proportion and on the blend of diesel - refined soybean oil - anhydrous ethanol mixed in 40:40:20 proportions.

## Conclusions

The blending of anhydrous ethanol up to 20 percent level with diesel was found feasible. The blending to this level forms a stable and homogeneous blend. Distinct phase separation was observed when 190º proof aqueous ethanol was blended with diesel as well as with refined soybean oil. Thus blending of aqueous ethanol of lower proof does not seem to be practical.

Stable and homogeneous blends of refined soybean oil and diesel were formed when 10 to 90 percent refined soybean oil was blended. The blending of diesel, refined soybean oil and anhydrous ethanol was found to produce blends without any sign of phase separation when the level of anhydrous ethanol was kept between 5 to 20 percent and that of refined soybean oil between 10 to 40 percent

The blending of refined soybean oil and anhydrous ethanol mixed in the proportion of 85:15 also formed a stable and homogeneous blend. However, mixing 20 percent anhydrous ethanol to this resulted in an unstable blend

The observed results of engine short-term test reveled that the selected hybrid fuels had similar power producing capability, slightly more fuel consumption and comparable thermal efficiency. The performance of the engine on them was also found compatible with diesel.

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**Table 6** Fuel consumption of Kirloskar AVI engine on different fuels

| Fuel type | Brake load, % | | | | | |
|---|---|---|---|---|---|---|
| | No load | 25 | 50 | 75 | 100 | 110 |
| | Fuel consumption, l/h | | | | | |
| Diesel | 0.493 | 0.671 | 0.870 | 1.069 | 1.336 | 1.449 |
| Diesel - anhydrous ethanol blend (80:20) | 0.620 | 0.757 | 0.932 | 1.172 | 1.478 | 1.611 |
| Diesel - refined soybean oil blend (80:20) | 0.483 | 0.659 | 0.868 | 1.100 | 1.371 | 1.461 |
| Diesel - refined soybean oil - anhydrous ethanol blend (40:40:20) | 0.596 | 0.760 | 0.899 | 1.133 | 1.354 | 1.483 |

**Table 7** Brake thermal efficiency of Kirloskar AVI engine on different fuels

| Fuel type | Brake load, % | | | | | |
|---|---|---|---|---|---|---|
| | No load | 25 | 50 | 75 | 100 | 110 |
| | Brake thermal efficiency, % | | | | | |
| Diesel | - | 12.6 | 19.4 | 23.2 | 24.7 | 24.8 |
| Diesel - anhydrous ethanol blend (80:20) | - | 11.2 | 18.0 | 21.7 | 22.9 | 22.9 |
| Diesel - refined soybean oil blend (80:20) | - | 13.1 | 20.0 | 24.3 | 24.6 | 25.1 |
| Diesel - refined soybean oil - anhydrous ethanol blend (40:40:20) | - | 11.1 | 18.3 | 22.0 | 24.5 | 24.4 |

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# Effect of Whole Body Vibration of Riding Type Power Tiller


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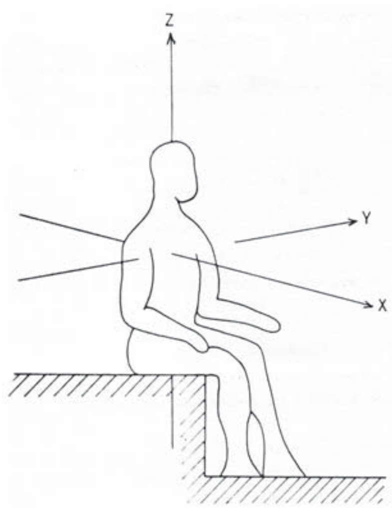
## Abstract

The whole body vibration of a riding type power tiller was investigated in accordance with ISO 2631 (1985). For measuring whole body vibration, triaxial seat accelerometer type 4322 was used as a transducer. The accelerometer was placed on the operator's seat at a point on the interface between the operator and his seat. Whole body vibration was measured using the portable four channel B & K PULSE multi-analyzer system. Whole body vibration was measured as frequency weighted r.m.s value of acceleration for the one-third octave band, having centre frequencies from 1 to 80 Hz (ISO 2631). All the transducers were calibrated before the trials. The whole body vibration was measured for the x, y, and z directions. The experiments were conducted during rototilling with rotovator in untilled and tilled field conditions and during transport mode of riding type power tiller with empty trailer on farm roads and bitumen roads. Measurements were made at different forward speeds, viz. 1.5 km $h^{-1}$, 1.8 km $h^{-1}$, 2.1 km $h^{-1}$ and 2.4 km $h^{-1}$ during field trials and 3.5 km $h^{-1}$, 4.0 km $h^{-1}$, 4.5 km $h^{-1}$ and 5.0 km $h^{-1}$ during transport mode. The whole body vibration varied from 0.823 to 1.21 m $s^{-2}$ and 0.776 to 1.11 m $s^{-2}$ during rototilling in untilled and tilled fields, respectively. The overall ride vibration level increased by 6.05 to 9.09 percent in an untilled field when compared to tilled field. The safe exposure limit varied from 4-8 h to 2.5-4 h with the increase in forward speed from 3.5 to 5.0 km $h^{-1}$ in an untilled and tilled field. The human reaction was "fairly uncomfortable" to "uncomfortable" during field operation. The whole body vibration varied from 0.686 to 1.06 m $s^{-2}$ and 0.660 to 0.967 m $s^{-2}$ during transport on farm and bitumen roads, respectively. The safe exposure limit was 4 to 8 h during transport on farm and bitumen roads. The likely human reaction was "fairly uncomfortable". In general the increase in forward speed


**Fig. 1** Directions of coordinate system for mechanical vibrations influencing human




Legend
X axis: Longitudinal direction (back-to-chest), Y axis: Lateral direction (right side to left side), Z axis: Vertical direction (foot or buttrocks to head)

resulted in increase of whole body vibration. Vibration dose values (VDV) for whole body vibration were within the maximum recommended limit of VDV (BS 6841, 1987) of 15 $ms^{-1.75}$ for all operations.

## Introduction

Mechanization in agriculture has changed the characteristics of labour and it also influences the workload. Need for timeliness of operation and increased capacity, has led to higher speeds and bigger and heavier machines. The operation of these machines increases workload on the operators as well as occupational hazards and diseases that impair the performance of the operator. In farm works, the fatigue and discomfort to which human beings are subjected is not only due to physical labour, but to vibration and noise as well (Huang and Suggs, 1968). Exposure to whole body vibration causes a complex distribution of oscillatory motions and forces within the human body for a power tiller with seating attachment. The low frequency ride vibrations to which the operator is subjected results from both linear displacement of the power tiller and rotational oscillations of the pitch and roll modes (Mehta et al., 1997). Exposure to the whole body can either cause permanent physical damage, or disturb the nervous system. The four principal effects of ride vibrations are considered to be (i) degraded health, (ii) impaired activities, (iii) impaired comfort and (iv) motion sickness. Hence, measurement and evaluation of ride vibrations are necessary for assessing operator's comfort and to suggest limits for the continuous operation of power tillers with seating attachment.

## Review of Literature

Higher vibration in the vertical and longitudinal directions resulted in an increased ventilation rate (Huang and Suggs, 1967). Liljedahl et al. (1979) reported that ride vibration intensities had a positive correlation with ground speed and often become intolerable as speed is increased. Vladimirov et al. (1985) measured vibration of a tractor cab seat of a wheeled tractor with a two-axle trailer in the field. Three passes in two types of terrain (straw stubble and farm road) were made and vibrations were measured in three directions on the cab seat and on the tractor chassis. Spectral densities of vertical vibrations and the correlation functions showed that the driving speed and the weight of the trailer played the key role in seat vibrations. They reported that there was an increase in acceleration with forward speed. Mehta et al. (1997) measured ride vibrations on a 7.5 kW rotary power tiller under different operating conditions. The overall ride vibration level (SUM) increased with forward speed of travel under all operating conditions. Clijmans et al. (1998) reported that the rotating parts within the machine and the soil roughness in combination with driving speed, contribute to the tractor vibrations. Kawakani et al. (1999) evaluated a medium class tractor on a gravel road and on pasture for ride vibrations. Vertical vibration had the highest acceleration level in the tractor driven on a gravel road without any implements attached, and during that ride 20-50 percent of the vertical vibrations were transmitted to the seat. Accelerations in the one-third octave band of the vertical vibrations remained under ISO exposure limit of 8 h. Mehta et al. (2000) quantified the ride vibration of a low horse power tractor-implement system. He reported that the SUM vibration levels increased as forward speed of travel increased under most of the operating conditions.

## Materials and Methods

The whole body vibration of the power tiller was measured and analyzed using the portable PULSE multi-analyzer system (Brüel & Kjær Type 3560 C). The PULSE multi-analyzer system is a versatile, task oriented analysis system for vibration and noise analysis. It provided the platform for a range of PC-based measurement solutions. Type 3650 C is a portable system powered by internal batteries or an external DC supply. The base software for a PULSE system is vibra-

**Fig. 2** Triaxial seat accelerometer placed on metallic seat of power tiller B

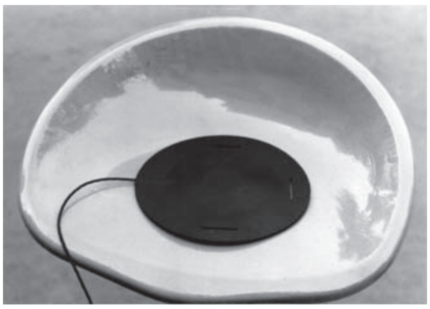


**Fig. 3** Triaxial seat accelerometer placed on the trailer seat

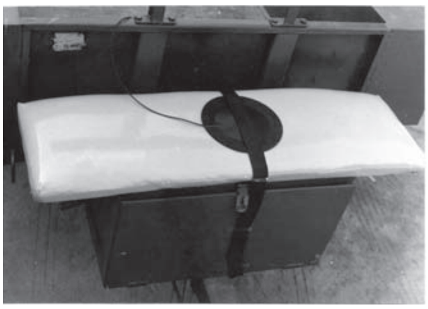


**Fig. 4** Instrumentation set up for measureing WBV of power tiller

tion and noise analysis type 7700. On this base, pulse software such as data recorder type 7701 was installed. The entire system consisted of a portable data acquisition unit-front end type 2827, vibration and noise analysis software type 7700, data recorder type 7701 and triaxial seat accelerometer type 4322.

The power tiller was put in proper test condition before conducting the experiments, that is, in full working order with full fuel tank and radiator, without optional front weights, tire ballast and any specialized components. Tires used for the tests were of standard size and depth of treads was not less than 70 percent of the depth of a new thread. Pneumatic wheels with recommended tyre pressure of 1.5 kg $cm^{-2}$ and 2.5 kg $cm^{-2}$ were used during rototilling and transporting operations, respectively. There were no known mechanical defects that would result in abnormal vibration in both power tillers.

For measuring whole body vibration, a triaxial seat accelerometer type 4322 was used as a transducer (Mehta et al., 1997; Sorainen et al., 1998; and Mehta et al., 2000). The accelerometer was placed on the operator's seat at a point on the interface between the operator and his seat (Lovesey, 1970; Mehta et al.,1997; and Mehta et al., 2000). This point corresponds to the ischial tuberosites of the human body. A triaxial seat accelerometer contained three independent accelerometers which simultaneously measured the vibration level along three mutually perpendicular axes, viz. vertical ($a_z$), longitudinal ($a_x$) and lateral ($a_y$) according to the International Standard 2631 (1985) as shown in **Fig. 1**. The views of Triaxial seat accelerometer placed on the metallic seat of power tiller and trailer seat are shown in **Figs. 2** and **3**, respectively.

Whole body vibration was measured as frequency weighted r.m.s value of acceleration for the one-third octave band having centre frequencies from 6.3 to 1250 Hz (ISO 2631). All the transducers were calibrated before the trials. The instrument set up for measuring whole body vibration of power tiller is shown in **Fig. 4**. The whole body vibration was measured for the x, y, and z directions.

The experiments were conducted during rototilling with rotavator in untilled and tilled field conditions and during transport mode of power tiller with empty trailer on farm road and bitumen road. The depth of operation was maintained at a constant level of about 15 cm during rototilling. The subjects were instructed to hold the handle grip with a light and constant compression force. The subjects were requested to keep upright posture during the whole body vibration measurement because the upper body spinal axis is aligned with the vertical vibration vector when sitting upright (Wilder et al., 1994). The natural frequency of the upright posture was greater than the equivalent natural frequency of the forward and full back postures. The higher natural frequency of the upright posture indicated that the subject was mechanically stiffer

**Table 1** Whole body vibration

| Forward speed, km $h^{-1}$ | Human criteria for assessment of WBV as per ISO 2631 (1985) | | | |
|---|---|---|---|---|
| | Mean value of vector sum, m $s^{-2}$, 4-8 Hz | Fatigue decreased proficiency boundary, h | Exposure limit, h | Reduced comfort boundary, h |
| A. Rototilling in untilled field | | | | |
| 1.5 | 0.823 | 1-2.5 | 4-8 | 1-16 |
| 1.8 | 0.966 | 1-2.5 | 4-8 | 1-16 |
| 2.1 | 1.10 | 1-2.5 | 2.5-4 | 1-16 |
| 2.4 | 1.21 | 0.42-1 | 2.5-4 | 1-16 |
| B. Rototilling in tilled field | | | | |
| 1.5 | 0.776 | 1-2.5 | 4-8 | 1-16 |
| 1.8 | 0.859 | 1-2.5 | 4-8 | 1-16 |
| 2.1 | 1.030 | 1-2.5 | 4-8 | 1-16 |
| 2.4 | 1.110 | 1-2.5 | 2.5-4 | 1-16 |
| C. Transport in farm road | | | | |
| 3.5 | 0.686 | 2.5-4 | 4-8 | 16-25 |
| 4.0 | 0.759 | 1-2.5 | 4-8 | 1-16 |
| 4.5 | 0.963 | 1-2.5 | 4-8 | 1-16 |
| 5.0 | 1.060 | 1-2.5 | 4-8 | 1-16 |
| D. Transport in bitumen road | | | | |
| 3.5 | 0.660 | 2.5-4 | 4-8 | 16-25 |
| 4.0 | 0.726 | 1-2.5 | 4-8 | 1-16 |
| 4.5 | 0.951 | 1-2.5 | 4-8 | 1-16 |
| 5.0 | 0.967 | 1-2.5 | 4-8 | 1-16 |

**Table 2** Vibration dose value for 8 h exposure time for selected operations

| Forward speed, km $h^{-1}$ | Vibration dose volue, (VDV) - (m $s^{-1.75}$) |
|---|---|
| A. Rototilling in untilled field | |
| 1.5 | 10.72 |
| 1.8 | 12.58 |
| 2.1 | 14.32 |
| 2.4 | 15.76 |
| B. Rototilling in tilled field | |
| 1.5 | 10.10 |
| 1.8 | 11.19 |
| 2.1 | 13.41 |
| 2.4 | 14.46 |
| C. Transport in farm road | |
| 3.5 | 8.94 |
| 4.0 | 9.89 |
| 4.5 | 12.54 |
| 5.0 | 13.81 |
| D. Transport in bitumen road | |
| 3.5 | 8.59 |
| 4.0 | 9.46 |
| 4.5 | 12.39 |
| 5.0 | 12.59 |

when sitting upright.

Measurements were made at different forward speeds, viz. 1.5 km $h^{-1}$, 1.8 km $h^{-1}$, 2.1 km $h^{-1}$ and 2.4 km $h^{-1}$ during field trials and 3.5 km $h^{-1}$, 4.0 km $h^{-1}$, 4.5 km $h^{-1}$ and 5.0 km $h^{-1}$ during transport mode of a riding type power tiller provided with a metallic seat. The PULSE programme was activated after the power tiller was started for the operation and the measurement was recorded with an acquisition period of 60 seconds (Ying et al., 1998). Each trial was repeated five times for all operating conditions. The same procedure was repeated for all the selected subjects.

The British Standard (6841) specifies limiting values that specify approximate indications of the likely human reactions to various magnitudes of frequency weighted r.m.s acceleration levels. The overall weighted acceleration values for different operating conditions are compared with the values and the human reactions for all the power tiller operations were determined. The vibration dose value was given by the fourth root of the integral of the fourth power of the acceleration after it has been frequency weighted. Vibration dose values for 8 hour exposure time were calculated for each selected forward speed under different operating conditions and the results were compared with the maximum recommended limit of VDV (BSI 6841, 1987) of 15 $ms^{-1.75}$.

## Results and discussion

The mean values of acceleration in x, y and z direction of each subject at selected levels of forward speed for power tiller B during rototilling in an untilled field are furnished in **Table 1**.

There was an increase in r.m.s. weighted acceleration with the increase in forward speed. It is inferred that ride vibration levels in untilled field were within the 1 to 2.5 hour fatigue decreased proficiency boundary limit during rototilling at forward speeds of 1.5, 1.8 and 2.1 km $h^{-1}$, but limited to 0.42-1.0 h at the forward speed of 2.4 km $h^{-1}$. The results indicated that the safe exposure limit during rototilling in untilled was 4-8 h at the forward speed of 1.5 km $h^{-1}$ and 1.8 km $h^{-1}$, respectively. But further increase in forward speed from 1.8 to 2.4 km $h^{-1}$, the exposure limit was restricted to 2.5-4 h (Mehta et al., 1997). Exceeding the exposure limit will reduce the health and safety of the subject and may cause severe discomfort, pain and injury (ISO, 2631).

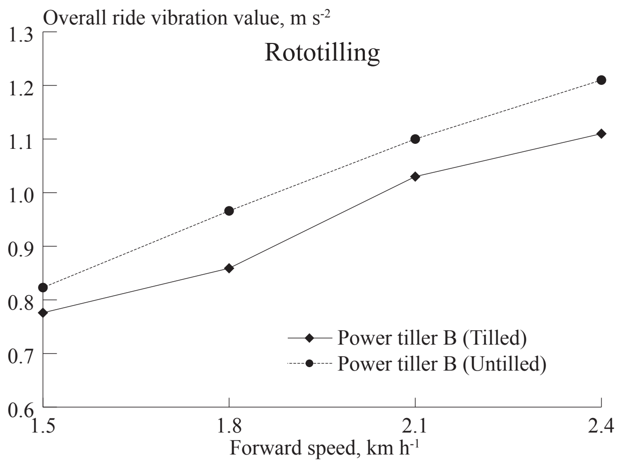
The increase in forward speed had no effect on the fatigue decreased proficiency boundary limit of 1-2.5 h of the subjects. The overall ride vibration values (SUM) were within the 4-8 h exposure limit when the power tiller was operated at the forward speeds of 1.5, 1.8 and 2.1 km $h^{-1}$ but limited to 2.5-4 h at the forward speed of 2.4 km $h^{-1}$, respectively. The comfort of the subject was reduced within 16 minutes of operation for all the selected levels of forward speed.

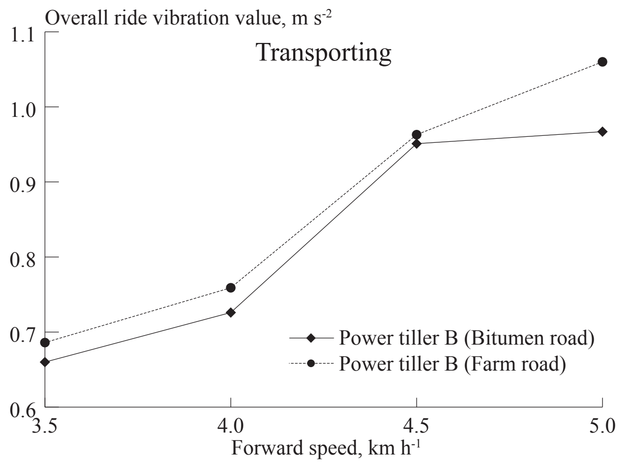
Ride vibration levels during transport on farm roads were up to 4 h fatigue decreased proficiency boundary limit at the forward speed of 3.5 km $h^{-1}$, but limited to 2.5 h at the forward speeds of 4.0, 4.5 and 5.0 km $h^{-1}$, respectively and the safe exposure limit was 4-8 hours at all selected levels of forward speeds. With the increase in speed from 3.5 to 5.0 km $h^{-1}$, the comfort of the subject was reduced from 25 to 16 minutes of operation.

Comparison of ride vibration values between untilled and tilled showed (**Fig. 5**) that the peak value was less in tilled field. This might be due to the more cushioning effect of the tilled soil below the wheels. The increase in forward speed from 1.5 to 2.4 km $h^{-1}$ resulted in an increased overall ride vibration level by 6.05 to 9.09 percent in untilled field when compared to tilled field. The result clearly showed the effect of terrain condition in inducing vibration (Clijmans et al., 1998).

Comparison of ride vibration

**Fig. 5** Whole body vibration for different seat



values in farm and bitumen road showed (**Fig. 5**) that the peak value was less on bitumen roads. The increase in forward speed from 3.5 to 5.0 km $h^{-1}$ resulted in an increased overall ride vibration level by 1.3 to 6.5 percent in bitumen roads when compared to farm roads. The acceleration values were higher in the field condition when compared to transport mode. The rotating parts within the machine and the soil roughness in combination with forward speed contribute to relatively more vibration in field conditions than during transport mode.

The vector sum acceleration was compared with the limiting values prescribed in BS 6841 and the human reaction to overall weighted r.m.s. acceleration were "uncomfortable" at all levels of forward speed selected during the operation of rototilling in untilled and tilled field. The overall weighted r.m.s. acceleration were "fairly uncomfortable" for all levels of forward speed selected during transport mode with empty trailer on farm and bitumen road.

Vibration dose values for each selected level of forward speed for different operating conditions are presented in **Table 2**.

The results were compared with the maximum recommended limit of VDV (BS 6841, 1987) of 15 $ms^{-1.75}$. It is quite clear that almost all the values are within the recommended limit. The results showed that VDV increased with forward speed of travel.

## Conclusions

- The whole body vibration varied from 0.823 to 1.21 m $s^{-2}$ and 0.776 to 1.11 m $s^{-2}$ during rototilling in untilled and tilled field respectively.
- The safe exposure limit varied from 4-8 h to 2.5-4 h with the increase in forward speed from 3.5 to 5.0 km $h^{-1}$ in untilled and tilled field. The human reaction was "fairly uncomfortable" to "uncomfortable" during field operation.
- The whole body vibration varied from 0.686 to 1.06 m $s^{-2}$ and 0.660 to 0.967 m s - during transport with (8.95kW) power tiller on farm and bitumen roads respectively.
- The safe exposure limit was 4 to 8 h during transport on farm and bitumen roads. The likely human reaction was "fairly uncomfortable".
- In general the increase in forward speed resulted in increase of whole body vibration at all conditions tested. The increase in forward speed from 1.5 to 2.4 km $h^{-1}$ resulted in an increased overall ride vibration level by 6.05 to 9.09 percent in an untilled field when compared to tilled field.
- The increase in forward speed from 3.5 to 5.0 km $h^{-1}$ resulted in an increased overall ride vibration level by 1.3 to 6.5 percent in bitumen road when compared to farm road.
- Vibration dose values (VDV) for whole body vibration were within the maximum recommended limit of VDV (BS 6841, 1987) of 15 $ms^{-1.75}$ for all operations.

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# Post Harvest Practices of Betel Leaves in Orissa, India

by

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## Abstract

A large number of small and marginal farmers of Orissa, India solely depend on betelvine cultivation for their family maintenance. It is not only a local consumable commodity but also is exported to other states of India and abroad. In addition to the medicinal value, the betel leaves also have a good nutritional value. The essential oil of the betel leaves contains around 30 different compounds. This essential oil has high market value, which is used in the production of perfume, medicine, talc, beverages, food additives and mouthwash. Moreover, the betel vine cultivation, being labour intensive, provides employment throughout the year for cultivation, harvesting, grading, packing and marketing operations. The movement of the betel leaves starts from the growers' field to the consumer point through different ways. After plucking, the leaves are washed, graded and then packed. The manner of packing varies with the processing operation to be followed. The green leaves are directly sold to the local pan vendors in local markets or to retailers with about 2 to 5 days to reach to the consumers. But a greater percentage of leaves are sold to the traders who further process it to export outside the state. Processors usually take about 10 to 15 days to condition the leaves to be exported outside the state. These leaves reach the end users after about one month. Conditioning is a process in which the green colour of the leaves is changed to yellow/white, which is in high demand by a group of consumers. The process not only fetches a high price because of consumer preference but also increases the storability of the leaves to a noticeable extent. The traditional post harvest practice of betel leaves as followed in the state of Orissa was studied. This paper identifies the points that require R & D intervention for better utilization of the crop.

## Introduction

Betelvine, commonly known as Pan (piper betle L.) is a perennial, dioecious, evergreen creeper grown in moist, tropical and sub-tropical regions of India. The betel leaf is cultivated either under forest ecosystem with support or in artificially created shaded condition, locally known as "baraja" (**Fig. 1** and **Fig. 2**). Though betelvine was originated in Malaysia, at present it is an important cash crop in different parts of India. In India, it is cultivated in about 55,000 hectares (Jan. 1996) with an annual return of over of nine billion rupees and provides livelihood to about 15 million people. The annual yield of the betel leaf in India varies from 600 to 700 bundles/ha (1 bundle = 10,000 leaves) and the average yield per plant varies from 60 to 80 leaves/year. In Orissa betelvine is cultivated in an area of over 4,000 ha in the coastal districts of Balasore, Bhadrak, Cuttack, Puri, Khurda, Jagatsingpur, Kendrapara, Ganjam, Gajapati, Nayagarh and small pockets in the interior of Phulbani, Bolangir and Sambalpur districts. Godi Bangla, Noua Cuttack, Sanchi, Birkoli are some popular varieties grown in Orissa.

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## Uses of Betel Leaves

Betel leaves have been in human use since the time immemorial. In "Vedas and Ayurbeda Sastra" the use of "Tambula" has been mentioned. Betel leaf with a bit of betel nut has been used in Hindu rituals as a pious offering to God in many auspicious occasions and to elder people as a mark of respect during ceremonies. Chewing of "pan" has also been said to be popular among "aryas" and credited with many medicinal properties as indicated in "Susruta Samhita". Since then, betel leaves have occupied a magnificent place in daily life of Indian people. In addition to the above legendary effects, the betel leaf has also the following qualities.

- The leaf is rich in Vitamin B, C & E.
- It has stimulatory effect on heart, brain and liver.
- It cleans the mouth and throat
- It helps in digestion by increasing salivation and neutralizes excess acid with lime.
- It is good for teeth as it contains chlorophyll.
- It is useful in catarrhal, pulmonary infections and night blindness.
- Fresh leaf powder is used as lotion for patients suffering from small pox and enlarged glands.
- It is used with honey as a remedy for cough.
- Betel leaf extract may be used as an antioxidant for storage of oily products such as fish, fish oil, ghee etc.
- Betel leaf may be used for the manufacture of essential oil, perfume and food additives.

Cultivation of betel vine is labour intensive process with pre-harvest and post-harvest operations like earthing, tying, plucking, washing, sorting, counting, grading, depetoilation arranging, bundling, packaging and transportation, which provides employment to rural people throughout the year.

## Methodology

A survey was conducted in Cuttack, Puri, Balasore, Paradeep, Khurda and Ganjam districts of the state of Orissa, India, to study the traditional harvest and post harvest practices of betel leaves followed by the farmers. Large and small-scale processors were also contacted to study the existing practices of processing. Information regarding methods used for different unit operations and problems encountered were collected through questionnaire sheets to identify the area where post-harvest approach is needed. Detailed flow charts for the post-harvest practices of betel leaves followed by the farmers in the state of Orissa are given in **Fig. 3** and **Fig. 4**.

## Harvest and Post-Harvest Operations

**Harvesting**

The leaves that are sufficiently matured are plucked along with a portion of the petiole. Leaves are plucked by hand without any aid. However, the maturity level is decided based on the consumer preference in the local area. In Orissa the leaves are plucked at an interval of 7 to 15 days yielding, about 50 to 70 leaves per plant per year. About seven to eight million leaves are harvested annually from one hectare of betel vine garden.

**Cleaning and Sorting**

After plucking, the leaves are sorted for damaged/diseased leaves and made into bundles of 50 to 100. These are washed thoroughly and packed in bamboo strip baskets or gunny cloth according to the prevailing tradition of the area. During this operation the damaged/rotten leaves are discarded. Freshly plucked leaves packed as mentioned below are sold in the local pan markets either to local pan vendors or to middlemen/processors.

**Packaging**

After sorting the leaves into different grades (damaged, rotten) the good quality leaves are separated, depetioled and bundled into 50 and 100 and then packed in bamboo bas-

**Fig. 1** Outside view "Pan baraj"

**Fig. 2** Inside view of "Pan baraj" showing plants and supporting structures

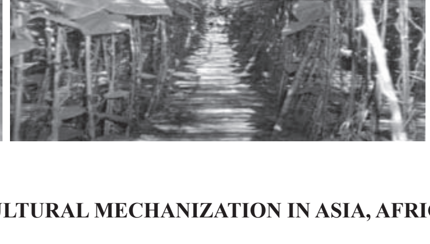


**Table 1** Area under betel leave cultivation in different states of India

| Name of the State | Area under cultivation, ha |
|---|---|
| West Bengal | 18,209 |
| Assam | 7,850 |
| Karnataka | 6,682 |
| Tamil Nadu | 4,795 |
| Orissa | 4,007 |
| Andhra Pradesh | 3,865 |
| Bihar | 3,116 |
| Uttar Pradesh | 2,214 |
| Maharastra | 1,419 |
| Kerala | 1,280 |
| Madhya Pradesh | 600 |
| Others | 600 |

**Table 2** Export of betel leaves from India during 1975-2000

| Year of export | Quantity, tonnes | Value, Thousand Rupees |
|---|---|---|
| 1975-80 | 932 | 8,007 |
| 1981-85 | 1,347 | 13,226 |
| 1986-90 | 402 | 3,429 |
| 1991-95 | 435 | 4,002 |
| 1996-2000 | 574 | 6,162 |

kets. As per the existing practice, the packaging is done in a very specific manner. A layer of wet cloth/gunny cloth is placed in the empty basket and then the depetioled betel leaf bundles are arranged towards the periphery of the basket in a circular manner so that a cavity is created at the centre. Then the basket along with the leaves is covered by a layer of gunny cloth on its top and stitched properly. When the leaves are not depetioled, the leaves are arranged so that the petioles project towards the periphery (**Fig. 5**). When the green betel leaves with petioles are exported to other states, ice packs (ice inside gunny cloth) are provided in the cavity to have better cooling effect at the rate of about 2 to 3 kg per 4,000 leaves (**Fig. 6**). In one basket, 36 to 40 bundles of 50 leaves each amounting to about 1,800 to 2,000 leaves are accommodated. Sometimes bigger size baskets are used with more leaves. During export to other states, the stitched baskets are transported either in single or with double layer of gunny cloth cover or two baskets stitched face to face with single layer of gunny cloth cover. Transportation of bundles is carried out by trucks within the state and to outside the state through railways.

