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# AMA

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YOSHISUKE KISHIDA

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This is the 154th issue since its maiden isue in the Spring of 1971

# EDITORIAL

I hope all the readers have had a nice New Year holiday. Time flies; it is already the 13th New Year of the 21st century. For people promoting agricultural mechanization like us, the role we must play in this world is getting larger and larger. The world population, which was 2.5 billion in 1950, grew to 6 billion in 2000. It is expected to reach 9 billion by 2050. The country that embraces the largest population seems to be India with more than 1.5 billion people in one country. On the other hand, China, one of the most populated countries today, seems to putting on the brakes to the bursting population. The total population of China in 2050 has been estimated to be slightly less than 1.4 billion. To sustain this great number of people, the agricultural area for food production was already 590 million ha in 1950. The total production area grew to 730 million ha in 1981, but gradually decreased to 670 million ha in 2004. The crop acreage per person in 1950 was 0.23 ha. In 2000, it dropped to 0.11, and is expected to reach to reach 0.07 by 2050. According to this situation, land productivity needs to be greatly improved.

Farm land is not the only factor that supports food production. Last year, horrible drought in North America damaged the production of crops such as corn. Scarce water resource is also a global problem. The amount of underground water used today is, obviously, far more than the amount of rainfall. It is clear that the underground water is decreasing.

Also, due to the economic activities by humans, greenhouse gases continue to increase, which leads to an increase in global temperature. Current research warns that when the average ambient temperature increases by one degree Celsius, the total production of crops, such as wheat and corn, will drop by 10 %. To prevent global warming, the use of renewable energy is increasing around the world. The amount of sugar cane and corn to produce alcohol is growing rapidly recently. To prevent the use of edible crops to make alcohol, some researchers are trying to make alcohol from stem and leaf.

Many countries are facing the problem of decreasing farm lands by urbanization, deforestation and breakdown of fishing areas. For Japanese people, losing fishing area because of environmental change is a crisis, since many Japanese take protein from fish.

How can we conquer this severe environmental condition in front of us? The more the farming conditions get oppressed, the more we need to make our farm work timely and accurate. For this, agricultural mechanization is indispensable. Accurate farm work will be accomplished in two ways; mechanical accuracy and detailed information pointing out what type of work is needed for the existing conditions. Research on, and implementation of, precision agriculture are progressing at an accelerated pace. It is no exaggeration to call it an agricultural information technology revolution. The ICT revolution is created in various sectors and I expect that a dramatic effect will be seen in the agricultural and agricultural machinery sector that will greatly increase agricultural productivity.

Plenty of food is necessary to realize a peaceful world. It is my hope that the people involved in agricultural mechanization will reconfirm the importance of their task, and cooperate with each other to make a happy and peaceful world.

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

January, 2013

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## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

**Vol.44, No.1, Winter 2013**

# Minimum Drift During Spraying Process

by
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## Abstract

Very low percentages of Nalco-E-102 (0.05 to 0.15 %) were tested with flat nozzles of different sizes at low working pressures. Adding a every low percentage of Nalco-Trol to the spraying fluid reduced the driftable size to less than 200 microns (P). The (P) values were 60, 42, and 20 % for concentrations 0.0, 0.05 and 0.1 % of Nalco-Trol, respectively. The droplet size at (P) values were also decreased by increasing the nozzle size. The measured V.M.D. was checked from the flow number or the viscosity formula and gave very close results. To achieve a reasonable V.M.D. with less variation between the upper and lower limits of the spray spectrum, it was recommended to add a 0.05 to 0.1 % of Nalco-E102 and adjust the designed working pressure to give less percentage of the driftable size with high spraying performance

## Introduction

Spraying for weed and insect control is a precision operation. It has tremendous potential for saving a crop or increasing the yield. The droplet size distribution of spray spectra issuing from conventional spray nozzles are too wide for most efficient use of the chemical. The proportion of small to large droplets depends upon the design and size of the particular nozzle as well as the characteristics of spray liquid. Usually the small droplets make up only a fraction of the total volume output but they account to nearly all of the spray drift that takes place. Drift can be a very serious problem, particularly when applying hazardous materials. In addition, representing inefficient use of material, drift may cause serious damage either by injury to susceptible crop plants in nearby fields or as a result of poisonous deposits left on edible plants. Undesirable drift from the spraying of the chemical materials may occur in two ways. First, spray drift occurs as a result of the smaller droplets in the spray being carried away from the target by wind or convectional currents. Second, the vapor from a volatile chemical may be carried away from the target area during or after the spraying by vapor drift. Recently, attention has been given to the influence of the liquid properties on the breakup process and consequently on the droplet size in order to reduce the driftable size.

The aim of this research was to select the proper size and type of nozzle with inodification in the liquid properties to avoid such as usually any possibilities of damage for the crop and environment.

**Review of Literature**

The first attempt at increasing viscosity was studied by Kaupke and Yates (1966) and Colthurst *et al*. (1966). They used an "invert" or water-in-oil in order to increase the spray mixture viscosity. There are many materials available that that should reduce the drift when properly added to the mixture. Many are too expensive while others require too precise control of conditions. Those which have been introduced and seem nearest to widespread acceptance are Dacagin (Diamond Alkali Co.), Norbak (Dow Chemical Co.), and Vistik (Hercules Power Co.) (1971). They are available in dry form to add to water based sprays, and have been used almost exclusively with herbicides. These materials as well as the invert emulsions require care in mixing.

A laboratory study by Butler *et al*. (1969) examined the previous materials under simulated field conditions. Their results showed the ability of adjuvant materials to eliminate fine drops. Sprayberry and Curry (1966) discussed the drift reduction potential of Decagin. Suggitt (1965) reported excellent control of "brown-out" or drift and a cost reduction by the widespread use of Vistik thickened sprays on power line right of way in Ontario. Semoure *et al*. (1961) and Byrd *et al*. (1966) reported laboratory and field studies that showed the Norbak reduction potential.

Igwe (1971) studied the effect of the use of viscosity modifiers (Vistik, Norbak and Dacagin) on spray droplet formation with high speed photography. He noted that the liquid sheet with the highest viscosity was the most resistant to disruption while, on the other hand, the easiest liquid to disintegrate had the low viscosity with its region of breakup occurring near the nozzle. Later, Younis (1973) studied the effect of subatmospheric air density on liquid disintegration with thickener materials (Nalco-E102).

Various observers have indicated that the drop size variation with viscosity ranges from $d_1\ \alpha\ p\alpha\mu^{\circ.2}$ to dxμ αμ (see the Eqns below). For liquid sheet, the disintegration process is a little more complicated and has been considered in two phases: liquid sheet breakup and ligament breakup (Fraser, 1958). The former is described by the expression:

$DVE\alpha \{(Q_s\sigma^2) / (LO_p^2V^2_E)\}\ 1/3$ ... (1)

where

D = Volume Median Diameter

$V_E$ = Velocity of emission of liquid from the nozzle.

$Q_s$ = Volume of liquid emitted into the sheet per second.

σ = Liquid surface tension.

L = Length of the intact sheet.

O = The angle subtended at the nozzle by the leading edge of the sheet.

P = Density of the liquid.

The latter process of ligament breakup is presented (6) by

$D / d_1 = \{\mu / (d_1\sigma p)\ 1/2\}\ 1/4$ ....... (2)

where:

μ = Dynamic viscosity.

$d_1$ = Diameter of the ligament which can be calculated using

$d_1 = (2Q_1 / \pi V_E)\ 1/2$ .................. (3)

where:

$Q_1$ = Volume of liquid emitted into the ligament per second.

Whether **Eqn 1** or **2** should be used to predict droplet size in any given set of circumstances depends on the design of the nozzle and the Reynolds number for the flow through the orifice.

**Experimental Investigation**

Flat nozzles No.8001-E, 8002-E and 8004-E of the Spraying System Company were tested. The flat nozzles had rated capacities of 375, 750, 1,400 cm$^3$/min (0.1, 0.2, and 0.4 G.P.M ),respectively, at a pressure of 274 kPa (40 psi).

The thickener material used as the viscosity modifier was Nalco-E102 from Nalco Chemical Company, Chicago, Illinois. This material was used in a liquid form and its viscosity recorded by Younis (1973) and shown in **Fig. 1**. The sprayer consisted of a tank, a pump, two pressure regulators, an air chamber and a set of nozzles fitted on a boom.

The field experiments were conducted on the Experiment Station Farm of the Faculty of Agriculture. **Fig. 2** shows the complete layout of the experiment and illustrates the line of spraying and the line of the drift. Plotting paper was used as a sampling device to detect the lateral droplet movement from the spraying line. Methylene Blue dye with a concentration of approximately 0.01 % was used to facilitate the detection of the drops.

The spraying fluid was essentially water, Caylone, Methylene Blue, and the viscosity modifier. The Eaylone was added to water at a concentration of 1.5 %; it was used on a large scale for pest control in the previous season. The viscosity modifier was Nalco-E102 and was premixed for twenty minutes before running the experiment.

## Results and Discussion

The results are presented in **Graphs 3**, **4**, **5** and **6** as a cumulative volume percentage versus the drop diameter. In each test, the atmospheric conditions, such as wind velocity, relative humidity and temperature were recorded. **Fig. 4** shows that the drop size spectrum invariably shifted in the direction of larger droplets as the nozzle size was increased. For droplets with diameters less than 200 microns, (P) (a value chosen because the droplets in this range were likely to give rise

**Fig. 1** Viscosity versus shear rate for varying concentrations of Nalco E-102 (Younis 1973)

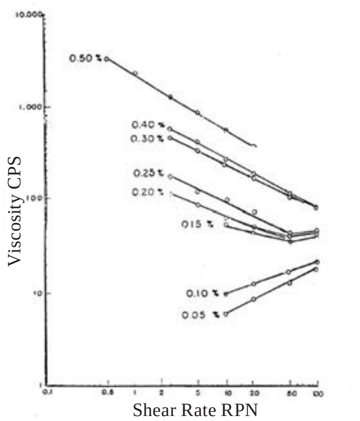



**Fig. 2** The layout of the drift experiment

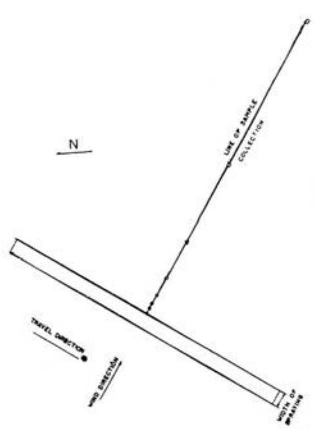
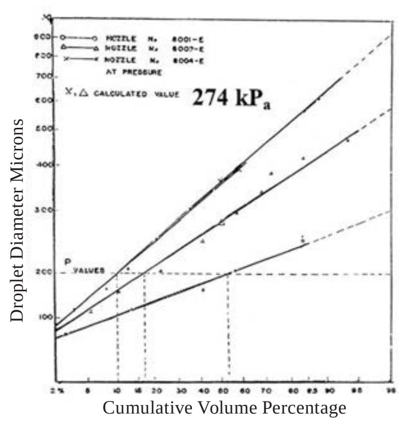



**Fig. 3** Droplet size distribution curves for water alone with different sizes of flat nozzle



to drift) the percentage size of the spray, showed that the proportion of drift susceptible droplets was very much greater with small nozzles. The (P) values were 54, 18, and 10 % with nozzle numbers 8001-E, 8002-E and 8004-E, respectively. The same trend was obtained from **Figs. 5**, **6** and **7** with different concentrations of Nalco-E102. The results showed a decrease in these percentages as the nozzle size and / or the concentration of Nalco-E102 were increased.

It was shown by Fraser (1958) that, for fan nozzles, the volume median diameter (V.M.D.) increased with increasing nozzle size. The author gave a relationship between the (V.M.D.) and the nozzle size in terms of the flow number (FN) that was V.M.D.= const. (FN/P)1/3. Since the pressure was constant in this test, the V.M.D. was proportional to the cubic root of the FN. The calculations are shown as a big sign on each graph, and were calculated relative to the lower V.M.D. to avoid any complication in determining the constant of each nozzle. The difference between the calculated and measured V.M.D. was much closer at the lower concentration of Nalco-E202. The differences were significant at the higher concentration of Nalco-E202, i.e. higher viscosity, because the previous formula did not include in its concept the viscosity effect. **Eqn. 2** shows that the droplet size was proportional to the fluid viscosity to the power of one sixth. Probably, the differences were getting too small if the calculated values were multiplied by the correction mentioned in **Eqn. 2**.

The driftable size (P) value was decreased by increasing the concentration of Nalco-E102. The reduction was due to higher viscosity of the spraying fluid as reported by Igwe (1971). The breakup mechanism of the modifier fluid took longer for each stage, which gave the fluid a chance to transfer from one part to another and delayed the drop separation from its ligament and resulted in shifting the spray spectrum to large drops. The ability of the ligament to withdraw part of fluid into the nodes to join each other should also eliminate most of the small drops that caused the drift hazards.

The wind speeds ranged from 4.827 to 8.045 km/hr. It could be assumed that the differences between the treatments were only due to the differences in the wind speed which changed from one day to another during the test but the real limiting factors were the time consumed in each treatment and the capacity of the sprayer tank which lead to running a single test every day. Therefore, a separate test was run under constant atmospheric conditions with nozzle number 8001-E. **Fig. 7** indicates a similar result to the previous test. The (P) values were 9, 18 and 53 % for pressures 128, 206 and 271 kPa, respectively. The calculated V.M.D. values from the flow number formula were approximately the measured ones since the test did not include the viscosity effect. Another test was done with different concentrations of Nalco-Trol with nozzle number 8001-E at 274 kPa. The results are shown in **Fig. 8**. The driftable size percentages (P) were 60, 42 and 20 % and the V.M.D. values were 170, 220 and 258 microns for concentrations of 0.0, 0.05 and 0.1 %, respectively. Since the fluid, which was used in this test, was highly viscous the FN formula was not applied in this case to calculate the V.M.D. By inspection of **Eqn. 2**, it appeared that the droplet diameter was proportional to the fluid viscosity to the power of one sixth if the other factors were held constant. From **Fig. 1**, the upper and lower viscosities were found for each concentration then the V.M.F. was calculated. The values were (222 to 261) and (241 to 276) microns for percentages of 0.05 and 0.1 %, respectively, and the previously measured values were located in these ranges. This reduction

**Fig. 4** Droplet size distribution curves for 0.05 % concentration of Nalco-Trol with different sizes of flat nozzle

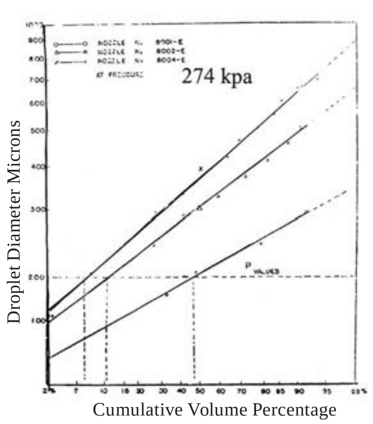



**Fig. 5** Droplet size distribution curves for 0.1 % concentration of Nalco-Trol with different sizes of flat nozzle

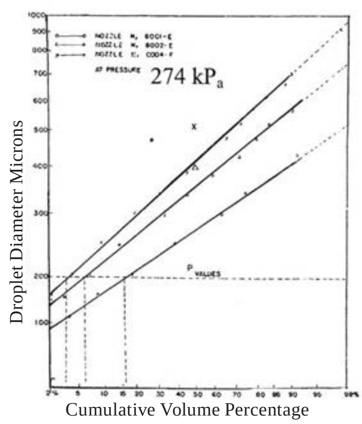



**Fig. 6** Droplet size distribution curves for 0.15 % concentration of Nalco-Trol with different sizes of flat nozzle

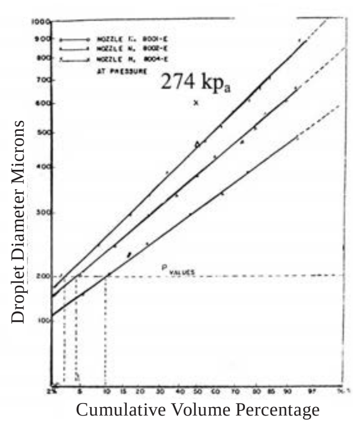


**Table 1** The (P) values with different discharge rate and viscosity moodier percentage

| Nozzle Number | Discharge* Rate$^3$/min | Viscosity Modifier % | | | |
|---|---|---|---|---|---|
| | | 0 | 0.05 | 0.10 | 0.15 |
| 800 1E | 375 | 58 | 43 | 18 | 10 |
| 800 2E | 750 | 17 | 11 | 6 | 5 |
| 800 4E | 1,500 | 10 | 7 | 3 | 3 |

* At Pressure 274 kPa

due to that a part of the fluid was evaporated from the drops when they moved in a stream of air. But the rate of evaporation was less with higher concentration of Nalco-Trol and vice versa.

The previous graphs showed a very important point. The slope of the lower line in each graph was smaller than those of the others, i.e. the variations between the spray spectra were less for the lower lines than the upper lines. The best spraying characteristics need smaller slope with reasonable V.M.D. and this could be accomplished by using small size nozzles at low pressure with very small concentrations of Nalco-E102. Therefore, the percentages at (P) values less than 20 % were very easy to get with the nozzles and pressures used here in these tests. The percentage of Nalco-E102 had to be increased to 0.1 % on windy days. This enabled the spraying procedure at a low pressure and volume with minimum driftable droplets to save power and time and, at the same time keep the cost of the viscosity modifier (0.05 to 0.1 %) low. In addition to the previous advantage, the reduction was great in the drift hazards, which can cause very serious injuries to human beings, animals, plants and other environment.

From **Figs. 3** to **6**, the values of (P) at different percentages are tabulated in **Table 1**. **Fig. 9** shows the presentation of these data. The value of (P) decreased of with increasing the discharge rate (cm$^3$/ min) by about 80 % while adding a viscosity modifier up to 0.15 % decreased the values of (P) by about 71 %. This reduction can be written in the following from:

$P = f(x_1, x_2)$

where:

$x_1$: the discharge rate (Q)

$x_2$: the Nalico –E102 (N) %

The following equation was determined from regression analysis:

$P = 62.6 - 0.04\,Q - 362\,N + 0.25\,GN$

with R = 80 %

## Conclusion

A study was made to select the proper nozzle size with modification in liquid properties to avoid any possibilities of damage for the crop and environment . A very low percentage of Nalco-Trol (viscosity modifier) was tested with two types of nozzles (flat and swirl) of different sizes at low working pressure. The driftable size of spraying droplet was reduced to a minimum value with using adequate concentration of the viscosity modifier according to the condition of spraying.

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**Fig. 7** Droplet size distribution curves for water alone at different pressures with flat nozzle No. 8001- E

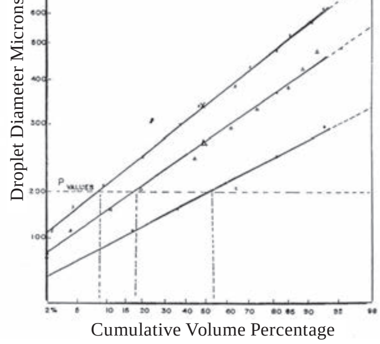



**Fig. 8** Droplet size distribution curves at pressure 274 kPa for flat nozzle No. 8001–E with different concentrations of Nalco - Trol

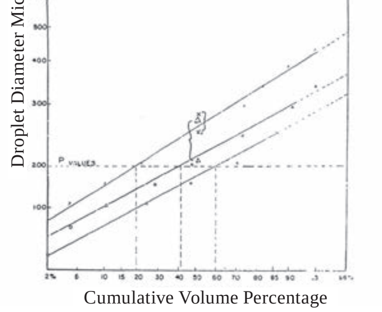
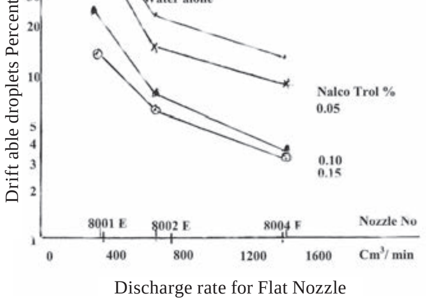



**Fig. 9** The (P) Values with different discharge Rate



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# 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.

**1116**

**Effect of Drip and Surface Irrigation on Yield, Water-use-efficiency and Economics of Capsicum Grown under Mulch and non Mulch Conditions in eastern coastal India:** **J. C. Paul**, Associate Professor, College of Agricultural Engineering and Technology, OUAT, Bhubaneswar -751 003, INDIA, jagadishc_paul@rediffmail.com; **J. N. Mishra**, Associate Professor, same, jnmishra64@gmail.com; **P. L. Pradhan**, Associate Professor, same, plp_ouat@yahoo.co.in; **B. Panigrahi**, Professor, same, kajal_bp@yahoo.co.in

A field experiments was conducted on the loamy sand soil at Bhubaneswar in eastern coastal of India for two years (2007-08 and 2008-09) to evaluate the yield, water-use-efficiency and economic feasibility of capsicum grown under drip and surface irrigation with non-mulch and black Linear Low Density Poly Ethylene (LLDPE) plastic mulch. Actual evapotranspiration for capsicum crop was estimated using modified pan evaporation method. The net irrigation volume (V) was determined after deducting the effective rainfall. Effect of three irrigation levels viz. VD, 0.8 VD and 0.6 VD (VD = full irrigation volume with drip) in conjunction with LLDPE mulch and no mulch were studied on biometric and yield response of capsicum crop. The results of surface irrigation were compared with drip irrigation system under no mulch and in conjunction with LLDPE mulch. The study indicated better plant growth, more number of fruits per plant and enhancement in the yield under drip irrigation system with LLDPE mulch. The highest yield (28.7 t/ha) was recorded under 100 % net irrigation volume with drip irrigation (VD) and plastic mulching as compared to other treatments. This system increased the yield and net seasonal income by 57 % and 54 % respectively as compared to conventional surface irrigation without mulch with a benefit cost ratio of 2.01. The benefit cost ratio was found to be the highest (2.44) for the treatment VD without mulch. Drip irrigation system could increase the yield by 28 % over surface irrigation even in the absence of mulch. Similarly, LLDPE mulch alone could increase the yield by 13 % even in the absence of drip irrigation system.

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# Measurement of Tractor Performance

by
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## Abstract

Tractor test systems were examined to evaluate the effect of the modified systems on the value of tractor performance compared to the systems used in the tractor test station. The developed device consisted of a transducer, signal conditioner and recorded unit. The hydraulic pull dynamometer, strain gage pull dynamometer, load cell, hydraulic PTO dynamometer, magnetic pickup transducers and fifth wheel were used to measure tractor parameters. Statistical analysis showed no significant between the developed device (named system 1) and the system used in the tractor test station (named system 2). The developed device was expected to be a worthy one for establishing reliable data of the performance parameters of tractors and implements.

## Introduction

Many instrumentation systems have been developed and reported by researchers that identify the field performance of tractors and implements operating under different field conditions. Most of them were designed exclusively for a particular tractor. Also, most of the developed systems were used to measure parameters like drawbar pull, ground speed, and drive wheel speed. From these measurements drawbar power and wheel slip could be calculated. It was difficult and expensive to instrument one tractor and take it to different farm sites to make a complete field performance data bank for the tractors and implements. So, it was necessary to have a simple instrumentation system that was easily adaptable to a wide range of agricultural tractors for different farm sites. And, if any part of the instrumentation system was damaged it would be necessary to find another part.

Raheman and Jha (2007) developed a microcontroller-based slip sensor for a 2WD tractor to indicate slip values during on-farm use. This system included a power supply, sensing of throttle position, gear position, and wheel rpm along with the processing of collected data and a display unit. Power was taken from the tractor battery.

Mohamed *et al.* (2004) designed and calibrated the drawbar pin which could be used as a force transducer to measure the draft of trailed implements. This pin transducer consists of a pin on which was mounted a total of four strain gauges. Nada (2003) and Elgwadi (2005) presented a direct method of estimating tractor power by measuring torque and number of revolutions of the tractor power take off shaft during operation of a rotating agricultural implement in actual field work.

Miszczak (2005) mentioned that there were many models describing the work of rotary tillers, including torque evaluation because the torque requirement might be very important for designers as well as for other experts applying such machines in field operations. Strain gage load devices converted the load into electrical signals. The gages themselves were bonded onto a structural member that deformed when weight was applied. In most cases, four strain gages were used to obtain maximum sensitivity and temperature compensation.

Elashry (2002) used a separate apparatus for fuel consumption. It was installed and connected to the tractor fuel tank through hoses and two 2-way valves. The secondary tank was first filled with fuel to the mark on the top of the tab. During the actual run, the tractor was first let go on its fuel from the main tank. To measure the fuel consumption during a specific field operation, the secondary tank was utilized through valves (1) and (2). At the end of the run, the valves were turned off. The secondary tank was refilled to the mark on the tube from a graduated cylinder and the amount taken as fuel consumption during the specific operation.

Elashry *et al.* (1994), Al-Janobi *et al.* (1998) and Nada (2003) used a 5th wheel to measure the travel speed that was made from a motorcycle wheel and tire with a medium knobby tread. It was connected to the tractor via a spring loaded 4-bar linkage. Chen *et al*. (2007) developed a 2D double extended octagonal ring (DEOR) drawbar dynamometer with a draft capacity of 180 kN.

The objectives of this search were to construct and calibrate a local system that was simple and cheap, to measure the field performance such as PTO torque, drawbar pull, travel speed, fuel consumption and temperature of fuel, oil and cooling.

## Materials and Methods

**Components of the Measurement System**

***A- Fuel apparatus***

A separate apparatus was used to measure fuel consumption that consisted of a secondary tank of 4.5 liters capacity with a level marked tube and bulb with a volume of 127.4 $cm^3$.

***B- Strain gage pull dynamometer***

A strain gage pull dynamometer was designed and constructed at the tractor test station to measure the draft of the tractor under test on the concrete road and in field test. The draft was used to determine the power requirement. The pull transducer was constructed by machining a middle section of G10180 (1.5 × 1.9 cm) hot-rolled (HR) steel. The maximum anticipated stresses for the tractor used. The transducer dimensions were 24 × 1.9 cm and it was machined down to (1.5 × 1.9 cm) in cross section at the point where the gages were mounted. The strain gage pull dynamometer is illustrated in **Fig. 1**.

**Fig. 1** The strain gage pull dynamometer

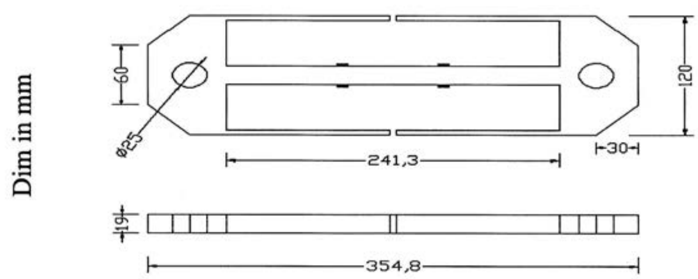
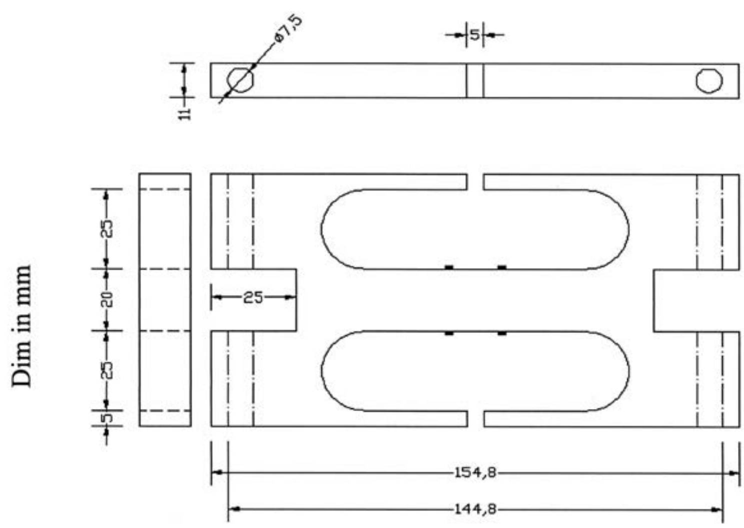



**Fig. 2** The strain gage load cell




***C- Strain gage indicator***

The strain gage indicator was a portable, battery powered, precision instrument for use with resistive strain gages and transducers. The strain gage indicator accepted full, half, or quarter bridge.

***D- Modified System Description***

The developed device was installed at the Testing and Research Station for Tractors and Farm Machinery, Alexandria Governorate. The modified system had stages and a lot of components. It consisted of an amplifier circuit, digital multimeter and computer and was used to measure drawbar pull, PTO torque, rotational speed, ground speed, oil temperature, cooling temperature and fuel temperature.

***E- Strain gage load cell***

The objective of constructing this load cell transducer was to measure the vertical force, which applied to do torque with PTO dynamometer arm from which the power requirements could be determined. The load cell was constructed by machining down the middle section of G10180 (20 mm × 11 mm) hot-rolled (HR) steel. The maximum anticipated stresses were calculated for the tractor intended for this design. The transducer dimension was 15.5 cm × 8 cm and was machined down to (20 mm ×11 mm) in cross section at the point where the gages were mounted. The strain–gage load cell design is illustrated in **Fig. 2**.

***F- Hydraulic drawbar dynamometer***

For agricultural work, hydraulic drawbar dynamometers are widely used. The pressure set up in the fluid contained in a hydraulic link is transmitted to a small recording cylinder in which a plunger acts against the force of a spring. The movement of the plunger may be read directly. A hydraulic drawbar dynamometer, 8,000 kg, was used to calibrate the strain gage pull. The indicator was analog but it had liquid in the indicator box to reduce the movement of the indicator when values were read.

**Specifications of Tractors**

Three tractors were used in this study and numbered from 1 to 3. Tractors No. 1 and 2 were used as loading tractors and the other was used for testing the instrumented trailer. The specifications of the three tractors are tabulated in **Table 1**.

**Measurements**

The measurements required to determine tractor performance were fuel consumption, drawbar pull, PTO torque, ground speed, rotational speed, slip, fuel, oil and cool temperature.

***A- Fuel consumption***

A separate apparatus was used to measure fuel consumption. It consisted of a 4.5 l secondary tank with a level marked tube and bulb with a volume 127.4 $cm^3$. The apparatus was installed and connected to the tractor fuel tank through hoses and two valves. The secondary tank was first filled with fuel during the actual run. The tractor was first let go on its fuel from the main tank. To measure the fuel consumption during a specific field operation, the secondary tank was utilized through the valves to fill the bulb. Then, the valves were turned off and a stop watch used when the fuel arrived at the first mark of the bulb. After that, when the fuel arrived at the second mark, the stop watch was turned off. Because the bulb had constant volume, it was easy to calculate the fuel consumption.

***B- Drawbar pull***

Drawbar pull was measured using a strain gage pull dynamometer. The calibrated hydraulic dynamometer (5 ton capacity) at the Faculty of Engineering, Alexandria University was used to calibrate the pull meter strain gage.

***C- Tractor PTO torque***

The PTO hydraulic dynamometer was used to measure the PTO torque and PTO rpm to determine PTO power. Two methods were used to measure the PTO torque. The first method developed used the device with the load cell to measure the torque. A known torque was applied to the transducers. The value of the known load was read with the new instrument. In the second method the same procedures was followed with the strain meter.

***D- Ground speed***

Two methods were used to measure the ground speed; using a fifth wheel and the traditional method. In the first method the true ground speed was measured using a fifth wheel mounted on a tool bar directly behind the right front wheel. **Fig. 3** shows the fifth wheel mechanism.

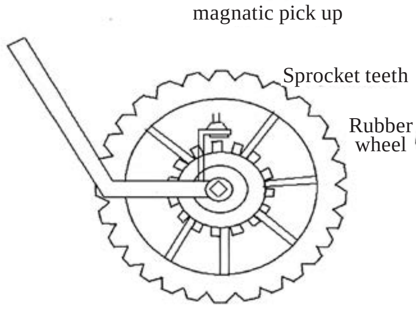
***E- P.T.O rotational speed***

For high rotational speed, two methods of measurement were used. The first method was mechanical revolution counters that required time to be measured by stop watch. Electrical and electronic units automatically counted the number of revolutions over a period of time and the results were displayed and continually updated. The second method used a new instrument with a magnetic pick up to calculate the number of revolutions after calibration. The wheel speed transducer is illustrating in **Fig. 4**.

**Table 1** Specifications of the tractors

| Specifications | Tractor No. 1 | Tractor No. 2 | Tractor No. 3 |
|---|---|---|---|
| Make | U.S.A | U.S.A | --- |
| Model | John Deere | John Deere | --- |
| Number of driving wheel | 4 × 4 | 4 × 4 | 4 × 4 |
| **Engine** | | | |
| Model | 6076 TRWO4 | 6076 TRW08 | --- |
| Type | Diesel | Diesel | Diesel |
| Cylinders | 6 (Vertical) | 6 (Vertical) | 6 (Vertical) |
| Bore × stroke | 115.8 × 120.7 | 115.8 × 120.7 | |
| Cubic capacity | 7,634 cc | 7,634 cc | 7,500 cc |
| **Fuel system** | | | |
| Feed system | In-line | In-line | In-line |
| Fuel tank capacity | 246 liters | 246 liters | 220 liters |
| Rated engine Power | 88 kW at 2,200 rpm | 80 kW at 2,200 rpm | 120 kW at 2,100 rpm |
| **Cooling system** | | | |
| Type of coolant | Water | Water | Water |
| **Power take off** | | | |
| Type | Independent | Independent | Independent |
| Actuation | Electro hydraulic, gradual, operator controlled | Electro hydraulic, gradual, operator controlled | Electro hydraulic, gradual, operator controlled |
| Speed | 540 /1,000 rpm | 540 /1,000 rpm | 540 /1,000 rpm |
| **Tractor Dimensions** | | | |
| Length (mm) | 4,023 | 4,027 | 4,266 |
| Width (mm) | 2,438 | 2,870 | 2,523 |
| Height (mm) | 2,959 | 3,173 | 2,989 |
| Wheel base | 2,676 | 2,675 | 2,723 |
| **Tractor weight** | | | |
| Total (kg) | 6,415 | 6,329 | 6,300 |

**Fig. 3** The fifth wheel mechanism



***F- Fuel, oil and cool temperatures***

A digital multimeter was used to measure temperature. The DT92 Advanced series digital multimeter was compact, precision and battery operated.

***G- Slip ratio***

Slip is defined as the relative movement in the direction of travel at the traction device-soil interface. It is generally expressed as:

$S = 1 \times (V_a / V_t)$

where:

S = wheel slip (-)

$V_a$ = actual travel speed

$V_t$ = theoretical wheel speed = r × ω

ω = angular velocity of wheel (1/sec)

r = actual rolling radius of wheel on hard surface (m)

The following equation represents the calibration data.

$Y = 0.0008X + 0.0667$

where

Y = device reading mv;

X = Rotation speed, rpm

**Calibration**

***A- Strain gage pull dynamometer calibration***

The pull dynamometer was attached to a steel column which was fixed to a tractor. The calibrated hydraulic dynamometer was attached in series with the pull meter strain gage. The load was applied to the transducer using a pre-calibration unit. The calibration equation between hydraulic and strain gage dynamometer was expressed as follows:

$Y = 0.2121X$

Y = value of strain gage dynamometer, kN

X = Value of hydraulic dynamometer, kN

***B- Load cell calibration***

Torque was recorded with the new instrument and/or strain indicator. A known torque was applied from no load to the maximum allowed torque and then reduced in approximately the same steps back to no load. Load cell transducers were excited by a stabilized dc voltage supply with an input 9-volt battery. The new instrument read the voltage with the same torque and strain indicator reading the torque with the same strain or mV.