**Processing**

As shown in the flowcharts, the movement of the betel leaves starts from the growers' field to the consumer point through different ways. After plucking, the leaves are washed, graded and then packed (**Fig. 7**). The manner of packing varies with the processing operation to be followed. The green leaves may be directly sold to the local pan vendors in local markets or to retailers. It takes about 2 to 5 days to reach to the consumers. But a greater percentage of leaves are sold to the traders who further process it to export to outside the state. Processors

**Fig. 3** Flow chart of movement of betel leaves from producer to consumer

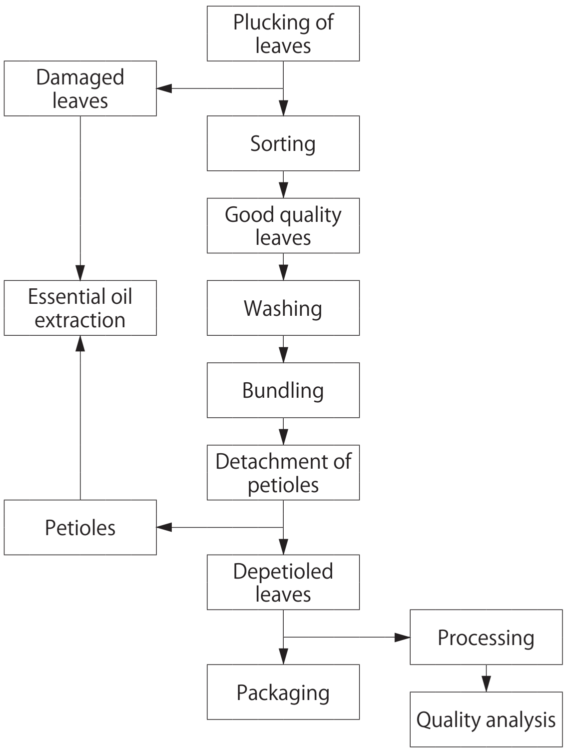



**Fig. 4** Flow chart of traditional conditioning of betel leaves

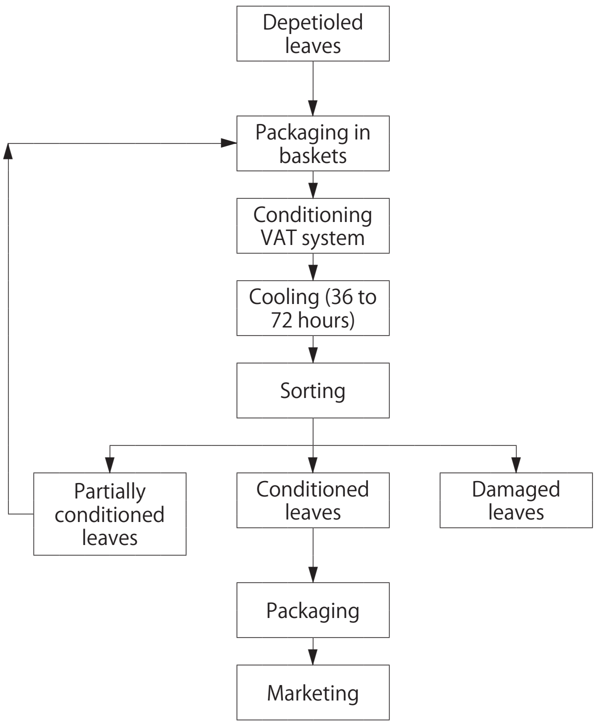



**Fig. 5** Wholesale packaging of betel leaves in local market

**Fig. 6** Packaging of betel leaves with ice cubes

**Fig. 7** Packaging of leaves for export/processing

usually take about 10 to 15 days to condition the leaves to be exported outside the state, which takes about 1 month to reach to the end users.

**Conditioning**

To preserve the delicacy of the betel leaves for many days, they are artificially ripened or bleached before transportation or storage. Conditioning is a process in which the green colour of the leaves is changed to yellow/white, which is highly demanded by a group of consumers. The process not only fetches a high price because of consumer preference but also increases the storability of the leaves to a noticeable extent. In the traditional method of conditioning, a small chamber (called as Bhatti) made up of brick and mud is used. The chambers are of various sizes ranging from 1.2 x 1.2 x 2.4 m to 2.7 x 2.7 x 2.4 m depending on the capacity. The vats are usually constructed inside the house. Walls of the vat are constructed with brickwork of mud plaster some times accompanied by a layer of cow dung. The floor is also either cemented or covered by an even layer of clay and dung to make it air proof. An insulated door of 0.75 x 1.8 m is provided at the front that is fabricated with bamboo mat frame covered with straw and gunny cloth. The door is about 15 cm larger on each side by the dimension of the door opening. Enough care is taken to make it air tight as well as insulated by restricting the opening of the door. Inside the vat at a height of 30 cm from the ground level, bamboo racks are provided at an interval of 45 cm to 60 cm between the racks on all sides of the chamber excluding the entrance side. After plucking from the plant, the betel leaves are sorted for damaged and diseased leaves that are discarded. After removing the petioles, the leaves are bundled into 50 to 100 and are arranged in the baskets of uniform size. The inner side of the baskets is lined with Sal leaves or a layer of wet gunny cloth. Then leaves are arranged in the specific way as described earlier to have a cavity at the centre for proper ventilation to remove the heat of respiration. The bundles are placed in such a manner that the front and backside of the leaves are exposed alternately. Then the baskets are covered with moist gunny cloth and arranged in the racks in order. At a given time, about 10 to 40 baskets each containing about 2,000 leaves can be kept in the chamber. The number varies according to the size of the chamber.

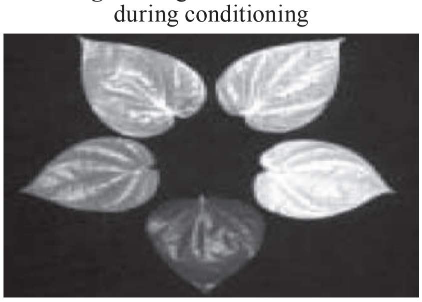
In one corner of the room a small chullah is kept in which wood charcoal is burnt during conditioning. About 2 to 3 kg of charcoal are required for one charging. After firing the movable chullah is kept at a corner away from the racks to avoid direct heat. The door is also properly covered to avoid any leakage of heat from the chamber. After 10 to 12 hours of charging the baskets are taken out for cooling. The cooling period varies between 36 to 72 hours depending upon the weather conditions. During the cooling period the leaves are sorted (**Fig. 9**) and reshuffled (by keeping the top layers at the bottom and the bottom layers on top). Before subjecting the baskets to a second phase of charging, the damaged or rotten leaves are discarded. Then the process is repeated until all the leaves are conditioned, i.e. the green colour of the leaves change to yellow colour (**Fig. 10**). After the second phase the amount of fuel is gradually reduced. The requirement of fuel for obtaining the desired temperature range, as well as to achieve the final conditioned stage of betel leaves, is mainly decided through personal experience as no such rule or scientific formula exists. Temperature requirement varies with the variety and quality of leaves. During the summer season, the leaves are fully conditioned with 2 to 3 chargings. But in winter, sometimes, it requires even a 5th charging. The conditioned leaves are finally packed in bamboo baskets as described earlier to be exported to other cities.

In a chamber of 2.7 x 2.7 x 2.4 m, around 30 to 40 baskets can be accommodated at any given time for conditioning (each carrying 1,800 to 2,000 leaves). This method of processing of betel leaves not only enhances the taste (for a particular group) but also extends the storage life of the leaves about 7 to 10 days in summer and 15 to 20 days in winter. The cost of such conditioned leaves is much higher than the general unprocessed ones. The intensity and quality of conditioning is dependent

**Fig. 8** Outside and inside view of traditional conditioning chamber (VAT) along with arrangement of baskets

**Fig. 9** Sorting and arranging the conditioned leaves

**Fig. 10** Stages of betel leaves during conditioning



on many influencing parameters like time and intensity of heating, quality of green leaves, size of chamber and external climatic conditions.

**Limitations of the Traditional Processing System**

- Labour consuming
- Time consuming
- Tedious
- Does not work during rainy season

**Marketing**

Around 4,000 hectares of land is in use for betel vine cultivation in Orissa. Each hactare yields an average of seven to eight million leaves per year. Farmers sale their leaves with an average price of Rs.50 to Rs.200 per 1,000 leaves depending upon the season and demand, where as, the conditioned leaves are sold for Rs.200 to Rs.500 per thousand leaves. Middle men/traders primarily do the conditioning. They collect leaves from different farmers and export to other parts of the country after conditioning in baskets of about 2,000 leaves. On an average, 2,000 to 3,000 baskets are exported out of the state daily (**Fig. 12**).

## Future Research Needs on Post Harvest Technology of Betel Leaves

During the rainy season, the leaf production is so high that, the leaves remain unsold or sold at a very low price. Therefore, manufacturing of essential oil, pan masala, talc, medicinal compounds, perfume, beverage and food additives may be useful in establishing the market price of the crop year-round. Standardisation of different parameters of each of these processes is essential in order to reduce the losses. Following are the thrust areas on which future research may be carried out.

- Development of process technology and low cost equipment for extraction of essential oil from betel leaves and petioles.
- Development of process technology for manufacture of mouth fresheners, perfume, talc, food additives and beverages etc.
- Study on the antioxidant and anti-inflammatory properties of betel leaf extract.
- Scientific packaging and storage of betel leaves for shelf life enhancement.

## Conclusion

Cultivation of this potential crop is handicapped by various constraints. No official data is available on acreage, yield and processing methods. No systematic efforts have been made so far to improve the processing, packaging and marketing of this potential cash crop though a large number of villagers exclusively engage themselves traditionally in this cultivation. The business is mostly carried out based on personal experience. Scientific study on the optimisation of all the above said parameters will no doubt lead to the minimisation of losses. If the processing and packaging methods can be scientifically standardised, then the leaves can be processed and packed at the garden level, which will earn more profits to the growers. It will also increase export by improving the quality as well as storability.

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**Fig. 11** Betel leaves in local pan market

**Fig. 12** Baskets of betel leaves at railway station for transportation

# Effect of Design and Operating Parameters of Performance of Inter-cultivation Sweep in Vertisols

by

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## Abstract

Effect of approach angle, gang width, moisture content and speed on specific draft and weeding efficiency were studied in the laboratory and field. Specific draft was lower and weeding efficiency was higher for 70º approach angle sweep. The relationship between approach angle and specific draft was a polynomial and that of speed and specific draft was linear. As the moisture content increased the specific draft increased. The effect of approach angle and gang width on weeding efficiency was also significant. Weeding efficiency was highest for 300 mm gang width at 15 % moisture content. Trend of specific draft and weeding efficiency in the laboratory and field was similar. From the field test, it was observed that 250 mm gang width may be used in 350 mm row spaced crop as it gave reasonable weeding and field efficiency with comparatively less plant damage (1.32 %) and high (0.20 ha/h) field capacity.

## Introduction

Soybean (Glycin - max) crop is the major monsoon crop of Madhya Pradesh state of India. Higher weed infestation is a serious problem for growing soybean. High temperature accompanied by high humidity prevailing during the early monsoon facilitates weeds growth in the state. It is estimated that during monsoon about 5 million-hectare are left fallow in the state due to the weed problem. A lot of work has been done to evaluate the performance of various designs of inter-cultivation tools (Tewari, 1993; Biswas, 1993; Sial, 1978; Dransfield, 1964). Girma (1992) reported that in the ploughing process, most of the energy dissipation is a function of speed. Speed also plays an important role for dynamic stability and draft control. Some scientific approaches for design of soil working components are available (Bernacki, 1972; Goryachkin, 1968). Power operated inter-cultivation machines are available but their expediency in narrow row spaced crop is limited and most of them are region specific. Therefore, geometry of soil working tools suitable for narrow row spacing crop is required. Various types of weeders and weeding mechanism are being used according to cultural practices and climatic conditions. Different design parameters such as rake angle, approach angle, tilt angle, lift angle, blade width, blade thickness, sharpness angle, speed, depth of operation and geometry were considered as design parameters by various researchers.

It was found from the review of literature that shape, size, geometry and operating parameters affect the performance of the inter-cultivation tools. It has also been observed that the sweep is the most suitable (Sial, 1978; Tewari, 1993; Biswas, 1999) soil working tool under black soil conditions. Bernacki (1972) recommended that apex angle should be in the range of 60 to 90º. Previous studies on approach angle are limited. It was decided to test the weeder with a different geometry of sweep that had a small width but in gang instead of single sweep. Therefore, the objective of the present study was to design a sweep (**Fig. 1**) and to study the effect of approach angle and gang width on performance of weeder at various operating parameters and testing it in the filed.

## Materials and Methods

Soil of the region is characterized as black soil that contains predominantly montmorillonite clay. The soil has good moisture holding capacity and it swells considerably with moisture content. When dry, the soil shrinks and forms cracks. The moisture content at field capacity of the soil is about 28 % and the wilting point is about 11 %. Soil used in the bin has clay texture with 14.79 % sand, 10.51 % silt and 54.70 % clay.

Four different shapes of sweep were tested in laboratory and field for determination of optimum design parameters of sweep under vertisols.

**Variables:**

***(a) Independent Variables***

i. Approach Angle (º)

$\theta_1 = 60$ $\theta_2 = 70$

$\theta_3 = 80$ $\theta_4 = 90$

ii. Gang Width (mm)

$G_1 = 225$ $G_2 = 250$

$G_3 = 275$ $G_4 = 300$

iii. Speed of Operation (m $s^{-1}$)

$S_1 = 0.28$ $S_2 = 0.42$

$S_3 = 0.56$ $S_4 = 0.70$

iv. Soil Moisture (%, db)

$M_1 = 12$ $M_2 = 15$

$M_3 = 18$ $M_4 = 21$

***(b) Dependent Variables***

i. Specific Draft

ii. Weeding Efficiency

The range of gang width was taken from 225 mm to 300 mm as it was most suitable for the crop sown at 350 mm row spacing. The approach angle was from 60º to 90º based on theoretical considerations (Barnacki et al., 1972). Similarly, the range of speed was from 0.28 m $s^{-1}$ to 0.70 m $s^{-1}$, which was ergonomically best suited for walking behind implements. The workable range of moisture content was between 12 % and 21 % considering the water field capacity and wilting point. The dependent variables taken were unit draft and weeding efficiency.

## Experimental Procedure

The laboratory soil tray was filled with the soil to a depth of 250 mm. Water was sprinkled on the soil to maintained desired soil moisture, thoroughly hand mixed, leveled and compacted. A hand held cone penetrometer was used to measure the cone penetration resistance of the soil. The penetrometer had a cone angle of 30º and base area of 491.1 $mm^2$. Readings were taken up to a depth of 100 mm. The value of cone penetration resistance was reasonably uniform and ranged from 0.120 to 0.121 N $mm^{-2}$.

The statistical layout was split-split plot design with the approach angle in the sub-sub plot to have the maximum precision with the approach angle. The experiment was conducted in the soil bin shown in (**Fig. 2**). Moisture of soil in the bin was maintained at nearly 12 %. Three sweeps of 60º approach angle were mounted on the tool holder by keeping the gang width 225 mm. The transducer (purposely designed for the present study) was fitted to the tool holder with the help of a flange. A digital strain indicator was connected to transducer. The bridge circuits of the transducer were connected to a strain indicator through a switching and balancing unit. The draft exerted on the tool was displayed in terms of strain that was calibrated in terms of draft. In this way, the total draft was measured and was divided by gang width to

**Fig. 1** Drawing of designed sweep showing dimensions and different parts

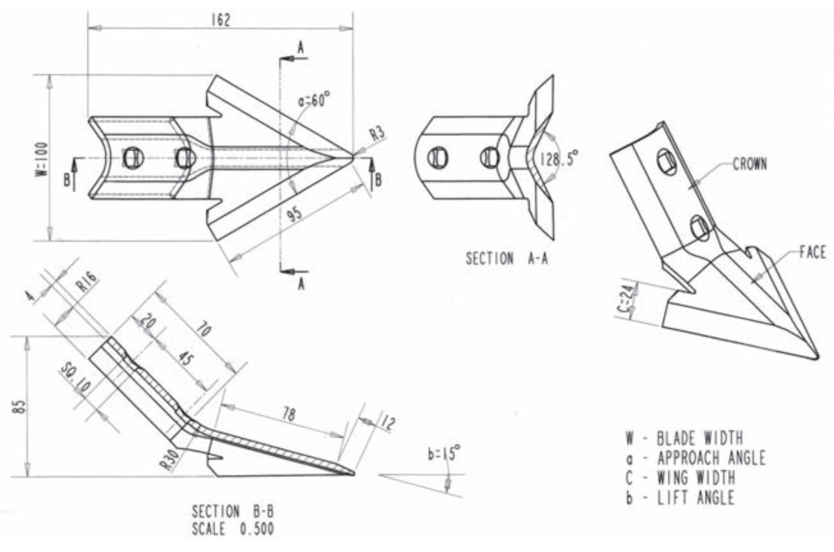



**Fig. 2** Laboratory test set-up used for measuring the draft

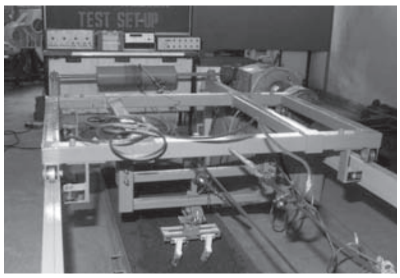


**Fig. 3** Field testing of power weeder attached for optimized sweep

obtain the draft per unit working width (termed as specific draft in this study). One hundred pearled head pins were randomly inserted in to the soil on the path of the tool in the 350 mm band to represent the weeds in the row. Depth of operation was maintained at 50 mm. The trolley was pulled at 0.28 m $s^{-1}$ speed. The horizontal force was recorded with the help of the strain indicator. The undisturbed pins were counted. Soil was brought to its original condition and speed was changed to 0.42 m $s^{-1}$. The horizontal force and undisturbed pins were recorded. The procedure was repeated for speeds of 0.56 m $s^{-1}$ and 0.70 m $s^{-1}$. After completion of tests, at all four speeds, the gang width was changed to 250, 275 and 300 mm, respectively and the same procedures adopted as for 225 mm. The identical test was conducted with approach angles 70º, 80º, and 90º tools at 15 %, 18 % and 21 % moisture content. The data were subjected to statistical analysis on window based WINDOWSTAT and SPSS statistical software.

### Field Testing

The field test was conducted on a soybean crop sown at 350 mm row spacing (**Fig. 3**). The operating speed of the weeder was maintained at a rate to prevent fatigue and crop damage. Three gangs at a time were used to cover three inter row spacing so as that the field capacity of the weeder would be high. The weeder was tested at four gang widths to obtain the optimum gang width for maximum weeding efficiency and least crop damage.

The test was conducted to cover 400 $m^2$ area and was replicated three times. RNAM test code and test procedure (1983) was followed for field testing.

## Results and Discussion

### Optimization of Approach Angle (θ) and Gang Width (G)

The effects of approach angle on specific draft and weeding efficiency at various operating parameters such as soil moisture and operating speed at various gang widths have been studied. The details of the effect are as follows:

### Effect of Approach Angle (θ) and Gang Width (G) on Specific Draft ($U_d$)

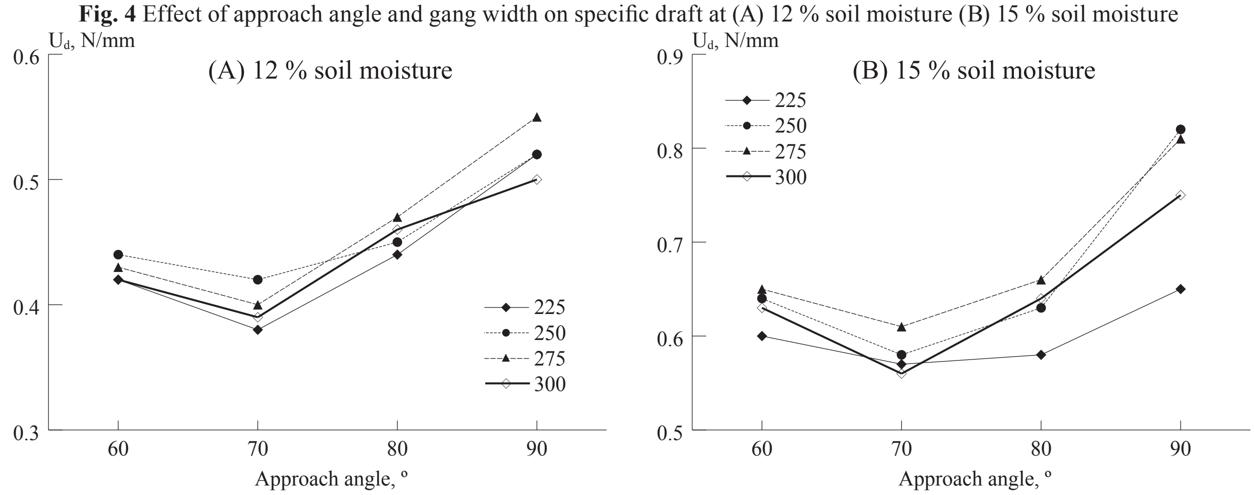
The effect of approach angles and gang widths on specific draft ($U_d$) at 0.28 m $s^{-1}$ operating speed have been presented in **Fig. 4** and **5** at different moisture content.

It is evident from the **Fig. 4** and **5** that the specific draft ($U_d$) is lower for the 70º approach angle sweep for all the gang widths and moisture content. Similar trends were also observed for

**Table 1** Analysis of variance to test the effect of approach angle and gang width on specific draft and weeding efficiency

| Source of variation | df | For specific draft | | | For weeding efficiency | | |
|---|---|---|---|---|---|---|---|
| | | Sum of squares | Mean squares | F ratio | Sum of squares | Mean squares | F ratio |
| Replicates | 2 | 0.00048 | 0.0002 | 0.75 | 3.292 | 1.646 | 1.47 |
| θ | 3 | 0.10427 | 0.0347 | 137.13*** | 101.229 | 33.74 | 30.18*** |
| Linear | 1 | 0.07176 | 0.0718 | 283.11*** | 2.60417 | 2.604 | 2.33 |
| Quadratic | 1 | 0.02950 | 0.0295 | 116.39*** | 93.5208 | 93.52 | 83.65*** |
| Cubic | 1 | 0.00301 | 0.0030 | 11.88*** | 5.10417 | 5.104 | 4.57 |
| Error A | 6 | 0.00152 | 0.0003 | | 6.70833 | 1.118 | |
| G | 3 | 0.00361 | 0.0012 | 4.44* | 396.229 | 132.1 | 101.2*** |
| Linear | 1 | 0.00001 | 0.00001 | 0.04 | 387.604 | 387.604 | 296.9*** |
| Quadratic | 1 | 0.0035 | 0.0035 | 12.93** | 0.1875 | 0.1875 | 0.14 |
| Cubic | 1 | 0.000094 | 0.000094 | 0.35 | 8.4375 | 8.4375 | 6.46* |
| θ*G | 9 | 0.00457 | 0.0005 | 1.87 | 9.1875 | 1.02083 | 0.78 |
| Error B | 24 | 0.0065 | 0.0003 | | 31.333 | 1.30556 | |
| Total | 47 | 0.12085 | 0.00257 | | 547.98 | 11.6591 | |

**Fig. 4** Effect of approach angle and gang width on specific draft at (A) 12 % soil moisture (B) 15 % soil moisture



other operating speeds. There is little effect of gang width on specific draft but it is lower for 225 mm gang at lower moisture content however, at 21 % moisture content it was lower for 300 mm gang width. As the moisture content increased the unit draft increased. A second degree polynomial relationship exists between approach angle and specific draft.

From **Table 1**, the calculated F ratio for θ and G are higher than the tabulated F ratio. It is therefore, concluded that the effect of approach angle and gang width on specific draft is highly significant.

The lowest draft at 70º approach angle could be explained by physico mechanical properties of soils, trihedral wedge theory, theory of rupture and cutting theory given by Goryachkin (1968) and Sineokov (1977). Change in approach angle causes change in flow pattern of the soil along the tool surface. The change in flow pattern causes significant variations in draft (Girma, 1992). To prevent sticking, the direction of cut can be made normal to the working face of the wedge, and for that it is necessary that $\varphi = 90^{o} - \alpha$, where $\varphi$ is angle of internal friction and $\alpha$ is cutting angle. The forces acting on the implements are (a) force causing forward travel, P, acting at an angle to the horizontal (b) the weight, G, of the implement (c) the resistance of the working surface (d) the reactions of the supporting surface, R, which includes normal and tangential frictional forces. The frictional forces can be eliminated by changing the inclination of the working and supporting planes by the angle of friction. The resultant of all above forces must lie in the same line. For minimum draft, the force causing forward travel 'P' must make an angle with horizontal equal to the angle of friction. The draft in the present study was lowest for 70º approach angle, which might be due to fulfilling of this condition. Other researchers (Biswas, 1990; Tewari, 1993) have also reported similar findings.

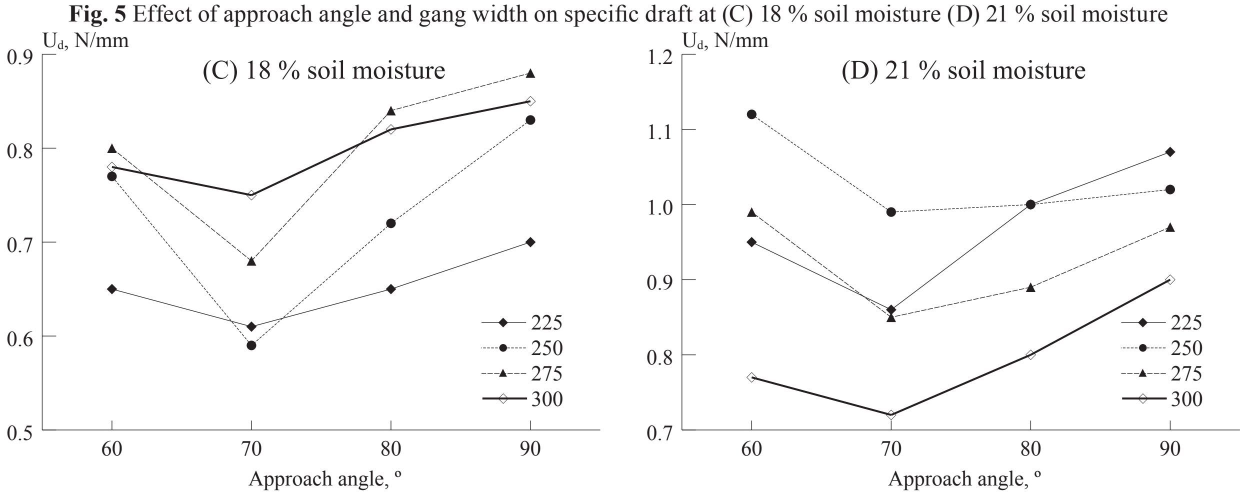
**Table 2** Analysis of variance to test the effect of soil moisture and operating spped on specific draft and weeding efficiency

| Source of variation | df | For specific draft | | | For weeding efficiency | | |
|---|---|---|---|---|---|---|---|
| | | Sum of squares | Mean squares | F ratio | Sum of squares | Mean squares | F ratio |
| Replicates | 2 | 0.00060 | 0.0003 | 1.13 | 0.875 | 0.4375 | 0.80 |
| M | 3 | 8.16031 | 2.7201 | 10207*** | 3389.96 | 1130.0 | 2060*** |
| Linear | 1 | 7.581 | 7.581 | 28447*** | 2306.4 | 2306.4 | 4204*** |
| Quadratic | 1 | 0.12556 | 0.12556 | 471..2*** | 638.02 | 638.02 | 1163*** |
| Cubic | 1 | 0.45371 | 0.45371 | 1703*** | 445.34 | 445.54 | 812*** |
| Error A | 6 | 0.0016 | 0.00026 | | 3.292 | 0.5486 | |
| G | 3 | 0.14121 | 0.04707 | 172.04*** | 980.291 | 326.76 | 359.2*** |
| Linear | 1 | 0.05415 | 0.05415 | 197.91*** | 980.104 | 980.104 | 1077*** |
| Quadratic | 1 | 0.04532 | 0.04532 | 165.66*** | 0.0833 | 0.0833 | 0.09 |
| Cubic | 1 | 0.04173 | 0.04173 | 152.55*** | 0.10416 | 0.10416 | 0.11 |
| M*G | 9 | 0.81891 | 0.0099 | 332.25*** | 80.75 | 8.97222 | 9.86*** |
| Error B | 24 | 0.00656 | 0.00027 | | 21.8333 | 0.9097 | |
| S | 3 | 0.59953 | 0.19984 | 736.96*** | 223.416 | 74.472 | 60.59*** |
| Linear | 1 | 0.5995 | 0.5995 | 2210*** | 160.066 | 160.066 | 130.2*** |
| Quadratic | 1 | 0.000005 | 0.000005 | 0.02 | 44.0833 | 44.0833 | 35.86*** |
| Cubic | 1 | 0.00003 | 0.0003 | 0.11 | 19.2666 | 19.2666 | 15.67*** |
| M*S | 9 | 0.2094 | 0.02326 | 85.79*** | 264.458 | 29.384 | 23.91*** |
| G*S | 9 | 0.02812 | 0.00312 | 11.52*** | 13.4583 | 1.4954 | 1.22 |
| M*G*S | 27 | 0.04506 | 0.00167 | 6.15*** | 43.6667 | 1.6172 | 1.32 |
| Error C | 96 | 0.02603 | 0.0003 | | 118 | 1.22917 | |
| Total | 101 | 10.0373 | 0.05255 | | 5140 | 26.911 | |

### Effect of Approach Angle (θ) and Gang Width (G) on Weeding Efficiency ($W_e$)

The effect of approach angle and

**Fig. 5** Effect of approach angle and gang width on specific draft at (C) 18 % soil moisture (D) 21 % soil moisture



gang width on weeding efficiency ($W_e$) is given in **Fig. 6** and **7**.

It is evident from **Fig. 6** and **7** that the weeding efficiency is higher for the 70º approach angle sweep for all the gang width and moisture content at 0.28 m $s^{-1}$ operating speed. The similar trends were also observed for 0.42 m $s^{-1}$, 0.56 m $s^{-1}$, and 0.70 m $s^{-1}$ operating speed. A polynomial relationship between approach angle and weeding efficiency exists. It is also seen from **Fig. 6** and **7** that the weeding efficiency is lower for lower gang width and higher for higher gang width. Higher weeding efficiency at higher gang width may be due to more area coverage in between the rows. It is seen from Table 1 that the F ratio for approach angle and gang width are higher than the tabulated F ratio. It is therefore, concluded that the effect of approach angle and gang width on weeding efficiency is highly significant.

The specific draft is lower and weeding efficiency is higher for 70º approach angle sweep. Therefore, sweep of 70º approach angle is considered to be optimum. In case of gang width, the specific draft was lower for 225 mm gang width but the weeding efficiency was higher for 300 mm gang width. Considering the objective of the tool, 300 mm gang width is considered to be optimum subject to the crop row spacing.

**Optimization of Operating Speed (S) and Moisture Content (M)**

The optimized tool, which is 70º approach angle sweep, was tested at four levels of operating speed namely 0.28 m $s^{-1}$, 0.42 m $s^{-1}$, 0.56 m $s^{-1}$ and 0.70 m $s^{-1}$ and four levels of soil moisture namely 12 %, 15 %, 18 % and 21 % and their effect on specific draft and weeding efficiency were observed in the soil bin. The graphical presentations of the relationship are shown in **Fig. 8**. The statistical analysis to test the significance of effect of speed (S) and its interaction effect on dependent variables, i.e. specific draft and weeding efficiency, are given in **Table 2**.

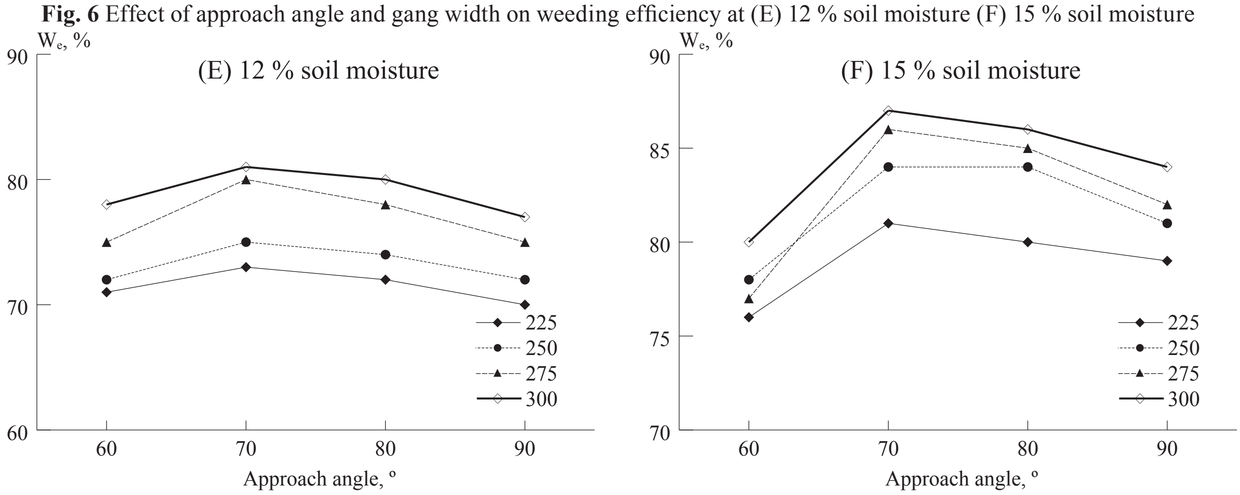
It is observed from **Fig. 8** that the relation between speed and specific draft ($U_d$) is linear and increases as the speed increases. The $U_d$ is lower for 12 % moisture for all the speeds tested in the present study and highest for 21 % moisture content. The weeding efficiency decreases as the speed increases and is higher at 0.28 m $s^{-1}$ and lowest at 0.70 m $s^{-1}$. In case of specific draft the calculated F ratio for S, M and interaction effect M*S, and M*G*S are highly significant. It is, therefore, concluded that the effect of speed and moisture content on specific draft is highly significant.