The following equation expressed the relationship between applied torque and the developed instrument and strain meter device:

$Y_1 = 0.3845X_1$

where

$Y_1$ = new instrument reading, mv;

$X_1$ = applied torque kN

**Fig. 4** The rotational speed transducer

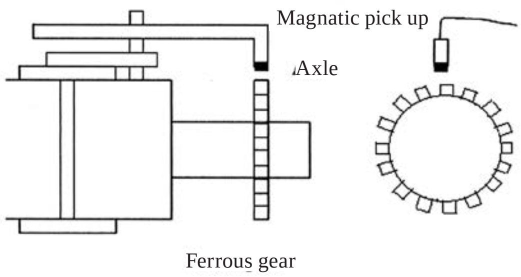



**Table 2** The statistical analysis of PTO test for system 1 and system 2

| | SYSTEM 1 | | SYSTEM 2 | |
|---|---|---|---|---|
| | torque (N.m) | power (kW) | torque (N.m) | power (kW) |
| Average | 494 | 92 | 496 | 93 |
| No. of reading | 26 | 26 | 26 | 26 |
| Max. value | 635 | 116 | 634 | 118 |
| Median value | 579 | 109 | 579 | 109 |
| Min. value | 0 | 0 | 0 | 0 |
| T cal, | 0.98041 | | 0.94194422 | |
| T table | 2.009 | | 2.009 | |

**Fig. 5** PTO performance of tractor using system 1

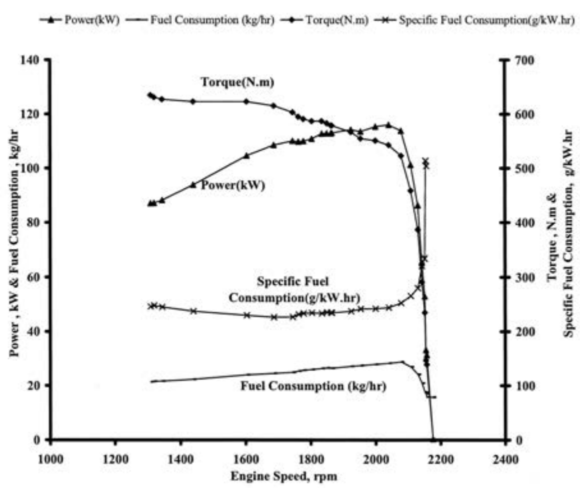
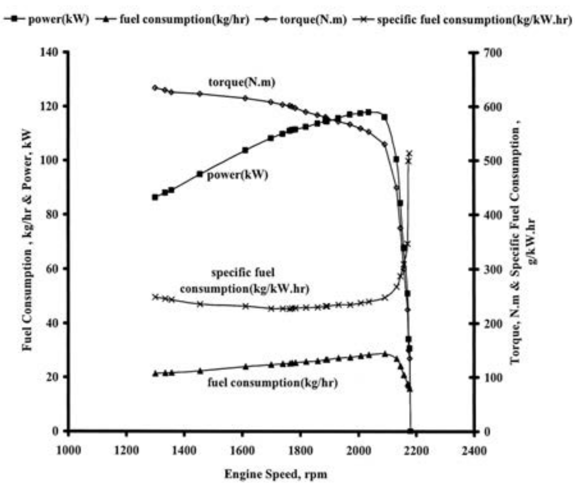



**Fig. 6** PTO performance of tractor using system 2



*C- Fifth wheel calibration*

The fifth wheel was calibrated on a concrete road at a known forward speed in equal steps from no speed to the maximum allowed speed and then reduced in approximately the same steps back to no speed with a magnetic pickup using a 120 tooth sprocket. The following equation represented the calibration data by using the fifth wheel.

$Y = 0.63X$

where

Y = Device reading, mv

X = Forward speed, km/hr

## Result and Discussion

The statistical analysis (**Table 2**) shows the T test of torque and power for different systems during the PTO test that there was no significant difference between system 1 and system 2. Fuel temperature

**Table 3** Data of drawbar pull measured using improved system 1

| | Gear high | | | | | | Gear low | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
| Drawbar Pull at max power, kN | 49.0 | 47.4 | 44.4 | 43.3 | 36.2 | 33.4 | 40.2 | 34.6 | 30.3 |
| Speed at Max Drawbar Power, km/h | 1.77 | 2.31 | 2.94 | 3.89 | 4.91 | 6.7 | 4.84 | 5.77 | 7.75 |
| Slip at Max Drawbar Power, % | 12.19 | 9.7 | 10.8 | 7.8 | 10.1 | 7.7 | 7.9 | 8.9 | 5.3 |
| Max Drawbar Power, kW | 24.04 | 30.42 | 36.3 | 46.79 | 49.43 | 62.25 | 50.05 | 55.45 | 65.16 |
| Fuel consumption at Max Drawbar Power, kg/h | 18.97 | 18.8 | 18.6 | 17.84 | 18.91 | 18.1 | 18.5 | 19.29 | 17.2 |
| Specific fuel consumption at Max Drawbar Power, g/kW.h | 0.79 | 0.62 | 0.51 | 0.38 | 0.38 | 0.29 | 0.37 | 0.35 | 0.26 |
| Min specific fuel consumption, g/kW.h | 0.75 | 0.6 | 0.5 | 0.38 | 0.37 | 0.28 | 0.37 | 0.34 | 0.26 |
| Slip at Min specific fuel consumption, % | 7.78 | 6.7 | 7.0 | 7.8 | 13.2 | 10.2 | 7.9 | 5.6 | 7.7 |
| Fuel consumption Min specific fuel consumption | 15.71 | 16.84 | 17.47 | 17.84 | 18.29 | 17.4 | 18.5 | 17.6 | 16.8 |
| Drawbar Power at Min specific fuel consumption, kg/h | 20.87 | 27.78 | 35.08 | 46.79 | 49.22 | 61.27 | 50.05 | 51.71 | 64.69 |
| Speed at Min specific fuel consumption, km/h | 1.85 | 2.39 | 3.11 | 3.89 | 4.74 | 6.52 | 4.84 | 5.99 | 7.56 |
| Drawbar Pull at Min specific fuel consumption, kN | 40.5 | 42.0 | 40.6 | 43.3 | 37.4 | 33.8 | 40.2 | 31.1 | 30.8 |

**Table 4** Data of drawbar pull measured using system 2

| | Gear high | | | | | | Gear low | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
| Drawbar Pull at max power, kN | 48.9 | 46.5 | 43.7 | 43.2 | 36.8 | 33.5 | 40.0 | 34.8 | 29.1 |
| Speed at Max Drawbar Power, km/h | 1.77 | 2.31 | 2.94 | 3.9 | 4.9 | 6.72 | 4.94 | 5.9 | 7.7 |
| Slip at Max Drawbar Power, % | 11.83 | 9.44 | 11.99 | 8.42 | 10.61 | 7.94 | 7.8 | 6.76 | 7.8 |
| Max Drawbar Power, kW | 24.05 | 29.8 | 35.67 | 46.84 | 50.09 | 62.58 | 49.84 | 57.09 | 62.31 |
| Fuel consumption at Max Drawbar Power, kg/h | 18.97 | 18.8 | 18.66 | 17.84 | 18.2 | 18.4 | 18.5 | 19.22 | 18.8 |
| Specific fuel consumption at Max Drawbar Power, g/kW.h | 0.79 | 0.63 | 0.52 | 0.38 | 0.36 | 0.29 | 0.37 | 0.34 | 0.3 |
| Min specific fuel consumption, g/kW.h | 0.75 | 0.61 | 0.5 | 0.38 | 0.36 | 0.28 | 0.37 | 0.34 | 0.28 |
| Slip at Min specific fuel consumption, % | 7.85 | 6.2 | 5.97 | 8.42 | 10.6 | 10.6 | 7.8 | 4.97 | 13.7 |
| Fuel consumption Min specific fuel consumption | 15.71 | 16.55 | 16.9 | 17.84 | 18.2 | 17.3 | 18.5 | 18.6 | 16.8 |
| Drawbar Power at Min specific fuel consumption, kg/h | 20.85 | 27.1 | 33.59 | 46.84 | 50.09 | 61.6 | 49.84 | 53.47 | 6.27 |
| Speed at Min specific fuel consumption, km/h | 1.85 | 2.39 | 3.15 | 3.90 | 4.9 | 6.52 | 4.94 | 6.02 | 7.21 |
| Drawbar Pull at Min specific fuel consumption, kN | 40.5 | 40.8 | 38.4 | 43.2 | 36.8 | 34 | 40 | 32 | 30 |

ranged between 45-46 ºC, oil temperature ranged between 95-97 ºC and cool temperature was 81 ºC.

**Figs. 5** and **6** show the relationship between engine speed, fuel consumption, specific fuel consumption, PTO torque and PTO power for the two systems under study. The maximum value of PTO torque at low engine speeds of 1,310 and 1,300 rpm was 635 and 634 kN m for system 1 and system 2, respectively. The maximum value of PTO power at engine speeds of 2041 and 2,036 was 116 and 118 kW for system 1 and system 2, respectively.

## Effect of Tractor Forward Speed on Tractor Performance

The performance of the drawbar test was determined for forward speed and fuel consumption (kg/hr). **Tables 3** and **4** show the data for the drawbar test for systems 1 and 2 at two levels of speed (six gears were at low level speed and three gears were at high level speed). **Table 4** shows that the maximum drawbar power affected by drawbar pull using system 1 for gears (6th low gear, 3rd high gear). The maximum value of drawbar power at the lowest drawbar pull of 33.4 and 30.3 kN was 62.25 and 65.16 kW and at the highest forward speed of 6.7 and 7.75 km/hr for system 1, respectively. The minimum value of drawbar power at the highest drawbar pull using system 1 for gears (1st low, 2nd low) of (50.8 and 49 kN) was 14.59 and 23.95 kW and at the lowest forward speed of 1.03 and 1.76 km/hr for system 1, respectively.

**Table 5** shows the maximum power and maximum pull for systems 1 and 2. The maximum drawbar power affected by drawbar pull using system 1 for gears is parented in **Fig. 7** (6th low gear, 3rd high gear). The maximum value of drawbar power at the lowest drawbar pull (33.5 and 29.1 kN.m) was 62.58 and 62.31 kW and at the highest forward speed (6.72 and 7.7 km/hr) for system 2 and at (33.4 and 30.3 kN m) was 62.25 and 65.16 kW and at the highest forward speed of (6.7 and 7.75 km/hr) for system 1, respectively. The minimum drawbar power at highest drawbar pull us-

**Fig. 7** Drawbar power for different tractor gear using system 1

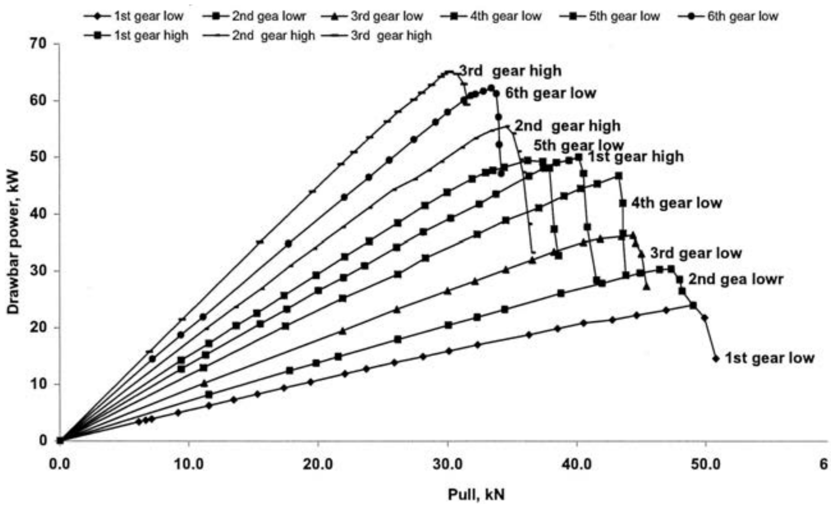



**Table 5** Maximum power and maximum pull

| | | System 2 | | | System 1 | | |
|---|---|---|---|---|---|---|---|
| | | Max Power, kW | Pull, kN | Speed, km/hr | Max Power, kW | Pull, kN | Speed, km/hr |
| Gear high | 1st | 24.05 | 48.9 | 1.77 | 24.04 | 49 | 1.77 |
| | 2nd | 29.8 | 46.5 | 2.31 | 30.42 | 47.4 | 2.31 |
| | 3rd | 35.67 | 43.7 | 2.94 | 36.3 | 44.4 | 2.94 |
| | 4th | 46.84 | 43.2 | 3.9 | 46.79 | 43.3 | 3.89 |
| | 5th | 50.09 | 36.8 | 4.9 | 49.22 | 37.4 | 4.74 |
| | 6th | 62.52 | 33.5 | 6.72 | 62.25 | 33.4 | 6.7 |
| Gear low | 7th | 49.84 | 40 | 4.49 | 50.05 | 40.2 | 4.48 |
| | 8th | 57.09 | 34.8 | 5.9 | 55.45 | 34.6 | 5.77 |
| | 9th | 62.31 | 29.1 | 7.7 | 65.16 | 30.3 | 7.75 |
| | | Max Pull, kN | Power, kW | Speed, km/hr | Max Pull, kN | Power, kW | Speed, km/hr |
| Gear high | 1st | 50.8 | 14.46 | 1.02 | 30.42 | 14.59 | 1.03 |
| | 2nd | 48.9 | 23.94 | 1.76 | 49 | 23.95 | 1.76 |
| | 3rd | 45.4 | 27.07 | 2.15 | 45.4 | 27.35 | 2.17 |
| | 4th | 43.9 | 29.41 | 2.41 | 43.8 | 29.29 | 2.41 |
| | 5th | 38.1 | 32.37 | 3.06 | 38.6 | 32.75 | 3.05 |
| | 6th | 34.3 | 47.36 | 4.97 | 34.2 | 47.15 | 4.96 |
| Gear low | 7th | 41.6 | 28.6 | 2.47 | 41.5 | 28.42 | 2.46 |
| | 8th | 36.7 | 33.57 | 3.29 | 36.5 | 33.24 | 3.27 |
| | 9th | 30 | 56.41 | 6.77 | 31.6 | 59.33 | 6.77 |

ing system 2 and system 1 for gears (1st, 2nd) was 50.8 and 48.9 kN m was 14.46 and 23.94 kW, and at the lowest forward speeds of (1.02 and 1.76 km/hr) for system 2 and 50.8 and 49kN m was 14.59 and 23.95 kW and at the lowest forward speed (1.03 and 1.76 km/hr) for system 1, respectively.

## Conclusion

- The preliminary data showed no significant difference between the modified system (system 1) and the system used in the tractor test station (system 2).
- The modified system was expected to be a worthy one to establish reliable data of the performance parameters of tractors and implements.

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**Editors Note**

With great sorrow, we annouce the sad demise of Dr. Samir Younis, writer of the papers from p.7 to p.18.

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# Determination of Engineering Properties of *Jatropha Curcas L.*

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## Abstract

Handling losses during threshing and mechanical conveying of Jatropha are affected by the size, shape and engineering properties of Jatropha seed. These parameters were studied for 5 varieties of Jatropha Shu 03001, Shu 03002, Shu 03004 , Shu 03005 and Shu 04004. Physical measurements of the size along three perpendicular axes were made. The average size of the Jatropha seed varied according to variety. The average length was maximum for Shu 03005 and the average width and average thickness was maximum for Shu 03001. Overall dimensions were minimum for Shu 03004 and maximum for Shu 03001. Equivalent diameter was minimum for Shu 03002 and maximum for Shu 03001. Specific surface area was minimum for Shu 03001 and maximum for Shu 03004. Sphericity was minimum for Shu 03004 and maximum for Shu 03001. Average value of angle of repose for Jatropha was 33.824 degrees. The test weight was maximum for Shu 03005 and was minimum for Shu 04004. The average value of bulk density of Jatropha seed was minimum for Shu 03001 and was maximum for Shu 03004. True density was minimum for Shu 03001 and maximum for Shu 04004. Porosity was minimum for Shu 03004 and maximum for Shu 04004. Angle of internal friction with wooden and smooth mild steel surface was maximum for Shu 03001 and for corroded mild steel surface it was maximum for Shu 03005. Weight of a single seed was maximum for Shu 03005 and minimum for Shu 03001. A reverse trend was observed for hardness. It was concluded that the cylinder concave clearance for design of a thresher depended on the overall dimension of seed. This clearance should not be less than 13.489 mm for a Jatropha thresher. Impact force should be less than 6.026 kg for threshing without damage of Jatropha seed with the thresher. These results provided the necessary information for designers of equipment for handling, sorting, grading and threshing machinery of Jatropha seed. From this study it was recommended that the minimum cylinder-concave clearance should be 13.489 mm to avoid breakage of seed during threshing and the impact force should be less than 6.026 kg for threshing of Jatropha without damage.

## Introduction

Jatropha curcas is a multipurpose bush/small tree belonging to the family of Euphorbiaceae. Jatropha curcas plants grow on poor degraded soils and are able to ensure a reasonable production of seeds with very little input. It is not grazed by animals and is highly pest and disease resistant. It is a small tree or shrub with smooth gray bark, which exudes a whitish colored, watery, latex when cut. Normally, it grows between three and five meters in height, but can attain a height of up to eight or ten meters under favourable conditions.

Climatically, *Jatropha curcas (Ratnajyot)* is found in the tropics and subtropics and likes heat, although it does well even in lower temperatures and can withstand a light frost. Its water requirement is extremely low and it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss. *Jatropha curcas (Ratnajyot)* is also suitable for preventing soil erosion and shifting of sand dunes.

It is significant to point out that, the non-edible vegetable oil of *Jatropha curcas (Ratnajyot)* has the requisite potential of providing a promising and commercially viable alternative to diesel oil since it has desirable physicochemical and performance characteristics comparable to diesel. Cars could be run with *Jatropha curcas (Ratnajyot)* without requiring much change in design. Fruits are produced in winter when the shrub is leafless, or it may produce several crops during the year if soil moisture is good and temperatures are sufficiently high. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits. Time taken for nut yield is between 2 and 5 years based on soil and rainfall conditions. Yield varies from 0.5 to 12 T/hectare based on soil and rainfall condition. An average seed production of about 5 tonnes per hectare can be expected under optimum condition. A yield of 0.75 to 2 tonnes of biodiesel could be expected per hectare per year from fifth year onwards to 40 years. Jatropha cultivation generates an income of Rupees (Rs). 25,000 per hectare in a year. In India 200 districts in 19 states have been identified on the basis of availability of wasteland, rural poverty ratio, below poverty line (BPL) census and agro-climatic condition suitable for jatropha cultivation. Each district will be treated as a block and under each block 15,000 hectare jatropha plantation will be undertaken through coverage to about 3 million hectare of wasteland through plantation of Jatropha in 200 identified districts over a period of 3 years.