Observations made above indicate that the unit draft is lower at 0.28 m $s^{-1}$ but the weeding efficiency was higher at 0.42 m $s^{-1}$ speed. Since 0.42 m $s^{-1}$ provides higher field capacity and also gives more weeding efficiency, 0.42 m $s^{-1}$ speed is considered to be optimum. Similarly, the specific draft and weeding efficiency is moderate at both 12 % and 15 % moisture content but 15 % moisture content can be considered optimum as it gives reasonably higher working range.

The increase of draft with speed might be explained by change in zone of influence and strain hardening (Sial, 1978). Also, soil strength became larger as the rate of shear increased (Rowe, 1961). When the tilling tool is operated at higher speed, instead of inverting and throwing soil, the plough carried soil along with it, which results in bulking and heaving of soil on the implement base. Increase in specific draft requirement with increase in speed has been reported by Shrestha (2001).

Up to a particular limit, the increase of moisture increased the friction coefficient. The increase in the friction coefficient with moisture increase was explained by the growth in the forces of molecular attraction of the soil particle to the steel surface. With increase in unit pressure on the surface of contact, adhesiveness increased, which depended on the furrow slice weight. Therefore, increase in frictional coefficient and adhesiveness might be the reason for higher specific draft at higher soil moisture.

**Fig. 6** Effect of approach angle and gang width on weeding efficiency at (E) 12 % soil moisture (F) 15 % soil moisture



### Field Testing

The average specific draft required for the weeder was 0.57, 0.56, 0.53 and 0.49 N $mm^{-1}$ at average depth of operation of 58, 67, 61 and 64 mm and the average speed of operation was 0.53, 0.56, 0.49 and 0.47 m $s^{-1}$ for 225 mm, 250 mm, 275 mm and 300 mm gang width, respectively. The weeder worked in the field satisfactorily with occasional clogging and scouring. The percentage crop damage was 0.67, 1.32, 2.08 and 3.03 % for 225, 250, 275 and 300 mm gang width respectively. The crop damage was lower for 225 mm gang width because of more space available within the row. Similarly the field capacity was 0.19, 0.20, 0.17 and 0.17 ha/h. The weeding efficiency was 74.04, 77.60, 78.92 and 80.25 % and field efficiency was 71.38, 69.94, 73.51 and 74.27 % for the above gang widths. From the field performance study, it was concluded that the 250 mm gang width may be used in 350 mm row spaced crop as it gives reasonably high weeding and field efficiency with comparatively less plant damage (1.32 %) but with high (0.20 ha/h) field capacity. The magnitudes of specific draft and weeding efficiency at the identical conditions of the laboratory study were 0.67, 0.64, 0.73 and 0.78 N $mm^{-1}$ and 72, 72, 74 and 78 %, respectively. The trend of variation of specific draft in the field was similar to the trend obtained in the laboratory. The trend for weeding efficiency in both laboratory and field was similar and as the speed increased, the weeding efficiency decreased. The specific draft obtained in the laboratory test was higher than field testing because of difference in bulk density of soil. The soil in the laboratory was compacted where as the soil in the field was in natural condition. Although, in the laboratory test, the 300 mm gang width was optimum. However, it was a little inconvenient for the operator to steer the weeder at this gang width with only one meter working width. This gave only a small margin of error to avoid plant damage.

### Multiple Nonlinear Regression Equation for Specific Draft and Weeding Efficiency

To see the combined effect of all the four independent variables namely, approach angles, gang widths, soil moisture and operational speed on the dependent variable, namely, specific draft, the data was subjected to regression analysis by using SPSS computer program. The equation obtained is given below.

$$U_d = -0.527 - 5.741 \times 10^{-2} \times \theta + 1.143 \times 10^{-2} \times m + 1.947 \times 10^{-2} \times g + 0.337 \times s + 4.059 \times 10^{-4} \times \theta^2 + 1.523 \times 10^{-3} \times m^2 - 3.781 \times 10^{-5} \times g^2 + 4.556 \times 10^{-2} \times s^2$$

Where,

$U_d$ = Specific draft ($Nmm^{-1}$)

$\theta$ = Approach angle ($0^o$)

m = Soil moisture (db), (%)

g = Gang width (mm)

s = Operating speed (m $s^{-1}$)

The calculated 'F' value of the estimated multiple nonlinear regression equation was 190.21 which is significant at 1 % level. Thus, the combined nonlinear effects of all the four independent variables contributed significantly to the variation in specific draft. The coefficient of determination ($R^2$) of the regression equation obtained above was 0.86, which indicated that about 86 % of the total variation in the specific draft was explained by the nonlinear function of the independent variables.

The multiple nonlinear regression equation obtained for the weeding efficiency is given below:

$$W_e = -58.737 + 2.24 \times \theta + 5.5 \times m + 3.725 \times 10^{-2} \times g + 13.68 \times s - 1.48 \times 10^{-2} \times \theta^2 - 0.2 \times m^2 + 7.5 \times 10^{-5} \times g^2 - 19.534 \times s^2$$

Where,

$W_e$ = Weeding efficiency (%)

$\theta$ = Approach angle ($0^o$)

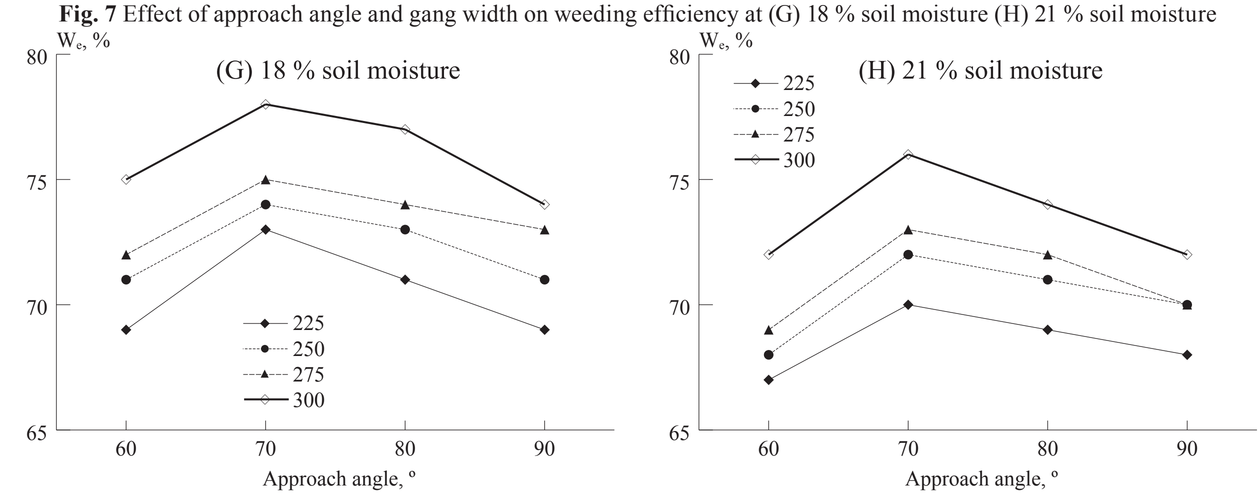
m = Soil moisture (db), (%)

g = Gang width (mm)

s = Operating speed (m $s^{-1}$)

The calculated 'F' value of the estimated multiple nonlinear regression was 139.321, which was significant at the 1 % level. Thus, the combined nonlinear effects of all the four independent variables contributed significantly to the variation in weed-

**Fig. 7** Effect of approach angle and gang width on weeding efficiency at (G) 18 % soil moisture (H) 21 % soil moisture



ing efficiency. The coefficient of determination ($R^2$) of the regression equation obtained above was 0.819, which indicate that about 82 % of the total variation in the specific draft is explained by the nonlinear function of the independent variables.

## Conclusion

The conclusions drawn from the study are given below.

1. The effect of approach angle on specific draft and weeding efficiency was significant and the relationship was quadratic. The specific draft was lower and weeding efficiency was higher for 70º approach angle sweep.
2. The effect of gang width on specific draft was significant. Specific draft was lower for 225 mm gang width at lower moisture content and 300 mm for 21 % soil moisture.
3. Effect of gang width on weeding efficiency was significant. It increased linearly with gang width.
4. The specific draft increased as moisture content increased and the relationship was quadratic.
5. The weeding efficiency initially increased and then decreased with increase in moisture content and was higher at 15 % moisture content.
6. The relationship between speed and specific draft was linear for all speeds, moisture contents and gang widths.
7. In the field, the weeder with 70º approach angle tool spaced at 250 mm operated at around 0.56 m $s^{-1}$ speed gave the best performance.

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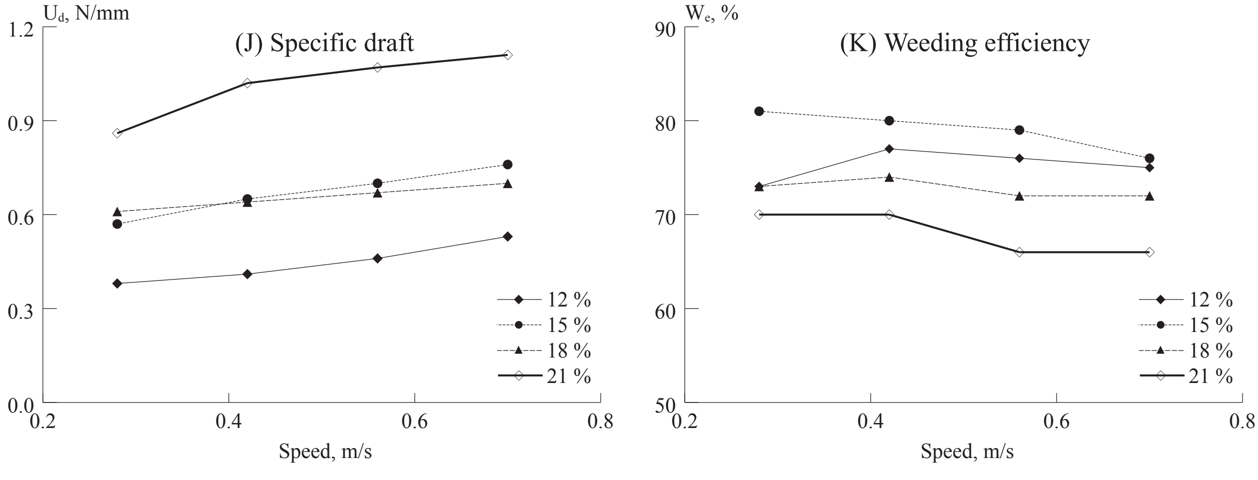
**Fig. 8** Effect of operating speed and soil moisture at 225 mm gang width on (J) specific draft (K) weeding efficiency



# Development and Evaluation of a Light Weight Power Tiller Operated Seed Drill for Hilly Region

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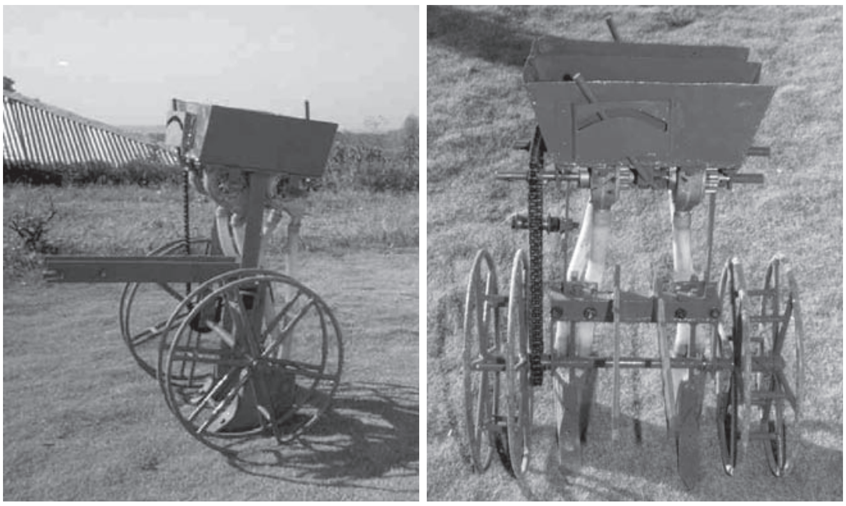
## Abstract

A light weight power tiller operated seed drill was developed for sowing wheat in hilly terraces where vertical interval between terraces is high. Field trials were conducted at the university farm and at the farmers' field to determine the performance of the seed drill in comparison to the traditional method of sowing. The effective capacity of the machine was 0.09 ha/h with field efficiency about 74 %. The machine was efficient and economical as indicated by net saving of 78 % labor and 62 % cost of sowing over the traditional method.

## Introduction

Most of the farmlands in the hill region are in small and undulating terraces. Manual and bullock power is predominantly used on farms. Farm equipment for the hill region must suit the terrain. Machines designed for plains are not suitable in the hills due to topography and size of land holdings. The average size of land holdings in Himachal Pradesh is about 0.6 ha only, indicating that small and marginal farmers are predominant in the state (Kingra and Singh, 1986). Topography and undulating terrain limits the introduction of large tractors. Thus, equipment is restricted to a lightweight power source. The power source needed for this purpose must be in the range of 100-110 kilogram, which can be lifted by one or two men from one terrace to another where vertical interval ranges from 0.5-1.0 meter. Sowing is the single field operation that makes the prospects of a crop. The farmers in Himachal Pradesh still use traditional methods of sowing, i.e. broadcasting or hand dropping behind a plough. These methods result in lower yield due to uneven distribution of seed and fertilizer, low germination and excessive weed growth. Although a number of animal-drawn seed-cum-fertilizer drills (3-5 rows) have been developed in the country (Singh and Bhardwaj, 1985) these could not be adopted by the farmers of the hill areas due to

**Fig. 1** Side and front view of the seed-cum-fertilizer drill



their heavy weight. Manual/power tiller operated multicrop planters have been developed by Gupta, et al. (1999) and Vatsa et al. (2000) for the hilly region. However, there is need for a lightweight power operated seed drill/planter for terraced land where there is a large vertical interval. Maize and wheat are the major crops grown in Himachal Pradesh. Wheat is grown in an area of 377.3 thousand hectare with average yield 1,700 kg/ha (Anon. 1999). Presently, there is no suitable lightweight power operated drill/planter available in the country that can sow these crops in hilly areas. Thus, a lightweight power operated seed-cum-fertilizer drill was developed and evaluated for sowing wheat in the hills.

## Material and Methods

**Design Considerations**

The basic design considerations in the development of the seed-cum-fertilizer drill were:

i. It should be suitable for operation with a lightweight power tiller (100-110 kg).
ii. It should be light in weight so that it can be transported easily from one terrace to another.
iii. It should be easily fabricated by local manufacturers.
iv. The cost of the machine with power source should be within the purchasing power of small and marginal farmers.
v. It should be able to sow the wheat crop.

**Constructional Details**

The machine consisted of a main frame, ground wheels, seed and fertilizer hoppers, furrow opener, power transmission system and hitch (**Fig. 1**). The metering of seeds and fertilizer was accomplished with fluted rollers. The metering shaft was driven by a sproket and chain from the ground wheels. The depth of sowing was adjusted by lowering and raising the furrow opener. The machine was easily attached to the lightweight power tiller by a bolt. The estimated cost of the machine was about Rs 2,000/-. The major specifications of the machine are as given in **Table 1**.

**Field Evaluation**

Field trials were conducted at the university farm and at the farmers' field to evaluate the two row seed-cum-fertilizer drill attached to a 5.5 hp Amar power tiller for sowing wheat. Machine performance parameters like effective field capacity, field efficiency, speed of operation, fuel consumption, depth of sowing and labor requirements were determined. For comparing the performance of the drill with the traditional method of sowing at the farmers' field, a minimum plot size of 10 x 8 m$^2$ was taken with three replications for both the methods. Field data were also collected to determine the capacity, efficiency, labor requirement and cost of the sowing operation by the traditional method.

**Cost Analysis**

A cost analysis was made based on the procedure given in the IS Code (Anon, 1979). The useful life of seed drill was assumed to be 8 years and the annual use was assumed to be 50 hours.

## Results and Discussion

The field performance data of the seed drill and bullock system are given in **Table 2**. The values are an average of three replications. The machine was operated at a speed of 2.1 km/h. The soil moisture and bulk density were 17.4 % and 1.14

**Table 1** Major specifications of the machine

| Parameters | Value |
|---|---|
| Overall dimensions | |
| Length, mm | 550 |
| Width, mm | 610 |
| Height, mm | 770 |
| Total weight, kg | 27 |
| Power source | Amar power tiller (110 kg wt., 5.5 hp petrol start kerosene run engine) |
| Number of rows | 2 |
| Hopper capacity | |
| Seed, kg | 3.0 |
| Fertilizer, kg | 3.5 |
| Row spacing, mm | 220 |
| Operational width, mm | 450 |
| Depth of sowing | Adjustable up to 100 mm |
| Seed and fertilizer metering device | Fluted roller made of Aluminium |
| Power transmission to metering device | From ground wheel through sprocket and chain arrangement |

**Fig. 2** Seed drill attached with power tiller in stationary and in operation

g/cc, respectively. The actual seed and fertilizer rates with the machine were 126 and 276 kg/ha, which was lower than the broadcasting method. The effective field capacity was 0.09 ha/h and 0.02 ha/h with the seed drill and traditional method, respectively. The labour requirement was only 22 man-h/ha with the seed drill as compared to 100 man-h/ha with the traditional method, which was a labour saving of 78 %. The cost of sowing with the seed drill was Rs 922/ha as compared to Rs 2,438/ha with traditional method, resulting in net savings of Rs 1,516/ha (62.18 %).

## Conclusion

A seed-cum-fertilizer drill attached to a lightweight power tiller (100-110 kg) has tremendous possibilities for the small and medium sized farmers of the hilly region due to its higher capacity and low cost of operation as compared to the traditional method of sowing. The fact that it can be used for tasks other than ploughing/weeding will help to popularize the lightweight power tiller among farmers of the hilly state

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**Table 2** Comparative performance of seed drill for sowing of wheat crop

| Parameters | Seed drill | Traditional method* |
|---|---|---|
| Soil moisture, % (db) | 17.4 | 17.8 |
| Bulk density of the soil, g/cc | 1.19 | 1.20 |
| Speed of operation, km/h | 2.1 | 2.0 |
| Row spacing, mm | 225 | - |
| Depth of seeding, mm | 56 | - |
| Actual seed rate, kg/ha | 126 | 141 |
| Actual fertilizer rate, kg/ha | 276 | 280 |
| Effective field capacity, ha/h | 0.09 | 0.02 |
| Field efficiency, % | 73.77 | 56.20 |
| Labour requirement, man-h/ha | 22 | 100 |
| Fuel consumption, l/h | 1.32 | - |
| Cost of seeding, Rs/ha | 922 | 2,438 |

*Traditional method (Broadcasting of seeds then ploughing and planking with bullocks)

# An Airtight Paddy Storage System for Small-scale Farmers in Sri Lanka

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## Abstract

The farmers in Sri Lanka's dry zone are the main contributors to the paddy production in the country. However, due to various reasons, they face difficulties in obtaining a reasonable income for their produce at harvesting time. According to the survey carried out in the paddy producing regions, it was found that one possible solution to reduce this problem is to enable the farmers to sell their produce at a time when prices are higher than at harvest time. To enable the farmers to keep their paddy on-farm for some time with a minimum loss of quality and quantity, some reliable and affordable storage facility has to be developed.

To achieve this, an airtight storage system of 2.5 tons was developed by a four-step approach, which consists of: preliminary study to investigate the actual need, definition of the core problem, definition of the main function to be fulfilled by the designed system and finally, assessment of applicable working principles, to achieve a viable solution of the problem.

This paper describes in detail the steps in the approach to achieve an efficient and inexpensive system acceptable to the farmers.

## Introduction

In Sri Lanka, there are two rice harvests per year: the Maha season in February and March and the Yala season in September and October. Typical paddy production of small holders is 5 t/season from an area of about 1 ha. Half the harvest is stored in simple open wooden boxes or bags for home consumption and the other half is sold as cash crop (Fernando et al., 1985). A few decades back, farmers were able to sell their paddy at a guaranteed price to the Paddy Marketing Board (PMB) or at free prices to private traders. With the liquidation of the PMB in 1999, the paddy marketing system was privatised, leading to a price decrease especially during the harvest period. For example, the price of paddy of the long white variety, during the harvest season in September 2003, was US$ 0.108/kg (Rs 10.50/kg) and increased to US$ 0.165/kg (Rs 16.00/kg) in December 2003, shortly before the next harvest. The price of the short variety increased from US$ 0.123/kg (Rs 12.00/kg) to US$ 0.206/kg (Rs 20.00/kg) during the same period. Prices are fixed by the traders and farmers have a weak position in negotiations as they have to dispose their produce anyhow. There are two main reasons, preventing farmers from benefiting from the seasonal difference in price:

(a) many farmers have to pay back the loans they took from agricultural suppliers and
(b) storage losses are high due to the high air relative humidity right after the harvest and the absence of reliable on-farm storage facilities.

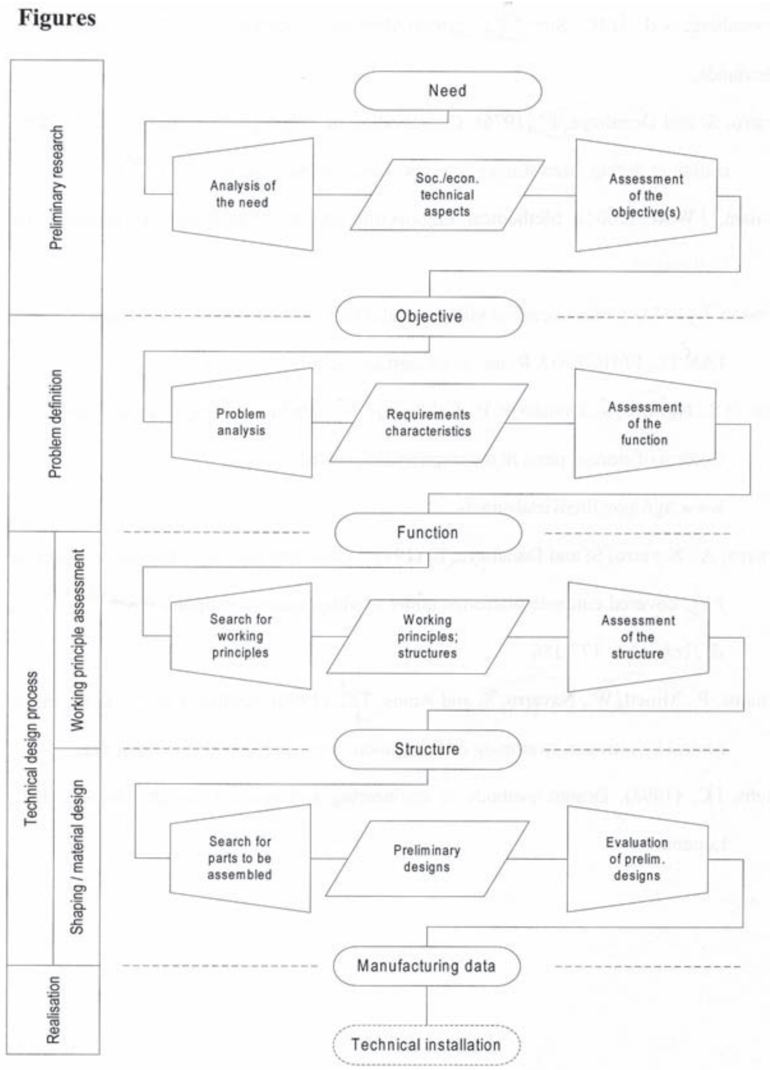
To tackle the first problem, the Government has started a program to furnish the smallholders a loan of US$ 0.10 (Rs 10.00/kg) per kg of stored rice. So farmers are able to pay back the expensive private loans without selling paddy. The second problem only can be solved by providing the small holders a reliable means of keeping their produce on their farm for some months. Since insects cause most of the storage losses, special focus has to be put on insect protection in an attempt to provide a solution.

Since the 70s, airtight storage - also called hermetic storage - proved to be an alternative to fumigation of storage systems under tropical conditions. De Lima (1990) stated that airtight storage is considered as the most effective method of storage at the high temperature and humidity in tropical regions. If the store is sealed to prevent air exchange of inside ecosystem with ambient, respiratory metabolism of insects, micro-organisms and the paddy itself will lower the oxygen content and raise the carbon dioxide content of the inter-granular atmosphere. As a result, insects are die and growth of moulds is hampered as well as the respiration of paddy, thus reducing the corresponding dry matter losses. Although low $O_2$-concentration is more important than high $CO_2$ in causing mortality of insects, there is a synergetic effect of concomitant $O_2$-depletion and $CO_2$- accumulation (Calderon and Navarro, 1980).

Early application of hermetic storage for small-scale farmers has been the storage of grain in sealed gourds, empty oil drums and other metal drums (Pattinson, 1970). Hyde et al. (1973) developed concrete lined conical pits, surmounted by domed concrete-shell roofs. Improved versions of these structures were later constructed in Kenya for hermetic storage of the national grain reserve (De Lima, 1990). The Indian Grain Storage Institute (IGSI) has developed various airtight containers for farm level storage (Birewar et al., 1983). Amongst them were partly underground bins made of reinforced concrete and brick, which showed that underground structures are only suitable for low rainfall and deep water table areas. In Thailand airtight above ground silos have been developed using a ferrocement technique by the Siam Cement Groups (Anon., 1973). The Asian Institute of Technology has developed a farm level storage bin using ferrocement technology, which can be converted into an airtight container for storage at farm level (Athapol et al., 1990). Also conventional galvanized iron silos have been used successfully by sealing them with a polyvinyl resin formula from inside (Williams et al., 1990).

In the 70s, flexible airtight structures were developed in England as emergency storage systems, wrapping bulks or stacks in butyl liners (Kenneford & O'Dowd, 1981). Such systems were also tested in the tropics, however the liners were found to deteriorate due to high UV radiation and showed increased gas permeability to a level where the liners could no longer be used for hermetic storage (Beeny et al., 1972; Navarro & Donahaye, 1976). More recently, the method of covering and sealing stacks inside warehouses with PVC liners for storage under carbon dioxide enriched atmospheres has been developed by the CSIRO (Annis et al., 1984). Large-scale outdoor

**Fig. 1** Flow chart of Kroonenberg-method of systematic design process



systems based on PVC liners proved to work under Mediterranean conditions (Varnava et al., 1995; Sabio et al., 1995) and even under tropical conditions in the Philippines and Sri Lanka (Anon., 2000; Donahaye et al., 1991).

The objective of this research was to develop or adapt an airtight storage system, meeting the site-specific natural and socio-economic requirements of small-scale paddy farmers in Sri Lanka. The Kroonenberg-method for a systematic design process was chosen to prevent a tunnel view caused by already existing solutions (Kroonenberg & Siers, 1998).

## Method

The design process introduced by the Kroonenberg-method is a tool, which enables the development of a viable technical solution to a design problem before making it into a reality. This method of designing is a systematic approach, which consists of four phases;

- Preliminary research to identify the problem
- Definition of requirements that the technical solution should meet
- Technical design process to asses working principles
- Realization of the solution

A schematic chart, depicting the distinctive stages in the process is shown in **Fig. 1**. In the first phase -preliminary research-, problems and difficulties faced by the farmers in paddy cultivation were investigated through interviews, questionnaires and inquiries, taking socio-economic as well as technical aspects into consideration. It helps to identify the real need of the farmers and establish the objectives of the design.

In the second phase, requirements to be fulfilled by the final solution and their characteristics were investigated by analysing the problems to define quantitative justifications. Next step in this phase is to identify and assess the functions to be executed in order to fulfil the requirements. For the formulation of the requirements, consultation of farmers, stakeholders and other sources in the field is essential.

The third phase is to explore the working principles that are suitable to execute the functions. Several methods such as the morphological survey, brainstorming, and patent search can be used to explore the working principles. Several options or alternative combinations are selected, considering their mutual interdependence. By evaluating and assessing the selected combinations, the most viable combination is selected as the solution to the problem.

In the final phase, the solution will be materialised after detailed designing of the components.

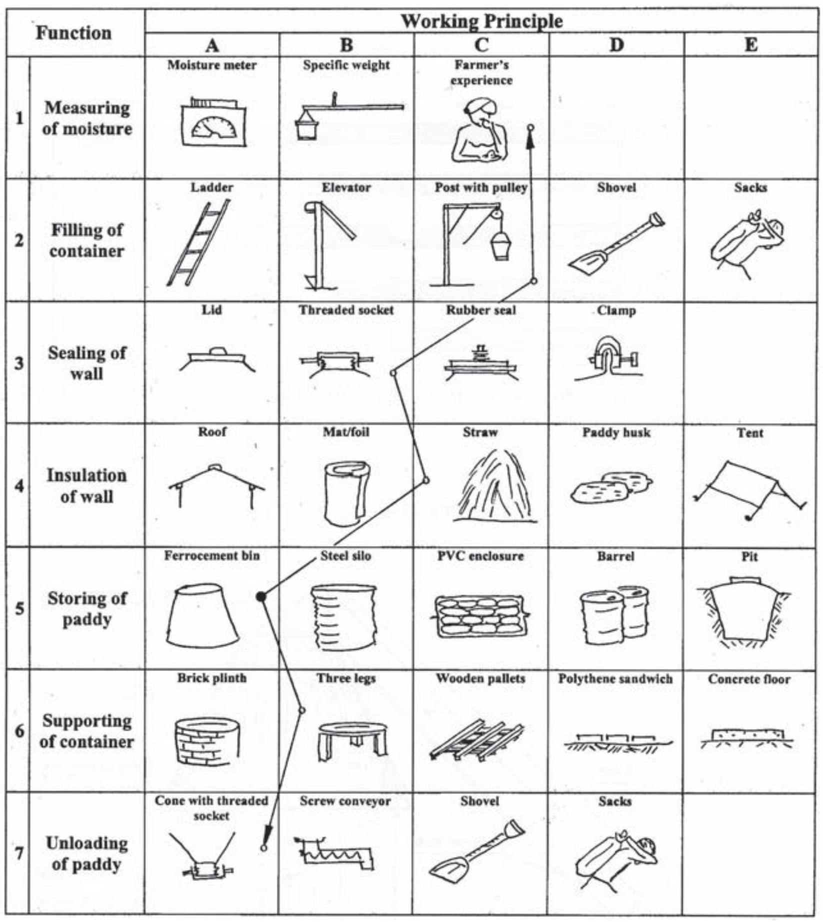
## Results and Discussion

**Requirements of an Airtight Storage Systems**

According to a survey carried out in the major paddy growing regions in Sri Lanka, it was found that an urgent need exists for an on-farm storage system to preserve paddy until the price increases before next harvest. An airtight storage system was identified as an appropriate method to store paddy at the farm level (unpublished data).

Following the Kroonenberg-method, the requirements of an airtight paddy storage system have been identified in consultation with farmers, who are stakeholders and sources of indigenous knowledge in storing paddy. In **Table 1**, the identified requirements are categorized into three categories according the relevance as basic, variable and de-

**Fig. 2** Morphological chart for airtight storage systems



sirable. As such, any selected storage system has to satisfy all the basic requirements. However, the variable requirements have to comply to a certain extent while the desirable requirements are not binding in selecting a suitable solution. There are four basic requirements to be fulfilled by the storage system. The system has to hold 2.5 tons of paddy without structural failure, it has to protect the paddy from entrance of water into the system, the cost of the system must not exceed US$ 520 and the storage losses have to be less than in conventional systems. Any system that cannot satisfy the above requirements is not acceptable as a viable solution. The wishes of the farmer establish three desirable requirements: it must store in bulk; have good appearance; and have the ability to store other food grains. All other requirements are considered as the variable requirements, which play the decisive roll in selecting the most viable storage system in terms of the farmers' needs.

**Functions and Working Principles of an Airtight Storage System**

The proposed storage system should perform several functions in order to fulfil the requirements, namely, measuring moisture content of paddy for safe storage, filling the paddy into the container, sealing the container to maintain airtight condition, insulating the container to prevent from heating and cooling, storing paddy with minimum deterioration in terms of quality and quantity, supporting the container

**Table 1** General requirements for an airtight on-farm storage system for paddy

| | Requirement | | Justification |
|---|---|---|---|
| 1 | To hold 2.5 t or 5 $m^3$ of paddy without structural failure | B | Average land area is 1 ha and the yield is 4.5-5 t/ha. Half of the production is available for sale. |
| 2 | To be installed on small area (3m x 3m) | V | Farmers prefer to construct storage facilities within their courtyards. |
| 3 | To be constructed with locally available materials | V | Imported material is expensive and not always available on demand. |
| 4 | To provide flexibility in terms of storage capacity | V | Farm size, paddy yield and share of cash crop paddy are subject to fluctuations. |
| 5 | To protect the structure from water entrance | B | In wet season, rainfall may exceed 2000 mm and floods may damage storage facilities. |
| 6 | To protect structure from termite attack | V | Termites are destroying wooden structures in short time. |
| 7 | To protect structure from elephants | V | Attacks of wild elephants are a problem in some villages. |
| 8 | To enable to store paddy in bulk | D | Costs of sacks are high, lifetime is short. |
| 9 | To achieve an aesthetic appearance of the store | D | Good appearance will improve the prestige of the farmer. |
| 10 | To construct the storage facility at a cost of less than 520 US$ | B | Banks provide loans to the farmer up to a maximum of 520 US$. |
| 11 | To achieve a short payback period of the initial costs (2-3 years) | V | Short payback periods are a bank requirement to get loans. |
| 12 | To achieve a long effective lifetime (>10 years) | V | Long effective lifetime will lower the annual cost of the storage system. |
| 13 | To enable maintenance and repair by the farmer and /or semi-skilled workers | V | Skilled labor is expensive and difficult to find in rural areas. |
| 14 | To keep storage losses below 4 % | B | Minimum losses of present storage systems are 4 %. |
| 15 | To protect the paddy from insect attack | V | Insect attack is causing most of the losses in present storage systems. |
| 16 | To protect paddy from rodent attack | V | Rodents are penetrating if the structure material used is not resistant enough. |
| 17 | To protect paddy from theft | V | Theft may be a problem in some areas. |
| 18 | To prevent soil moisture migration through bottom of the storage facility | V | Water table may sometimes rise to the ground level or above during rainy season. |
| 19 | To protect the content from absorbing moisture from ambient air | V | Insects and moulds develop at moisture levels beyond 15 % MC. |
| 20 | To protect paddy from temperature variations | V | Heating in daytime and cooling down in night may cause condensation of moisture on paddy. |
| 21 | To minimize air exchange with ambient to maintain $O_2$ at or below 3 % | V | To make the atmosphere in the bin anoxic for insects. |
| 22 | To be loaded within short period (2 t/hr) | V | Possible shortage of labor at harvesting time. |
| 23 | To be unloaded by one person (4 t/hr) | V | Paddy has to be filled in sacks for transport. |
| 24 | To store alternative food grains | D | Farmers grow other grains like soybeans and maize that could be stored . |

Note: B - Basic requirements, V - Variable requirements, D- Desirable requirements to protect it from soil moisture, and finally, unloading the paddy for disposal.

**Fig. 2** shows the morphological chart for airtight storage systems. The various functions of the system are arranged in the vertical axis of the chart, while in the horizontal axis, certain working principles are shown that are suitable to fulfil the concerned function. Alternative working principles for each of the functions are discussed below.

Measuring moisture content: If the moisture content of the paddy is above the equilibrium level, metabolic activity of the grain increases the production of heat and creates hot spots within the grain bulk. A high moisture and temperature environment is favourable for mould growth on paddy grains. For safe storage, the paddy has to be dried to a moisture content of 14 % w.b. or below. To identify the moisture content, three methods are suggested; use of a moisture meter, measuring the specific weight and using farmers' experience by checking brittleness by biting a few grains.

***Filling the container***: Paddy brought from the field, has to be transferred into the container for storage. Five methods are proposed to fill the storage container; namely, use of a ladder by climbing up with a bag, elevator, post with a pulley, shovelling and finally manual stacking of sacks.

***Sealing the inlet***: The function of the inlet is to feed the bin as well as to close it in order to make the container airtight. Four methods of sealing are suggested; namely, lid with a sealant in the groove, inlet with a threaded socket, lid with a rubber seal and connecting cover sheets using a clamp.

***Insulation of the wall***: Insulation of the bin wall is required to protect the content from heating up due to solar radiation and also, to prevent moisture condensation inside the wall during the night due to cooling. Five methods of insulation are suggested; namely, the construction of a shelter, the application of a foil or mat on the wall, to cover the bin surface with straw, to place a pile of paddy husk bags on the bin surface, and to make a tent over the store.

***Storing the paddy***: The main function of the bin is to preserve the quality of the paddy by controlling insect activity and moisture migration. Since insects are controlled by creating an unfavourable condition inside the bin, air exchange through the wall should be minimal to finally create an anoxic atmosphere by decreasing the oxygen level below 3 %. Five storage methods are proposed which are suitable to maintain air tightness. A ferrocement bin, a steel silo, a PVC enclosure, PVC or steel empty oil drums, and underground lined pit are considered.

***Supporting the container***: Supporting the storage structure is required to protect the paddy from soil moisture. A brick wall plinth, concrete pillars, wooden pallets, a base with a polythene sandwich in it and a concrete floor are considered as alternatives to support the store.

***Unloading the paddy***: Paddy, stored in the container has to be transferred into sacks/bags for sale. Therefore, the container should also have an outlet, provided with a facility to close the container airtight. Four methods were suggested: a conical hopper with a threaded socket, a screw conveyor, a shovel, and finally, manual discharge with sacks are suggested.

**Selection of Alternative Systems**

Combining the working principles for each function will result in alternative storage systems. To facilitate the selection, the working principles are presented by pictograms. Exemplarily, one suitable combination of working principles is connected by a line. As the most crucial function among the others is the actual storing function, the selection process is initiated from the storage method. Other appropriate functions suitable for the particular storage method are selected by moving upward and downward. To prevent overloading **Fig. 2**, most suitable alternative combinations are presented separately in **Table 2**.

***Ferrocement bin system***: For the

**Fig. 3** Comparison of storage systems

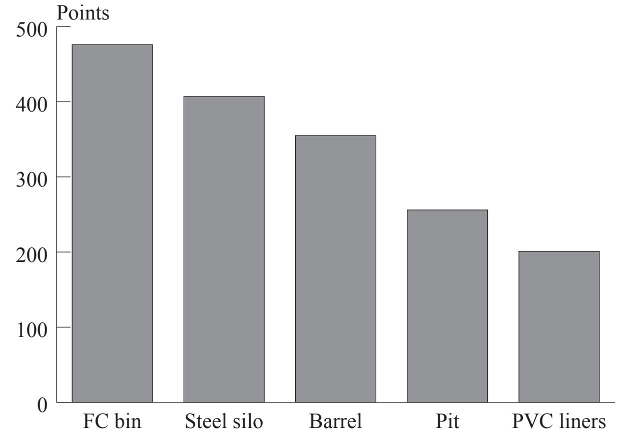
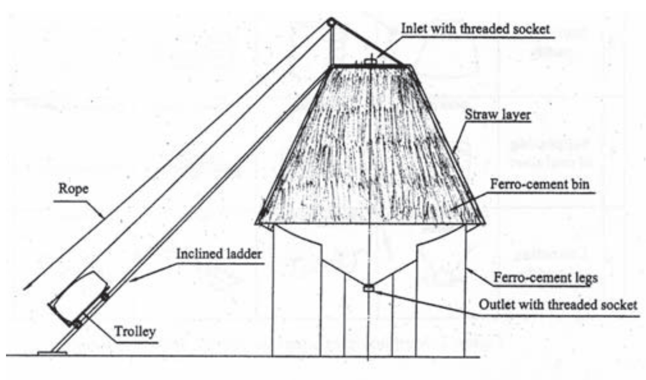



**Fig. 4** Final design concept of the on-farm airtight storage system



ferrocement bin, the suitable insulating method would be covering with a straw layer. A lid with a threaded socket can be used to feed the bin as well as to close it airtight as the socket can be embedded in the ferrocement lid. A post with a pulley can be used to lift the paddy about 3 meters high. For moisture determination, farmer's experience of checking brittleness of grain would be sufficient. The most suitable method to discharge the paddy from the ferrocement store would be the cone with a threaded socket, hence, the three pillars would be the most suitable support for the system as the paddy can be taken out easily.

***Steel silo system***: The steel silo is the most expensive storage system among the others. This system would be suitable for a rich farmer. For insulation of the bin, a shelter can be built up. Also, the bin surface can be covered with an aluminium foil. Threaded socket for closing, an elevator for feeding the bin and a moisture meter for moisture determination would be suitable and affordable to the farmer. Three pillars to support the bin and a hopper bottom cone with a threaded socket to close the outlet would be other appropriate components for the steel silo system.

***PVC enclosure system***: For PVC enclosure, paddy is stored in sacks and covered by PVC plastic liners. The suitable method of protecting from sun would be a tent. Sealing of the enclosure can be done by closing two liners using a clamp with nuts and bolts. Manual stacking the paddy sacks would be the most convenient method of filling the store. Moisture content can be checked according to the farmer's experience. Wooden pallets would be the most suitable base for stacking of paddy sacks and manual labour can be used to unload the store.

***Barrel system***: Empty drums or PVC containers can be used to store paddy. These containers can be kept under a roof to protect them from the sun. The threaded cap of the container would be sufficient to close and seal it. A shovel with a bucket or a funnel can be used to fill the barrel and the farmer's experience would be sufficient to check the moisture content of paddy. These barrels can be kept on a raised concrete plinth. Paddy can be removed by unloading into sacks using a shovel.

***Underground lined pit system***: The store can be constructed below the ground level and placing husk bags over it would be sufficient to prevent from heating up. A lid can be kept over the dome with a sealant material in the groove. Manual feeding with sacks would be the suitable method of feeding. Farmer's experience would be sufficient to check the moisture content of paddy. A polythene sheet can be sandwiched to the wall to prevent soil moisture penetration. For unloading of the paddy, a bucket and a shovel can be used to fill sacks when unloading.

**Table 2** Alternative systems for airtight storage

| | Measurig moisture | Filling | Sealing | Insulation | Storing | Support | Unloading |
|---|---|---|---|---|---|---|---|
| Ferrocement bin | 1C | 2C | 3B | 4C | 5A | 6B | 7A |
| Steel silo | 1A | 2B | 3B | 4A | 5B | 6B | 7A |
| PVC enclosure | 1C | 2E | 3D | 4E | 5C | 6C | 7D |
| Barrel | 1C | 2D | 3B | 4A | 5D | 6E | 7C |
| Pit | 1C | 2E | 3A | 4D | 5E | 6D | 7C |

### Selection of the Most Promising Storage Concept

To select the most promising stor-

**Table 3** Matrix to determine the weight factor of assessment criteria

| Criterion | Investment | Useful life | Flexibility | Thieves | Rodents | Insects | Rain | Soil moisture | Air moisture | Temperature variation | Air tightness | Handling | Space requirement | Aesthetics | Points | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 8 | 9 |
| Useful life | 0 | | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 8 |
| Flexibility | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 4 |
| Thieves | 1 | 1 | 1 | | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 13 |
| Rodents | 1 | 1 | 1 | 0 | | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 | 12 |
| Insects | 1 | 1 | 1 | 0 | 0 | | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 | 11 |
| Rain | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 | 14 |
| Soil moisture | 1 | 1 | 1 | 0 | 0 | 0 | 0 | | 1 | 1 | 1 | 1 | 1 | 1 | 9 | 10 |
| Air moisture | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 1 | 1 | 1 | 6 | 7 |
| Temperature variation | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 1 | 1 | 5 | 6 |
| Air tightness | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 1 | 4 | 5 |
| Handling | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 2 | 3 |
| Space requirement | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 2 |
| Aesthetics | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 |

age system out of the five alternatives shown in **Table 2**, the systems have to be assessed considering the requirements listed in **Table 1**. As the requirements are not of equal importance, a matrix was used to determine the relative importance of various criteria that are representing the requirements. **Table 3** shows the matrix that compares the criteria with each other. The value '1' is given, if the importance of the criterion in the row is higher than that of the criterion in the column, otherwise, '0' is given. The sum of the values in a row plus one is taken as weighting factor. According to the above evaluation procedure, protection from rain received the highest weighting factor of 14, while the aesthetics received the lowest factor of 1. Similarly, other criteria are given weighting factors according to their points received.

In evaluation of the five concepts against the criteria, 1 to 5 points are given depending on the fulfilment of the requirements (**Table 4**). Finally, the given points are multiplied by the relevant weighting factor and summed up for ranking.

Among the storage systems, the ferrocement bin system is placed at the highest rank as it received the highest points for most of the high weighted factors of evaluating criteria. When considering the flexibility, the system has a fixed holding capacity and therefore, it received the lowest point for that criterion.

The steel silo system is placed at the second rank. It received high points for the criteria of high weighted factors and it received the lowest point for poor air tightness, high investment, less flexibility and high temperature variation inside the bin.

The barrel system is placed at the third rank and it received lowest point for easy access for theft, high investment for barrels, high temperature variation and poor handling of grains such as filling and discharging of paddy.

Although the pit system received the highest points for low investment and low temperature variation inside the bin, other high weighted criteria such as poor protection from rain, soil moisture, rodent and heating received the lowest point. Also due to difficulties in taking out the grains from the pit, it received the lowest point.

Points received by each storage concept are depicted in **Fig. 3** and it shows that the ferrocement bin system is the most viable concept of storing paddy as it meets best the requirements identified by the farmers.

**Final Design Concept of the On-farm Airtight Storage System**

The working principles considered in the morphological survey are incorporated into a final design by refining modifications as shown in **Fig. 4**. The ferrocement bin consists of a frustum of a cone with a conical bottom to minimize the joints in construction in order to obtain maximum air tightness. The bin is constructed on a three V-cross sectioned pillars for convenient unloading into sacks. A lid with a threaded socket is provided for filling the bin and closes it airtight. Conical bottom with an outlet having a threaded socket is provided for easy and complete discharge of the bin. Covering of the upper cone with a straw layer provides sufficient insulation from excessive heating and cooling of the paddy inside the bin. A metal cone is placed on the top to protect from rain. An inclined ladder with a plastic container, which can be pulled by a rope, is provided to feed the bin.

## Conclusions

A design for a viable and cost effective storage system for on-farm storage of paddy was achieved by following a methodical design process according to Kroonenberg. The method adapted for the study consists of three major phases; namely, investigation of problems of paddy farmers, definition of requirements and finally, assessment of working principles for a solution.

An urgent need for an on-farm storage system was identified by investigating the problems of the farmers during the first phase. By analysing the need, an airtight storage system was identified as the most viable system for the paddy farmers. In the second phase, requirements and characteristics of an airtight storage system were

**Table 4** Evaluation of five storage concepts against crieria

| System | Rain | Thieves | Rodents | Insects | Soil moisture | Investment | Useful life | Air moisture | Temperature variation | Air tightness | Flexibility | Handling | Space requirement | Aesthetics | Total points | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | | |
| Barrel | 5 | 1 | 5 | 5 | 5 | 1 | 2 | 4 | 1 | 4 | 4 | 1 | 3 | 3 | 355 | 3 |
| Pit | 1 | 3 | 1 | 3 | 1 | 5 | 3 | 3 | 5 | 2 | 2 | 1 | 2 | 3 | 256 | 4 |
| Steel silo | 5 | 5 | 5 | 5 | 5 | 1 | 4 | 3 | 1 | 1 | 1 | 5 | 5 | 5 | 407 | 2 |
| FC bin | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 3 | 4 | 1 | 5 | 5 | 5 | 476 | 1 |
| PVC liners | 2 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 2 | 5 | 2 | 2 | 2 | 201 | 5 |

established with five functions to be performed by the system. In the final phase, working principles were identified for each function to be executed and the most viable concept was selected by assessing them.

This systematic approach provided insight in the problems the farmers encounter in the cultivation of paddy and enabled to identify the farmers needs. After establishing the socio-economic background and the available technologies, it showed to be possible to achieve an appropriate solution.

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# Soybean Threshing Efficiency and Power Consumption for Different Concave Materials

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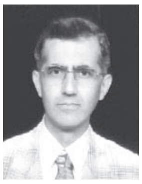

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## Abstract

Soybean is one of the most slowly established crops in many developing countries. During recent years, greater interest has been given to the cultivation and mechanization of soybean. Particularly, soybean threshing is an important problem because of the product loss. Most of the trials for soybean threshing have been on the structure of beaters, although the type and structure of contrbeaters are as important as structure of beaters. This work designed and tested concaves made of different materials with respect to threshing efficiency, power requirement and specific power consumption at various feed rates and drum peripheral speeds. Regression equations have been established. The multiple regression technique was used to study the relationship among different variables, namely, concave type, feed rate and drum peripheral speed in relation to three dependent variables, namely, threshing efficiency, power requirement and specific power consumption. An experimental model of a soybean thresher without a cleaning and separating unit was developed. The threshing machine had a peg-tooth drum and was powered by a 4 kW electricity motor. Also, four concaves made of different materials were used for the trials. SA-88 soybean variety was used for the trials.

The four concave types were PVC, rubber, chromium, and steel plate with three feed rates (360 kg/h, 720 kg/h, and 1,080 kg/h) and five beater peripheral speeds (7.95 m/s, 9.10 m/s, 10.54 m/s, 12.16 m/s, 14.66 m/s).

Speed and feed rate were found to a have a significant effect ($p < 0.01$) on power requirement. The power requirement increased with increasing feed rate and drum peripheral speed. The specific power consumption decreased with increasing feed rate. Threshing efficiency decreased with increasing feed rate and increased drum peripheral velocity significantly improved the threshing efficiency. The highest threshing efficiency was achieved with the chromium type of contrbeater, followed by PVC, the sheet iron, and the rubber.

## Introduction

Soybean, one of the oldest cultivated crops in the world, has a vital role in supplying protein needs of an expanding population, and this is becoming one of the leading cash crops in world (Mesquita et al., 1997). Its protein content ranges from 30 to 45 % (Sharma and Devnani, 1980; Tandon and Panwar, 1989). It also contents calcium, phosphorus, and vitamin B. It can also be used for animal feed (Sharma and Devnani, 1980; Chinsuwan and Vejasit, 1991). However, soybean is one of the most slowly established crops in Turkey. During recent years greater interest has been given to the cultivation of soybean on account of its dietic, industrial, agricultural and medical importance. In Turkey, after the 1980's the areas of soybean sowing and production rate have been increased in parallel with the increasing soybean production in the world.

In soybean production, during the harvesting and threshing, there occurs an important product loss arising from physical structure of soybean. Mechanization becomes more important during the harvesting and threshing which are the most critical steps and expensive operations in soybean production (Yadav and Yadav, 1985; Tandon et al., 1988; Mesquita and Hanna, 1993). Various harvesting and threshing methods are used even though the classic type combine harvesters are commonly used in Turkey as well as USA and the other western countries. However, this type of combine harvester is not suitable for harvesting beans due to pod distribution along the plants.

Product losses are around 10 %, and sometimes reach to 30 %. However, combines are successfully used for soybean harvesting, even though they are not designed for this purpose (Nave et al., 1972; Tandon and Panwar, 1988; Mesquita et al., 1997). The designed threshing unit for a small enterprise may be more practical and economical than combines since the the cost is high and they involve high-energy consumption and high seed losses.

## Material and Methods

The soybean-threshing unit seen in **Fig. 1** was made for the purpose of threshing trials and consisted of a spike-tooth drum. The length of the contrbeater was 0.885 m. The diameter and length of threshing drum were 0.885 m and 0.365 m, respectively. The concave clearance was fixed at about 30 mm for all combinations of speed and feeding rate.

Five threshing beater speeds of 415 $min^{-1}$, 475 $min^{-1}$, 550 $min^{-1}$, 635 $min^{-1}$ and 765 $min^{-1}$, equivalent to peripheral velocities of 7.95 m/s, 9.10 m/s, 10.54 m/s, 12.16 m/s, and 14.66 m/s, respectively.

The threshing drum was operated from a 4 kW electricity motor, which was placed on a special frame. A belt-pulley system provided the movement transfer between the threshing beater and the motor (**Fig. 1**). The three feed rates, 360, 720 and 1,080 kg/h, were used for testing. The independent variables studied were contrbeater type, beater speed and feed rate. Material was loaded on the belt conveyor and feed into the hopper. The drive to the belt conveyor was provided and controlled by an electric motor.

The commonly grown secondary crop soybean variety, SA-88, was used for this experiment. It was harvested by the conventional method. The moisture content of the grain, head and straw was determined by oven-drying method (ASAE, 1984). The average moisture content of seeds and stalk were 11.66 and 13.47 % w.b., respectively.

Moment Measuring Device (Torqumeter) and Multi-Measuring Device (Multimeter) were used to measure the rotating moment (**Fig. 1**). The power requirement was calculated by using the formula given by Yavuzcan et al. (1987) and Tezer et al. (1993).

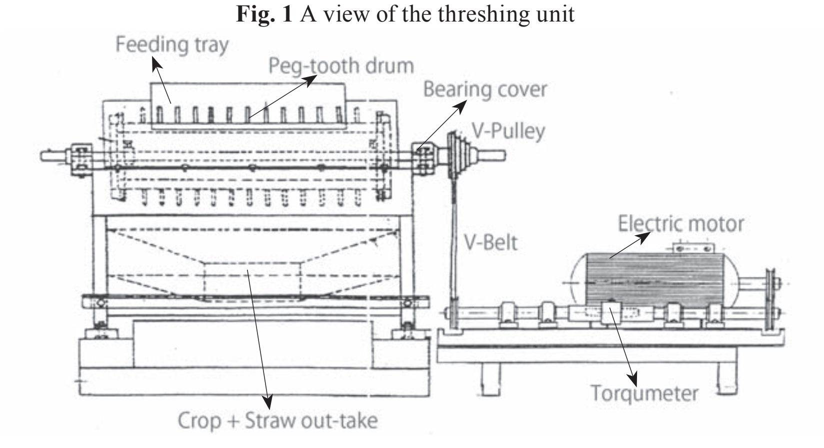
Consumed specific power values for threshing 1 ton of stalk product were mean power values. Unthreshed seeds were separated from pods and the collected seeds were weighed after threshing and cleaned by hand to determine the threshing efficiency as a percentage of total seeds collected (Sharma and Devnani, 1980; Bhutta et al., 1997; Sessiz, 1998).

The performance of the developed threshing unit was analysed against different concave, threshing speed and feed rates by using a randomized complete block design of a 4 by 5 by 3 factorial experiment with three replications in each treatment. All measured variables were considered in the statistical development of the multiple linear regression models. The linear model of maximum correlation was determined. Using Excel tested data, the normal form of multiple linear regression model was represented by an equation of the following type:

$Y = a + bX_1 + cX_2$

Where: Y was the estimated power requirement, specific power consumption and threshing efficiency value, a was the constant, b and c was the coefficient of power requirement, specific power consumption and threshing efficiency, $X_1$ was the drum speed and $X_2$ was the feed rate.

**Fig. 1** A view of the threshing unit




## Results and Discussion

**Influence of Concave Type on Power Requirement and Specific Energy Consumption**

The type of contrbeater, beater, peripheral speed and feed rate significantly affected the power consumption and specific energy consumption at the 1 % level of significance. The linear multiple regression equations derived for each concave are given in **Table 1**. The peripheral speed (V) and the feed rate (C) had a significant effect on the power consumption (Sharma ve Devnani, 1980). Increasing the V and the C raised the power consumption because of the positive coefficient value. The power requirement of the drum increased with drum speed because of the increased feed rate, which accounted for the extra energy required for threshing material. The increasing feed rate required greater compression of the material as it passed between the threshing drum and concave and caused an increase in power requirement (Sudajan at al., 2002).

Minimum power requirement was obtained with chromium and PVC, whereas a maximum consumption was achieved with rubber conrabeater type.

The multiple regression equations of the specific power consumption (SPC) are seen in **Table 2**, indicating a inversed relationship between the feed rate and all contrbeaters types.

The power consumed by the drum for threshing the product decreases with increasing feed rate. All equations indicate that all parameters have a significant effect on threshing efficiency. A maximum SPC was obtained with the rubber covered contribeater whereas a minimum consumption was gained with the PVC type.

According to the regression equations, the V has positive values, hence, increasing the V raises the SPC and increasing the C reduces the SPC due to the negative coefficient value.

For each contrabeater type, power requirement values and specific power requirement were obtained using a drum speed of 14.66 m/s and feed rate of 1,080 kg/h. The results are presented in **Fig. 2**. The maximum power requirement and specific power consumption was obtained with the rubber type contrbeater, while the values gained for PVC and chromium were lowest and similar. This indicates that the friction coefficient of PVC and chromium material were low, and hence they consumed less power.

**Influence of Concave Type on Threshing Efficiency**

The regression equations are given in **Table 3** for each concave type, depending on peripheral speed and feed rate. Threshing efficiency (TE) was significiantly affected by the peripheral speed and feeding rate, the speed had a possitive effect, whereas the feeding had a negative effect (Tandon et al., 1988). The effect of V was higher than C (Chinsuwan and Vejasit, 1991). Because the partial regression coefficient of V is positive it increased the TE, whereas the effect of C was decreased due to negative coefficient. The partial regression coefficient in the equations showed that the unit variation for V was greater than C. The regression coefficient of speed and feeding rate on threshing efficiency were highly significant at the 1 % level in all concave types.

The TE values were obtained using the drum peripheral speed of 14.66 m/s and feed rate 1,080 kg/h for each contrbeater type are given in **Fig. 3**. It shows that the highest TE (92.8 %) was gained with the chromium contrbeater type, followed by PVC (90.92 %), steel plate (87.51), and rubber (81.54 %).

PVC and chromium type contrbeaters had the lowest power consumption with the highest TE values. Hence, the use of PVC and chromium type contrbeaters reduced product loses as well as power cost. Equations derived for each contrbeater may used to estimate the power consumption and TE. This study showed that to increase the threshing efficiency the speed must be kept between 10.54 m/s and 14.66 m/s. Thus, the best period is between 550 d/d and 765 d/d. The trials proved that the lowest threshing efficiency was gained with the rubber-covered concave, whereas the highest value was obtained with the chromium contrbeater.

## Conclusions

It was concluded that the concave

**Fig. 2** Changes in power requirement and the SPC depending concave type (FR: 1,080 kg/h, V: 14.66 m/s)

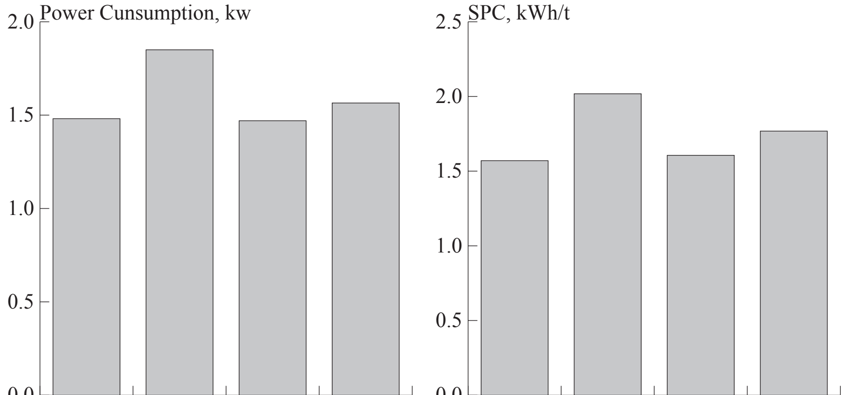
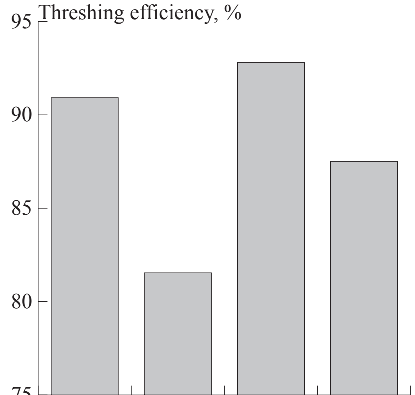



**Fig. 3** Changes in the TE depending concave type



type has a significant effect on power requirement, specific power consumption and threshing efficiency.

The power requirement and special power consumption of chromium type concave were lower than the others. The power consumption increased with all concave types depending on the increase in the speed and the feeding rate. The highest power consumption was obtained with the rubber-covered concave. The lowest consumption was obtained with the cromium type. The lowest specific energy consumption was with chromium type at all drum speeds and feed rates.

Threshing efficiency increased with increasing BPS with all contrbeater types. The highest increase was achieved with the chromium type and the lowest with the rubber-covered type.

**Table 1** The multiple regression results for the power requirement

| Type of countabeater | Fitted regression equations | Multiple correlation coefficient (R) | Standard error of estimate |
|---|---|---|---|
| PVC | P = -1.356 + 0.149V** + 0.000682C** | 0.959 | 0.122 |
| Rubber | P = -1.102 + 0.151V** + 0.000684C** | 0.971 | 0.103 |
| Cromium | P = -0.802 + 0.126V** + 0.000394C** | 0.983 | 0.06 |
| Sheet iron | P = -0.792 + 1.085V** + 0.000632C** | 0.969 | 0.127 |

**Significant at 1 % level. P: Predicted value of power cunsumption, kW. V: Beater peripheral speed, m/s. C: Feeding rate, kg/h

**Table 2** The multiple regression results for the specifice power cunsumption

| Type of countabeater | Fitted regression equations | Multiple correlation coefficient (R) | Standard error of estimate |
|---|---|---|---|
| PVC | P = -0.850 + 0.225V** - 0.000630C** | 0.963 | 0.161 |
| Rubber | P = -0.0593 + 0.239V** - 0.00132C** | 0.950 | 0.232 |
| Cromium | P = 0.193 + 0.204V** - 0.00146C** | 0.944 | 0.233 |
| Sheet iron | P = 0.169 + 0.166V** - 0.000948C** | 0.968 | 0.127 |

**Significant at 1 % level. P: Specifice power cunsumption, kWh/t. V: Drum peripheral speed, m/s. C: Feeding rate, kg/h

**Table 3** The multiple regression equations of the threshing efficiency

| Type of countabeater | Fitted regression equations | Multiple correlation coefficient (R) | Standard error of estimate |
|---|---|---|---|
| PVC | TE = 82.27 + 0.946V** - 0.0039C** | 0.57 | 3.73 |
| Rubber | TE = 64.66 + 1.999V** - 0.0115C** | 0.68 | 6.30 |
| Cromium | TE = 84.67 + 1.233V** - 0.0092C** | 0.63 | 4.94 |
| Sheet iron | TE = 77.29 + 1.287V** - 0.0080C** | 0.61 | 5.12 |

**Significant at 5 % level. TE: Threshing efficiency, %. V: Drum peripheral speed, m/s. C: Feeding rate, kg/h

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# Evaluation of the Agricultural Tractor Park of Ecuador

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## Abstract

The principal objectives of this work were to establish the tractor hours demanded by the agricultural production systems of Ecuador; to compare this demand with the actual tractor park and the total power available for agriculture; and to analyze the mechanization indicators of Ecuadorian agriculture.

The main sources of information were the 2000 Agricultural Census, the Ministry of Agriculture, the Institute of Agricultural Research, the Central Bank of Ecuador, the Technical University of Manabi, the University of Loja, several agricultural engineers working in mechanization programs, and 18 producers in the provinces of Pichincha, Cotopaxi and Loja (Sierra Region) and Guayas, Los Rios and Manabi (Coastal Region).

The production systems, cultivated area with 24 main annual and perennial (tree) crops, tractor hours demanded by these systems, human, animal and tractor power were established. The mechanization level indicators obtained were compared with levels recommended for developing countries and with the levels existing in other Latin American countries.

The results show that the productive systems of annual and perennial crops have similar areas with about 1.2 million hectares each. To this, 3.3 million hectares of cultivated pastures were added. Annual crops have a much larger demand (2.56 times) of yearly tractor hours than perennial crops; cultivated pastures use very little tractor hours.