All attempts to increase its production and productivity, oil extraction by application of appropriate technology, product development and diversification and policies that will protect and promote national interest would be welcome. Undertaking a plantation of *Jatropha curcas (Ratnajyot)*, collection of seed and processing of seeds for producing oil will be a part of processing it to biodiesel. The oil cake is rich in nutrients and will give bio-gas and very good compost for our soils which are getting increasingly deficient in carbon and nutrients. Every component of the programme will generate massive employment for the poor belonging to the Scheduled Tribes, Scheduled castes and other underprivileged categories living mostly in backward areas which have experienced the adverse impact of forest degradation, and loss of natural resources.

Assuming oil content of 35% and 94% extraction, one hectare of plantation will give 1.6 MT of oil if the soil is average, 0.75 MT if the soil is lateritic, and 1.0 MT if the soil is of the type found in Kutch (Gujarat). One hectare of plantation on average soil will, on an average, give 1.6 Metric tones of oil. Plantation per hectare on poorer soils will give 0.9 MT of oil.

Keeping the above utilization of Jatropha into mind, it is desirable that a scientific study to determine the physical and rheological properties be made for designing a thresher and oil extraction plants.

## Materials and Methods

Determination of physical properties of five varieties of Jatropha was made in the laboratory by using standard methods. The following parameters of different physical properties were determined.

**Dimension of Seed**

Dimension of seed was determined using a vernier caliper having least count of 0.001 mm by taking a sample of 1000 seeds. This parameter helped in deciding the size of seed hopper.

**Overall Dimension**

To determine overall dimension of five varieties of Jatropha, values of length, width and thickness were used. The overall dimension was determined using the following **Eqn.**:

Overall dimension = $(abc)^{1/3}$

Where,

a = Length of seed, mm

b = Width of seed, mm and

c = Thickness of seed, mm

**Equivalent Diameter**

For determination of equivalent diameter of five varieties of Jatropha seed, length, width and thickness of different varieties was used. The equivalent diameter was determined by the following **Eqns.**:

$$\text{Equivalent diameter} = (F_1 + F_2 + F_3) / 3$$

Where,

$$F_1 = (a + b + c) / 3,\ F_2 = (abc)^{1/3} \text{ and } F_3 = \{(ab + bc + ca) / 3\}^{1/2}$$

a = Length of seed, mm

b = Width of seed, mm and

c = Thickness of seed, mm

In this paper, the above equation was employed to compute the sphericity.

**Specific Surface Area**

Specific surface area of the different varieties of Jatropha seed was determined using the **Eqn.**:

$$\text{Specific surface area} = 6/D_E$$

Where,

$D_E$ = Equivalent diameter, mm

**Sphericity**

Sphericity expresses the shape character of the grain relative to that of a sphere of the same volume (Mohsenin, 1980) and is defined as:

$$\text{Sphericity} = d_c / d_e$$

Where,

$d_c$ = Diameter of a sphere of the same volume as that of grain

$d_e$= Diameter of the smallest circumscribing sphere or the longest diameter of the grain

For determination of sphericity of different varieties of Jatropha seed, the seed is considered to be a triaxial ellipsoid with length, width and thickness as intercepts a, b and c, respectively. Sphericity of Jatropha seed was determined using following **Eqn.**:

$$\text{Sphericity} = (abc)^{1/3} / a$$

Where,

a = Length of seed, mm

b = Width of seed, mm and

c = Thickness of seed, mm

**Angle of Repose**

Angle of repose is defined as the

angle with the horizontal made when a granular material is allowed to flow freely from a point in to a pile. The apparatus for measuring angle of repose consisted of a conical hopper mounted above a circular base plate. A scale was attached to this setup for measuring the height of heap above the base. The sprouted seeds were poured through the conical hopper so that it formed a conical heap on the base plate. The pouring of sprouted seeds was continued till the base plate was completely filled and the excess seeds started dropping downward from the base plate. The pointer attached with scale was lowered down till it touched the top of the heap again and then the final reading of the scale was taken. The difference in these two readings gave the height of the heap. The angle of repose was determined using the following **Eqn.**:

$$\text{Angle of repose } (\varphi r) = \tan^{-1} \times (2h / D_p)$$

where,

h = Height of heap, cm

$D_p$= Diameter of the base plate, cm

**Table 1** Average values of selected engineering properties for five varieties of Jatropha curcas L. (Ratanjyot) seed

| Parameters | Varieties | | | | |
|---|---|---|---|---|---|
| | Shu 03001 | Shu 03002 | Shu 03004 | Shu 03005 | Shu 04004 |
| Length, mm | 17.786 | 16.690 | 16.332 | 17.946 | 17.816 |
| Width, mm | 11.674 | 10.516 | 10.284 | 11.494 | 11.018 |
| Thickness, mm | 8.888 | 8.362 | 8.140 | 8.716 | 8.842 |
| Overall dimension, mm | 12.27 | 11.36 | 11.15 | 12.16 | 12.02 |
| Equivalent diameter, mm | 12.520 | 11.604 | 11.399 | 12.433 | 12.280 |
| Specific surface area, mm | 0.479 | 0.517 | 0.526 | 0.483 | 0.489 |
| Sphericity | 0.690 | 0.681 | 0.674 | 0.678 | 0.675 |
| Angle of Repose, degree | - | - | - | - | - |
| Thousand seed weight, g | 559.6 | 596.7 | 602.8 | 747.2 | 651.2 |
| Bulk density, g/cc | 0.3098 | 0.3993 | 0.4239 | 0.4089 | 0.3509 |
| True density, g/cc | 0.63 | 0.68 | 0.72 | 0.70 | 0.75 |
| Porosity, % | 50.825 | 41.279 | 41.125 | 41.586 | 53.213 |
| Angle of internal friction, degree | | | | | |
| a. Wood surface | 32.00 | 29.97 | 27.83 | 29.79 | 29.46 |
| b. Smooth mild steel surface | 30.71 | 29.60 | 29.09 | 29.17 | 29.03 |
| c. Corroded mild steel surface | 32.29 | 30.98 | 31.35 | 33.99 | 32.82 |
| Single seed weight, g | 0.559 | 0.597 | 0.603 | 0.747 | 0.651 |
| Hardness, kg | 5.88 | 6.62 | 8.03 | 4.38 | 5.22 |

**Test Weight of Seed**

The test weight of seed was determined in the laboratory by counting 1,000 seeds manually and weighing them with an electronic balance.

**Bulk Density**

In order to determine the bulk density of seed, the volume of seed was determined by filling the seeds in a measuring cylinder up to a certain level. Thereafter, the seeds were taken out and weighed on an electronic balance. The bulk density of the seed was determined as follows:

$$\text{Bulk Density (g/cc)} = M/V$$

where,

M = Weight of seed in sample, g

V = Volume of seed in sample, cc

$$\text{Volume of seed (V), cc} = \pi/4 \times D^2L$$

where,

D = Diameter of cylinder, cm

L = Height of cylinder, cm

**True Density**

In order to determine the true density of seed, the measuring cylinder was filled with water to a certain level. After that weighed seed (single) was poured into the measuring cylinder, which is already filled with water. The difference in the level of water before pouring and after pouring of seed gave the volume of water displaced with single seed. After measuring the volume of water displaced with each seed and weight, true density of the jatropha seed was determined by the following **Eqn.**:

**Porosity**

Porosity is the ratio of the volume of the pores to the total volume. The porosity of the seed sample was determined from the bulk density and true density values by the equation given below:

$$\text{Porosity, } (\in) = \{1 - (p_b / p_t)\} \times 100$$

Where,

$\in$ = Porosity, %

$p_b$ = bulk density

$p_t$ = true density

**Angle of Internal Friction**

For determination of angle of internal friction of different variety of Jatropha seed, a tilting table top setup was used. It consists of a supporting wooden plank fixed on two adjustable screws and two wooden blocks. Another wooden plank 620 × 280 × 15 mm was hinged to one end of the lower plank. The seed container used was a square wooden box 300 × 300 × 25 mm. The surface of the grain was levelled. The surface was raised gradually using the screw device until the box just started sliding down. The angle of tilt was measured. The tangent of angle with the horizontal was angle of internal friction. The experiments were conducted for different variety of Jatropha seed and with different surfaces (wood, smooth mild steel sheet and corroded mild steel sheet).

**Weight of Single Seed**

The weight of single seed of different varieties of Jatropha was determined in the laboratory by counting 1,000 seeds manually and weighing them with an electronic balance.

**Hardness (Breaking Strength)**

The hardness of the individual

**Table 2** Summary of physical measurement taken to determine the size of Jatropha seed

| Variety | Length | | Width | | Thickness | | Overall dimension | |
|---|---|---|---|---|---|---|---|---|
| | Mean, mm | Standard deviation | Mean, mm | Standard deviation | Mean, mm | Standard deviation | Mean, mm | Standard deviation |
| Shu 03001 | 17.786 | 0.474637 | 11.674 | 0.573157 | 8.888 | 0.418712 | 12.27 | 0.406362 |
| Shu 03002 | 16.690 | 0.721526 | 10.516 | 0.434488 | 8.362 | 0.424464 | 11.36 | 0.418175 |
| Shu 03004 | 16.552 | 0.521124 | 10.284 | 0.34195 | 8.148 | 0.184986 | 11.15 | 0.186601 |
| Shu 03005 | 17.946 | 0.817912 | 11.494 | 0.498026 | 8.716 | 0.360181 | 12.16 | 0.344064 |
| Shu 04004 | 17.816 | 0.615614 | 11.018 | 0.453178 | 8.842 | 0.702723 | 12.02 | 0.570456 |

seed of different varieties of Jatropha was determined by a hardness tester. The seeds were subjected to forces perpendicular to cleavage plane. The seed was placed below the ram of the hardness tester after that the ram was lowered down manually until it breaks the seed. After breaking of seed the force required to break the seed was noted from dial of hardness of the tester in kg.

## Results

Experiments were conducted to determine some selected physical properties of five varieties of jatropha in the laboratory of the department of Farm Machinery and Power Engineering and in the department of Post Harvest Process and Food Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar using standard methods. The following parameters of different physical properties for various varieties of Jatropha were determined.

### Dimension of Seed

Dimension of seed was determined using a Vernier Caliper having a least count of 0.001 mm by taking a sample of 1000 seeds in one replication. The average length of Shu 03001, Shu 03002, Shu 03004 and Shu 03005, Shu 04004 varieties were 17.786, 16.690, 16.552, 17.946 and 17.816 mm, respectively. The average value of width for the five varieties were 11.674, 10.516, 10.284, 11.494 and 11.018 mm, respectively, with average value of thickness of 8.888, 8.362, 8.148, 8.716, 8.842 and 8.974 mm for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively (**Table 1**). The length (average) was maximum for Shu 03005, width (average) was maximum for Shu 03001 and the average value of thickness was maximum for Shu 03001 (**Fig. 1**).

### Overall Dimension

For the overall dimension of five varieties of jatropha, values of length, width and thickness were used. The overall dimension for different varieties was determined using equations as discussed in the section on materials and methods. The overall dimensions for five varieties of jatropha were 12.27, 11.36, 11.15, 12.16 and 12.02 mm, respectively for Shu 03001, Shu 03002, Shu 03004, Shu 03005, Shu 04004 (**Table 1**). The average minimum and maximum values were 11.15 mm for Shu 03004 and 12.27 mm for Shu 03001, respectively (**Fig. 2**).

### Equivalent Diameter

For determination of equivalent diameter of five varieties of jatropha seed, length, width and thickness of different varieties was used. The equivalent diameter was determined with the equations discussed in the section on materials and method. Average values of equivalent diameter for different variety of seed were 12.520, 11.590, 11.604, 11.399, 12.433 and 12.280 mm for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively (**Table 1**). From **Table 2** it is clear that the average value of equivalent diameter was minimum for Shu 03002 variety and maximum for

**Fig. 1** Effect of varieties on dimension of seed

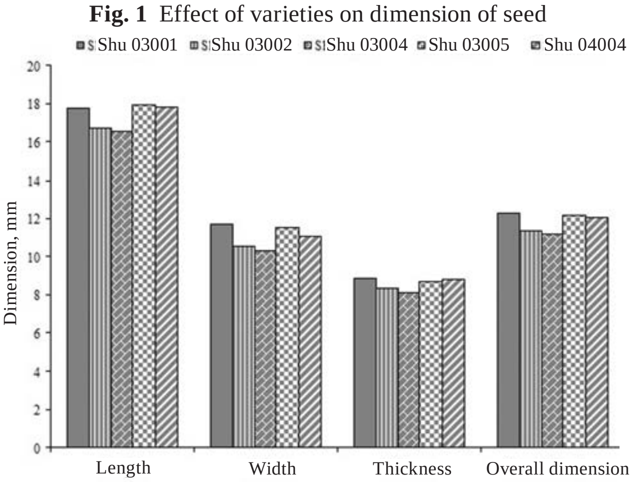
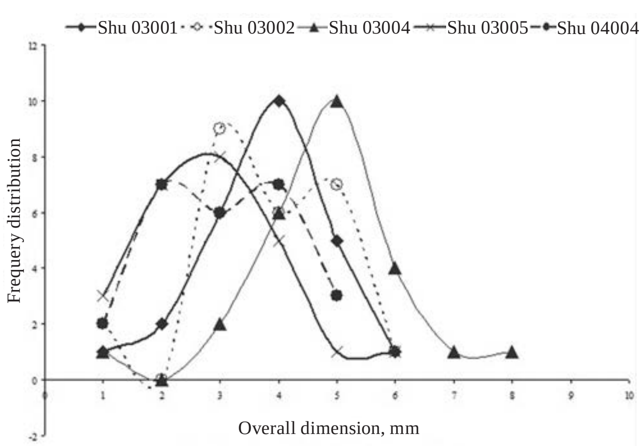



**Fig. 2** Effect of overall dimension on frequency of seed



Shu 03001 variety. It is also clear from the **Fig. 3** that the above values of minimum and maximum were the same as discussed above.

### Specific Surface Area

Specific surface area of the different varieties of jatropha seed was determined using the equation as described in section of materials and methods. The value of specific surface area for all (five) varieties were 0.479 mm for Shu 03001, 0.517 mm for Shu 03002, 0.526 mm for Shu 03004, 0.483 mm for Shu 03005 mm and 0.489 mm for Shu 04004 (**Table 1**). From values of specific surface area (**Fig. 3**), the average minimum value was 0.479 mm for Shu 03001 and maximum for Shu 03004.

### Sphericity

Sphericity expresses the shape character of the grain relative to that of a sphere of the same volume. For determination of sphericity of different varieties of jatropha seed, the seed was considered to be a triaxial ellipsoid with length, width and thickness as intercepts a, b and c, respectively. The values of sphericity for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004 were 0.690, 0.681, 0.674, 0.678 and 0.675 mm, respectively (**Table 1**). From **Table 1** and **Fig. 4** the range of sphericity from minimum to maximum was 0.674 to 0.690 mm.

### Angle of Repose

Angle of repose is defined as, the angle which the side of the pile makes with the horizontal when a granular material is allowed to flow freely from a point into a pile. The average value of angle of repose for Jatropha was 33.824 degrees (**Table 1**).

### Test Weight of Seed

The test weight of seed was determined in the laboratory by counting 1000 seeds manually and weighing them with an electronic balance. The average value of test weight was 559.6, 596.7, 602.8, 747.2 and 651.2 gm for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively (**Table 1**). It was also

**Fig. 3** Effect of varieties on equivalent diameter and surface area of seed

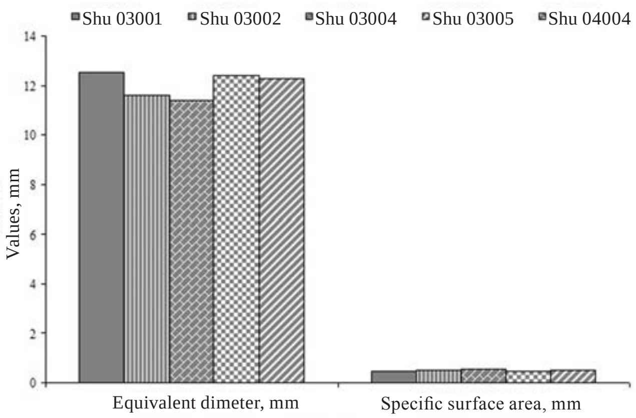



**Fig. 4** Effect of varieties on Sphericity of seed

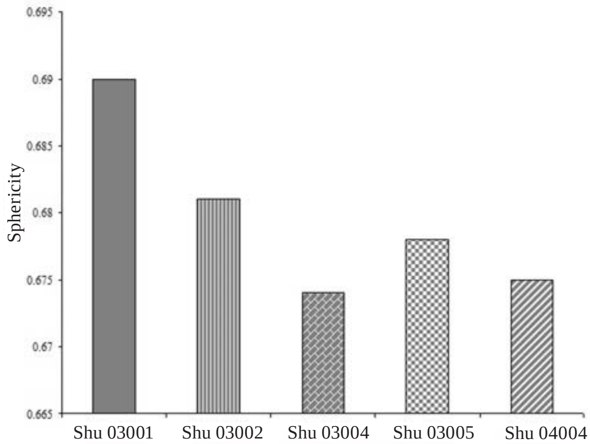



**Fig. 5** Effect of varieties on thousand seed weight

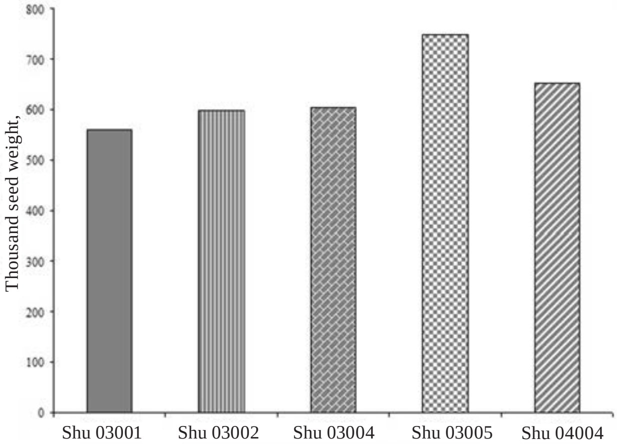
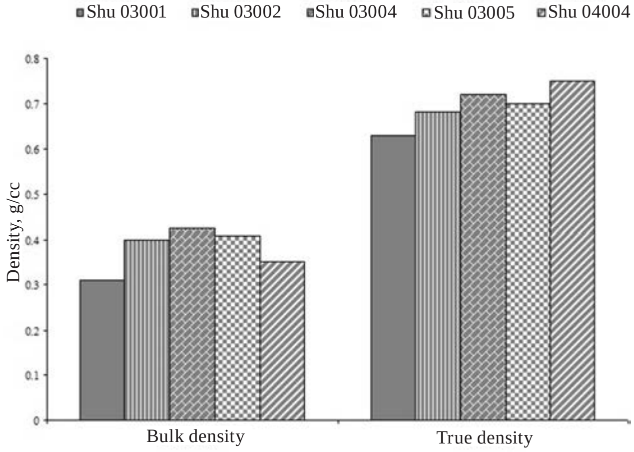



**Fig. 6** Effect of varieties on bulk density and true density of seed



clear from **Table 1** and **Fig. 5** that the test weight was maximum for Shu 03005 and minimum for Shu 04004.