The actual tractor park is 14,652 units that provide 716,880 kW of power. When the human and animal power are added, a grand total of 1,217,945 kW is reached. This power does not satisfy the yearly demand of annual and perennial crops, giving origin to a deficit of 2,600 tractors; larger deficits appear when pastures are considered and when recommended power levels for developing countries are considered.

The actual mechanization level of Ecuador is 0.30 kW per hectare of annual and perennial crops. This indicator would go up to 0.36 kW/ha if the tractor deficit of 2,600 units were added. These levels are far from the ones existing in the majority of the other Latin American countries and farther from the levels recommended for developing countries. Other indicators, such as hectares and rural workers per tractor, also show an agriculture with low levels of mechanization.

## Introduction

The Republic of Ecuador is located in northeastern South America, It has four well defined regions: Coast, Sierra, Amazonia and Galapagos. Its area is 271.667 km$^2$ and its population 12,156,608 inhabitants (INEC, 2002).

The Agricultural sector is one of the most important of the Ecuadorian economy, employing 38 % of the working population and producing 17 % of the GNP, The principal crops are caccao, maize, rice, coffee, banana, plantain, African palm and sugarcane.

The agricultural area of Ecuador is 12,355,831 hectares, distributed in natural and artificial pastures (36 %), forests (31 %), crops and fruit trees (24 %), very high dry moors and other uses (9 %) (INEC, 2002).

Land tenure is highly skewed, with a high number (366,058) of very small farmers (< 2 ha) owning only 2 % of the area and a small number (19,557) of large farmers (> 100 ha) owning 42 % of the agricul-

**Table 1** Agricultural area of Ecuador considered in this study

| Soil use | Area, ha |
|---|---|
| Annual crops [1] | 1,153,802 |
| Perennial crops [2] | 1,243,644 |
| Cultivated pastures | 3,357,167 |
| Land in recess | 381,304 |
| Total | 6,135,917 |

[1] Area seeded alone +50 % of associated area, [2] Area planted alone +25 % of associated area

tural area (INEC, 2002).

Agricultural mechanization in Ecuador is in its early stages of development, with much work carried out manually and with animal traction. Zambrano (1994) points out that there are 2,428,625 ha with tractor mechanization potential. Aldean (1991) and Jarre (2000) have established in some valleys of Ecuador, tractor mechanization levels of 0.1 to 0.3 HP per cultivated hectare.

Several authors (Giles, 1975; Campbell, 1992: Ortiz-Cañavate, 1993; Witney, 1995; Clarke, 1997; Clarke and Bishop, 2002) have indicated that the productivity of land and labor could be greatly increased and insure food security if the developing countries could reach mechanization levels in the range 0.50-0.75 kW per hectare of cultivated land.

The hipothesis put forward in this work is that the level of mechanization of Ecuadorian agriculture is below the recommended levels for developing countries and this is affecting negatively the productivity of land and labor in this country.

The main objectives of this work were to establish the tractor hours demanded by the agricultural production systems of Ecuador; to compare this demand with the actual tractor park and to analyze the mechanization indicators of agriculture in Ecuador.

**Table 2** Main annual crops in Ecuador

| Main annual crops | | | | |
|---|---|---|---|---|
| Annual crops | Seeded area, ha | | | |
| | Alone | Associated | Total | Study area [1] |
| Maize *(Zea mays)* | 349,346 | 122,199 | 471,545 | 410,446 |
| Rice *(Oryza sativa)* | 343,936 | 5,790 | 349,726 | 346,831 |
| Beans *(Phaseolus vulgaris L.)* | 24,379 | 97,212 | 121,591 | 72,985 |
| Soybean *(Glycine max L.)* | 54,350 | 1,630 | 55,980 | 55,165 |
| Barley *(Hordeum vulgare)* | 48,874 | 2,117 | 50,991 | 49,933 |
| Potato *(Solanum tuberosum)* | 47,494 | 2,225 | 49,719 | 48,607 |
| Broad bean *(Vicia faba L.)* | 18,338 | 24,836 | 43,174 | 30,756 |
| Wheat *(Triticum sativum)* | 21,945 | 747 | 22,692 | 22,319 |
| Yucca *(Manihot sculenta)* | 17,846 | 8,408 | 26,254 | 22,050 |
| Peas *(Pisum sativum L.)* | 13,571 | 4,506 | 18,077 | 15,824 |
| Onions *(Allium cepa)* | 11,471 | 763 | 12,234 | 11,853 |
| Peanuts *(Arachis hypogea)* | 7,624 | 4,444 | 12,068 | 9,846 |
| Others | 46,033 | 22,307 | 68,340 | 57,187 |
| National total | 1,005,207 | 297,184 | 1,302,391 | 1,153,802 |

Souce: INEC-III CNA 2000

[1] Area seeded alone +50 % associated area

**Table 3** Main perennial (tree) crops in Ecuador

| Main perennial crops | | | | |
|---|---|---|---|---|
| Perennial crops | Planted area, ha | | | |
| | Alone | Associated | Total | Study area [1] |
| Cacao *(Theobroma cacao L.)* | 243,146 | 191,272 | 434,418 | 290,964 |
| Banana *(Musa paradisiaca)* | 180,331 | 85,793 | 266,124 | 201,779 |
| Coffee *(Coffea sp.)* | 151,941 | 168,970 | 320,911 | 194,184 |
| African palm *(Elaeis guinee)* | 146,314 | 15,888 | 162,202 | 150,286 |
| Sugarcane *(Saccharum officinarm L.)* | 125,355 | 6,497 | 131,852 | 126,979 |
| Plantain *(Musa sp.)* | 82,341 | 101,258 | 183,599 | 107,656 |
| Maracuya *(Passiflora edulis S.)* | 28,747 | 2,892 | 31,639 | 29,470 |
| Mango *(Mangifera indica)* | 16,754 | 2,641 | 19,395 | 17,414 |
| Palmetto *(Trachycarpus fortunci)* | 14,752 | 606 | 15,358 | 14,904 |
| Abaca *(Musa textilis)* | 14,713 | 118 | 14,831 | 14,743 |
| Orange *(Citrus sinensis)* | 3,737 | 40,759 | 44,496 | 13,927 |
| Mandarin *(Citrus reticula)* | 2,077 | 12,873 | 14,950 | 5,295 |
| Others | 62,833 | 52,846 | 115,679 | 76,045 |
| National total | 1,073,041 | 682,413 | 1,755,454 | 1,243,644 |

Souce: INEC-III CNA 2000

[1] Area planted alone +25 % associated area

## Methodology

**Information Sources**

The main sources of information were the National Agricultural Census (INEC, 2002), the Ministry of Agriculture, the National Institute of Agricultural Research, the Central Bank of Ecuador (BCE, 2003), The Technical University of Manabi, The National University of Loja, six expert agricultural engineers working at Universities and mechanization programs, and 18 producers in the provinces of Pichincha, Cotopaxi and Loja (Sierra) and Guayas, Los Rios and Manabi (Coast).

**Production Systems and Cultivated Area**

The 12 most important annual and the 12 perennial crops were selected to establish their production systems and area utilized. The total area considered in the study included annual crops, fruit and industrial trees, cultivated pastures and land in recess.

To estimate the tractor hours per hectare two seasons were considered (winter and summer). For the summer season 28 % of the area was considered, since this is the irrigated area of the country.

**Tractor Hours Demanded**

To establish this demand the operative time (h/ha) of each one of the agricultural operations was determined according with the information gathered in the field and the standards proposed by Ibanez and Abarzua (1995).

To estimate the h/ha for perennial crops, the useful (commercial) life of the orchard was used to distribute the h/ha needed for the orchard establishment in the years of useful life. To cultivated pastures and land in recess 1.5 and 1.0 h/ha were assigned, respectively.

**Estimation of Human Power**

Of all the persons living in the Agricultural Productions Units (INEC, 2001), those with ages between 15 and 60 years were considered. The power equivalences used were 0.075 kW for men and 0.05 kW for women (Fluck, 1992; Stout, 1990). Of these values 100 % was used for ages 20 to 60 years and 90 % for ages 15 to 20 years.

**Estimation of Animal Power**

Of the animals counted in the census (INEC, 2002), 80 % of oxen, 60 % of horses, 50 % of donkeys and mules were considered, according to the field work in the 6 provinces.

The power equivalences used were 0.75 kW for horses, 0.56 kW for oxen, 0.52 kW for mules and 0.26 kW for donkeys (Fluck, 1992; Stout, 1990).

**Estimation of Tractor Power**

Tractors appearing in the Census (INEC, 2002) were classified in 3 age groups: < 5 years; 6-15 years, and > 15 years. An average power of 60 kW and 100 kW for tire and crawler tractors was used (Zambrano, 1994; Jarre, 2000; Aldeán, 1991); His power was decreased according to age: 60 kW for < 5 years, 50 kW for 6-15 years, and 25 kW for > 15 years, in tire tractors. For crawler tractors, 100 kW for < 5 years; 75 kW for 6-15 years, and 50 kW for > 15 years. An average annual use of 836 hours for these tractors was utilized (Reina and Hetz, 2003)

**Evaluation of the Demand and Availability of Power for Agriculture.**

(a) Tractor hours demand of the Ecuadorian agriculture and the capacity to satisfy it with the actual tractor park and the human and animal power available;
(b) Power available for cultivated area (kW/ha) including the human and animal power and its comparison to mechanization indicators recommended for developing countries of 0.50 - 0.75 kW/ha (Giles, 1975; Campbell, 1992; Ortiz-Cañavate, 1993; Witney, 1995; Clarke, 1997; Clarke and Bishop, 2002);
(c) General mechanization indicators, like rural population per tractor and hectares per tractor compared with those published by FAO and those of other Latin American countries.

## Results and Discussions

**Areas and Species Considered in This Study**

**Table 1** shows the agricultural area considered in this study. Annual and perennial crops cover about 1.2 million hectares each, with cultivated pastures covering 3.36 million hectares, for a total considered of 6.14 million hectares.

**Tables 2** and **3** show the different species and area covered by the 24 principal annual and perennial crops. The main annual crops are maize, rice, bean, soybean, barley and potatoes. Caccao, banana, coffee, African palm, sugarcane and plantain are among the tree crops.

**Power Demand of the Production Systems**

**Table 4** shows that the production systems of the 12 principal annual crops demand 17.29 million tractor hours per year. On the other hand, the 12 principal tree crops demand

**Fig. 1** Ecuador in South America


**Fig. 2** power study to agricultural in Ecuador

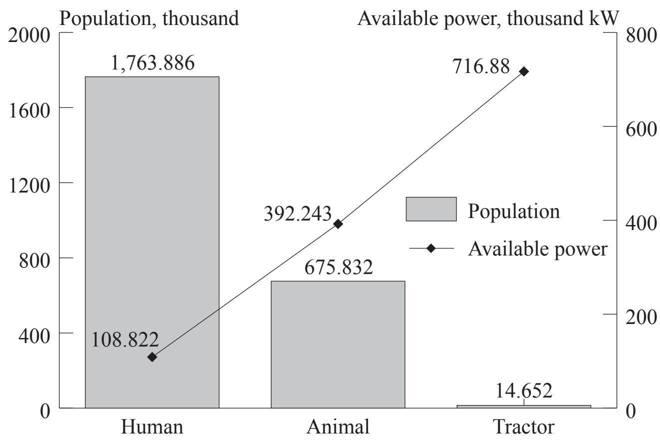


**Table 4** Mechanized operations of the 12 main annual crops in Ecuador

| Crops | Total[1], ha | Mechanized operations, h/ha | | | | | | | | | | | | | Hours/year[4] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Soil preparation | | | | | | Crops maintenance | | | | | Season | | | | |
| | | Ground clearing | Plow | Harrow | Rome plow | Furrow | Seeding | Herbicide applic. | Fertiliz. | Culti-vator | Pesticide[2] applic. | Harvest transp. | Summer | Winter[3] | Summer | Winter | Total |
| Maize | 410,446 | 1 | 2.5 | 1.3 | | 1.2 | 1.3 | 0.5 | 0.5 | 1.2 | 1.5 | 1.5 | 12.5 | 11.3 | 1,436,561 | 4,638,040 | 6,074,601 |
| Rice[5] | 346,831 | 1 | 2.5 | 1.3 | 2.7 | | 1.3 | 0.5 | 0.5 | | 1.5 | 1.5 | 12.8 | 12.8 | 1,243,042 | 4,439,437 | 5,682,479 |
| Bean | 72,985 | 1 | 2.5 | 1.3 | | 1.2 | 1.3 | 0.5 | | 1.2 | 1.5 | 1.5 | 12 | 10.8 | 245,230 | 788,238 | 1,033,468 |
| Soybean | 55,165 | 1 | 2.5 | 1.3 | 1.2 | 1.2 | 1.3 | 0.5 | 0.5 | 1.2 | 1.5 | 1 | 13.2 | 12 | 203,890 | 661,980 | 865,870 |
| Barley | 49,933 | 1 | 2.5 | 1.3 | | 1.2 | 1 | 0.5 | 0.5 | | 1.5 | 1 | 10.5 | 9.3 | 146,803 | 464,377 | 611,180 |
| Potato | 48,607 | 1 | 2.5 | 1.3 | 1.2 | 1.2 | | 0.5 | 0.5 | 1.2 | 1.5 | 3 | 13.9 | 13.9 | 189,178 | 675,637 | 864,816 |
| Broad bean | 30,756 | 1 | 2.5 | 1.3 | | 1.2 | 1.3 | 0.5 | | 1.2 | 1.5 | 1 | 11.5 | 10.3 | 99,034 | 316,787 | 415,821 |
| Yucca | 22,050 | 1 | 2.5 | 1.3 | | 1.2 | | | | | | 3 | 9 | 7.8 | 55,566 | 171,990 | 227,556 |
| Wheat | 22,319 | 1 | 2.5 | 1.3 | | 1.2 | 1 | 0.5 | 0.5 | | 1.5 | 1 | 10.5 | 9.3 | 65,618 | 207,567 | 273,185 |
| Peas | 15,824 | 1 | 2.5 | 1.3 | | 1.2 | 1.3 | 0.5 | | 1.2 | 1.5 | 1.5 | 12 | 10.8 | 53,169 | 170,899 | 224,068 |
| Onions | 11,853 | 1 | 2.5 | 1.3 | | 1.2 | | 0.5 | 0.5 | | 1.5 | 1.8 | 11.9 | 10.7 | 39,494 | 126,827 | 166,321 |
| Peanuts | 9,846 | 1 | 2.5 | 1.3 | | 1.2 | 1.3 | 0.5 | | 1.2 | 1.5 | 1.5 | 12 | 10.8 | 33,083 | 106,337 | 139,419 |
| Others | 57,187 | 1 | 2.5 | 1.3 | | 1.2 | | 0.5 | 0.5 | 1.2 | 1.5 | 1 | 10.7 | 9.5 | 171,332 | 543,277 | 719,609 |
| National total | 1,153,802 | | | | | | | | | | | | | Total | 3,982,000 | 13,311,392 | 17,293,392 |

[1] Area seeded alone +50 % associated area; [2] Two pesticide applications and one leaf fertilization (0.5 h/ha x 3 applic.); [3] In his season furrow area not made, except in potato; [4] To estimate h/year 28 % of irrigated area was considered is summer and 100 % winter; [5] Rome-plow is 1.2 h/ha plus 1.5 h/ha for mudding; [6] Harrowing is 1.3 h/ha plus 1.6 h/ha of rotavator

**Table 5** Mechanized operations of the 12 main perennial crops in Ecuador

| Crops | Total[1], ha | Mechanized operations, h/ha | | | | | | | | | | | | | | Total, h/year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Establishment | | | | | | Commer-cial life | Total, h/ha | Crops maintenance | | | | | | |
| | | Ground clearing | Plow | Harrow | Rome plow | Furrow | Seeding | | | Herbicide applic. | Fertiliz. | Culti-vator[3] | Pesticide[4] applic. | Harvest transp. | Total, h/ha | |
| Cacao | 290,964 | 20 | | | | | | 16 | 1.25 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 1,934,911 |
| Banana[5] | 201,779 | 20 | | 3 | 2.5 | | | 4 | 3.87 | | | | | | 0 | 780,885 |
| Coffee | 194,184 | 20 | | | | | | 12 | 1.66 | 0.5 | | | 1 | 1.5 | 3 | 904,897 |
| African palm | 150,286 | 20 | | | | | | 18 | 1.11 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 978,362 |
| Sugarcane | 126,979 | 1 | | 2.5 | 1.3 | 1.2 | 1.2 | 5 | 1.44 | 0.5 | 0.5 | | 1 | 1.5 | 3.5 | 627,276 |
| Plantain[5] | 107,656 | 10 | 3 | 2.5 | | | | 4 | 3.87 | | | | | | 0 | 416,629 |
| Maracuya | 29,470 | 5 | | 2.5 | 1.3 | | | 3 | 2.93 | 0.5 | | | 1 | 1.5 | 3 | 174,757 |
| Mango | 17,414 | 20 | 3 | 2.5 | 1.3 | | | 15 | 1.78 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 125,033 |
| Palmetto | 14,904 | 20 | | | | | | 20 | 1 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 95,386 |
| Abaca | 14,743 | 10 | 3 | 2.5 | | | | 15 | 1.03 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 94,797 |
| Orange | 13,927 | 20 | 3 | 2.5 | 1.3 | | | 15 | 1.78 | 0.5 | | | 1 | 1.5 | 3 | 66,571 |
| Mandarin | 5,295 | 20 | 3 | 2.5 | 1.3 | | | 15 | 1.78 | 0.5 | | | 1 | 1.5 | 3 | 25,310 |
| Others | 76,043 | 10 | 3 | 2.5 | 1.3 | | | 10 | 1.68 | 0.5 | | 2.4 | 1 | 1.5 | 5.4 | 538,384 |
| National total | 1,243,644 | | | | | | | | | | | | | | Total | 6,763,198 |

[1] Area seeded alone +25 % associated, [2] Land clearing with crawter tractor, [3] In perennial crops two weeding per year (0.5 h/ha x 2), [4] Two pesticide applications (0.5 h/ha x 2 applications), [5] Pesticide applications in banana are dome with aeroplane or manually

6.76 million tractor hours per year, as it is shown in **Table 5**. It can be seen that the largest demand (77 %) occurs in the winter season when all the area is utilized taking advantage of the rain; in the summer season only the irrigated area is seeded and the demand of tractor hours is much smaller.

Perennial tree crops demand a low number of tractor hours given that their maintenance, especially pesticide applicactions, is carried out with airplanes and the tractor hours needed for their establishment are distributed in the years of commercial life.

**Total Yearly Demand of Tractor Hours in Ecuador**

**Table 6** shows that the total yearly demand of tractor hours for the annual and perennial crops is 24 million, to which the demand of cultivated pastures and land in recess is to be added to reach a grand total of 29.5 million h/yr. Taking away the work carried out manually and with animal traction leaves the 17.7 million h/yr that are to be carried out with tractors.

**Agricultural Tractor Park of Ecuador**

**Table 7** shows there are 12,928 tractors with pneumatic tires and 1,724 crawler tractors, which together provide a total of 716,880 kW of power.

**Total Power Supply to Agriculture in Ecuador**

**Figure 2** shows the total provision of power to agriculture, consisting of 108,822 kW (9 %) of human power, 392,243 kW (32 %) provided by animals and 716,880 kW (59 %) by tractors, for a grand total of 1,217,945 kW.

**Demand and Supply of Tractor Hours for Agriculture in Ecuador**

**Table 8** shows that the yearly demand of tractor hours for the area with annual and perennial crops (2,397,446 ha) corresponds to a bit more than 24 million hours. For the area that includes cultivated pastures (6,135,917 ha) the power demand reaches 29.5 million h/yr.

When the human and animal work is substracted, the hours to be carried out with tractors comes down to 14.4 million h/yr and 17.7 million h/yr without and with the pastures, respectively. With tractors working an average of 836 h/yr (Reina and Hetz, 2003) a demand of 17,265 and 21,153 tractors appear for the two areas considered. Substracting the actual tractor park of 14,652 units, deficits of 2,613 and 6,501 tractors appear, for the two areas considered.

Taking into consideration the average annual historic rate of tractor importation into Ecuador of 423 tractors/yr (FAOSTAT, 2004), the covering of the first deficit of 2,613 units would take many years, going from 7 to 12 years according to a new importation rate of 100 % or 50 % above the actual rate. These are decisions not to be taken lightly and should consider the long range plans and policies of agricultural development of the country.

**Table 6** Total yearly demand of tractor hours in Ecuador

| Soil use | Area, ha | Number hours/year | Human [3] and animal operations, 40% | Total hours with tractor/year |
|---|---|---|---|---|
| Crops [1] | 2,397,446 | 24,056,590 | 9,622,636 | 14,433,954 |
| Cultivated pastures [2] | 3,357,167 | 5,035,571 | 2,014,229 | 3,021,342 |
| Land in recess | 381,304 | 381,304 | 152,522 | 228,782 |
| Total | 6,135,917 | 29,473,465 | 11,789,386 | 17,684,079 |

[1] Annual and perennial crops; [2] To estimate the no. of h/year, 1.5 h/ha for pastures and 1 h/ha for recess; [3] Human and animal share

**Table 7** Agricultural tractor park of Ecuador

| Age, year | Tire tractors | | | Crawler tractors | | | Total power, kW |
|---|---|---|---|---|---|---|---|
| | No. tractor | Mean power, kW | Power available, kW | No. tractor | Mean power, kW | Power available, kW | |
| < 5 | 2,548 | 60 | 152,880 | 259 | 100 | 25,900 | 178,780 |
| 6 - 15 | 7,266 | 50 | 363,300 | 948 | 75 | 71,100 | 434,400 |
| > 15 | 3,114 | 25 | 77,850 | 517 | 50 | 25,850 | 103,700 |
| Total | 12,928 | | 594,030 | 1,724 | | 122,850 | 716,880 |

Source: Elaborated by the Author upon data INEC (2002)

**Table 8** Demand and supply of tracor hours for agriculture in Ecuador

| | Area considered, ha | Demand of hours/year | Human and animal operations, 40% | Tractor hours demand, hours/year | Tractor [1] annual use, hours/year | Tractors required | Exisiting tractor | Tractor deficit |
|---|---|---|---|---|---|---|---|---|
| Annual and perennial crops | 2,397,446 | 24,056,950 | 9,622,636 | 14,433,954 | 836 | 17,265 | 14,652 | 2,613 |
| Pastures and recess | 6,135,917 | 29,473,465 | 11,789,386 | 17,684,079 | 836 | 21,153 | 14,652 | 6,501 |

[1] Reina and Hetz (2003)

## Power Indicators in Ecuadorian Agriculture

**Figure 3** shows the actual power indicators for the area with annual and perennial crops and for the area that includes the cultivated pastures. There are also projected indicators that include the tractor deficit established, excluding and including the human and animal power.

These indicators go from as low as 0.12 kW/ha for the area with pastures to a high of 0.57 kW/ha when only the area with annual and perennial crops is considered and the human and animal power is included. The most representative of these six indicators would be 0.30 kW/ha that considers only the tractor power for the annual and perennial crops area.

These power levels are far from the level of 0.75 kW/ha recommended for developing countries (Giles, 1975; Stout, 1990; Fluck, 1992; Campbell, 1992; Ortiz-Cañavate, 1993; Witney, 1995; Clarke, 1997; Clarke and Bishop, 2002). They are also below the levels of Chile (0.56 kW/ha), Argentina (0.60 kW/ha), Mexico (0.77 kW/ha), and Venezuela (0.79 kW/ha), being close to those of Colombia and Peru (0.23 and 0.14 kW/ha).

## Tractor Power Deficit to Reach 0.75 kW/ha

**Table 9** shows that to go from the actual power available in Ecuador to the recommended level of 0.75 kW/ha, only in the area with annual and perennial crops and maintaining the use of human and animal power, the actual tractor park would have to increase by 9,205 units. This increment would easily take 20 to 25 years.

This power level, of 0.75 kW per hectare of cultivated land, has been recommended by the authors previously mentioned, and has been validated by the authors of this study for several countries of Latin American, as it is shown in **Figure 4**, where it is clear that to a larger power level corresponds a larger per capita income.

## Other Agricultural Mechanization Indicators

**Table 10** shows general mechanization indicators. It shows there are from 164 to 419 hectares per tractor, according to the area considered;

**Table 9** Tractor power deficit in Ecuador to reach 0.75 kW/ha

| | Area considered, ha | Sugested indicator, kW/ha | Total power needed, kW | Actual [1] power, kW | Deficit, kW | Required tractors [2] | |
|---|---|---|---|---|---|---|---|
| | | | | | | Tire tractors | Crawlers |
| Annual and perennial crops | 2,397,446 | 0.75 | 1,798,085 | 1,217,945 | 580,140 | 8,509 | 696 |

[1] It includes human, animal and tractor power; [2] 88 % tire tracotrs and 12 % crawlers

**Table 10** Other mechanization indicators for Ecuador

| | Area considered, ha | Rural population | Actual number of tractors | Required tractors | General indicators | | |
|---|---|---|---|---|---|---|---|
| | | | | | ha/tractor | | Rural pop./ tractor |
| | | | | | Actual | Projected | Actural |
| Annual and perennial crops | 2,397,446 | 3,061,917 | 14,652 | 16,907 | 164 | 142 | 209 |
| Pastures and recess | 6,135,917 | 3,061,917 | 14,652 | 21,153 | 419 | 290 | 209 |

**Fig. 3** Power indicators in Euadorian agriculture

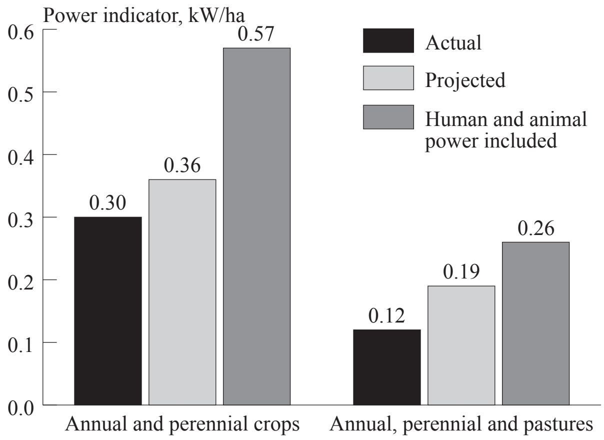
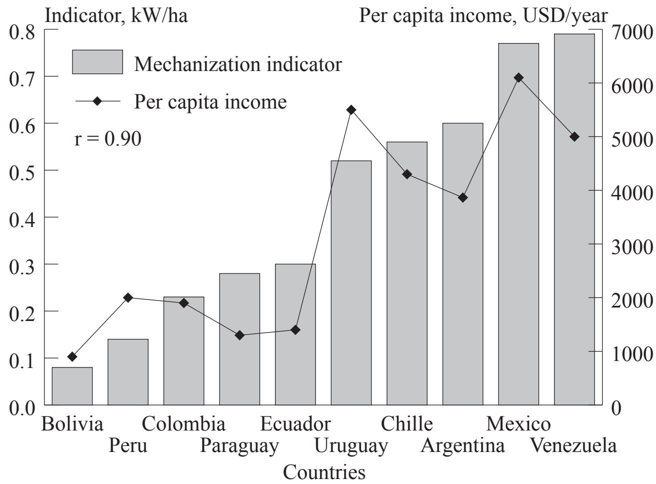



**Fig. 4** Agricultural power indicators and per capita income of several Latin American countries




Sources: Elaborated by the Author on data of FAOSTAT (2004), National Agricultural Census and the International Monetary Fund these values go down to 142 and 290 hectares per tractor, when no deficits are considered. They are far from the ones existing in Chile (90) and Venezuela (69), closer to Peru (319) and Colombia (216), but better than Bolivia (522).

On the other hand, **Table 10** also shows the number of rural persons per tractor, with 209 for Ecuador, smaller than those in Bolivia (596), Peru (593) and Colombia (417), but quite larger than those of Chile (48), Venezuela (47), and Argentina with only 13 persons per tractor.

In summary, it can be said that the hypothesis put forward in this work is true, that is to say the Ecuadorian agriculture could achieve an important growth in its production and productivity of land and labor by increasing its level of mechanization.

## Conclusions

The productive systems of the Ecuadorian agriculture have similar areas, about 1.2 million hectares, of annual and perennial (tree) crops. Annual crops produce a second harvest in the irrigated area. A large area of cultivated pastures exists alongside the annual and perennial crops.

The average yearly demand of tractor hours per hectare of the annual crops is much larger than that of the perennial crops; as a result, the total yearly demand of tractor hours of the annual crops is more than twice (2.56) the demand of the perennial crops. Very little tractor hours are used in the cultivated pastures.

The actual tractor park is 14,652 units that provide 716,880 kW of power. When the human and animal power is added a grand total of 1,217,945 kW is reached. This power does not satisfy the yearly demand of the annual and perennial crops, giving origin to a deficit of 2,600 tractors. When the area with cultivated pastures is added, the deficit reaches 6,500 units. If the power level recommended for developing countries is to be reached the deficit goes up to more than 9,000 tractors.

The actual agricultural mechanization indicator of Ecuador is 0.30 kW per hectare of annual and perennial crops. This indicator would go up to 0.36 kW per hectare if the established tractor deficit is added; however when the cultivated pastures are included the indicator is very much reduced. All these values are far from the ones existing in the majority of the other Latin American countries and from the power levels recommended for developing countries.

Other indicators, such as hectares per tractor and rural workers per tractor, also show an agriculture with levels of mechanization far below the levels of the majority of the other Latin American countries.

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# Improvement of the Modified Grain Thresher for Groundnut Threshing

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## Abstract

After successful modification of the Oztarim grain thresher for groundnut threshing, other parts were designed to improve its threshing operation efficiency, to facilitate automatic collection of crop residue for animal feeding and to solve the problem of soil particles accumulation underneath the thresher shaker. This was achieved through the design of a conveyor feeding belt, a cyclone vines collector and soil particle handcarts. Their specifications were identified. The improved and modified thresher with conveyor feeding belt was compared with the modified grain thresher with direct feeding, commercial thresher as a stationary thresher and manual threshing as the traditional threshing method in the Gezira scheme.

Results indicated significant differences (P = 0.05) between the threshing methods for the required man-hrs/ha and between threshing machines for fuel consumption/ha. The improved modified thresher resulted in savings of about 2 man-hrs/ha and about 3 liter/ha of fuel consumption compared to the modified grain thresher with direct feeding. The use of a conveyor feeding belt increased the material capacity of the modified grain thresher with direct feeding from 41 % to 64 % as compared to the commercial thresher with no significant difference in cleaning efficiency. Manual threshing resulted in significantly lower cleaning efficiency. The cyclone vine collector resulted in savings of about 2 min/sack, which was the time for manual bagging of vines, and in a significant (P = 0.05) reduction in the required number of sacks/ha in comparison with manual filling operation. The use of handcarts for soil particle removal allowed continuous working of the improved thresher without changing its position near the groundnut heap. Therefore, the designed parts could be recommended for the modified grain thresher to improve its groundnut threshing performance.

## Introduction

Sudan ranks fourth in world groundnut production. The crop is grown to meet the local demands for oil and cakes and provides a surplus for export (Ahmed, 1994). The crop residue is an excellent protein source for ruminant livestock feed.

Elmahdi (1996) stated that the groundnut harvesting in the New Halfa scheme (25,000 ha) is comprised of three operations, which are digging, collection and threshing. The harvesting operation utilizes about 39 % of the total labour force used in groundnut production and constitutes about 44 % of the total production cost. The pulled crop is collected into five heaps per tenancy (2.1 ha) and fed manually to the stationary thresher. Ahmed (1996) reported that harvesting of groundnut in the Rahad scheme (27,000 ha) is comprised of four operations, which are digging, collection, threshing and manual residue collection. Harvesting utilizes 50 % of the labour for groundnut production and constitutes 20 % of the production cost. Manual digging and collection utilizes 20 % of the labour force and constitutes 13 % of the total production cost. The machine does 85 % of the groundnut threshing operation. Threshing operation utilizes 14 % of the labour force and constitutes about 10 % of the total production cost. Stationary threshers do about 70 % of the threshing operation due to their low crop losses and easy collection of the hay crop. Mobile threshers contribute about 30 % and crop residue collection is done manually where residue is divided equally between the farmer and the labourer. Due to the lack of groundnut harvesters in the Gezira scheme (90,000 ha), manual harvesting is the traditional method for groundnut threshing, which is a time-consuming with high crop losses. Delay in threshing the stacked heaps of groundnut results in delay of the following cotton land preparation and they may act as source of rats to attack groundnut pods as well as wheat crop before combine harvesting (El-Awad, 2000). These situations necessitate the introduction of new methods and machinery for crop harvesting.

The calculations based on tractor requirements per area of the principal crops showed that with the present number of tractors (for operating stationary threshers and combine harvesters) it is not possible to achieve timely harvesting of all crops (FAO, 1995). This called for local manufacturing of agricultural equipment, and advised that local assembly of tractors is hardly feasible due to the relatively small market size. It also indicated that the promotion of imported threshers to satisfy local needs is highly appreciated.

Different models of stationary grain threshers have been imported to the Sudan (G.A.S., 1996). They are simple in design, easily maintained, consume little power (35 to 40 hp) and have been designed with simple threshing, cleaning and bagging units. El-Awad (2000) successfully modified the Oztarim grain thresher for groundnut threshing. The modified parts were made to be replaceable, which were the concave, the soil particle and the seed sieves, aspirator fan pulley, the delivery gate and bagging system (optional). The field capacity of the modified grain thresher was found to be 41 % as compared to the commercial groundnut thresher (Lilliston). Therefore, attempts were made to design some parts for further improvement of the modified grain thresher in order to:

1. Increase the capacity of the thresher by introducing a mechanical feeding device for the crop.
2. Improve the crop residue collection by modifying the chaffer unit of the thresher.
3. Solve the problem of the accumulation of soil particles underneath the stationary thresher.

By studying the technical specifications of eight different models of grain threshers, it can be inferred that the modifications on the Oztarim grain thresher for groundnut threshing (El-Awad, 2000) could be adopted successfully for all models that have been imported to the Sudan.

## Modified Parts for the Thresher Performance Improvement

The modified parts of the grain thresher developed by El-Awad (2000) were employed in the Oztarim grain thresher, Model 1200-SPX, which was intended to be improved in the areas of material feeding, crop residue collection and removal of soil particles underneath the shaker. The design of the parts for the improvement was carried out at Masaad Training Center Workshop in the year 2002 and comprised the following:

**The Belt Conveyor**

The designed conveyor-feeding belt consisted of a frame and rollers, a special selected conveyor belt and a belt drive. The assembled belt conveyor in operation is shown in **Fig. 1a**. The designed conveyor frame consisted of an inclined table and ground wheels with the following specifications:

***The Inclined Table***

The inclined table was constructed as a rectangular table (320 x 118 cm) from a 75-mm steel angle. It was designed with these dimensions to help in handling the groundnut from the heap at an inclined surface of 35º to the feeding platform, which is at a height of 160 cm above the ground surface. This angle of elevation was determined through a micro-test by putting some dry groundnuts on a flat and smooth metal sheet, which was raised slowly from the horizontal position. The groundnut started to slide at an angle of 37º. Therefore, a smaller angle of 35º was chosen for calculation of the total length of the conveyor belt table by dividing the vertical height of the feeding platform (160 cm) by sine 35º. Then an extra 40 cm was added to extend the length towards the threshing unit for a total length of 320 cm. The width of the thresher feeding platform was 120 cm. Therefore, the width of conveyor belt table was taken as 118 cm with 1 cm clearance at each side in order to have as great as possible conveyor belt area. Two side fenders, made from sheet metal (20 x 315 cm), were attached to each side of the conveyor table to prevent the conveyed crop from falling to the sides.

Three rollers 100 cm long and 10.8 cm diameter were installed to support the conveyor belt. The rollers were made of galvanized steel tubes welded to a steel shaft 35 mm diameter and 115 cm long. Each roller was supported by two pillow-block ball bearings. The front drive roller shaft was 162 x 3.5 cm, which was extended 17 cm to one side and 45 cm to the other side (the driven pulley side). A keyway of 20 x 0.5 x 0.5 cm was milled on the shaft for connecting its motion to the driven pulleys.

***Ground Wheels***

The ground wheels carried the whole conveyor belt assembly and were used for changing the conveyor belt ground clearance and the angle of elevation (**Fig. 1a**). The wheel assembly consisted of two rubber wheels (6.00 x 16), a 220-cm wheel axle, supporting pipes and a drawing (pulling) shaft. The rubber wheels were mounted on a 50 mm galvanized tube axle, which had the same length as the rubber wheel axle. Each wheel was supported on two ball bearings at the wheel spindle. The ground wheels supported the conveyor belt assembly through the two supporting pipes. The conveyor belt assembly was drawn behind the thresher by two pulling shafts. Since the thresher was used on rough agricultural land, the shafts were supplied with springs that serve as shock absorbers. Each supporting pipe consisted of two telescoping pipes. The inner pipe diameter was 35 mm, while the outer pipe diameter was 42 mm. The pipes were connected to the conveyor belt table and wheels axle through pin joints. The length supporting pipes have ranged between 70-120 cm to provide a ground clearance from 6 to 60 cm and an angle of elevation from 35º to 19º respectively.

***The Conveyor Belt***

A light, endless rubber belt 100 x 635 cm was used for the conveying operation. Eight metal slats (90 x 5 cm) were riveted to the belt after four to six tines (fingers) were attached. The tines held the crop while being conveyed to the threshing unit. The tines were made from a 0.5 cm metal rod 5 cm long.

***The Belt Drive***

ASAE (1979) reported that, for drives with two sheaves (pulleys) the relationship between the center distance and the belt length was:

$$L = 2C + 1.57 (D + d) + (D - d) / 4C \quad \text{.............................(1)}$$

Where:

L = Effective length of the belt.

C = Distance between centers of pulleys.

D = Effective outside diameter of the large pulley (sheave).

d = Effective outside diameter of the small pulley (sheave).

The cylinder (Bator) shaft of the Oztarim thresher had a five-groove pulley attached to it at its right side. One of the grooves was used for driving the aspirator fan pulley and another for driving the shaker and the soil particle sieve. One of the three remaining grooves, which had an effective diameter of 12.5 cm was used as a driving pulley. This pulley ran at the same speed as the cylinder (400-450 rpm). The distance between the centers of the driving shaft (Bator shaft) and the driven shaft (roller shaft) was 73.5 cm. Three different pulleys with diameters of 13.5, 21.5 and 35 cm were chosen to give conveyor feeding belt speeds that ranged from 370 to 416, 232 to 261 and 143 to 151 rpm, respectively. The driven pulleys were attached to the roller shaft. The driven pulley speed can be calculated by the following equation:

$$V = (d/D) \times N \quad \text{..............................(2)}$$

Where:

V = Driven pulley speed (rpm).

d = Driving pulley diameter (cm).

D = Driven pulley diameter (cm).

N = Driving pulley speed (rpm).

The conveyor feeding belt speed was calculated using equation (2). The V-belts with measurement of B-75, B-80 and 17 x 2350 were used for power transmission to the roller shaft when using each of the three pulleys (13.5, 21.5 and 35 cm diameter) that were made available from the local market. A tension pulley with a diameter of 22 cm was provided with a rotating arm and a spring with an adjusting arm to keep the belt at the proper tension.

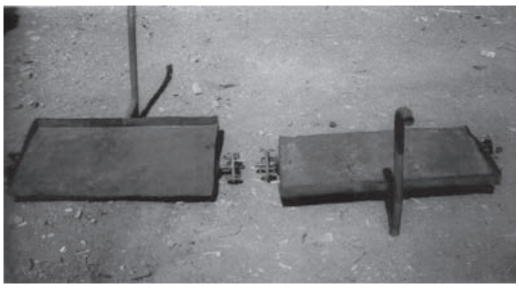
**The Cyclone Vines Collector**

In the Oztarim thresher, the pneumatic conveying system introduced the trash directly by gravity and then discharged directly out by the fan. The vines were separated from the air by a cyclone collector, which was developed and attached to the chaffer outlet (**Fig. 1b**). The groundnut vines were collected in the bagging sacks. The cyclone collector consisted of an inner cylinder with a diameter of 39 cm and a length of 41.5 cm, an outer cylinder of 49-cm diameter and a length of 47 cm and a cone with a bottom circle diameter of 23 cm and a vertical height of 66 cm. The vines were delivered inside the cyclone through a side opening (60 x 25 cm) around the outer cylinder diameter, and driven by the air pressure. When the vines entered the cyclone they start rotating around the inner cylinder and

**Fig. 1a** The belt conveyor at operation

**Fig. 1b** The cyclone vines collector

**Fig. 2** Two soil particles handcarts



passed down through the discharge cone bottom opening, while the air moved up through the inner cylinder to the outer space. The height of the discharge cone bottom opening from the ground was 93 cm, which facilitated the upright standing of the bagging sack. However, with the use of the conveyor feeding belt, the aspirator fan pulley 15 cm diameter (El-Awad, 2000) was changed by a 10-cm pulley to increase the cleaning efficiency through the high speed of fan.

**The Soil Particles Handcarts**

Usually, in clay soils, clay particles adhere to the lifted groundnut pods. During the threshing operation, the soil particles drop from the soil particle sieve and start to accumulate underneath the shaker. Unless they are removed or the position of the thresher is changed, a low cleaning efficiency will result. Therefore, for the thresher to operate in one position nearby the stacked heap, two simple handcarts with similar dimensions to the effective dimensions of the soil particles sieve (**Fig. 2**) were developed to be positioned under the soil particles sieve, one on either side of the thresher. When they were full, they could be easily drawn out, emptied and then replaced under the thresher.

## Comparative Evaluation of the Improved Modified Thresher

The experimental work of groundnut threshing was conducted in the Gezira scheme at Musallamia Group in 2002 to compare the performance of the following threshers and manual threshing method:

1. Improved modified thresher: Oztarim grain thresher that included El-Awad (2000) modified parts for groundnut threshing and the newly modified parts for threshing performance improvement, which were conveyor feeding belt, cyclone vines collector and soil particles removal handcarts.
2. The modified grain thresher: A modified Oztarim grain thresher that contained only the modified parts from by El-Awad (2000) for groundnut threshing.
3. Commercial thresher: A trail type Lilliston groundnut harvester, Model 1580, which was used as stationary thresher.
4. Manual threshing: The traditional threshing method in the Gezira scheme, in which the groundnut is threshed using wooden threshing paddles.

Groundnuts were pulled manually four weeks before threshing operation. It was left for four days in the field to dry before being gathered in heaps. The experiment was a randomized complete block design with five replications. The experimental work was done over a period of five days.

The three thresher machines, one at a time, were made ready beside a heap of groundnuts that were collected from a plot area of 0.42 ha. Five labourers were used in the threshing operation with the commercial thresher, while four labourers were used with the improved modified thresher and the modified grain thresher. The machine was first operated to determine the most suitable tractor engine and P.T.O. speed for the best threshing performance. The fuel tank of the tractor was topped with fuel. Man-hrs/ha, fuel consumption and the time to fill a sack with collected yield and to replace it with another were measured. Also, the time required for filling a sack with vines by the cyclone method and the time needed for removing the handcarts from underneath the shaker, emptying them and replacing them were recorded. At the same time two farmers were doing the manual threshing, wind cleaning, bagging of clean crop and bagging of vines. The time for each operation was determined. Samples of collected yields were taken from each threshing method to determine the cleaning efficiency.

Methods for determining the operational performance were as follows:

1. Man-hours per hectare was determined with the use of the following formula;
   Man-hours/ha = (L x t) / A ...(3)
   Where:
   L = Number of labourers.
   t = Spent time (hours).
   A = The area of collected crop (in this study was 0.42 ha).
2. Fuel consumption: After adjusting the engine rpm for the best threshing performance, the fuel tank was topped with fuel and the operation started. Using the graduated cylinder, the fuel tank of the tractor was retopped and the fuel used for retopping was recorded (F). Then the fuel consumption per unit area (A), which was 0.42 ha was calculated as follows:
   Fuel consumption per unit area (l/ha) = F/A ..............................(4)
3. Time required to fill a sack with collected clean crop yield during the threshing operation was recorded using the stopwatch.
4. Time consumed for a man-filled sack of vines and a cyclone-filled sack of vines were recorded using the stopwatch.
5. Time required for removing and emptying the two handcarts that were positioned underneath the shaker when filled with soil particles, and then repositioned underneath the shaker was recorded.
6. The number of cyclone-filled and man-filled sacks of vines per plot were counted.
7. Sorting of the clean crop samples: Random samples were taken from collected yield and weighed. After manual separation, the clean pods were weighed to find the percentage of the clean pods to the total sample weight.

8. Time required for manual machine operations: When operating the improved modified thresher, one labour was employed for emptying the handcarts, beside removing the cyclone-filled vines as well as removing the sacks of collected yield and putting an empty sack in its place. The time required for performing each job was determined.

## Results and Discussion

The results for man-hrs/ha, fuel consumption, time required to fill a sack with collected yield, time required to fill a sack with vines, number of filled sacks of vines/ha and crop yield cleaning efficiency are displayed in **Table 1**.

**Man-hours Per Hectare**

The obtained results (**Table 1**) indicated a significant difference (P = 0.05) between the threshing operation methods. As expected, manual-threshing operation resulted in the highest man-hrs/ha (138 hr) and the commercial thresher resulted in the lowest man-hrs/ha (22 hr). However, the improved modified thresher with conveyor feeding resulted in significant savings of 2 man-hrs/ha in comparison with the modified grain thresher with direct feeding. Therefore, the use of conveyor feeding belt reduces the required threshing time.

**Fuel Consumption**

A significant difference (P = 0.05) (**Table 1**) was evident for the fuel consumption by different thresher machines, which were 29, 32 and 19 liter/ha for the improved modified thresher with conveyor feeding, the modified grain thresher with direct feeding and the commercial thresher respectively. The available 86-HP Universal tractor operated the three thresher machines, although the commercial thresher required 65 HP and the improved and modified grain threshers required 35-40 HP. This explained the high fuel consumption and consequently a high loss of tractor power, especially with the use of the improved and modified grain threshers. Therefore, for economic threshing operation with the improved and modified grain threshers, a small tractor should be used. The improved modified thresher with conveyor feeding resulted in savings of about 3 l/ha of fuel consumption compared to the modified grain thresher with direct feeding.

**Time Required to Fill a Sack with Collected Yield**

The analysis of variance showed a significant difference (P = 0.05) between the threshing methods for the time required to fill a sack with collected yield. Here again, as expected, the highest required time was obtained with manual threshing (109 min), while the commercial thresher resulted in the lowest required time (7 min). No significant difference was detected between the improved modified thresher with conveyor feeding (11 min) and the modified grain thresher with direct feeding (12 min) (**Table 1**). The time required to fill a sack with collected yield is an indication of the productivity of the threshing method used. El-Awad (2000) reported that the modified grain thresher capacity was be 41 % in relation to the commercial thresher. In this study, the improved modified thresher capacity was increased to 64 %. This improvement was due to the use of the designed conveyor-feeding belt, which facilitated the quick and continuous material feeding.

**The Required Time to Fill a Sack with Vines**

The designed cyclone resulted in significantly longer time (4 min) to fill a sack with vines in comparison with manual-filling method (2 min) (**Table 1**). This was due to the fact that the two farmers started bagging the crop vines after finishing the threshing and cleaning operations and from a prepared vine heap while the cyclone bagging was done within the complete threshing and cleaning operations with the use of the improved modified thresher. Therefore, the cyclone method saved a time, a hand labourer and efforts in manual vines collection.

**Table 1** Groundnut threshing operation performance with different threshing methods

| Thresher machine | Man-hr/ha | Fuel consumption, l/ha | Time for filling a sack of collected yield, min | Time for filling a sack of vines, min | No. of filled sacks with vines, No./ha | Clean pods, % |
|---|---|---|---|---|---|---|
| Improved modified thresher | 28 b | 29 b | 11 b | 4 a | 100 b | 91 a |
| Modified grain thresher | 30 c | 32 a | 12 b | | | |
| Commercial thresher | 22 d | 19 c | 7 c | | | 92 a |
| Manual Thresher | 138 a | | 109 a | 2 b | 114 a | 85 b |
| Means | 48 | 27 | 35 | 3 | 107 | 89 |
| SE ± | 0.4 | 2.1 | 3.6 | 0.1 | 0.9 | 0.5 |
| CV % | 4.2 | 10 | 2.1 | 5.2 | 4.3 | 1.1 |

= Not including for the parameter measurement
Means with the same letter are not significantly different at P = 0.05 according to Duncan's multible range test.

**Number of Filled Sacks of Vines/ha**

The cyclone filling resulted in significantly (P = 0.05) lower number of filled sacks with vines per ha (100 sacks) compared to the manual-filling method (114 sacks). This was due to the proper filling of sack with vines with the use of cyclone method rather than the manual filling operation. Therefore, the cyclone-filling operation reduced the required number of sacks/ha and, hence, reduced the cost of production.

**Cleaning Efficiency**

The cleaning efficiency was measured by separation of clean pods from the other constituent parts of the collected yield. Despite the preciseness of doing all kinds of adjustment stated in the operator manual for improving the cleaning efficiency of the threshers, some impurities appeared with collected yield. The threshers with conveyor and direct feeding showed no differences in the cleaning efficiency due to the use of the same cleaning system. Thus, the comparison was made for the improved modified thresher, commercial thresher and manual threshing.

The results showed no significant difference between the improved thresher (91 %) and the commercial thresher (92 %), but a significant difference (P = 0.05) in cleaning efficiency for manual threshing (85 %).

**General Observations**

During the complete cycle of threshing with the improved modified thresher, replicated five times, one labourer was used for changing the filled sack of collected yield, emptying the two handcarts from the soil particles and replacing them and changing the filled sack of vines. The respective required time to accomplishing these different operations were determined to be 18, 36 and 21 seconds, with a total time of 75 seconds. It could be seen that 4 and 11 minutes passed before another sack was filled with vines and another sack was filled with collected yield, respectively. Thus, the labourer could find enough time to perform all these jobs, which might infer that the designed parts of vines collector and the soil particles handcarts do not add another burden to the labourer, but he could find a time for some rest during the threshing cycle.

The designed conveyor-feeding belt could also be used in the thresher feeding of other grain types, so as to improve the threshing operation performance.

## Conclusion and Recommendation

The additional designed units of conveyor feeding belt, cyclone vines collector and soil particle handcarts were made from the locally available materials. The use of a conveyor feeding belt improved the modified thresher capacity from 41 to 64 % in comparison to the commercial groundnut thresher. In addition to that, the improved modified thresher significantly reduced the required man-hrs/ha compared to both the modified grain thresher and manual threshing. Also, it resulted in significantly lower fuel consumption in comparison with the modified grain thresher with direct feeding. However, manual threshing resulted in significantly lower cleaning efficiency of collected yield, but no significant difference was evident with the use of the improved modified thresher and the commercial one.

The cyclone method of crop vines bagging resulted in significant reduction of the required number of sacks/ha in comparison with manual bagging method, in addition to the savings of manual filling time.

The use of handcarts for soil particle removal resulted in continuous working of the thresher without changing its position nearby the groundnut heap. The time required to perform the job was about 36 seconds. However, the designed parts of vines collector and soil particles handcarts did not add a burden to the labourer that was responsible for the jobs related to them.

Therefore, the designed parts of conveyor feeding belt, cyclone vines collector and handcarts for soil particles removal could be recommended for the modified grain thresher to improve its groundnut threshing performance.

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# Design, Development and Evaluation of a Rotary Type Chilly Dryer


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## Abstract

A proto-type rotary dryer of 10.5 kg capacity (to hold chillies of 330 % d.b. moisture content) was designed, fabricated and evaluated. The cost of the dryer was US $ 475. The heat utilization factor was 0.62, 0.56 and 0.48 at the beginning and was almost same for nearly 3 hours of drying and finally reduced to 0.09, 0.08 and 0.08 for the capacities of 75, 50 and 25 % of dryer volume, respectively. The total heat efficiency was 0.55, 0.49 and 0.43 at the beginning and was almost same for nearly one hour of drying and finally reduced to 0.07, 0.07 and 0.08 for the capacities of 75, 50 and 25 % of dryer volume, respectively. On the basis of chillies output per hour, percentage of chillies with stalk, percentage of chillies without stalk and without a hole, percentage of chillies without stalk and with a hole, heat utilization factor and total heat efficiency, it was concluded that the chillies dried at a capacity of 75 % dryer volume was the best.


## Introduction

Chillies are the dried ripe fruits of the species of genus Capsicum. They are also called as red peppers of capsicums and they constitute an important commercial crop used as condiment, culinary supplement or as a vegetable. Chillies are cultivated mainly in tropical and subtropical countries namely Africa, India, Japan, Mexico, Turkey and USA. In India, among the spices consumed (per capita consumption), dried chillies contribute a major share (Pruthi, 1998).

Chillies, which contain high moisture content (300-400 % d.b.) after harvest, are highly perishable and, hence, its processing and storage are of considerable importance both to the farmers as well as to the processor and consumer. It is essential to reduce the moisture content and provide aeration to the chillies after harvesting to avoid development of microflora and subsequent loss of quality or total spoilage (Singh and Alam, 1982). Traditionally, fresh chillies are dried under the sun. The sun drying takes 14-21 days depending on weather. As sun drying method is weather dependent, it generally does not yield a good quality product due to breakage and loss of seeds. Some research work was done to reduce the drying time or improve the quality of chillies in mechanical dryers (Dhanegopal et al., 1988; Phirke et al., 1992; Mangaraj et al., 2001). As most of the drying will be done with a bed thickness of 10 cm or even less, it require more area to dry in thin-layer dryers. It was also noticed that non uniform drying results from in deep-bed drying (Kaleemullah, 2002). New paragraph in view of this an attempt was made to develop a rotary dryer for uniform drying of chillies. The major objectives of this study were: 1) to design and fabricate a proto type rotary dryer and 2) to test the performance of the dryer at different loading capacities.

## Materials and Methods

**Design of a Rotary Dryer**

The design of a batch type rotary dryer and the materials used to fabricate it are given below.

***Drying Chamber***

Drying of chillies takes place in cascading and mixing condition in the drying chamber of a rotary dryer. The maximum capacity of the dryer was assumed to be 10.5 kg per batch. A volume of 25 % of drying chamber was left free so as to have a free fall of chillies during rotation. Bulk density ($\rho_b$) of chillies at a moisture content of 329.44 % d.b. was 370.56 kg/m$^3$ (Kaleemullah, 2002). By assuming the radius (r) of the drying chamber as 20 cm, the length (L) of the cylindrical drying chamber for 10.5 kg capacity (m) was determined by using the following formula.

$$L = \frac{4 \times 10^6\, m}{3\rho_b \pi r^2} \quad \text{.............................(1)}$$

where

L = length of the dying chamber, cm

m = weight of chillies fed, kg

$\rho_b$ = bulk density of chillies, kg/m$^3$

r = radius of the drying chamber, cm

$$\therefore L = \frac{4 \times 10^6 \times 10.5}{3 \times 370.56 \times \pi \times (20)^2}$$

= 30 cm

The length of the drying chamber was fixed as 30 cm.

***Flights***

Uniform drying of chillies can be achieved by mixing them frequently in a rotary dryer. If mixing is vigorous, damage to fruits is more. To have optimum mixing, it was decided to lift chillies equivalent to 3 % of the volume of the drying chamber. The depth (D) and width (W) of flights were calculated as follows.

3 % volume of during chamber =

$$\pi r^2 L \times \frac{3}{100} \text{ cm}^3 \quad \text{......................(2)}$$

where

r = radius of the drying chamber, cm

L = length of the dying chamber, cm

Volume of each flight = L x W x D cm$^3$ .......................................(3)

where

W = width of the flight, cm

D = depth of the flight, cm

L = length of the flight, cm

Let W = 0.75 D

But Equation 2 = Equation 3

$$\therefore \pi r^2 L \times \frac{3}{100} = L \times W \times D = L \times 0.75D \times D$$

$\therefore$ D = 0.3545r cm = 0.3545 x 20 = 7.09 cm $\cong$ 7 cm

$\therefore$ W = 0.75D = 0.75 x 7 = 5.25 cm $\cong$ 5.5 cm

Based on the preliminary studies conducted with the rotary dryer, it was observed that 3 flights having a lip angle of 75º, thrown the chillies uniformly over the chillies bed. Hence, 3 flights with a lip angle of 75º and having dimensions of 30 x 7 x 5.5 cm were used in the rotary dryer.

***Heating Chamber***

The main function of the heating chamber was to accommodate the heating coils to heat the air coming from the blower. The size of the heating chamber was designed based on the size and capacity of the heating coil. The capacity of the heating coil was calculated based on the heat required to dry chillies. The heating chamber was insulated well to prevent the heat loss through its outer surface. The heat required for drying chillies was calculated as follows.

This was the sum of the sensible heat required to raise the temperature of chillies along with the moisture plus the heat of evaporation of moisture from chillies. These heat requirements were calculated by using the following formulae.

$$q_c = mc_p(t_{c2} - t_{c1}) \quad \text{..........................(4)}$$

where

$q_c$ = sensible heat of chillies along with its moisture, kJ

m = weight of fresh chillies along with its moisture, kg

$c_p$ = specific heat of chillies at $M_1$ moisture content, kJ/kg.ºC

$t_{c1}$ = initial temperature of chillies, ºC

$t_{c2}$ = final temperature of chillies, ºC

The equation to determine the latent heat of vapourization of moisture in chillies (Kaleemullah, 2002) was used to calculate the heat required for evaporation of moisture from $M_1$ to $M_2$ % d.b.

$$L_{c(M1 \text{ to } M2)} = \frac{-W_b}{100}\left[1.00934M - 7.40013e^{(-0.05948M)}\right]_{M1}^{M2} \times [2502.535 - 2.386t_{c2}] \quad \text{.................................(5)}$$

where

$L_{c(M1 \text{ to } M2)}$ = latent heat of vapourization of moisture in chillies within a moisture of $M_1$ and $M_2$, kJ

$W_b$ = weight of bone dry material of chillies, kg

$M_1$ = moisture content of fresh chillies, % d.b.

$M_2$ = moisture content of dried chillies, % d.b.

$$\therefore Q_r = 0.239[q_c + L_{c(M1 \text{ to } M2)}]$$

($\because$ 1 kJ = 0.239 kcal) ................. (6)

where

$Q_r$ = total heat required to remove the moisture in 'θ' hours of drying, kcal

The total heat required to remove the moisture in 'θ' hours of drying and the number of heating coils ($N_H$) required was calculated for the following conditions.

Ambient air temperature, ta1 = 25 ºC

R.H. of ambient air = 80 %

Initial moisture content of chillies, $M_1$ = 330 % d.b.

Final moisture content of chillies, $M_2$ = 11 % d.b.

Initial temperature of chillies, $t_{c1}$ = 25 ºC

Final temperature of chillies, $t_{c2}$ = 65 ºC

Heated air temperature, $t_{a3}$ = 70 ºC

Exhaust air temperature, $t_{a2}$ = 55 ºC

Weight of fresh chillies, m = 10.5 kg

Specific heat of chillies at 329.44 % d.b., $C_p$ = 4.172 kJ/kg.K (Kaleemullah, 2002)

Drying time, θ = 20 h

Heater efficiency, $\eta_H$ = 20 %

$$Q_r = 0.239[q_c + L_{c(M1 \text{ to } M2)}] = 0.239\left[mC_p(t_{c2} - t_{c1}) - \frac{W_b}{100}\left[1.00934M - 7.40013e^{-0.05948M}\right]_{M1}^{M2} - 2502.54 - 2.39t_{c2})\right] = 0.239 \times \left[[10.5 \times 4.172 \times (65 - 25)] - \left(\frac{2.441}{100}\right) \times \left[1.00934M - 7.40013e^{-0.05948M}\right]_{330}^{11} \times (2502.54 - 2.39 \times 65)\right] = 4{,}839.77 \text{ kcal} \quad \text{......(7)}$$

The number of heating coils ($N_H$) of capacity 1 kW required was calculated by using the following equation.

$$N_H = \frac{Q_r}{859.85\theta\eta_H}$$

$$= \frac{4839.77 \times 100}{859.85 \times 20 \times 20} = 1.42 \cong 2$$

Two heating coils having a capacity of 1 kW each are required for the above said dryer. A temperature controller cum indicator was connected to heating elements to provide and maintain the constant hot air temperature with an accuracy of ±1 ºC.

***Blower Capacity***

The airflow rate required for drying chillies was calculated based on the following formulae (Chakraverty, 1988).

$$Q_s = 60\bar{G}(0.24 + 0.45H)(t_{a3} - t_{a2})\theta \quad \text{............................(8)}$$

where

$Q_s$ = total heat supplied by air in 'θ' hours of drying, kcal

$\bar{G}$ = gravimetric air flow rate, kg/min

H = absolute humidity of ambient air at ambient air temperature ($t_{a1}$) and ambient R.H., kg/kg

$t_{a3}$ = heated air temperature, ºC

$t_{a2}$ = exhaust air temperature, ºC

But $Q_s \geq Q_r$

$$60\bar{G}(0.24 + 0.45H)(t_{a3} - t_{a2})\theta = Q_r \quad ............................(9)$$

$$\therefore G = \frac{Q_r}{60(0.24 + 0.45H)(t_{a3} - t_{a2})\theta} = \frac{4.839.77}{60 \times (0.24 + 0.45 \times 0.016) \times (70 - 55) \times 20}$$

$$= 1.088 \text{ kg/min} \quad ......................(10)$$

The rate of air supply can be expressed in volumetric flow rate as

$$G = \bar{G}v \quad ........................................(11)$$

where

G = volumetric flow rate of air, $m^3$/min

$\bar{G}$ = gravimetric air flow rate, kg/min

v = humid volume of dry air, $m^3$/kg

But $v = (0.00283 + 0.00456\ H)(t_{a1} + 273)$ ......................................(12)

where

H = absolute humidity of ambient air, kg/kg

$t_{a1}$ = ambient air temperature, ºC

$\therefore G = (0.00283 + 0.00456H)(t_{a1} + 273)$ ......................................(13)

$= 1.088\ (0.00283 + 0.00456 \times 0.016)(25+273) = 0.941\ m^3/min$

The quantity of air required from the blower is 0.941 $m^3$/min. Hence, a standard blower of 1.25 $m^3$/min capacity was fixed to the rotary dryer.

***Blower hp***

The blower horsepower can be obtained by calculating the air requirement per unit area per unit time. The air requirement was calculated by using the following formula.

$$V = \frac{G}{60A_sP_p} \quad ................................(14)$$

where

V = volume of air passed per unit time and per unit surface area of plenum chamber, $m^3/s.m^2$

G = volumetric flow rate of air, $m^3$/min

$A_s$ = surface area of plenum chamber (perpendicular to air flow) through which air passes, $m^2$

$P_p$ = perforations on the surface area of plenum chamber, %

Let $P_p$ = 60 %

But $A_s = \pi r^2 = \pi(20)^2\ cm^2 = 0.1257\ m^2$

$$\therefore V = \frac{0.941}{60 \times 0.1257 \times (60/100)} = 0.2\ m^3/s/m^2$$

Shedd's curve (Shedd, 1953) was used to determine the static pressure drop ($P_s$) per unit length for the value of 'V'.