### Bulk Density

In order to determine the bulk density of seed, the standard method was used as discussed in the section on materials and methods. The bulk density for five varieties of Jatropha seed was 0.3098, 0.3993, 0.4239, 0.4089 and 0.3509 g/cc for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively (**Table 1**). **Fig. 6** shows that the average value of bulk density of jatropha seed was minimum for Shu 03001 and maximum for Shu 03004.

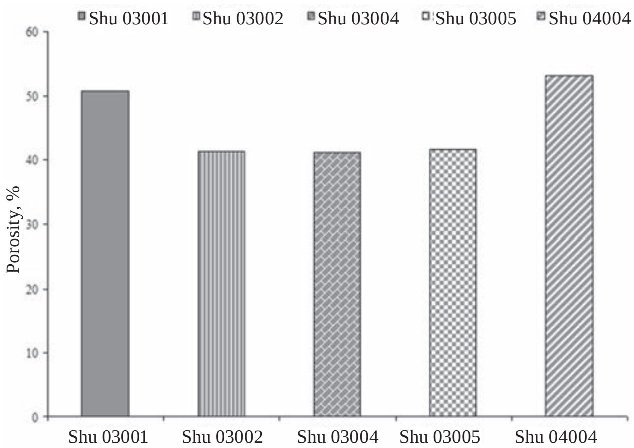
### True Density

To determine the average value of true density of Jatropha seed, samples were taken for different varieties and was 0.63, 0.68, 0.72, 0.70 and 0.75 g/cc for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively (**Table 1** and **Fig. 6**). True density was minimum for Shu 03001 and it maximum for Shu 04004.

### Porosity

The porosity of the seed sample was determined from the bulk density and true density values. The average values of Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004 were 50.825, 41.279, 41.125, 41.586 and 53.213, respectively (**Table 1** and **Fig. 7**). From the above discussion porosity was minimum for Shu 03004 and maximum for Shu 04004.

**Fig. 7** Effect of varieties on porosity of seed




### Angle of Internal Friction

To determine angle of internal friction, three different surfaces such as wood, smooth mild steel and corroded mild steel were taken and the seed were allowed to slide on these three surfaces as discussed in the section on materials and methods. **Table 1** shows the values of angle of repose for different varieties of Jatropha seed. The average value of angle of internal friction for wood surface was 32.00, 29.97, 27.83, 29.79 and 29.46 degrees, respectively, for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004. For smooth mild steel surface the average values of internal friction were 30.71, 29.60, 27.10, 29.17 and 29.03 degrees for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively, and 32.29, 30.98, 31.35, 33.99 and 32.82 degrees for corroded mild steel sheet for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004, respectively. It is clear from **Fig. 8** that the angle of internal friction with wooden and smooth mild steel surface was maximum for Shu 03001 and for corrugated mild

**Fig. 8** Effect of varieties on and surfaces on angle of internal friction of seed

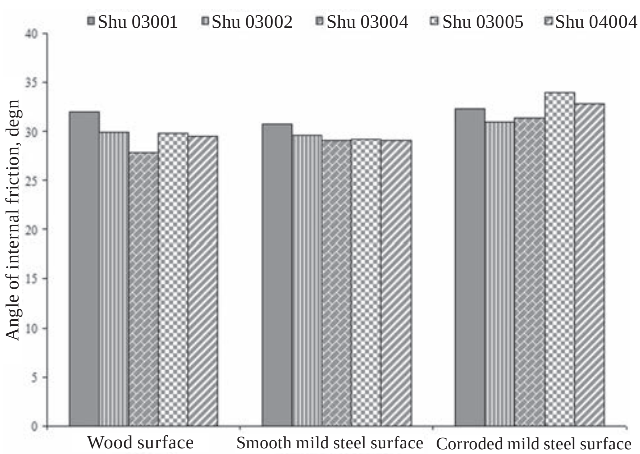
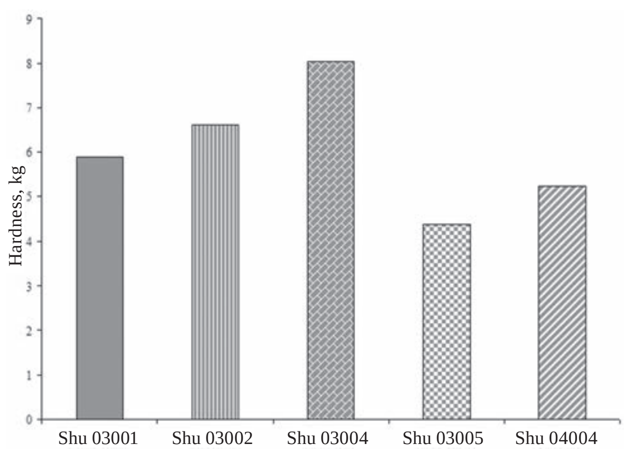



**Fig. 9** Effect of varieties on hardness of seed



steel surface it was maximum for Shu 03005.

**Weight of Single Seed**

The weight of a single seed of different varieties of Jatropha was determined in the laboratory with an electronic balance. It was determined that the average value of single seed for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004 were 0.5596, 0.5967, 0.6028, 0.7472 and 0.6512 gm, respectively (**Table 1**). Weight of a single seed was maximum for Shu 03005 and minimum for Shu 03001.

**Hardness (Breaking Strength)**

Hardness represents the minimum amount of force required to break the seed. It is necessary to know the hardness of seed for designing of the agricultural machinery for threshing of crop and other works related with design of equipments/machinery. The average value of hardness for Shu 03001, Shu 03002, Shu 03004, Shu 03005 and Shu 04004 was 5.88, 6.62, 8.03, 4.38 and 5.22 kg, respectively (**Table 1**). **Fig. 9** shows that the force requirement to break the jatropha seed is minimum for Shu 03001 and maximum for Shu 03005.

## Discussion

The average values of length, width, thickness and overall dimension of seed were maximum for Shu 03001 and minimum for Shu 03004. This may be due to the fact that the Shu 03001 variety was bigger than other varieties and Shu 03004 variety was smaller in comparison to all other varieties of Jatropha seeds. The average value of equivalent diameter and sphericity was maximum for Shu 03001 variety and the above value was minimum for Shu 03004. Specific surface area was maximum for Shu 03004 and minimum for Shu 03001. Sphericity of Shu 03001 variety was maximum due to the reason that the above variety was more spherical in shape than all others. Average value of a thousand seed weight was maximum for Shu 03005 that may be due to the fact that the weight of a single seed was more than the other varieties. Average value of bulk density and true density was maximum for Shu 03004 and Shu 04004 varieties but the above properties were minimum for Shu 03001. Minimum porosity and true density of this variety may be due to more pore spaces and less surface area of seeds. Average value of porosity was maximum for Shu 04004 and minimum for Shu 03004. It was almost the same for all other varieties than Shu 03001 and Shu 04004. Average value of angle of repose was almost the same for all the varieties of Jatropha seeds and the average value of angle of internal friction with wooden surface was maximum for Shu 03001 and minimum for Shu 03004. With smooth mild steel surface the above value was again maximum for same variety but minimum for Shu 04004 and with corroded mild steel surface. The above value was maximum for Shu 03005 and minimum for Shu 03003. The difference in angle of internal friction of same variety with different surfaces may be due to the different cohesion with different surfaces and same adhesion properties of seeds and surfaces. The average value of hardness of seed was maximum for Shu 03005 and minimum for Shu 03001. The results were similar for a thousand seed weight. This may be due to the fact that the Shu 03005 variety was harder than other all varieties studied.

The limits $\bar{x} \pm \sigma$ contain 68.27 percent, $\bar{x} \pm 2\sigma$ contain 95.45 percent and the limit $\bar{x} \pm 3\sigma$ contain 99.73 percent of the total Jatropha seed having a normal frequency distribution. These results were used to calculate the cylinder-concave clearance and concave openings of the thresher. For instance the clearance distance of at least $\bar{x} \pm 2\sigma$ i.e. 13.082724 mm would be desirable to allow 95.45 percent of the Jatropha to pass through the concave without damage while a clearance of $\bar{x} \pm 3\sigma$ i.e. 13.489086 mm will be required to allow 99.73 percent of the seed to pass without damage considering the largest dimension of Jatropha seed.

## Conclusions

1. The average length was maximum for the Shu 03005 variety and average width was maximum for Shu 03001 variety with the average value of thickness being maximum for Shu 03001 variety of jatropha seed.
2. Overall dimensions were minimum for Shu 03004 and maximum for Shu 03001 variety. Equivalent diameter was minimum for Shu 03002 variety and maximum for Shu 03001. Specific surface area was minimum for Shu 03001 and maximum for Shu 03004.
3. Sphericity was minimum for Shu 03004 and maximum for Shu 03001 variety. Average value of angle of repose for Jatropha was 33.824 degrees. Test weight was maximum for Shu 03005 and minimum for Shu 04004. Average value of bulk density of Jatropha seed was minimum for Shu 03001 and was maximum for Shu 03004. True density was minimum for Shu 03001 and maximum for Shu 04004.
4. Porosity was minimum for Shu 03004 and maximum for Shu 04004. Angle of internal friction with wooden and smooth mild steel surface was maximum for Shu 03001 and, for corrugated mild steel surface. It was maximum for Shu 03005. Weight of a single seed was maximum for Shu 03005 and minimum for Shu 03001. Hardness of jatropha seed was minimum for Shu 03001 and maximum for Shu 03005.

5. The cylinder concave clearance for design of the thresher depended on the overall dimensions of seed. The clearance should not be less than 13.489 mm for a jatropha thresher (**Table 2**). Impact force should be less than 6.026 kg for threshing without damage of Jatropha seed with thresher.

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# New Co-operating Editors

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# Optimization of Energy Inputs for Gram Production under Different Farming Systems in Madhya Pradesh

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## Abstract

The use of energy resources has increased greatly with the advancement in technology and agricultural development,. Traditional or low energy farming is being substituted by modern energy intensive farming wherever feasible in order to meet the growing demand for agricultural products, particularly food. The choice of energy resources has been dynamic due to preferences to chemical inputs and electro-mechanical power sources. A survey was conducted under the All India Coordinated Research Project on "Energy Requirements in the Agricultural Sector" for energy audit on crop production activity. A whole village approach was used in the different villages of Madhya Pradesh. In order to distinguish between the cultivation practices used by the farmers in the villages surveyed, the farms were grouped as follows: (a) irrigated, and (b) rainfed farms. Further sub-classification was done based on the power source used as (i) animal farms (using animal as draught power source), (ii) mixed farms (using animal and tractor as draught power) and (iii) tractor farms. Linear programming technique was used to determine the optimal energy inputs for maximum yield obtainable from the given data set of energy inputs used by the farmers and corresponding yields. Due to use of tractors with matching implements in mixed and tractor farms, machinery energy consumption on these farms was higher than that in animal farms. The mixed and tractor farms consumed 1.13 and 1.41 times higher machinery energy than the animal farms. The animal farms, consequently, had the highest renewable energy consumption (2,534 MJ/ha) while tractor farms had highest non-renewable energy consumption (4,971 MJ/ha and 2.5 times that of animal farms). The operational energy consumption patterns and energy resource allocation among the unit operations had been different in three farming systems. With the use of electro-mechanical power sources, the tractor farms had consumed the highest energy in the unit operations followed by mixed farms (using a mix of electro-mechanical and animal power source) and animal farms operating with only animal power. The energy consumption patterns in the present three farming systems indicated the changing energy resource use patterns with progressive mechanization. The quantum of indirect energy consumed in animal and mixed farms were similar while direct energy consumption in mixed farms was higher than animal farms. Use of direct and indirect energy was highest in the tractor farms. In the present cultivation system providing about 37 percent of potential yield, the reliance on commercial energy resources was high, and likely to further increase with increase in crop productivity. With increase in adoption of mechanization, demand of non-renewable energy resources were expected to increase significantly.

## Introduction

Madhya Pradesh state is situated in the central part of India. Gram is the major pulse crop in Madhya Pradesh and is mainly sown in October-November and harvested in February-March. The popularity of the crop has increased in the last 10 years because of its higher market price as compared to cereal crops. With the advancement in technology and agricultural development, the use of energy resources has increased greatly. Traditional or low energy farming is being substituted by modern energy intensive farming wherever feasible in order to meet the growing demand for agricultural products, particularly food. The choice of energy resources has been dynamic due to preferences in chemical inputs and electro-mechanical power sources. The use of non-renewable energy sources has been increasing in the process. The situation, therefore, demands exploring alternative energy-efficient systems for agricultural production so as to make agriculture energy-efficient and sustainable.

A farm is both an energy consumer and a producer, because with the use of different energy inputs. Energy output is produced in form of crop produce. Farming, thus, is a conversion process of energy in harnessing the yield potentialities in farm production. All farm inputs and operations in crop production require energy inputs in various forms and in varying magnitude. The pattern of utilizing the energy inputs in farm production is closely linked with the extent of their uses, cropping pattern and cropping intensities. Besides, energy invested and output derived varies with the individual farmer due to variation in inputs used and cultivation practices followed.

With the advancement in technology and agricultural development, the use of energy resources has increased greatly. Traditional or low energy farming is being substituted by modern, energy intensive farming wherever feasible in order to meet the growing demand for agricultural products, particularly food. The choice of energy resources has been dynamic due to preferences to chemical inputs and electro-mechanical power sources. The use of non-renewable energy sources has been increasing in the process. The situation, therefore, demands exploring alternative energy-efficient systems for agricultural production so as to make agriculture energy-efficient and sustainable. The paper attempts to (1) examine the existing energy input-output pattern for gram production in Madhya Pradesh; (2) estimate the optimal energy requirements at existing as well as improved level of technology; and (3) to estimate optimal allocation of energy inputs at different levels of productivity.

## Data and Methodology

On the basis of broad land features, the State is classified into five physiographic regions namely Northern low lying plains, Malwa and Vindhya plateau, Narmada valley, Satpura stretch, and Bastar plateau. It exhibits a great deal of diversity with areas ranging from less than 50 metres above mean sea level to more than 1,200 metres. Based on rainfall patterns, temperature, soil types and existing cropping patterns, ten agro-climatic zones have been identified in the state. The agro-climatic zones are Bastar Plateau Zone, Kymore Plateau and Satpura Hill Zone, Vindhya Plateau Zone, Central Narmada Valley Zone, Gird Zone, Bundelkhand Zone, Satpura Plateau Zone, Malwa Plateau Zone, Nimar Valley Zone and Jhabua Hill Zone.

A survey was conducted under the All India Coordinated Research Project on “Energy Requirements in Agricultural Sector” for energy audit on crop production activity considering whole village approach in different villages of Madhya Pradesh. In order to distinguish between the cultivation practices used by the farmers in the villages surveyed, the farms have been grouped in (a) irrigated, and (b) rainfed farms. Further sub-classification has been done based on power source use as (1) animal farms (using animal as draught power source), (2) mixed farms (using animal and tractor as draught power) and (3) tractor farms.

Necessary statistical techniques were applied for identification of outlier points, which were deleted for further analysis. A data point was considered as outlier if standardized residual value was beyond the +/− 3.

The physical values of different energy inputs used by the individual farmers were converted to mega joule (MJ) units by using energy co-efficients (**Table 1**). Energy consumed in each farm operation by each farmer was also calculated. In order to examine the energy use efficiency of various energy inputs used by the farmers on crop production, linear multiple regression function of the following form was used:

$y = b_i . x_i \ (i = 1, 2 \ldots \ n)$,

where,

$b_i$ = regression co-efficients or production elasticity

$x_i$ = energy inputs,

$n$ = number of energy inputs.

The value of co-efficient of multiple determination ($R^2$) for the fitted model was significant at 1 percent level, indicating that the linear multiple regression model was a good fit, and the model explained a significant amount of variation in the yield.

## Energy Optimizing Model

Since the production model was found to be linear in character, linear programming technique was used to determine the optimal energy inputs for maximum yield obtainable from the given data set of energy inputs used by the farmers and corresponding yields obtained.

Linear programming technique has been applied for crop production system analysis by different researchers. Major areas of application include allocation of labour employment (Desai, 1960; Sharma and Malik; Srivastava, 1984), land allocation among competitive crops (Bender *et al.*, 1984), cultivation practice optimizations (Al-Soboh *et al.*, 1986; Chang *et al.*, 1982), machinery use planning (Ozkan *et al.*, 1981; Von Bargen, 1980), land farm planning for minimum soil movement (Sirohi and Gangwar, 1968), governmental resource allocation for agriculture conservation programmes (Loftis and Ward, 1980). The technique has also been used in optimization of either farm return or energy use by different researchers (Adlakha, 1996; Anon., 1998; De *et al.*, 2001; Khan, *et al.*, 1984; Singh, 2010; Sowell *et al*., 1980) by considering energy consumption or other relevant parameters.

In the present study, the objective function considered the data of energy usage and productivity of each farmer of the data set as a separate activity.

Let $X_i$ denote the area allocated according to the energy usage of activity in hectares and $Y_i$ denote the yield (kg/ha) from the activity, i. Then the objective function is:

$$maximize\ \ yield = \sum_{i=1}^{n} Y_i X_i$$

***subject to the following constraints:***

$$A_1 \le \sum_{i=1}^{n} h_i X_i \le A_2 \quad \text{..................(1)}$$

where,

$h_i$ = human energy level for activity, *i*, MJ/ha

$A_1$ = Lower bound on human energy available per activity

$A_2$ = Upper bound on human energy available per activity

$$A_{1n} \le \sum_{i=1}^{n} an_i X_i \le A_{2n} \quad \text{..............(2)}$$

where,

$an_i$ = Animal energy level for activity, *i*, MJ/ha

$A_{1n}$ = Lower bound on animal energy available per activity

$A_{2n}$ = Upper bound on animal energy available per activity

$$D_1 \le \sum_{i=1}^{n} d_i X_i \le D_2 \quad \text{................(3)}$$

where,

$d_i$ = Diesel energy level for activity, *i*, MJ/ha

$D_1$ = Lower bound on diesel energy available per activity

$D_2$ = Upper bound on diesel energy available per activity

$$E_1 \le \sum_{i=1}^{n} e_i X_i \le E_2 \quad \text{..................(4)}$$

where,

$e_i$ = Electric energy level for activity, *i*, MJ/ha

$E_1$ = Lower bound on electric energy available per activity

$E_2$ = Upper bound on electric energy available per activity

$$S_1 \le \sum_{i=1}^{n} s_i X_i \le S_2 \quad \text{....................(5)}$$

where,

$s_i$ = Seed energy level for activity, *i*, MJ/ha

$S_1$ = Lower bound on seed energy available per activity

$S_2$ = Upper bound on seed energy available per activity

$$F_1 \le \sum_{i=1}^{n} f_i X_i \le F_2 \quad \text{....................(6)}$$

where,

$f_i$ = fertilizer energy level for activity, *i*, MJ/ha

$F_1$ = Lower bound on fertilizer energy available per activity

$F_2$ = Upper bound on fertilizer energy available per activity

$$M_1 \le \sum_{i=1}^{n} m_i X_i \le M_2 \quad \text{..................(7)}$$

where,

$m_i$ = Machine energy level for activity, *i*, MJ/ha

$M_1$ = Lower bound on machine energy available per activity

$M_2$ = Upper bound on machine energy available per activity

$$C_1 \le \sum_{i=1}^{n} c_i X_i \le C_2 \quad \text{..................(8)}$$

where,

$c_i$ = Agro-chemical energy level for activity, *i*, MJ/ha

$C_1$ = Lower bound on agro-chemical energy available per activity

$C_2$ = Upper bound on agro-chemical energy available per activity

$$T_1 \le \sum_{i=1}^{n} t_i X_i \le T_2 \quad \text{..................(9)}$$

where,

$t_i$ = Total energy consumed by activity, *i*, in MJ/ha

$T_1$ = Lower bound on total energy available per activity in MJ/ha

$T_2$ = Upper bound on total energy available per activity in MJ/ha

The upper bound on total energy should not exceed the sum of upper bounds on all other constraints. Similarly, the lower bound on total energy should not be less than the sum of lower bounds on all other energy sources. For the present analysis, the lower bound of all energy sources was taken as zero.

When $x_1 = 1, X_2 = X_3 = \dots X_n = 0$, we get yield ($Y_1$), obtained by the farmer, $X_1$, and the solution as same as the energies used by that activity (farmer). Hence, the objective func-

**Table 1** Equivalent coefficient for various sources of energy

| Energy source | Units | Equivalent energy, MJ |
|---|---|---|
| Human | Man-hour | 1.96<br>1 Adult woman = 0.8 Adult man 1 Child = 0.5 Adult man |
| Animal | Pair -hour | 10.10 (Body weight 350-450 kg) |
| Diesel | litre | 56.31 |
| Electric | kWh | 11.93 |
| Seed | kg | 14.7 |
| FYM | kg | 0.3 |
| Fertilizer | | |
| Nitrogen | kg | 60.6 |
| $P_2O_5$ | kg | 11.1 |
| $K_2O$ | kg | 6.7 |
| **Agro-chemicals** | | |
| Superior chemicals | kg | 120<br>Chemicals requiring dilution at the time of application |
| Inferior chemicals | kg | 10.0<br>Chemicals not requiring dilution at the time of application |
| **Machinery** | | |
| Electric motor | kg | 64.80 |
| Prime movers other than electric motors | kg | 68.40 |
| Farm machinery excluding self propelled machines | kg | 62.70 |

tion has logical interpretation.

***One more constraint was also defined as the following:***

$$\sum_{i=1}^{n} X_i = 1$$

This ensures that the maximization of yield per hectare basis gives equal weight to each of the activities. The number of decision variables (or activities) in the solution will be less than or equal to the number of constraints in the model.

Once the solution for $X_I$'s, say $X_i^*$'s, are obtained, the value of objective function (i.e. the value of the maximum yield) and usage of various energy sources are obtained using the expressions

$$\text{Yield} = \sum_{i=1}^{n} Y_i X_i^*$$

$$\text{Human Energy} = \sum_{i=1}^{n} h_i X_i^*$$

$$\text{Animal Energy} = \sum_{i=1}^{n} an_i X_i^*$$

$$\text{Diesel Energy} = \sum_{i=1}^{n} d_i X_i^*$$

$$\text{Electrical energy} = \sum_{i=1}^{n} e_i X_i^*$$

$$\text{Seed Energy} = \sum_{i=1}^{n} s_i X_i^*$$

$$\text{Fertilizer Energy} = \sum_{i=1}^{n} f_i X_i^*$$

$$\text{Machine Energy} = \sum_{i=1}^{n} m_i X_i^*$$

$$\text{Chemical Energy} = \sum_{i=1}^{n} c_i X_i^*$$

$$\text{Total Energy} = \sum_{i=1}^{n} t_i X_i^*$$

Since $t_i = h_i + an + d_i + E_i + f_i + s_i + m_i + c_i$, the sum of the energy usage from different sources shall be equal to the total energy usage. The values of the decision variables are similarly used for calculating the energy from each operation.

## Result and Discussion

### Energy Consumption Pattern on Irrigated Farms

Among the direct energy resources used for cultivation of gram in irrigated animal, mixed and tractor farms, human energy consumption was minimum in the mixed farms (**Fig. 1**). The animal farms used 7.5 percent higher human energy while the tractor farms used 17 percent higher energy. Manual operations such as harvesting with sickle and soil manipulations with spade for irrigation and untilled field corners consumed higher human energy on the tractor farms. The mixed farms used 50 percent less animal energy than that the animal farms. The tractor farms derived all tractive power from tractors only and, consequently, the diesel energy consumption was twice that of the mixed farms. All farm types used electricity for irrigation and threshing operations .The electricity consumption was lowest on animal farms (836 MJ/ha) due to minimum use (19.5 h/ha) of irrigation pumps among the farm types. With increased use of irrigation pumps, mixed farms used 10.5 percent higher electric energy while the tractor farms used 26 percent higher electric energy. Diesel was the major source of direct energy in the mixed and tractor farms, followed by electricity. On animal farms, electricity was the most consumed among the direct energy resources used followed by animal energy.

Among the indirect energy resources used on the different farm groups, variation of seed energy consumption rate was low. The consumption rate was similar on animal and mixed farms while the tractor farms consumed about 18 and 22 percent more seed than the animal and mixed farms, respectively. Fertilizer was the major indirect energy input. On tractor farms, its share was about 21 percent of the total energy used and the consumption was about 70 percent more than the animal and mixed farms. Crop productivity was the highest on tractor

**Fig. 1** Source-wise energy use pattern for cultivation of irrigated gram on animal, mixed and tractor farms

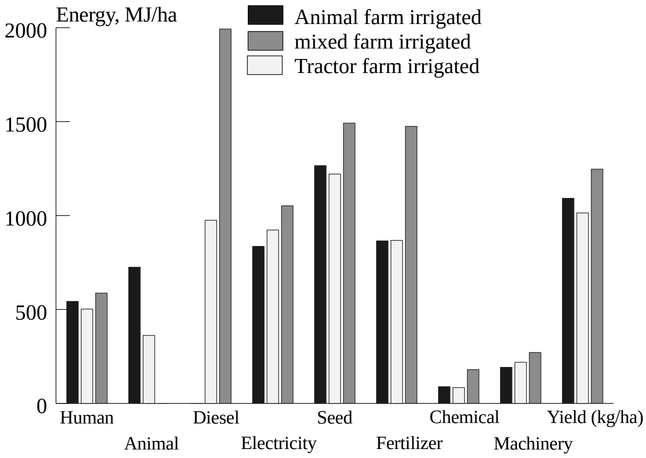
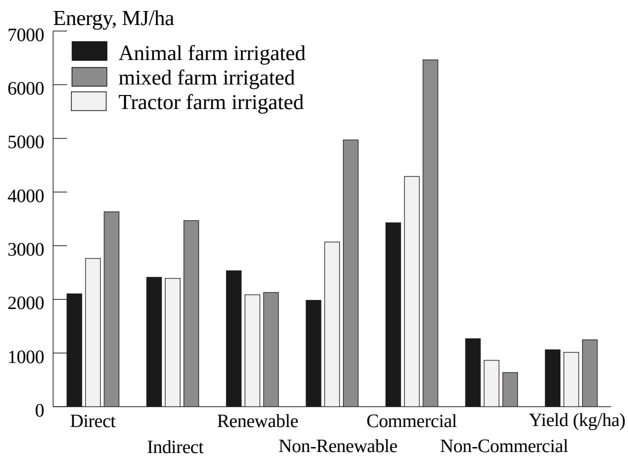



**Fig. 2** Energy use pattern from different sources for cultivation of irrigated gram on animal, mixed and tractor farms



farms. The consumption of agrochemicals was almost the same in animal and mixed farms while tractor farms consumed more than twice that of the other farms. Due to use of tractors with matching implements in mixed and tractor farms, machinery energy consumption on these farms was higher than that in animal farms. The mixed and tractor farms consumed 1.13 and 1.41 times higher machinery energy than the animal farms.

The energy consumption patterns in the present three farming systems indicated the changing energy use patterns with progressive mechanization. The quantum of indirect energy consumed in animal and mixed farms were similar while direct energy consumption on mixed farms was higher than animal farms (**Fig. 2**). Use of direct and indirect energy on tractor farms was higher than in the animal and mixed farms. However, the animal farms used 53.4 percent of the total indirect energy resources while the mixed and tractor farms used 46.4 and 49 percent, respectively. The share of direct energy consumption on the animal farms was 46.6 percent while the mixed and tractor farms consumed 53.6 and 51.2 percent, respectively. The animal farms consequently had highest renewable energy consumption (2,534 MJ/ha) while tractor farms had highest non-renewable energy consumption (4,971 MJ/ha and 2.5 times that of animal farms). Out of the total energy consumption, the animal farms consumed 56.11 percent renewable energy while mixed farms consumed 40.46 percent and tractor farms consumed 30 percent. Similarly, out of the total energy consumption, tractor farms consumed 70 percent of non-renewable energy while mixed farms consumed 59.5 percent and animal farms consumed 43.9 percent. The share of commercial energy consumption was maximum (91 percent) on the tractor farms followed by mixed farms (83.24 percent) and animal farms (72 percent). Consumption of non-commercial energy was low in all types of farms. On animal farms, the share of non-commercial energy consumption was 28 percent while on tractor farms it was only 9 percent.

The scenario, thus, reflects that in the present cultivation systems providing about 37 percent of potential yield, the reliance on commercial energy resources is high, and likely to further increase with increase in crop productivity. With increase in adoption of mechanization, demand of non-renewable energy resources would increase significantly.

The operational energy consumption patterns and energy resource allocation among the unit operations were different in the three farming systems. With use of electro-mechanical power sources, the tractor farms consumed highest energy in the unit operations followed by mixed farms (using a mix of electro-mechanical and animal power source) and animal farms operating with only animal power. The total operational energy consumption on tractor farms was 68 and 23 percent higher than the animal and mixed farms, respectively. The crop productivity of tractor farms was 17.42 and 23 percent higher than the animal and mixed farms, respectively. Among the unit operations, the largest variation occurred in the tillage operation for which the animal farms consumed 493 MJ/ha of energy (21.4 percent of the total operational energy) while the mixed farms consumed 800 MJ/ha (about 27 percent of the total operational energy). The tractor farms consumed 1,122 MJ/ha of tillage energy (29 percent of the total operational energy). Since mechanical power source was mostly used for tillage operation, the tractor farms and the mixed farms consumed 2.3 and 1.6 times higher tillage energy than the animal farms. In order to ensure timely completion of seedbed preparation, it was visible that adequate energy for tillage operation is to be invested. The sowing operation in animal farms consumed 262 MJ/ha of energy (about 11 percent of the total operational energy). With introduction of tractor operated seed drills, the mixed and tractor farms consumed about 49 and 125 percent more energy than the animal farms for sowing. Use of mechanical power sources required higher energy investment. Irrigation was the most energy consuming operation requiring 23 to 31 percent of operational energy. All farm types used electric motor operated pumps for lifting irrigation water. The variation in energy consumption for irrigation among the farm types was due to the extent of irrigation provided. The energy consumption patterns in harvesting and threshing operations in animal and mixed farms did not show many variations but the tractor farms used 43 and 47 percent more energy, possibly for handling higher volume of crop.

### Energy Consumption Pattern on Rainfed Farms

Among the energy sources used on animal farms seed, fertilizer, animal and human were the major energy sources contributing 32.3, 21.6, 17.7 and 17.1 percent of the total input energy, respectively, under rainfed conditions. These four-energy sources provided about 89 percent of the total energy. The animal farms consumed 4,110 MJ/ha of total input energy with crop productivity of 795 kg/ha. Total input energy consumption on the mixed farms was 4,797 MJ/ha, 16.7 percent higher than the animal farms. Diesel was the major energy source (32 percent of the total energy) followed by the seed (24.4 percent of the total energy) and fertilizer (17.6 percent of the total energy). Diesel, seed and fertilizer together consumed about 74 percent of the total input energy on the mixed farms. The tractor farms consumed 6,261

MJ/ha, which was 52 and 30.5 percent higher than that on animal and mixed farms respectively. Diesel, seed and fertilizer were the major energy sources used contributing 30.4, 24.3 and 22.8 percent of the total energy respectively. Tractor farms consumed 14.5 and 61.2 percent higher seed and fertilizer energy respectively than the animal farms. With no energy being spent on irrigation, total energy consumption under rainfed conditions was less than that irrigated conditions.

The patterns of direct energy consumption in the rainfed farms were similar to that on the irrigated farms. However, the direct energy consumption was about 59 percent on the mixed farms followed by tractor (45 percent) and animal (40.4) farms (**Fig. 3**). The animal farms used about 7 percent higher indirect energy than the mixed farms due to higher use of seed, fertilizer and agro-chemicals. Tractor farms used highest quantity of indirect energy due to highest seed, fertilizer and agro-chemical application. The indirect energy consumption, however, was 60 percent of total energy input in the animal farms while it was 55 and 48 percent on the tractor and mixed farms, respectively. The animal farms used maximum quantity of renewable energy while the tractor farms consumed maximum non-renewable energy. The share of renewable energy sources was 67 percent on the animal farms while that on the mixed farms was 41.5 percent and 35 percent on the tractor farms. Similarly, the share of non-renewable energy was maximum (65 percent) on the tractor farms, closely followed by mixed farms (58.5 percent). The reliance on commercial energy sources was visible on all farm types, the tractor farms required maximum quantity of the same. Out of the total energy consumed, the tractor farms required 89.4 percent of commercial energy while the mixed and animal farms consumed 83 and 65 percent, respectively. The patterns of consumption were similar in irrigated and rainfed farms.

The rainfed farms consumed less operational energy than the irrigated farms. On animal farms the total operational energy use was 1,743 MJ/ha of which 30.6 percent was used in tillage, 11.8 percent in sowing, 24.3 percent in harvesting, 18.8 percent in threshing and 11.4 percent in transportation. Tillage, harvesting and threshing operations were the major energy consuming operations and together consumed about 74 percent of the total operational energy. Mixed farms consumed 2,727 MJ/ha of total operational energy. Tillage, sowing and transportation were the major energy consuming operation and together consumed about 73 percent of the total operational energy. Mixed farms consumed 56.5 percent more operational energy than the animal farms due to use of tractors. The mixed farms consumed 101 and 164 percent higher energy in tillage and sowing, respectively, than the animal farms for the same reason. The total operational energy use on tractor farms (2,983 MJ/ha) was 71 and 10 percent higher than the animal and mixed farms. The tractor farms consumed 132 and 15 percent more energy in tillage than the animal and mixed farms. Tillage, harvesting and threshing were the energy consuming operations on tractor farms requiring about 73 percent of the total operational energy. With progress of mechanization, the operational energy consumption was, thus, seen to increase in order to achieve timeliness in operations.