From Shedd's curve,

Static pressure Drop for 0.2 $m^3/s/m^2$ for soybean* = 300 Pa/m length = 300 x 0.0010209 m of water/m length = 0.03063 m of water/m length

(*As there was no study report for chillies in Shedd's curve and as the porosity of soybean is on par with the chillies, the static pressure drop of soybean was considered for calculation purpose)

**Fig. 1** Loads acting on the shaft of a rotary dryer

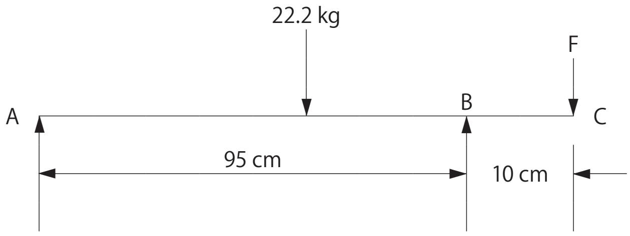
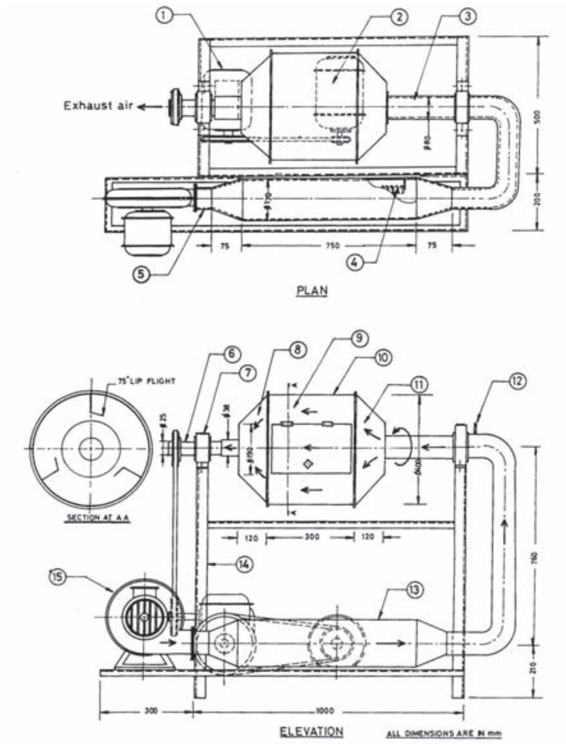
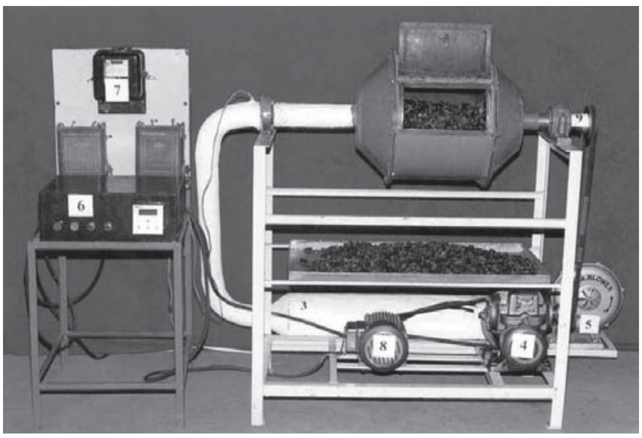



**Fig. 2** Schematic diagram of a rotary dryer




1. Reduction gear box, 2. Motor, 3. Hollow shaft, 4. Heating coil, 5. Insulator, 6. Exhaust pipe, 7. Bearing, 8. Exhaust chamber, 9. Drying chamber, 10. Rotary drum, 11. Plenum chamber, 12. Thermocouple, 13. Heating chamber, 14. Main frame, 15. Blower

**Fig. 3** Rotary dryer developed to dry chillies



The pressure drop in the drying chamber can be calculated by using the following formula (Chakraverty, 1988).

$$P_d = P_s L \frac{\rho_w}{\rho_a} \left(\frac{100}{100 - P_L}\right) \text{...............(15)}$$

where

$P_d$ = pressure drop in the dryer, m of air

$P_s$ = static pressure drop, m of water/m length

L = length of drying chamber, m

$\rho_w$ = density of water, kg/m$^3$

$\rho_a$ = density of air, kg/m$^3$

$p_L$ = pressure loss in heater and conveying pipes etc., %

$$\therefore P_d = 0.03063 \text{ x } 0.3 \text{ x } \frac{995.8}{1.177} \text{ x } \left(\frac{100}{100 - 50}\right) = 15.55 \text{ m of air}$$

The horsepower of a blower can be calculated by using the equation

$$hp = \frac{P_d \bar{G}}{4500} \text{ ..................................(16)}$$

where

hp = blower horse power

$P_d$ = pressure drop in the dryer, m of air

$\bar{G}$ = gravimetric air flow rate, kg/min

$$\therefore hp = \frac{15.55 \text{ x } 1.088}{4500} = 0.00376$$

Efficiency of the motor = 70 % (Assumed)

$$\therefore \text{hp of motor} = 0.00376 \text{ x } \frac{100}{70} = 0.00537$$

Hence, a blower motor of 0.25 hp (smallest hp motor available in the market) was used to pump the air into the dryer.

***Motor***

The following formula was used to calculate the horsepower of the motor, which is necessary to rotate the drum.

$$hp = \frac{2\pi NT}{4500\eta_m} \text{ ............................(17)}$$

where

hp = motor horse power

N = RPM of the drum

T = torque, kg-m

$\eta_m$ = motor efficiency, %

The total load of the drum including 10.5 kg of chillies and pipes that were resting on two ball bearings (A and B) was 22.2 kg. The load will be transferred to the pulley of the pipe while rotating the drum (**Fig. 1**). Hence, the load that was transferred to the pulley (C) of the pipe was calculated as given below.

Taking forces on 'B',

F x 10 = 22.2 x 47.5

$\therefore$ F = 105.45 kg

Let the maximum diameter of the pulley = 10" = 0.254 m

$\therefore$ Torque, T = F x Radius of pulley = 105.45 x 0.127 = 13.39 kg-m

Let N = 25 and $\eta_m$ = 70 %

$$\therefore hp = \frac{2\pi \text{ x } 25 \text{ x } 13.39}{4500 \text{ x } (70/100)} = 0.668$$

Hence, a one horsepower motor (standard size) that was available in the market was coupled to the reduction gearbox unit so as to rotate the drum at the desired RPM.

***Reduction Gearbox***

A reduction gearbox having a speed reduction ratio of 60:1 was used in conjunction with a motor and a set of pulleys to rotate the drying chamber (drum) at the required RPM.

***Main Frame***

A main frame was fabricated and used to support different components of the dryer such as the drying chamber, heating chamber, blower, reduction gearbox and motor. The frame was fabricated using 35 x 35 x 6 mm size mild steel L-angles.

**Experiment**

The experiments related to performance of a rotary dryer (**Fig. 2**) designed and developed at Tamil Nadu Agricultural University, Coimbatore (Kaleemullah, 2002) were conducted as follows.

Before conducting an experiment, the experimental set up was allowed to run for one hour till the desired drying condition attained steady state. All the experiments were conducted at a rotary dryer speed of 5 RPM so that all the chillies could be mixed and exposed uniformly to the drying air. Chillies were dried from 330 % d.b. initial moisture content, down to 11 % d.b. to be commensurate with the harvesting practices in India and

**Fig. 4** Heat utilization of chillies dried at 55 ºC and at various capacities in a rotary dryer

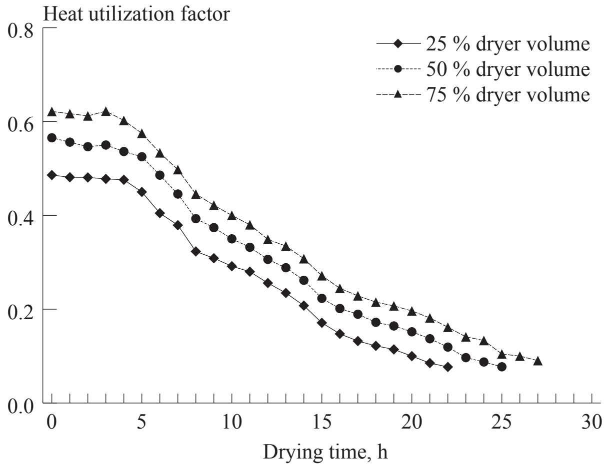
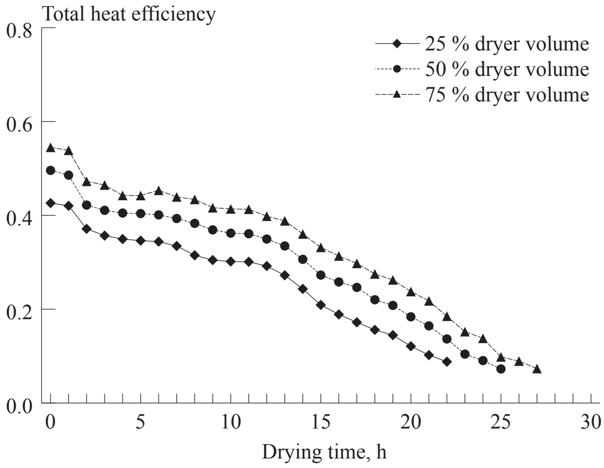



**Fig. 5** Total heat efficiency of chillies dried at 55 ºC and at various capacities in a rotary dryer



safe storage. The ambient air, inlet and exhaust hot air temperatures and relative humidities were recorded each hour by using a digital relative humidity cum temperature meter. After finishing the experiment, 15 g of the dried sample was dried once again in the experimental environmental condition until it gave a constant weight. This sample was used to determine the equilibrium moisture content of the sample in the experimental environmental condition.

A preliminary study was carried out to test the performance of the rotary dryer at different loading capacities. The loading capacity was optimised based on chillies output per hour, percentage of chillies with stalk, percentage of chillies without stalk and without a hole, percentage of chillies without stalk and with a hole, heat utilization factor and total heat efficiency. A score of 3 to 1 was given based on the best to the worst performance. As the hot air temperature of 55 ºC gave the overall best result in drying chillies in a thin-layer dryer, the same temperature, i.e. 55 ºC, was selected to conduct the drying experiment (Kaleemullah, 2002). Rotary drying experiments were conducted at three different loads, i.e. 25, 50 and 75 % dryer volume. Each experiment was replicated three times and the average values were used for analysis.

The chillies weights used for experiments at 25, 50 and 75 % of dryer volume were 3.5, 7 and 10.5 kg, respectively at a moisture content of 330 % d.b.. The initial moisture content of fresh red chillies was determined as per AOAC (1995) method. The required quantity of the sample was loaded and spread in the drying chamber so that 25, 50 and 75 % of the dryer volume was occupied. Drying was carried out at an air velocity of 0.15 m/s. The chillies were unloaded and weighed each hour on a balance having an accuracy of 0.1 g. Unloading, weighing and loading of the sample took about 3 minutes.

The heat utilization factor may be defined as the ratio of temperature decrease due to cooling of the air during drying and the temperature increase due to heating of air. The total heat efficiency considers the sensible heat in drying air as being the effective heat for drying and the total heat efficiency (Chakraverty, 1988). The heat utilization factor and the total heat efficiency were calculated by using the following formulae.

Heat utilization factor =

$$\frac{t_d - t_e}{t_d - t_a} \quad \text{.........................................(18)}$$

Total heat efficiency =

$$\frac{t_d - t_e}{t_d - t_{aw}} \quad \text{.........................................(19)}$$

where

$t_a$ = dry bulb temperature of the ambient air, ºC

$t_d$ = dry bulb temperature of the heated air, ºC

$t_e$ = dry bulb temperature of the exhaust air, ºC

$t_{aw}$ = wet bulb temperature of the heated air, ºC

**Table 1** Performance of rotary type chilly dryer dried at 55 ºC temperature and operated at different capacities of the dryer

| Contents | Dryer capacity | | |
|---|---|---|---|
| | 25 % dryer volume | 50 % dryer volume | 75 % dryer volume |
| Initial wt. of chillies, kg | 3.5 | 7.0 | 10.5 |
| Initial m.c., % d.b. | 331.24 | 328.45 | 330.02 |
| Final wt. of chillies, kg | 0.903 | 1.803 | 2.673 |
| Final m.c.,% d.b | 10.48 | 10.31 | 10.22 |
| Drying time, h | 22 | 25 | 27 |
| Chillies output, kg/h | 0.041 1* | 0.072 2 | 0.099 3 |
| Chillies with stalk, % | 47.50 1 | 50.00 2 | 52.00 3 |
| Chillies without stalk and without a hole, % | 50.00 3 | 48.00 2 | 46.50 1 |
| Chillies without stalk and with a hole, % | 2.50 1 | 2.00 2 | 1.50 3 |
| Heat utilization factor | Low 1 | Medium 2 | High 3 |
| Total heat efficiency | Low 1 | Medium 2 | High 3 |
| Total score | 8 | 12 | 16 |
| Rank | 3 | 2 | 1 |

* Score based on performance

## Results and Discussion

**Development of a Rotary Dryer**

The details of the main components of a rotary dryer (**Fig. 3**) designed and fabricated are given below.

The dimensions of the cylindrical drying chamber were calculated as 40 cm diameter and 30 cm length to hold 10.5 kg of fresh chillies (at 75 % of dryer's volume) at a moisture content of 330 % d.b. It was made with a 20-gauge galvanized iron sheet and was provided with a 28 x 18 cm door so as to load fresh chillies and unload dried chillies. The two ends of the cylinder were covered with a perforated sheet having 6 mm diameter holes. A plenum chamber and an exhaust chamber were provided on either sides of the drying chamber. A copper-constantan thermocouple connected to a thermostat was provided in the plenum chamber to sense the temperature of drying air with an accuracy of ±1 ºC and act accordingly to supply/cut off the power to the heating coil. Three flights of size 7 cm depth and 5.5 cm width throughout the length of the drying chamber (30 cm) were fixed inside the drying chamber. The lip angle of the flight was fixed as 75º so that the chillies can fall uniformly over the chillies bed.

Two heating coils, each having 1 kW capacity, was fixed in the heating chamber. The heating chamber was a cylindrical container made of 20-gauge thick galvanized iron sheet. The length of heating chamber was 90 cm with 15 cm diameter so as to accommodate two heating coils and facilitate air movement. Heating coils of finned type were used to increase the heat transfer from the coils to the air. A blower with a capacity of 1.25 $m^3$/min powered by 0.25 hp electric motor was provided, to supply sufficient quantity of air to dry chillies. A 3-phase, one horsepower electric motor was fixed to reduction gear box so as to rotate the drying chamber drum.

The main frame was fabricated with an angle iron (35 x 35 x 6 mm size) to support the heating chamber and drying chamber. A blower coupled with motor and the electric heating chamber were kept on a separate angle iron frame so that the outlet of blower and inlet of heating chamber were at the same level to facilitate air movement from blower to the heating chamber. The drying chamber and its outlet were fixed on a main frame with the help of ball bearings so that the drying chamber could rotate freely. The length, width and height of the main frame were 100, 50 and 90 cm, respectively.

**Performance of a Rotary Dryer**

The heat utilization factor of chillies was more at all the times in the case of chillies dried at a capacity of 75 % of dryer volume when compared to the chillies dried at lower capacities (**Fig. 4**). This permitted more chillies to be contacted at higher capacities, which in turn utilized the more drying air temperature. The heat utilization factor was 0.62, 0.56 and 0.48 at the beginning and was almost same for nearly 3 hours of drying and finally reduced to 0.09, 0.08 and 0.08 for the capacities of 75, 50 and 25 % of dryer volume, respectively. The amount of heat supplied to the drying air was constant for the whole drying experiment, but the amount of heat utilized decreased as exhaust air temperature was increased with the progress of drying time. Initially, some heat was used for heating the chillies and a considerable amount of heat was lost with the exhaust air. This may be the reason for falling of heat utilization factor of chillies with the progress of drying time. Similar results are reported by Chakraverty and More (1983) in the case of drying of raw and parboiled paddy in a baffle type grain dryer.

The total heat efficiency of chillies was more at all the times in the case of chillies dried at a capacity of 75 % of dryer volume when compared to the chillies dried at lower capacities (**Fig. 5**). The reason is that at higher capacities, more quantity of chillies contacted the drying air, which in turn required more heat present in the drying air. The total heat efficiency was 0.55, 0.49 and 0.43 at the beginning and was almost same for nearly one hour of drying and finally reduced to 0.07, 0.07 and 0.08 for the capacities of 75, 50 and 25 % of dryer volume, respectively. By definition, the total heat efficiency is always smaller than the heat utilization factor at any point of time and the same type of results was obtained in rotary drying of chillies also. Chakraverty and More (1983) obtained similar type of results in the case of drying of raw and parboiled paddy in a baffle type grain dryer.

The dried chillies output was 0.041, 0.072 and 0.099 kg/h (**Table 1**) for an input capacity of 25, 50 and 75 % dryer volume, respectively, which showed that the drying of chillies at a capacity of 75 % dryer volume was the best. The percentage of damaged chillies (chillies without stalk and with a hole) was less in the case of chillies dried at a capacity of 75 % dryer volume. The reason may be due to less height of fall of chillies at a capacity of 75 % dryer volume compared to the one at 25 and 50 % dryer volume. On the basis of chillies output per hour, percentage of chillies with stalk, percentage of chillies without stalk and without a hole, percentage of chillies without stalk and with a hole, heat utilization factor and total heat efficiency, it may be concluded that the chillies dried at a capacity of 75 % dryer volume is the best (**Table 1**).

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# Influence of Forward Speed and Terrain Condition on Hand Transmitted Vibration of Power Tiller

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## Abstract

The operator of a power tiller must endure various environments and stress. Vibration significantly accelerates fatigue and affects sensitivity and reaction rates of the operator. The hand transmitted vibration (HTV) of walking type (7.46 kW) and riding type (8.95 kW) power tiller was measured and analyzed with respect to exposure time as per the guidelines of International standards ISO 5349 (1986). The operations included rototilling in untilled and tilled field conditions at 1.5, 1.8, 2.1 and 2.4 km $h^{-1}$ forward speeds and transporting at 3.5, 4.0, 4.5 and 5.0 km $h^{-1}$ forward speeds on farm roads and bitumen roads. The HTV during rototilling with the 7.46 kW power tiller in an untilled field varied from 3.43 to 5.26 m $s^{-2}$ restricting the exposure time from 1/2-1 h to < 1/2 h. In the tilled field, the values were 2.66 to 4.55 m $s^{-2}$ and 1 to 2 h to < 1/2 h, respectively. The terrain condition of the untilled field resulted in 15.60 to 28.94 percent increased HTV. For the 8.95 kW power tiller, HTV varied from 3.31 to 5.09 m $s^{-2}$ with an exposure time of 1 to 2 h to < 1/2 h. In the tilled field the values were 2.66 to 4.55 m $s^{-2}$ and 1 to 2 h to < 1/2 h. The terrain condition of the untilled field was more pronounced with 16.47 to 30.31 percent increase in HTV. Among the power tillers, walking type power tiller registered 3.62 to 4.11 percent higher values of vibration. The HTV and exposure time during transport with the 7.46 kW power tiller on farm roads varied from 2.21 to 3.61 m $s^{-2}$ and 2 to 4 h to 1/2 to1 h. In the bitumen road the values were 1.67 to 2.77 m $s^{-2}$ and 2 to 4 h to 1 to 2 h. During transport with the 8.95 kW power tiller on farm roads the HTV and exposure time varied from 2.72 to 3.66 m $s^{-2}$ and 1 to 2 h to 1/2 to1 h with the increase in forward speed. In bitumen roads the values were 2.02 to 2.95 m $s^{-2}$ and 2 to 4 h to 1 to 2 h. The terrain induced vibration of the 8.95 kW power tiller was 1.38 to 23.07 percent more on farm roads and 20.96 to 6.49 percent more on bitumen roads as compared to the 7.46 kW power tiller.

## Introduction

The operator of a power tiller must endure various environments and stresses. The environment includes all the factors in the surroundings which have an effect on man-machine system. Among these factors, mechanical vibration is more important because it significantly accelerates fatigue and affects sensitivity and reaction rates of the operator. Excessive noise level, vibrations and uncomfortable posture are the important shortcomings in power tiller design (Pawar, 1978). Hand transmitted vibration of a walking tractor is very strong because the handle grip of a walking tractor is a cantilever beam and the power is obtained from a single cylinder diesel engine. Daily exposure to hand arm vibrations over a number of years can cause permanent physical damage known as "white finger syndrome", or it can damage the joints and muscles of the wrist and elbow. The hand transmitted vibration has seriously affected the health of drivers and resulted in many traffic accidents necessitating the study on the vibratory characteristics and anti-vibration solutions of the walking tractor (Lewis and Griffin, 1978). This is of great theoretical significance and high practical value. In this paper the influence of forward speed and terrain condition on HTV of riding and walking type power tillers are presented.

## Review of Literature

Araya (1986) reported that handle vibration in hand-operated tilling machines and tractors was mainly due to the reciprocating motion of the main moving parts. Jiao Qunying et al. (1989) concluded that the major excitations of the hand transmitted vibration of a walking tractor are the unbalanced inertia force of the engine and the unevenness of road surface. He also reported that the hand transmitted vibration caused by the unevenness of road makes up about 20 percent of the total hand transmitted vibration of the walking tractor (Jiao Qunying et al., 1993). Dong (1996) studied the main causes and characteristics of the vibration transmitted by handles of GN-5 walking tractor theoretically and experimentally. The vibrations of handles were evaluated in reference to ISO 5349. It was concluded that the main cause of vibration was the engine, and the vibration on the handles of the GN-5 walking tractor was very strong and seriously affects operator health. Mamansari (1998) reported that the vibration level increased with an increase of engine speed in the stationary and transport mode. Vertical vibration was significantly higher at the tip of handle of a power tiller, which had direct contact with the operator hand arm system. Ying et al. (1998) reported that the major excitation of the hand transmitted vibration of the walking tractor was the engine. The hand transmitted vibration was mainly composed of the harmonic waves of integer times and 1/2 times of the engine working frequencies. Major peaks in acceleration spectra varied from 2.683 m $s^{-2}$ to 20 m $s^{-2}$ while testing the walking tractor in stationary with engine rotating speed of 3000 rpm. The most serious vibration among the three directions was in the x-direction.

## Materials and Methods

The hand transmitted vibration of the power tiller was measured and analyzed using the portable PULSE multi-analyzer system (Brüel & Kjær Type 3560 C). The PULSE multi-analyzer system is a versatile, task oriented analysis system for vibration and noise analysis. It provides the platform for a range of PC-based measurement solutions. Type 3650 C is a portable system powered by internal batteries or an external DC supply. The base software for a PULSE system is vibration and noise analysis type 7700. On this base, pulse software such as data recorder type 7701 was installed. The entire system consisted of portable data acquisition unit- front end type 2827, vibration and noise analysis software type 7700, data recorder type 7701 and hand arm transducer type 4392. The power tiller was put in proper test condition before conducting the experiments, that is, in full working order with full fuel tank and radiator, without optional front weights, tire ballast and any specialized components. Tires used for the tests were of standard size and depth of treads was not less than 70 percent of the depth of a new thread. Pneumatic wheels with recommended tire pressure of 1.5 kg $cm^{-2}$ and 2.5 kg $cm^{-2}$ were used during rototilling and transporting operations respectively. There were no known mechanical defects that would result in abnormal vibration in both power tillers.

The vibration from the handle of the power tiller was transmitted to the hand and arm of the operator through the palm of his hand. The hand transmitted vibration was measured at handle-grip level as per the guide lines issued in ISO 5349 (1986). The transducer employed was a piezoelectric accelerometer (B&K, Type 4392) mounted on a hand adapter to insert between the fingers and the grip (Ying et al.,

**Fig. 1** Hand arm transducer inserted between the fingers and handle grip

**Fig. 2** Instrumentation set up for measuring HTV of power tiller A

**Fig. 3** Instrumentation set up for measuring HTV of power tiller B

1998 and Ragni, et al., 1999) and fixed on the grip by tape (**Fig. 1**). The transducer was inserted between the middle and index fingers of left hand of each subject since the force output from index and middle finger is larger than that from ring and little finger (Fransson and Winkel, 1991). The right hand was used for operating the controls.

The orientation of the measurement axes of the accelerometers was according to ISO 5349. The Z- axis was directed along the second metacarpus bone of the hand, X- axis perpendicular to the Z-axis (both these axes are normal to the longitudinal axis of the grip) and Y-axis parallel to the longitudinal axis of the grip.

Hand transmitted vibration was measured as frequency weighted r.m.s value of acceleration for the one-third octave band, having centre frequencies from 1 to 80 Hz (ISO 5349). All the transducers were calibrated before the trials. The instrument set up for measuring hand transmitted vibration of power tiller A is shown in **Fig. 2**. The instrument set up for measuring hand transmitted and whole body vibration of power tiller B is shown in **Fig. 3**.

The experiments were conducted during rototilling with rotavator in untilled and tilled field conditions and during transport mode of a walking type power tiller (7.46 kW) and riding type power tiller (8.95 kW) with empty trailer on farm roads and bitumen roads. The depth of operation was maintained at a constant level of about 15 cm during rototilling. The subjects were instructed to hold the handle grip with a light and constant compression force. Measurements were made at different forward speeds, viz. 1.5 km $h^{-1}$, 1.8 km $h^{-1}$, 2.1 km $h^{-1}$ and 2.4 km $h^{-1}$ during field trials and 3.5 km $h^{-1}$, 4.0 km $h^{-1}$, 4.5 km $h^{-1}$ and 5.0 km $h^{-1}$ during transport mode. The PULSE programme was activated after the power tiller was started for the operation and the measurement was recorded with an acquisition period of 60 seconds (Ying et al., 1998). Each trial was repeated five times for all operating conditions. The same procedure was repeated for all the selected subjects.

## Assessment of Human Exposure to Hand Transmitted Vibration

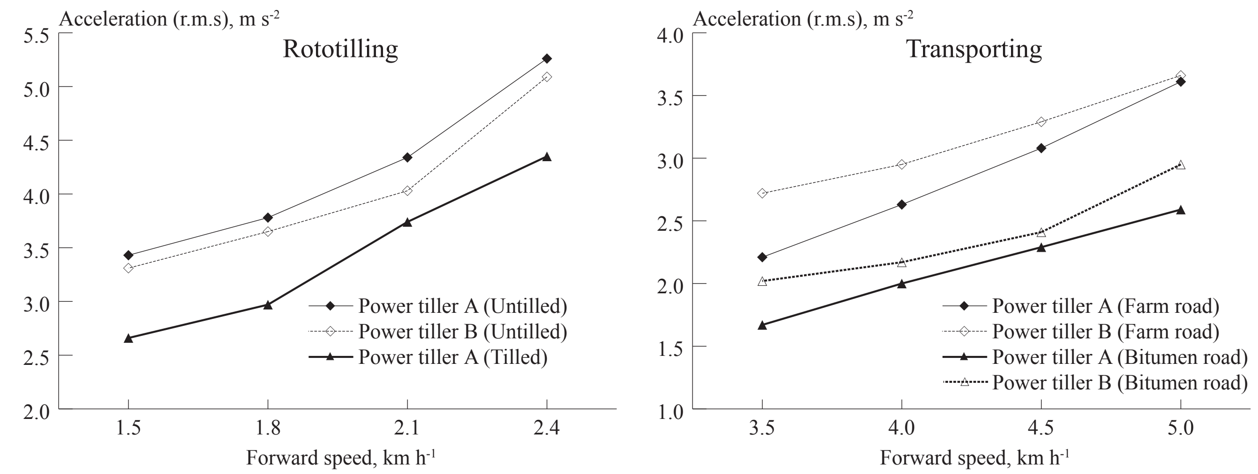
The values of HTV of 5 runs were averaged at corresponding frequency for one subject. The procedure was repeated for all the subjects and the mean value for three subjects for each selected levels of forward speed was computed. The exposure time limit was then predicted by superimposing the mean measured values of three subjects at each frequency on the exposure guide line. The same procedure was followed for all operating conditions. The ISO standard 5349 for hand arm vibrations does not define the limits for safe exposure. It only provides guidelines for the measurement and assessment of hand-transmitted vibration. Annexure A of the ISO 5349 provides information that allows one to predict the probability of white-finger syndrome as a function of the frequency weighted energy equivalent r.m.s acceleration value for a daily period of 4 h and exposure time in years for selected percentiles of an exposed population (Ragni, 1993).

## Results and Discussion

The predicted exposure limit of the subjects for the measured values of HTV under selected levels of variables is furnished in **Table 1**.

The safe exposure time limit for hand transmitted vibration of the two power tillers was of serious concern restricting the safe exposure to < 1/2 - 1-2 h in rototilling and 1-2 to 2-4 h in transporting respectively. On an average, the power tillers were used for more than 5 h in the study region. If the subjects were exposed to 5 h at this level of HTV,

**Fig. 4** Hand transmitted vibration of power tillers



the prevalence of vibration induced white finger (VWF) and numbness of the hands will start very earlier. Hence, in order to increase the exposure time, the HTV of test power tillers need to be reduced. The vibration at the handle can be reduced by providing vibration isolators.

The hand transmitted vibration of the two test power tillers at selected levels of forward speed during rototilling and transporting operation is shown in **Fig. 4**.

**a. Rototilling**

It is quite evident from the figure that power tiller A showed higher hand transmitted vibration values in both untilled and tilled field when compared to power tiller B (**Fig. 4**). The increase in hand transmitted vibration for power tiller A was 3.62 to 3.34 percent in the untilled field and 4.72 to 4.11 percent in the tilled field with the increase in forward speed from 1.5 to 2.4 km $h^{-1}$ when compared to power tiller B (Ragni et al., 1999). This might be due to the following reasons. Power tiller A was a walking type tractor and it was completely controlled by holding the handle in which the grip force applied might be more unlike that in power tiller B where the subject can sit comfortably and ride with relatively lesser grip force. An increase in grip force increased the vibration level transmitted to the hand as reported by Griffin et al. (1982) and Farkkila et al. (1979). Another reason for lower values of hand transmitted vibration in power tiller B might be due to the higher weight of power tiller B (517 kg) than that of power tiller A (442 kg). In addition to this, power tiller B being a riding type, the weight of the subject (64 kg) was also added to the total weight (581 kg), also the rear wheel provided beneath the operator's seat might have resulted in further damping of vibration. This was in close agreement with results of machine vibration at the root of the handle bar and handle where it was lower for power tiller B compared to the same parts of power tiller A in the field. In addition the energy expended by the subjects, the overall discomfort and the body part discomfort experienced by the subjects were lower during the operation of power tiller B when compared to power tiller A and, thus, permitting a healthier working environment for power tiller B during rototilling.

**b. Transporting**

Comparison between power tillers A and B during transport on farm roads and bitumen roads showed that (**Fig. 4**), hand transmitted vibration of power tiller B was higher, unlike that in field operation where HTV of power tiller B showed lower values than power tiller A. The increased value of hand transmitted vibration of power tiller B was 23.07 to 1.38 percent on farm road and 20.96 to 6.49 percent on bitumen road with the increase in forward speed from 3.5 to 5.0 km $h^{-1}$ as compared to power tiller A.

## Conclusions

- The hand transmitted vibration, exposure time and the probability of white finger syndrome during rototilling of walking type power tiller (7.46 kW) in an untilled field varied from 3.43 to 5.26 m $s^{-2}$, 1/2 - 1 h to < 1/2 h and 6.19 to 4.04 years with the increase in forward speed from 1.5 to 2.4 km $h^{-1}$. In a tilled field the values were 2.66 to 4.55 m $s^{-2}$, 1 to 2 h to < 1/2 h and 7.98 to 4.67 years, respectively.
- The terrain condition of the untilled field resulted in 15.60 to 28.94 percent increased vibration transmitted to the hand arm for walking type power tiller.
- The hand transmitted vibration, exposure time and the probability of white finger syndrome during rototilling of riding type power tiller (8.95 kW) in the untilled field varied from 3.31 to 5.09 m $s^{-2}$, 1 to 2 h to < 1/2 h and 6.19 to 4.04 years with the increase in forward speed from 1.5 to 2.4 km $h^{-1}$. In the tilled field, the values were 2.66 to 4.55 m $s^{-2}$, 1 to 2 h to < 1/2 h and 8.23 to 4.86 years, respectively.
- The terrain condition of the untilled field was more pronounced with 16.47 to 30.31 percent increase in hand transmitted vibration for riding type power tiller. Among the power tillers, the walking type power tiller registered 3.62 to 4.11 percent higher values of vibration.
- The hand transmitted vibration, exposure time and the probability of white finger syndrome during transport with 7.46 kW power tiller on farm roads varied from 2.21 to 3.61 m $s^{-2}$, 2 to 4 h to 1/2 to1 h and 9.59 to 5.88 years with the increase in forward speed from 3.5 to 5.0 km h-1. In bitumen roads, the val-

**Table 1** Exposure time limit of subjects under selected operating conditions

| Sl. No. | Forward speed, km $h^{-1}$ | HTV - Exposure time (h) of power tillers | |
|---|---|---|---|
| | | A | B |
| A. Rorotilling in untilled field | | | |
| i | 1.5 | 1/2 - 1 | 1 - 2 |
| ii | 1.8 | 1/2 - 1 | 1/2 - 1 |
| iii | 2.1 | < 1/2 | 1/2 - 1 |
| iv | 2.4 | < 1/2 | < 1/2 |
| B. Rorotilling in tilled field | | | |
| i | 1.5 | 1 - 2 | 1 - 2 |
| ii | 1.8 | 1 - 2 | 1 - 2 |
| iii | 2.1 | 1/2 - 1 | 1/2 - 1 |
| iv | 2.4 | < 1/2 | < 1/2 |
| C. Transporting on farm load | | | |
| i | 3.5 | 2 - 4 | 1 - 2 |
| ii | 4.0 | 1 - 2 | 1 - 2 |
| iii | 4.5 | 1 - 2 | 1 - 2 |
| iv | 5.0 | 1/2 -1 | 1/2 - 1 |
| D. Transporting on bitumen road | | | |
| i | 3.5 | 2 - 4 | 2 - 4 |
| ii | 4.0 | 2 - 4 | 2 - 4 |
| iii | 4.5 | 2 - 4 | 2 - 4 |
| iv | 5.0 | 1 - 2 | 1 - 2 |

ues are 1.67 to 2.77 m $s^{-2}$, 2 to 4 h to 1 to 2 h and 12.73 to 7.66 years, respectively.