In another survey, data on energy use in cultivation of gram crop were collected from 238 farms in the selected villages. Out of the 238 farms, irrigated cultivation was undertaken in 155 farms (65.1 percent) comprising of 56 tractor farms, 48 animal farms and 52 mixed farms

**Fig. 3** Energy use pattern from different sources for cultivation of rainfed gram on animal, mixed and tractor farms

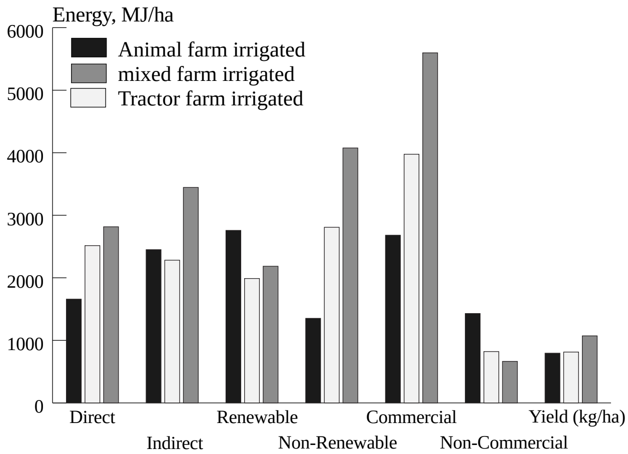



**Table 2** Source-wise energy use patter for gram production under existing farm practices

| Mixed Farms | Irrigated | Rainfed |
|---|---|---|
| Yield, kg/ha | 1,014 | 813 |
| Human labour, MJ/ha | 502 | 519 |
| Animal labour, MJ/ha | 362 | 302 |
| Diesel, MJ/ha | 975 | 1,534 |
| Electricity, MJ/ha | 923 | 160 |
| Seed, MJ/ha | 1,221 | 1,168 |
| Fertilizers, MJ/ha | 868 | 844 |
| Chemical, MJ/ha | 84 | - |
| Machine, MJ/ha | 219 | 270 |
| Total Expenditure, MJ/ha | 5,154 | 4,797 |
| Energy productivity, kg/MJ | 0.197 | 0.169 |

being 36, 30 and 34 percent, respectively, of the total irrigated farms. The average yield of the farms under the study area was 1,014 kg/ha for irrigated and 813 kg/ha in rainfed farms (**Table 2**). The irrigated farms in the study areas used energy from nine different sources viz; human, draught animal, diesel, electricity, seed, fertilizer, agro-chemical and machinery. Among the energy sources, seed, electricity, diesel and fertilizer were the main energy sources contributing, together, 77.4 percent of the total energy consumed. Diesel and electricity both consumed about 37 percent of the total energy. Use of electricity was for irrigation and threshing, while diesel was used only by tractors for tillage, sowing and transportation operations. Seed and fertilizer contributed about 41 percent of the total energy consumed.

The actual energy use patterns of irrigated farms indicated that the farms belonging to the peak regime of the regression model (group B) had obtained an average yield of 1,066 kg/ha by investing average total energy of 5,288 MJ/ha, **Fig. 4**. Farmers falling in the two adjacent tapering sides of the regression curve (groups A, C) had lower average yields. The regression model indicates that the farmers in group A had obtained an average yield of 951 kg/ha with minimum energy investments (4,236 MJ/ha) as compared to the other groups. Farmers belonging to the group B had obtained an additional 12 percent yield (1,066 kg/ha) as compared to the group A. The farmers in group B had used 50 percent more tractor hours (4.8 h/ha) for tillage, sowing and transportation operations with 14.6 percent less use of animal energy (35.4 h/ha), and thereby completing farm operations in time. Diesel energy consumption increased in the process with reduction in animal energy consumption. Fertilizer energy consumption by the farmers in Group B was 20 percent higher (898 MJ/ha), mainly nitrogenous (10.2 kg/ha) and phosphoric (27.2 kg/ha). Electric energy consumption was higher by 86.6 percent (1,086 MJ/ha) for irrigation and threshing operations. Human energy consumption was also higher by 18 percent (490 MJ/ha). The additional energy consumption were in tillage by 22.6 percent (812 MJ/ha), sowing by 34.4 percent (406 MJ/ha), irrigation by 108.6 percent (960 MJ/ha) and harvesting by 28.4 percent (253 MJ/ha). Energy savings of 2.7 percent (293 MJ/ha) in the threshing operation was achieved through more use of threshers. Farmers belonging to the group C had obtained an average yield of 939 kg/ha (less than group B) and had spent higher energy (6,500 MJ/ha). Compared to the group B, the additional energy consumptions were human with 54.4 percent (755 MJ/ha), diesel with 75.1 percent (1,702 MJ/ha), seed with 15.7 percent (1,389 MJ/ha) and fertilizer with 13.7 percent (1,021 MJ/ha). The farmers in group C had used 61 percent additional tractor hours (7.8 h/ha) and 22 percent lower animal hours (27.5 h/ha), signifying a shift to increased use of mechanical power. Compared to group B, the farmers in group C used 31.7 percent additional tillage energy (1,069 MJ/ha), 28.6 percent additional sowing energy (522 MJ/ha), 131 percent higher harvesting energy (585 MJ/ha) and 61.4 percent higher threshing energy (473 MJ/ha). Distinctive changes in implement uses were the absence of usage of the tractor plough and consequent higher use of the cultivator and use of tractor operated thresher (requiring more operational energy) by the farmers of group C.

For rainfed farms, diesel was the main energy source contributing 32.30 percent of the total energy consumed (**Fig. 5**). The shares of other energy sources (seed, fertiliz-

**Fig. 4** Energy use pattern for cultivation of irrigated gram on mixed farms

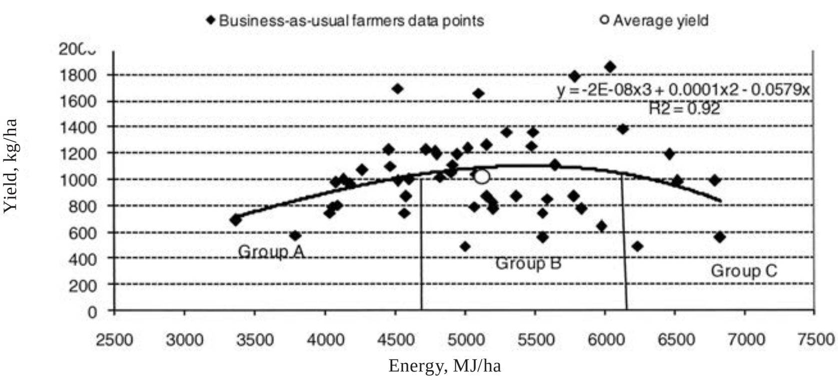
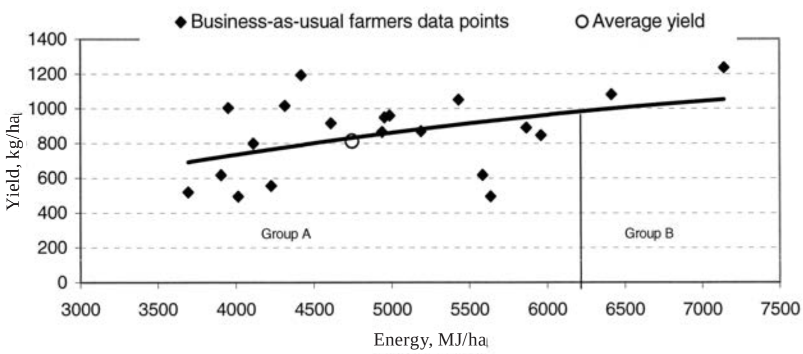



**Fig. 5** Energy use pattern for cultivation of rainfed gram on mixed farms



ers, human, animal, machinery and electricity) were 24.60, 17.8, 10.8, 6.4, 5.7 and 3.4 percent, respectively. Electricity was used only for threshing of the crop. The regression model of yield-total energy relationships of rainfed farms indicates that, for higher yields, the energy consumption increased. The trend suggested that maximum yield potential with use of conventional cultivation practices was not achieved, possibly due to restricted energy resource uses. Tractor (10 h/ha) and animal uses (44.9 h/ha) by the farmers of group B were 42.8 and 73 percent higher than that by group A. The farmers in group B used 33.2 percent additional human energy (650 MJ/ha), 70.6 percent animal energy (454 MJ/ha), 43.7 percent diesel energy (2,035 MJ/ha), 10 percent seed energy (1,262 MJ/ha), 12.8 percent fertiliser energy and 76.7 percent machinery energy (417 MJ/ha). Nitrogenous and phosphoric fertilisers usage were higher in rainfed farms. The additional yield of 33 percent (650 kg/ha) obtained by the farmers belonging to group B was obtained through consumption of 45 percent additional energy (6,347 MJ/ha). Operation-wise, 28.5 percent was used in tillage (1,309 MJ/ha), 25.3 percent in sowing (648 MJ/ha), 13.3 percent in harvesting (409 MJ/ha), 48.7 percent in threshing and 109 percent in transportation. Increase in tillage energy consumption was mainly due to additional usage of animal operated cultivator (49.4 h/ha) and planker (11.4 h/ha). Due to increased manual sowing, sowing energy consumption was higher in group B.

### Optimization of Energy Resources

**Figs. 6** and **7** indicate the patterns of animate (human and animal), direct commercial (diesel, electricity) energy and total direct energy consumption, respectively, at different yield levels of productivity when cultivated using conventional practices and with optimized energy resource allocations using improved practices. While the animate energy use in conventional practices was at the same level for different levels of productivity, reflecting inefficient use at lower levels of productivity, the improved cultivation practice requires increased use of animate energy with increased yield levels. Direct commercial energy use increased with yield in all types of cultivation practices, the improved practices requiring lower levels of energy than the conventional prac-

**Fig. 6** Comparison of animate energy use patterns for different levels of gram productivity under conventional and improved cultivation practices on irrigated mixed farms

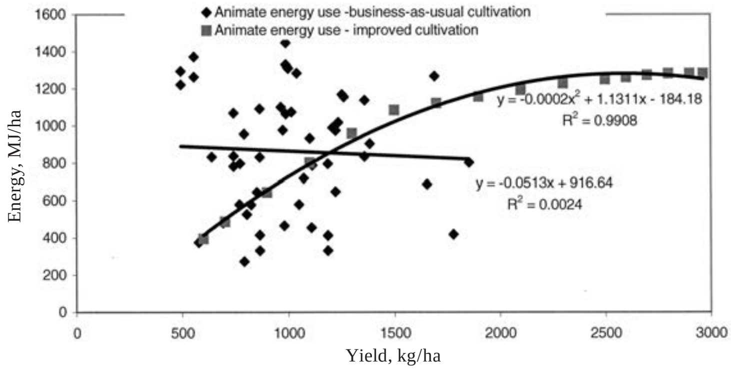



**Fig. 7** Comparison of direct commercial energy use patterns for different levels of gram productivity under conventional and improved cultivation practices on irrigated mixed farms

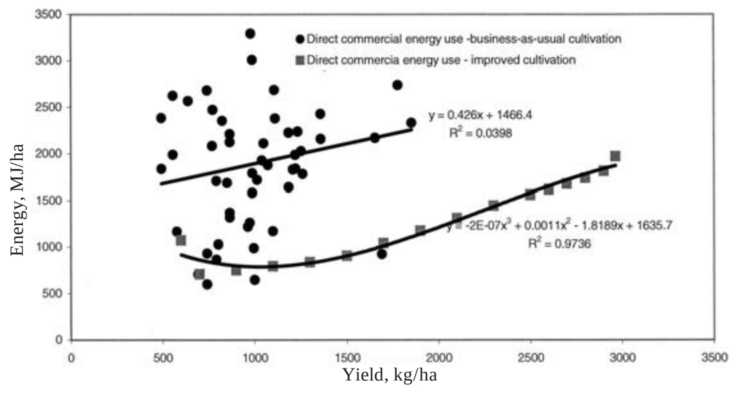
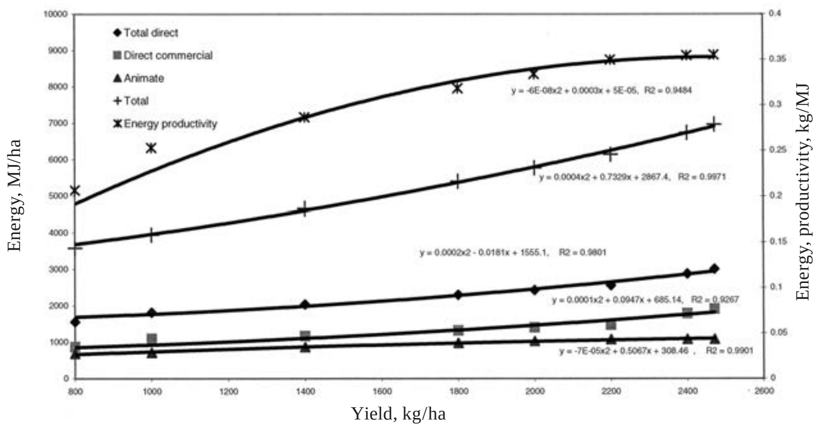



**Fig. 8** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for rainfed mixed farms



tice. The total direct energy consumption in conventional practice was more than the improved practice, the difference being higher at lower productivity levels on irrigated farms. For a yield of 1,500 kg/ha, diesel consumption would decrease by about 70 percent and electricity consumption would decrease by 47.63 percent. Similarly, for yields of 1,100 kg/ha, diesel consumption would decrease by 74.12 percent and electricity consumption would decrease by 48.10 percent. On rainfed farms, diesel consumption would reduce by 36.15 percent at the yield level of 1,000 kg/ha. The patterns are governed by the consumption of direct commercial energy.

**Figs. 8** and **9** represents the energy consumption patterns for improved cultivation practice. Total energy consumption increased with increase in productivity. The share of indirect energy increased faster than that of direct energy due to nearly 2.4 times increased use of fertiliser for productivity increase from 700 to 2,965 kg/ha on irrigated farms and 2.8 times for productivity increase from 600 to 2,471 kg/ha on rainfed farms (**Fig. 8**). Energy productivity shows a fast improvement until a yield of about 2,500 kg/ha on irrigated and up to 2,200 kg/ha on rainfed farms, and then slows down. Total direct energy consumption increased with increase in productivity, mainly due to increased consumption rate in tillage, harvesting, threshing and transportation. Energy consumption in tillage operation increased more than five times with increase in productivity from 700 to 2,700 kg/ha on irrigated (**Fig. 9**) and more than two times with the increase in productivity from 800 to 2,400 kg/ha on rainfed farms (**Fig. 8**) as a result of continued shift to tractor use in order to ensure timeliness in operation. Inadequate soil moisture regime in rainfed farms demanded higher tillage energy consumption even for low productivity level.

The data of 88 tractor operated farms, comprising 56 irrigated and 32 rainfed farms in different agro-climatic regions of Madhya Pradesh falling under different agro-climatic regions of the state were used for analysis. The average yield was 1,247 kg/ha in irrigated farms and 1,072 kg/ha on rainfed farms, **Table 3**. Among the different sources of energy, diesel, fertiliser and seed were the dominant sources of energy contributing about 71.3 and 82.3 percent of the total energy consumed on irrigated and rainfed farms, respectively.

The regression model of irrigated tractor farms (**Fig. 10**) have relatively uniform slope as compared to rainfed farms, reflecting less variation in yield's obtained by the farmers. The human energy consumption in existing farm practices followed increasing trends and was more in the improved cultivation practices, the difference being higher at moderate productivity levels (between

**Fig. 10** Energy use patterns for different levels of gram productivity for irrigated tractor farms

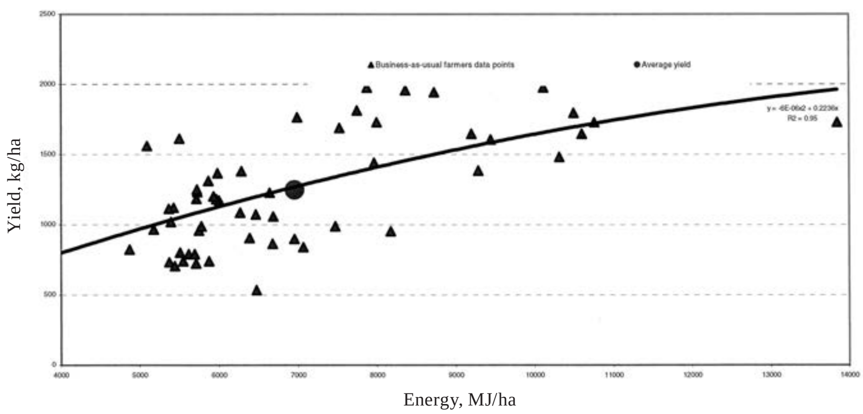



**Fig. 9** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for irrigated mixed farms

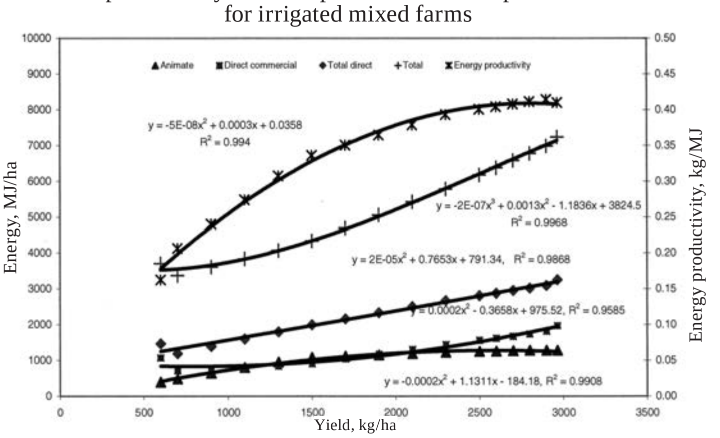



**Table 3** Source-wise energy use patter for gram production under existing farm practices

| Mixed Farms | Irrigated | Rainfed |
|---|---|---|
| Yield, kg/ha | 1,247 | 1,072 |
| Human labour, MJ/ha | 587 | 664 |
| Animal labour, MJ/ha | - | - |
| Diesel, MJ/ha | 1,993 | 1,906 |
| Electricity, MJ/ha | 1,052 | 246 |
| Seed, MJ/ha | 1,492 | 1,521 |
| FYM, MJ/ha | 50 | - |
| Fertilizers, MJ/ha | 1,475 | 1,430 |
| Chemical, MJ/ha | 180 | 263 |
| Machine, MJ/ha | 271 | 231 |
| Total Expenditure, MJ/ha | 6,956 | 5,903 |
| Energy productivity, kg/MJ | 0.183 | 0.184 |

1,000 to 1,800 kg/ha). Improved cultivation practices required a more uniform rate of human energy at all levels of productivity. For a yield of 1,400 kg/ha, human energy consumption decreased by 28.16 percent on irrigated farms and 46 percent under rainfed farms. The direct commercial energy use under conventional practice was also higher than the improved cultivation practices on irrigated and rainfed farms. While the trend of direct commercial energy consumption on irrigated farms increased with crop productivity, the consumption pattern with improved practices on rainfed farms was exponential due to increased energy consumption for seedbed preparation. For a yield of 1,800 kg/ha, direct commercial energy consumption on irrigated farms decreased by 38.5 percent. Diesel consumption decreased by 17.25 percent and electricity consumption decreased by 44.47 percent at the same productivity level.