- The hand transmitted vibration, exposure time and the probability of white finger syndrome during transport with 8.95 kW power tiller on farm roads varied from 2.72 to 3.66 m $s^{-2}$, 1 to 2 h to 1/2 to1 h and 7.8 to 5.79 years with the increase in forward speed from 3.5 to 5.0 km h-1. In bitumen roads the values are 2.02 to 2.95 $ms^{-2}$, 2 to 4 h to 1 to 2 h and 10.50 to 7.20 years, respectively.
- The terrain induced vibration of 8.95 kW power tiller was 1.38 to 23.07 percent more on farm roads and 20.96 to 6.49 percent more on bitumen roads as compared to 7. 46 kW power tiller.

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# Performance Evaluation of Implements for Incorporation of Cotton Stalks

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## Abstract

The soil fertility changes due to in-situ incorporation of cotton stalks and residual effect of crop residue management was investigated through a field experimental with post harvest stalks as standing crop. The treatments included operation with roto slasher followed by disc plough, operation of roto slasher followed by rotovator, operation of disc plough followed by rotovator and hand pulling of cotton stalks followed by disc ploughing and cultivator once. Tillage treatments were imposed as non-replicated and succeeding cowpea crop (Co.4) was raised in RBD with two replications. Pre- and post-experimental soil sampling was done using core sampler and were analyzed for physical properties such as saturated hydraulic conductivity, bulk density and total porosity at different soil depths, viz. 0-15, 15-30 and 30-45 cm. The chemical properties such as pH, EC, macro and micro nutrients were also analyzed at periodical intervals, viz. 10, 20 and 30 days after incorporation. Subsequently, the residual crop was sown and maintained till maturity. Treatments with a disc plough played a predominant role in lowering the bulk density and increasing the hydraulic conductivity and porosity. The residual effect observed showed that the pod and haulm yields of cowpea were maximum (10.38 and 55.2 q $ha^{-1}$, respectively) under roto slasher followed by disc plough ($T_1$). There was 21.6 percent increase in pod yield compared to farmers' practice. This was followed by disc plough followed by rotovator tilling ($T_3$). Farmers' practice ($T_4$) recorded the lowest pod and haulm yield (8.53 and 45.4 q $ha^{-1}$ respectively) due to non-incorporation of cotton stalks. Roto slashing of post-harvest cotton stubbles followed by incorporation through disc ploughing once was the best as it recorded the favourable soil physical and chemical properties and recorded the maximum pod and haulm yield of the succeeding cowpea crop, suggesting its suitability for crop residue management for sustainable crop production.

## Introduction

The area under cotton cultivation in Tamil Nadu is 250,000 ha with a production of 550,000 bales. In India, Tamil Nadu ranks ninth in position in respect of area as well as production. For the collection of information on the implements/machinery used by the farmers for performing the different operations in cotton cultivation, a survey was conducted with cotton growers. The requirement for the 770 mills in Tamil Nadu is around 5.0 to 5.5 million bales. Agricultural labour input is becoming increasingly costlier. Labour efficiency, turnover of work and duration of working hours are deplorably deteriorating, resulting in poor crop management, increasing cost of cultivation and poor income to the cotton farmers. Hence, farm mechanization is the need of the hour. The arduous operation of removal of cotton stalks from the soil and transporting the same to the yard manually is labour intensive.

## Review of Literature

Rochester et al. (1997) conducted a study on effects of cotton stubble removal on and incorporation on lint yield and N fertilizer recovery of three consecutive cotton crops. Soil mineral N content prior to planting was slightly higher where stubble was removed, but N fertilizer recovery was reduced by 10 %, averaged over the three seasons. Lint yield tended to decline with successive crops with stubble removal compared with stubble retention and in the third crop yield was reduced by 10 %. It was concluded that stubble retention promotes a more biologically active soil system that is conducive to more efficient use of N fertilizer and maintains higher cotton yields. Tiwari et al. (1998) reported that incorporation of ground nut haulm at 7.5 Mg $ha^{-1}$ significantly increased the grain and straw yields of wheat both at 50 and 100 kg levels of N application. There was considerable improvement in physical properties, viz. water holding capacity and bulk density of the soil. Ravendar Reddy et al. (2002) reported that the incorporation of crop residue like wheat straw at 5 t $ha^{-1}$ in combination with fertilizer application and tillage operations resulted in improvement of soil physical properties along with available nutrient status (available nitrogen, phosphorous and potassium).

## Methods and Materials

A field experiment was conducted in TNAU, Coimbatore between December, 2001 and April 2002 with post harvest stalks as standing crop.

The treatments selected were: $T_1$: Operation with roto slasher followed by disc plough, $T_2$: Operation of roto slasher followed by rotovator, $T_3$: Operation of disc plough followed by rotovator, $T_4$: Hand pulling of cotton stalks followed by disc ploughing and once (farmers' practice).

Tillage treatments were imposed as non-replicated and succeeding cowpea crop (Co.4) was raised in RBD with two replications. Pre- and post-experimental soil sampling was done using core sampler and were analyzed for physical properties such as saturated hydraulic conductivity, bulk density and total porosity at different soil depths, viz. 0-15, 15-30 and 30-45 cm. The chemical properties such as pH, EC, macro and micro nutrients were also analyzed at periodical intervals, viz. 10, 20 and 30 days after incorporation. Subsequently, the residual crop was sown and maintained until maturity.

## Results and Discussion

**i. Soil Physical Properties**

Analysis of soil physical properties showed a decrease in bulk density, an increase in hydraulic conductivity and variation in total porosity due to tillage. Bulk density, the most important physical property of the soil due to its control over root proliferation, air, water and nutrient movement decreased invariably in all treatments up to 30 cm depth and was unchanged under the treatment with roto slasher followed by disc plough after 30 cm. Though tillage practices lower bulk density, the reduction was marked under roto slashing followed by disc ploughing (**Table 1**).

The soil strength was positively correlated with bulk density and the uptake of N, P and K decreased when the bulk density of the soil increased from 1.5 Mg $m^{-3}$ for cowpea (Baskar et al., 1995). The saturated hydraulic conductivity increased in all tillage treatments and was more pronounced under roto slasher followed by disc plough -$T_1$ (from 0.76 to 1.83, 0.69 to 1.73 and 0.52 to 1.62 in 0-15, 15-30 and 30-45 cm depths, respectively, as furnished in **Table 2**. Variation in total porosity was observed at different depths. Reduction in bulk density and increase in hydraulic conductivity was observed under crop-residue management through tillage practices in alfisols (Vijayalakshmi and Saravanan, 2000).

Treatments with a disc plough played a predominant role in lowering the bulk density and increasing hydraulic conductivity and porosity.

**Table 2** Influence of tillage on the saturated hydraulic conductivity, mm $ha^{-1}$

| Treatments | 0-15 cm | | 15-30 cm | | 30-45 cm | |
|---|---|---|---|---|---|---|
| | Initial | 30 DAI | Initial | 30 DAI | Initial | 30 DAI |
| Roto slasher + disc plough ($T_1$) | 0.76 | 1.83 | 0.69 | 1.73 | 0.52 | 1.62 |
| Roto slasher + rotovator ($T_2$) | 0.75 | 1.10 | 0.69 | 0.95 | 0.51 | 0.80 |
| Disc plogh + rotovator ($T_3$) | 0.74 | 1.40 | 0.67 | 1.33 | 0.53 | 1.27 |
| Farmers' practice ($T_4$) | 0.82 | 1.48 | 0.72 | 1.26 | 0.46 | 1.05 |

**ii. Soil Fertility Changes Due to Insitu Incorporation of Cotton Stalks**

Changes in soil reaction, EC and available N, P and K and micronutrients Zn, Fe, Cu and Mn status are presented in **Table 3**. Incorporation of cotton stalks recorded a decrease

**Table 1** Influence of tillage on bulk density and total porosity of soil at different depths

| Treatments | Bulk density, mg $m^{-3}$ | | | | | | Total porosity, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-15 cm | | 15-30 cm | | 30-45 cm | | 0-15 cm | | 15-30 cm | | 30-45 cm | |
| | I | F | I | F | I | F | I | F | I | F | I | F |
| Roto slasher + disc plough ($T_1$) | 1.210 | 0.920 | 1.303 | 0.980 | 1.033 | 1.051 | 16.12 | 26.64 | 23.07 | 63.75 | 14.80 | 17.12 |
| Roto slasher + rotovator ($T_2$) | 1.208 | 1.035 | 1.302 | 1.370 | 1.033 | 1.395 | 12.55 | 9.31 | 23.38 | 45.32 | 15.53 | 45.24 |
| Disc plogh + rotovator ($T_3$) | 1.207 | 1.026 | 1.304 | 1.022 | 1.005 | 1.430 | 15.52 | 26.70 | 23.09 | 62.80 | 13.75 | 31.70 |
| Farmers' practice ($T_4$) | 1.314 | 1.110 | 1.378 | 1.240 | 1.173 | 1.372 | 19.65 | 9.85 | 16.01 | 40.40 | 18.06 | 44.50 |

in soil pH and slight increase in EC from its initial levels. An increase in soil pH and EC values were recorded in farmers' practice, which might be due to the complete removal of crop residue.

Progressive increase in macro and micro nutrient levels were observed in all cotton stalk incorporated treatments. Among the cotton stalk incorporated treatments, the increase in macro and micro nutrients were the highest for treatment $T_1$ (Rotoslasher + Disc plough). The percentage increase in macro and micro nutrients levels in this treatment when compared with farmers practice was 23.0, 21.0, 64.7, 15.35, 50.0, 19.5 and 9.4 for N, P, K, Fe, Zn, Mn and Cu, respectively.

***a. Residual Effect of Crop Residue Management***

The pod and haulm yields of cowpea were recorded at maturity and presented in **Table 4**.

Residual effect observed showed that the pod and haulm yields of cowpea were maximum (10.38 and 55.2 q $ha^{-1}$, respectively) under roto slasher followed by disc plough ($T_1$). There was 21.6 percent increase in pod yield compared to farmers' practice. This was followed by disc plough followed by rotovator tilling ($T_3$). Farmers' practice ($T_4$) recorded the lowest pod and haulm yield (8.53 and 45.4 q $ha^{-1}$, respectively) due to non-incorporation of cotton stalks.

## Conclusion

The chemical properties such as pH, EC, macro and micronutrients were also analyzed at periodical intervals viz. 10, 20 and 30 days after incorporation. Subsequently, the residual crop was sown and maintained until maturity. Treatments with a disc plough played a predominant role in lowering the bulk density, increasing the hydraulic conductivity and porosity. The residual effect observed showed that the pod and haulm yields of cowpea were maximum (10.38 and 55.2 q $ha^{-1}$, respectively) under roto slasher followed by disc plough ($T_1$). There was 21.6 percent increase in pod yield compared to farmers' practice. This was followed by disc plough followed by rotovator tilling ($T_3$). Farmers' practice ($T_4$) recorded the lowest pod and haulm yield (8.53 and 45.4 q $ha^{-1}$, respectively) due to non-incorporation of cotton stalks. Rotoslashing of post-harvest cotton stubbles followed by incorporation through disc ploughing once was the best as it recorded decrease in bulk density and increase in hydraulic conductivity, porosity, and micro, macro nutrient levels and recorded the maximum pod and haulm yield of the succeeding cowpea crop, which suggested its suitability for crop residue management for sustainable crop production.

**Table 4** Residual effect of tillage implements on pod and haulm yield (q $ha^{-1}$) of cowpea

| Treatments | Pod yield | Haulm yield |
|---|---|---|
| Roto slasher + disc plough ($T_1$) | 10.38 | 55.20 |
| Roto slasher + rotovator ($T_2$) | 9.14 | 50.50 |
| Disc plogh + rotovator ($T_3$) | 9.96 | 52.20 |
| Farmers' practice ($T_4$) | 8.53 | 45.40 |


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**Table 3** Influence of tillage on bulk density and total porosity of soil at different depths

| Treat. | Roto slasher + disc plough | | | | Roto slasher + rotovator | | | | Disc plough + rotovator | | | | Farmers' practice | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DA1 | Initial | 10 | 20 | 30 | Initial | 10 | 20 | 30 | Initial | 10 | 20 | 30 | Initial | 10 | 20 | 30 |
| $P^H$ | 8.8 | 8.8 | 8.7 | 8.6 | 8.8 | 8.8 | 8.7 | 8.7 | 8.8 | 8.7 | 8.7 | 8.6 | 8.8 | 8.9 | 8.9 | 8.9 |
| EC, $dsm^{-1}$ | 0.32 | 0.36 | 0.42 | 0.45 | 0.36 | 0.36 | 0.36 | 0.37 | 0.32 | 0.36 | 0.4 | 0.49 | 0.32 | 0.36 | 0.49 | 0.49 |
| N, kg/ha | 170 | 165 | 210 | 227.5 | 177.5 | 177.5 | 190.0 | 220.0 | 177.5 | 177.5 | 190.0 | 190.0 | 185.0 | 180.0 | 185.0 | 185.0 |
| P, kg/ha | 11.0 | 11.0 | 13.0 | 14.0 | 11.0 | 11.0 | 12.0 | 12.5 | 10.5 | 10.5 | 12.0 | 12.5 | 10.5 | 10.0 | 11.5 | 11.5 |
| K, kg/ha | 687.5 | 780.0 | 975.0 | 1,050 | 675.0 | 690.0 | 735.0 | 832.0 | 682.5 | 715.0 | 800.0 | 800.0 | 670.0 | 625.0 | 605.0 | 637.5 |
| Fc, ppm | 6.26 | 6.26 | 6.76 | 6.76 | 6.26 | 6.26 | 6.78 | 6.48 | 6.48 | 6.48 | 6.32 | 6.52 | 6.48 | 6.26 | 5.92 | 5.86 |
| Zn, ppm | 1.32 | 1.42 | 1.80 | 1.80 | 1.30 | 1.30 | 1.72 | 1.72 | 1.32 | 1.46 | 1.78 | 1.78 | 1.28 | 1.30 | 1.20 | 1.20 |
| Mn, ppm | 5.86 | 5.86 | 6.12 | 6.36 | 5.82 | 5.82 | 6.10 | 6.10 | 5.76 | 5.82 | 6.26 | 6.24 | 5.52 | 5.40 | 5.32 | 5.32 |
| Cu, ppm | 2.14 | 2.14 | 2.22 | 2.32 | 2.14 | 2.14 | 2.22 | 2.32 | 2.20 | 2.22 | 2.32 | 2.28 | 2.20 | 2.20 | 2.14 | 2.12 |

# ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

**415**

**Design of Tool Carrier for Tillage Studies of Disc in Field Conditions: B. K. Yadav**, Ex Student, Division of Agricultural Engineering, Indian Agricultural Research Institute, Pusa Campus, New Delhi - 110 012, India; **Indra Mani**, Sr. Scientist, same; **J. S. Panwar**, Principle Scientist, same.

A special disc carrier for mounting single disc (**Fig. 1**) was designed and fabricated which served as key component of test set up to study the effect of disc geometry and forward speed on draft and soil throw. Tool carrier was suitable to mount different geometry disc and change operational parameter. An experiment on performance evaluation of discs with varying geometry was done fordetermination of draft requirement and soil handling capability. Disc concavity showed pronounced effect on draft and soil throw. Information may provide the guidelines for manufactures and farmers in selecting optimum disc parameters for working desired soil manipulations. Information may also be useful for different organization working in field of farm mechanization including institutes standardize the disc parameters.

**Fig. 1** Disc carrier tool

**466**

**Grey Analysis of the Effects of Some Agricultural Inputs on Gross Crop Production in Sudan: Ballel Zaid Moayad**, The Key Laboratory of Terrain-Machine Bionics Engineering (Ministry of Education, China) and School of Biological and Agricultural Engineering, Jilin University (Nanling Campus), 5988 Renmin Street, Changchun 130025, P.R. China; **Jin Tong**, same; **Yinsheng Yang**, same.

The effect of some agricultural inputs such as total area under crops, number of population in agricultural sector, number of tractors, number of harvesters and threshers, quantities of fertilizers applied and total energy production on gross crop production concerned within the period 1992-2001 in Sudan were analysed. The emphasis of the inputs on gross crop output was investigated using the grey incidence analysis and the synthetic degree of incidences was presented. It was shown that crop production in Sudan is considerably affected by the number of people working in the agricultural sector, number of tractors and energy. The cultivated area has the least effect on increasing the production. Due to the sensitivity and timeliness characteristics of agricultural operations, labor and power factors must be given in priority when planning to increase crop production. Government should encourage people to enter the agricultural sector by providing better an environment for agricultural investment.

**476**

**Developing a Low Cost and Efficient Alternative for GA3 Application in F1 Hybrid Rice Seed production: Ricardo F. Orge**, Supervising SRS (Science Research Specialist)/Head, Philippine Rice Research Institute, Maligaya, Science City of Munoz, Nueva Ecija, Philippines; **Noel B. Hamor**, Seed Production and Health Division, SRS I, same; **Reynaldo E. Irang**, Seed Production and Health Division, SRS II, same.

A low volume (LV) nozzle was developed to provide hybrid rice seed growers a low cost but efficient alternative device of applying GA3 other than incurring another investment on the recommended ultra low volume (ULV) sprayer which is relatively expensive. It is also a more efficient alternative than the nozzle of existing knapsack sprayers which, because of its high discharge rate, requires more time and labor in performing the operation.

The prototype nozzle was fabricated out from polyvinyl chloride (PVC) couplings and other commercially available materials. It is easy to use since it fits on the lance of traditional (Taiwan) knapsack sprayers which most, if not all, of the hybrid rice seed growers already have.

Field test results showed that the number of tankloads per hectare was reduced from 10-13 in the traditional nozzle to 2-4 in the designed LV nozzle. This resulted to savings in time and cost of performing the GA3 application.

Results of survey conducted after a pilot testing showed that all of the 21 respondents preferred to use the designed nozzle over their existing nozzles. Eighteen of Them (86 %) expressed their interests to acquire a unit once it will be commercialized.

**477**

**Digital Image Analysis of Spray Deposit Using Matlab: C. Divaker Durairaj**, Professor, Farm Machinery, Tamil Nadu Agricultural University, Coimbatore, India.

Image analysis is being used widely to assess the spray deposition patterns through measurement of droplet size distributions, leading to the calculation of Number and Volume Mean Diameters. Though commercial hardware and software are available for such purpose in the international market, there is a felt need in the developing countries for a simpler and more understandable system that can do the image analysis. Such a software has been developed in MATLAB(r), which serves for analyzing a directly scanned or a photocopied-scanned image in the personal computer. The algorithm uses the extensive MATLAB(r) image processing toolbox and is able to segment and separate overlapping deposits to accurately measure their sizes, finally yielding the NMD and VMD value too. The routines were tested on computer generated images as well as real spray deposit images and found to assess the size distribution within an error margin of 3.0 percent.

**488**

**Ergonomic Studies on the Operation of Clutch Pedal of the Tractor:** **Vinay Madan**, Research Fellow, Dept. of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, India; **H. S. Dhingra**, Assistant Professor (Sl. Sc.) of Agricultural Engineering, same; **Santokh Singh**, Professor of Agricultural Engineering, same.

The present study deals with the force applied by the operator on clutch pedal while performing different field operations. Force measurement was made with a designed and developed instrumentation package, which included the load cell, signal conditioner and readout device. Load cell was calibrated by applying step loading of 5 kg from 0 to 30 kg and data was recorded for both loading and unloading. The performance of load cell was upto the mark and worked well during study. The amount of force varied by changing the implements through the subject was same. Average force value in operating various implements in the field ranged between 202.37 to 212.00 N. the similar trend was observed in the heart rate which varied from 86.30 to 98.60 beats per minute for the corresponding implements.

**498**

**Studies on Gravitational Settling of Cassava Starch on an Inclined Plane:** **Shama Rao P.**, Tamil Nadu Agricultural University, Coimbatore, India; **R. Kailappan**, same; **M. Kannnan**, same.

Cassava or tapioca (Manihot esculanta Crantz) is an important tuber crop cultivated in many tropical countries of the world. Cassava is considered as an industrial crop for its high starch content (78.1-90.15 % on dry basis). Tamil Nadu stands top in processing of cassava in to starch and sago. Out of 1,000 sago industries in Tamil Nadu, 800 are located in and around Salem district, Tamil Nadu, India.

Extraction of starch from raw tubers involves washing, peeling, rasping, screening, gravitational settling, pulverization and drying. On an average, it requires 6.5 $m^3$ of water per tonne of tubers and about 90-95 % of the water used goes as effluent. Settling of starch particles through settling tank takes about 10-12 h in the secondary settling tank and this longer detention time causes fermentation; producing alcohol and organic acids, which gave foul smell polluting the entire area and atmosphere in and around the sago industry. An easy and quick separation of starch, which consumes minimum water and eliminates effluent disposal problem theoretically becomes an immediate requirement for the starch industry to operate the same in a pollution free environment.

A study was undertaken to fabricate a model gravitational settling plane to study the settling of starch particles under gravitational force in order to understand the process of separation of starch from the starch milk and recycle the fruit water collected for rasping operation. Studies were conducted with model starch settling unit with the process parameters namely length, slope, feed rate and starch concentration in the fruit water. The process parameters were varied and experiments were conducted to optimize the parameters for the best operating condition. A starch settling plane 36 m length and 0.25 % slope was found to be best for draining fruit water with a starch concentration of 0.05 % for a maximum feed rate of 8 lit/min studied.

As the BOD value of the fruit water with 0.05 % starch concentration was only 90 mg/lit after 24 h which is less than the safe limit. Hence, it can be recycled for rasping operation and finally for washing of tubers and then used for irrigation purpose.

The design calculations for a 50 tonnes capacity starch industry revealed that the size of the starch settling floor required is 36 x 12 m, size of the water tank and secondary settling tank are 10 and 40 $m^3$, respectively. It was also found that 97 % of the water could be saved through this method of starch separation from starch milk as compared to the conventional method. By following this method of starch separation from the starch milk not only reduces the water consumption but also eliminates the effluent treatment plant theoretically. Computer programme to assist the design for various capacities of the sago industry was also written in C++ language.

# NEWS

## Agro Reinforces Its Harvesting Pole

**Joint venture between AGCO and Laverda to improve positioning in the markets of Europe, Africa and Middle East**

Breganze June 25th, 2007. AGCO, the Italian Industrial Group owner of long tradition and great value brands such as Laverda, Landini, Fella, Gallignani, McCormick, Valpadana, Pegoraro, specialized in the production of agricultural machines and equipment has announced officially today the establishment of a 50 % joint venture between Laverda S.p.A., leader of its harvesting pole and owner of Fella and Gallignani shared at 50 %, and AGCO Corporation.

Laverda has been operating since 2004 in close partnership with AGCO supplying the Corporation based in Duluth (Georgia) with its top and medium range combines declined in the Massey Farguson, Fendt and Challenger brands destined to the distribution in the markets of Europe, Africa and Middle East, where they have met a great success thanks to their features of reliability, productivity and profitability.

The very good relationships established and the good results obtained during these years of cooperation have persuaded the two groups to pursue the maximum stability in the partnership with the common aim of taking a leading position in the EAME harvesting business.

The partnership agreement ratified today will allow Laverda, the Breganze Company settled in 1873 and since that date fully dedicated to the manufacturing of agricultural machines and equipments, to associate the expertise acquired in over 50 years of activity in the production of self-propelled combine-harvesters with the knowledge of AGCO, enlarging its offer also in those market segments where it is not present today.

The synergy between Laverda and AGCO in terms of research and development will further increase the rapidity in the response to the demand of the market of the Breganze Company, which has always taken the customers' needs into the maximum cosideration.

Besides Laverda, the joint venture involves also Fella-Werke, Feucht (Germany) dedicated to the production of hay and grass machinery, and Gallignani, Russi (RA), dedicated to the production of balers.

This will allow AGCO, as well as the increase of its volumes in the combine market thanks to the machines manufactured in Breganze, to have a direct access to the remaining products strategic for the completion of the offer in the segment of harvesting machines.

Valerio Morra will be in charge as President of the joint venture. Headquarters of the joint venture will be in Laverda, at the Breganze plant, where the management is confirmed with all its functions.

All strategies and actions in support of the brand will be carried on in the sign of Laverda.

The Company policy related to the marketing, distribution and sales of the combine-harvesters with Laverda brand will remain unchanged.

"This agreement is the best way to grant the development of the manufacturing volumes which can actually be effected by Laverda and Fella, since they have the structure, the organization, the men and the means to sustain an important growth" has declared Valerio Morra, President of ARGO.

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# Book Review

## Agroecosystems in a Changing Climate

**Authors:** Paul C.D. Newton (AgResearch, Palmerston North, New Zealand), R. Andrew Carran (same), Grant R. Edwards (Lincoln University, Canterbury, New Zealand), Pascal A. Niklaus (ETH Zurich, Switzerland)

**Detailed Description:**

Agroecosystems in a Changing Climate considers the consequences of changes in the atmosphere and climate on the integrity, stability, and productivity of agroecosystems. The book adopts a novel approach by bringing together theoretical contributions from ecologists and the applied interpretations of agriculturalists. Drawing these two approaches together, the book provides the theoretical underpinning that guides scientists on what phenomena to look for, looking beyond first-order responses in the creation of sustainable agroecosystems. This unique approach provides an interpretation of ecological insights and general theory, and then relates them to agroecosystem performance.

Each section of the book combines general principles of response with an examination of the applied consequences. The authors cover the supply of resources necessary to sustain agriculture in the future and discuss the incidence of pests, weeds, diseases, and their control. They provide an understanding of how the population biology of organisms will change and the adaptations that might be possible. The book also explores plant breeding solutions and the capacity for adaptation that exists in plant populations. In addition to the full chapters, the book includes Special Example chapters that deal in more detail with specific issues.

Presenting a global perspective of climate change effects on agricultural production, Agroecosystems in a Changing Climate establishes connections between the immediate effects of change and the longer-term processes that will ultimately determine the consequences for agroecosystems and therefore the potential for adaptation.

**376 pp., Price: $129.95 / £74.99**

**Published:** CRC Press / Taylor & Francis Group, LLC, 6000 Broken Sound Parkway NW, Suite 3000, Boca Raton, FL33487, USA

## GIS Applications in Agriculture

**Authors:** F.J. Pierce (Washington State University, Professor, USA), David Clay (South Dakota State University, Brookings, USA)

**Detailed Description:**

The increased efficiency and profitability that the proper application of technology can provide has made precision agriculture the hottest developing area within traditional agriculture. The first single-source volume to cover GIS applications in agronomy, GIS Applications in Agriculture examines ways that this powerful technology can help farmers produce a greater abundance of crops with more efficiency and at lower costs.

Each chapter describes the nature of a problem, examines the purpose and scope of a GIS application, presents the methods used to develop the application, and then goes on to provide results and offer a conclusion as well as supporting information. When appropriate, the chapters present the underlying statistical approach for the GIS software that is used. The text also includes a CD-ROM featuring data sets and color maps produced by the use of GIS.

Concentrating more on the approach and less on the specific software, the authors describe the methods used to develop an application and discuss limitations to the algorithms and the programming code used. They then summarize the application in terms of what it does, how it works, its limitations, and its potential uses. The book provides a toolkit for the acquisition, management, and analysis of spatial data throughout the agriculture value chain.

**224 pp., Price: $119.95 / £68.99**

**Published:** CRC Press / Taylor & Francis Group, LLC, 6000 Broken Sound Parkway NW, Suite 3000, Boca Raton, FL33487, USA

## Biological Approaches to Sustainable Soil Systems

**Authors**: Norman Uphoff, Andrew S. Ball, Erick Fernandes, Hans Herren, Olivier Husson, Mark Laing, Cheryl Palm, Jules Pretty and Pedro Sanchez

**Detailed Description:**

Global agriculture is now at the crossroads. The Green Revolution of the last century, which helped developing countries meet their food needs for several decades, is now losing momentum. Rates of growth in food production are now declining, with land and water resources becoming scarcer, while world population continues to grow. We need to continue to identify and share the knowledge that will support successful and sustainable agriculture systems in this new century. These depend crucially on soil.

Biological Approaches to Sustainable Soil Systems brings together 102 experts from multiple disciplines and 28 countries to report on the science and the innovation going on for sustainable soil-system management. While accepting some continuing role for chemical and other external inputs in 21st-century agriculture, this book presents a variety of ways in which crops can be produced more abundantly and more cheaply with lessened dependence on the exogenous resources that have driven the expansion of agriculture in the past.

Including the work of both researchers and practitioners around the world, Biological Approaches to Sustainable Soil Systems.

**784 pp., Price: $149.95 / £85.00**

**Published:** CRC Press / Taylor & Francis Group, LLC, 6000 Broken Sound Parkway NW, Suite 3000, Boca Raton, FL33487, USA

## Machine Elements: Life and Design

**Authors:** Boris M. Klebanov (Beer-Sheva, Israel), David M. Barlam (Ben Gurion University, Beer-Sheva, Israel), Frederic E. Nystrom (Racine, Wisconsin, USA)

**Detailed Description:**

Focusing on how a machine "feels" and behaves while operating, Machine Elements: Life and Design seeks to impart both intellectual and emotional comprehension regarding the "life" of a machine. It presents a detailed description of how machines elements function, seeking to form a sympathetic attitude toward the machine and to ensure its well-being through more careful and proper design.

The book is divided into three parts for accessibility and ease of comprehension. The first section is devoted to microscopic deformations and displacements both in permanent connections and within the bodies of stressed parts. Topics include relative movements in interference fit connections and bolted joints, visual demonstrations and clarifications of the phenomenon of stress concentration, and increasing the load capacity of parts using prior elasto-plastic deformation and surface plastic deformation.

The second part examines machine elements and units. Topics include load capacity calculations of interference fit connections under bending, new considerations about the role of the interference fit in key joints, a detailed examination of bolts loaded by eccentrically applied tension forces, resistance of cylindrical roller bearings to axial displacement under load, and a new approach to the choice of fits for rolling contact bearings.

The third section addresses strength calculations and life prediction of machine parts. It includes information on the phenomena of static strength and fatigue', correlation between calculated and real strength and safety factors; and error migration.

**440 pp., Price: $129.95 / £74.99**

**Published:** CRC Press / Taylor & Francis Group, LLC, 6000 Broken Sound Parkway NW, Suite 3000, Boca Raton, FL33487, USA

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# Co-operating Editors


B Kayombo


M F Fonteh


A A K El Behery


A M El Hossary


B S Pathak


R J Bani


I K Djokoto


D K Some


K Houmy


J C Igbeka


E U-Odigboh


K C Oni


N G Kuyembeh


A H Abdoun


A B Saeed


A I Khatibu


E A Baryeh


S Tembo


H A Cetrangolo


I de A Nääs




A E Ghaly


E J Hetz


A A Valenzuela


R Aguirre


O Ulloa-Torres


S G C Magana


H Ortiz-Laurel


W J Chancellor


M R Goyal


A K Mahapatra


G R Quick


S M Farouk


Daoulat Hussain


M A Mazed


Chetem Wangchen


Wang Wanjun


S Illangantileke


S M Ilyas


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M Behroozi-Lar


Saeid Minaei


J Sakai


B A Snorbar


C J Chung


C C Lee


M Z Bardaie




M P Pariyar


D B Ampratwum


E S Eldin


L U Opera


A D Chaudhry


A Q Mughal


R ur Rehmen


B T Devrajani


N A Abu-Khalaf


Surya Nath


R M Lantin


R P Venturina


S A Al-Suhaibani


A M S Al-Amri


S F Chang


T S Peng


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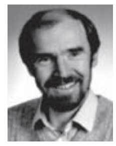
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