On the rainfed farms, maximum decrease in direct commercial energy consumption occured at the lower levels of productivity (**Fig. 11**). For the yield level of 600 kg/ha the direct commercial energy decreased by 48.4 percent. The reduction in diesel energy consumption was about 52 percent and that of electric energy consumption by 26.2 percent at the same crop productivity. As a cumulative effect, the total direct energy consumption in conventional practice was also higher in comparison to improved cultivation practice on irrigated and rainfed farms. The total direct energy consumption increased with increased in yield mainly because of increased consumption in tillage and harvesting on irrigated farms while in tillage, sowing, harvesting and threshing on rainfed farms. Energy consumption in tillage and harvesting operation increased by about 1.7 and 2.6 times with increase in productivity from 700 to 2,965 kg/ha on irrigated farms while on rainfed farms energy consumption in tillage, sowing, harvesting and threshing operation increased by about 2.06, 16.73, 1.89 and 2.22 times, respectively. The difference in energy consumption was more at higher productivity levels on irrigated farms and was higher on lower yield levels on rainfed farms.

**Figs. 12** and **13** represents the

**Fig. 11** Energy use patterns for different levels of gram productivity for rainfed tractor farms

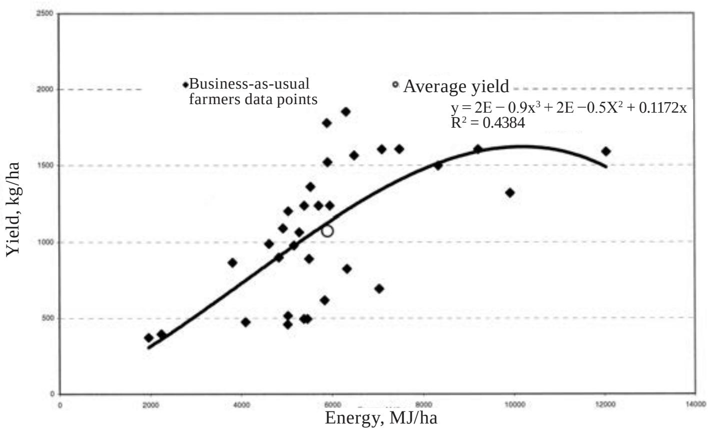



**Fig. 12** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for irrigated tractor farms

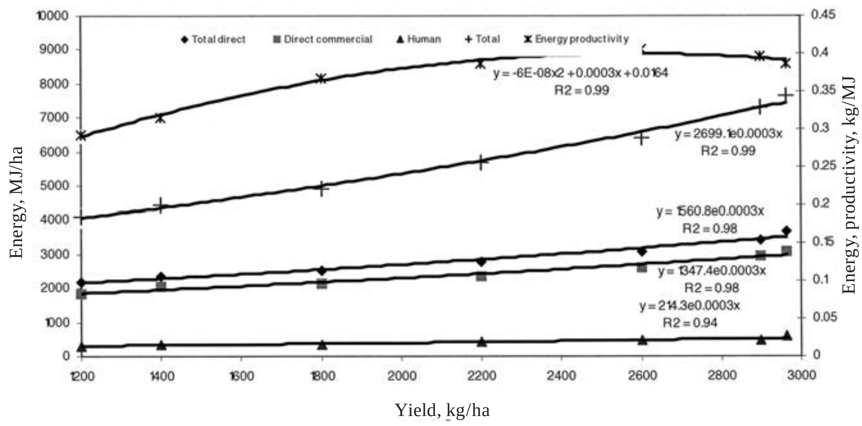
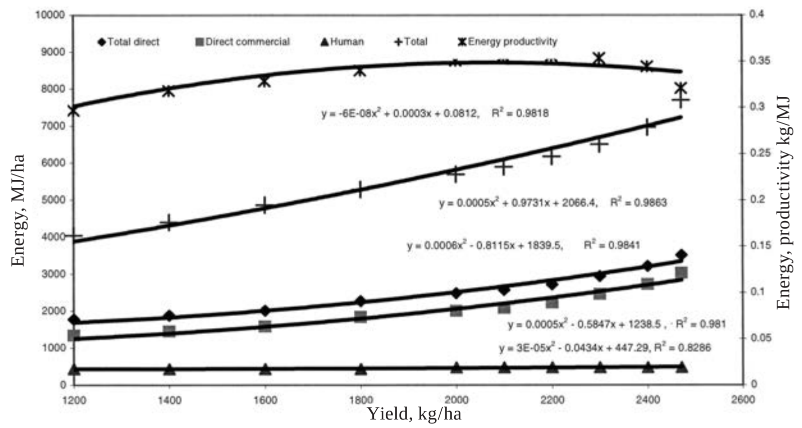



**Fig. 13** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for rainfed tractor farms



energy consumption patterns for improved cultivation practices on irrigated and rainfed tractor farms. For improved cultivation practices, the total energy consumption increased with increase in productivity. The share of indirect energy increased faster than that of direct energy because of 1.70 and 8.68 times increased use of fertilizer for a yield increase from 700 to 2,965 kg/ha on irrigated and 500 to 247 kg/ha on rainfed farms. Energy productivity shows a fast improvement until about a yield of 1,800 kg/ha on irrigated farms and 1,200 kg/ha on rainfed farms, and, subsequently, slows down.

The regression models of yield-total energy relationships for irrigated and rainfed farms (**Figs. 14** and **15**) indicate increasing energy consumption rates (3,343 to 6,006 MJ/ha) with higher yields (577 to 1,765 kg/ha). The major increment in energy consumption with higher levels of yield has been due to increased consumption of electricity (700 to 1,200 MJ/ha for increased yield from 1,043 to 1,116 kg/ha) for irrigated farms.

On rainfed farms, the increase in human (730 to 880 MJ/ha), animal (562 to 944 MJ/ha) and electric energy (165 to 290 MJ/ha) consumption was utilized for tillage, harvesting and threshing operations with an increase in crop yield from 730 to 880 kg/ha. While the patterns of consumption of seed and fertilizers on irrigated farms did not variy significantly, the seed rate on rainfed farms varied from 84 to 99 kg/ha for the increase in yield indicated above. More consistency in farm practices is, thus, observed on irrigated farms.

**Figs. 16** and **17** show the patterns of animate (human and animal) direct commercial (diesel and electricity) energy and total direct energy consumption, respectively, at different levels of productivity when cultivated under existing and improved cultivation practice on irrigated and rainfed animal farms. In both types of farms, animate energy consumption increased with productivity. However, conventional practice required more animate energy as compared to improved cultivation practices, the difference being higher at productivity levels between 800 to 1,200 kg/ha on irrigated farms and between 500 to 800 kg/ha on rain-

**Fig. 14** Energy use patterns for different levels of gram productivity for irrigated animal farms

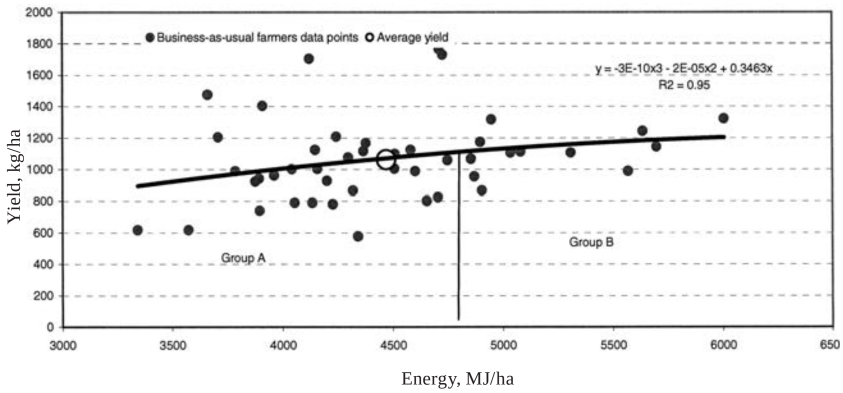



**Fig. 15** Energy use patterns for different levels of gram productivity for rainfed animal farms

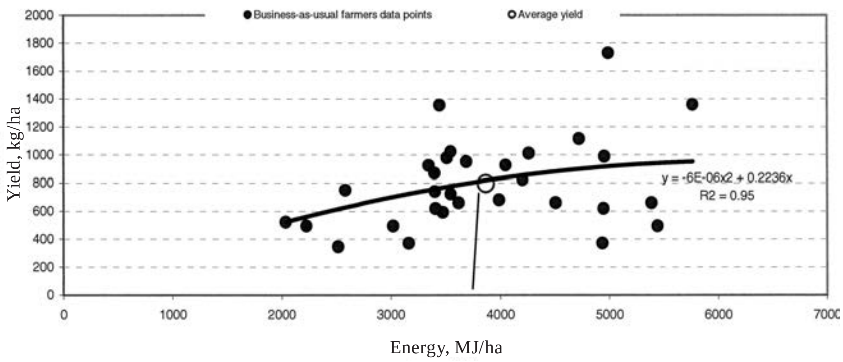
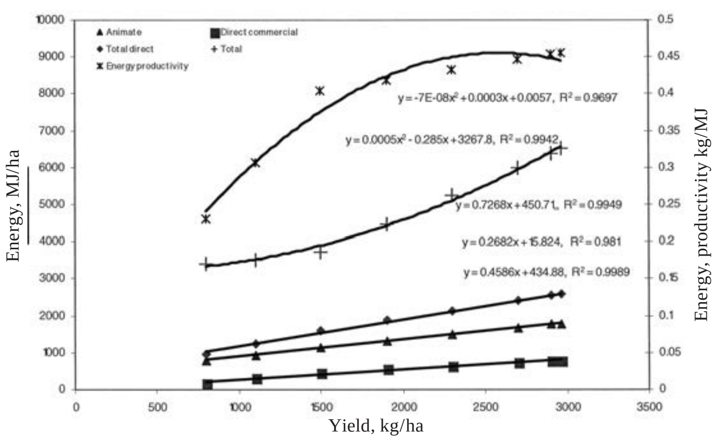



**Fig. 16** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for irrigated animal farms



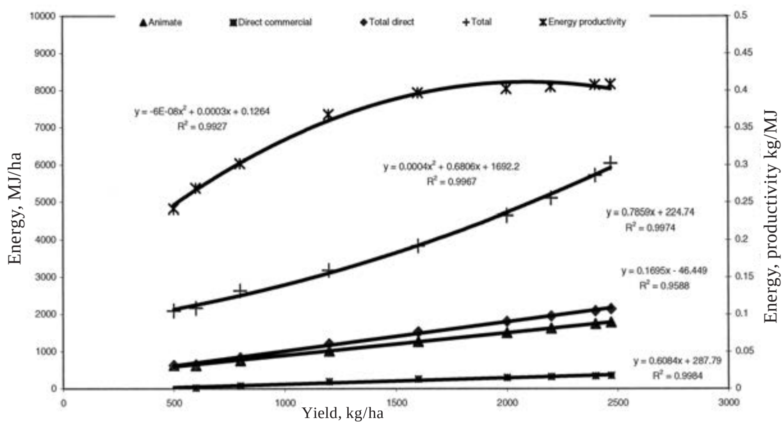
fed farms. The direct commercial energy on animal farm accounted for electricity consumption for various operations. Rainfed farms used electricity only for threshing while irrigated farms use it for operating pumps and threshers resulting in higher electric consumption. Direct energy consumption under conventional cultivation practices was, also, higher as compared to improved cultivation practices on both types of farms. For a yield of 1,100 kg/ha, electricity consumption decreased by 72 percent on irrigated farms. With use of improved threshers, 88 percent electric energy was saved with improved practices (at a yield level of 800 kg/ha) as compared to conventional practice on rainfed farms. The total direct energy consumption pattern on both types of farms also showed a similar pattern of behavior for conventional and improved cultivation practices. Total energy consumption increased with increase in yield level on irrigated farms. The share of indirect energy increased faster than that of direct energy due to increase use of fertilizer and seeds. For an increase in crop productivity from 800 kg/ha to 2,965 kg/ha, the fertilizer consumption increased by about two times in irrigated farms and on rainfed farms, with increase in productivity from 600 kg/ha to 2,471 kg/ha, fertilizer consumption increased by about 2.3 times.

Total direct energy consumption rate increased with increased yield level, mainly due to increased consumption rate in tillage, sowing and threshing on irrigated farms and in tillage, sowing, harvesting and threshing on rainfed farms. On irrigated farms, energy consumption in tillage, sowing and harvesting operations increased by 3.31, 4.82 and 1.52 percent, respectively, with an increase in productivity from 800 to 2,965 kg/ha. On rainfed farms, energy consumption in tillage, sowing and threshing operations increased by 6.2, 59.5 and 3.0 times, respectively, with an increase in yield from 500 to 2,471 kg/ha.

## Conclusions

The operational energy consumption patterns and energy resource allocation among the unit operations were different in the three farming systems. With use of electro-mechanical power sources, the tractor farms consumed the highest energy in the unit operations followed by mixed farms (using a mix of electro-mechanical and animal power source) and animal farms operating with only animal power. The total energy consumption on mixed and tractor farms were 14 and 56 percent higher than the animal farms (4,516 MJ/ha), and obtained 17.4 and 23 percent higher crop yield. The energy consumption patterns in the present three farming systems indicated the changing energy resource use patterns with progressive mechanization. The quantum of indirect energy consumed in animal and mixed farms were similar while direct energy consumption in mixed farms was higher than animal farms. Use of direct and indirect energy was highest in tractor farm. In the present cultivation system providing about 37 percent of potential yield, the reliance on commercial energy resources is high, and likely to further increase with increase in crop productivity. With increase in adoption of mechanization, demand of non-renewable energy resources would increase significantly.

**Fig. 17** Pattern of energy consumption at different levels of gram productivity under improved cultivation practices for rainfed animal farm

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# Development and Performance Evaluation of a Solar Dryer for Bulb Onion (*Allium cepa L.*)*

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## Abstract

An experimental solar dryer for dehydration of bulb onion (*Allium cepa L.*) had been designed by the first author and constructed at the workshop of South China Agricultural University- Guangzhou in which efficiency, cost and durability were optimally combined. The data were recorded by a programmable data acquisition system including microprocessor control, recorded data at ten minutes intervals. During winter season (Dec. 2000), solar heated air was 30.1 ºC on average, relative humidity of 59.3 % on average, and flow rate of 72.7 $m^3$/ (h.$m^2$. coll.surface). The temperatures rises of solar system was 1.7 ºC and 16.1 ºC, for those temperatures the average collection efficiency was about 54.7 %. Some drying parameters were calculated and results indicated that the numerical values were satisfactory. A techno-feasibility study gave a good result for the possibility of using the developed dryer in rural area.

## Introduction

Crop drying is the second biggest user of energy in crop production (Ritchie, 1983). Therefore, crop drying is an energy intensive operation that will be increasingly affected by the growing conventional energy shortage. Solar energy is believed to be one of the most promising of the alternative supplementary energy sources that may cope up with the problem (Garg *et al*., 1982). Solar dryers, in which air is heated by solar energy, are the most available option for developing countries, which are within the belt good solar radiation.

Solar dryer is advice for drying agricultural products under controlled conditions. The controlled drying means controlling the drying parameters like drying air temperatures, humidity, drying rate, moisture content, and air flow rate. A solar dryer must designed carefully keeping all the above drying parameters in mind. Since there are many options in the design of the solar dryers, there is large variety of solar dryers (Garg, 1990).

Although many types of solar dryers have been developed during the last two decades, their applications are still limited, mainly due to their unreliable performance and high investment cost relative to production capacity. A reduction of losses, an improvement of quality of product and an investment cost are also important criteria dictating the adoption of the solar dryer. A number of solar dryers do not meet these criteria. Therefore, development of a well-performed solar dryer is of significant economic importance. The main objective of the study was reducing the post-harvest loss of bulb onion using dehydration by designed a small scale solar dryer and assessment of the performance of the developed solar dryer integrated in the drying set-up.

## Materials and Methods

### Construction Methods and Material

A small scale solar dryer (Indirect solar dryer) with a simple structure was designed by the authors and constructed in South China Agricultural University Workshop- Guangzhou for dehydration of bulb onion (*Allium cepa L.*). The principal components of the dryer of active solar system as follow (**Fig. 1**):

**a. The main collector:**

***1. Absorber:*** ***Coolant:*** Air

Material: 0.5 mm thick corru-

* Part of a thesis submitted by the first author to South China Agricultural University, Guangzhou in partial fulfilment of the requirements for the master degree of Agricultural Mechanization.

gated aluminium foil

Aperture area: 2 $m^2$

Absorber area: 2 $m^2$

Flow rate: 0.025 $m^3 s^{-1} m^{-2}$

Absorber surface: Flat-black paint

Emittance of plate: 0.9 (Goedseels *et al.*, 1986)

Coefficient of absorption of visible light: 0.96 (Goedseels *et al.*, 1986)

Note: The air that was being heated up flows between absorber and insulation. There was a sealed gap between cover plate and absorber plate to reduce connective heat exchange.

***2. Glazing:*** Emittance of glass: 0.82 (Goedseels et al., 1986)

Number of glass cover: One

Material: Glass of high iron-content

Special characteristics: Window glass with greenish edges (5 mm thick)

Gasket: U-shaped EPDM gasket

Note: The glass and gasket sit on the collector case, and a glass cap was used to seal the glass to the collector case.

***3. Insulation:*** Polyurethane foam, 4 cm (bottom)

Polyurethane foam, 5 cm (sides)

***4. Collector case:*** Aluminium bar (100 × 25 × 1.2 mm)

***5. Sealant:*** Silicone sealant 5 mm thick

***6. Mounting:*** Orientation: North-South

Tilt: Latitude of Guangzhou city (23-30’ N)

**b. The assistant collector:**

***1. Absorber:*** Coolant: Air

Material: 0.5 mm thick corrugated aluminium foil

Aperture area: 0.25 $m^2$

Absorber area: 0.25 $m^2$

Flow rate: 0.04 $m^3 s^{-1} m^{-2}$

Absorber surface: Flat-black paint

Emittance of plate: 0.9 (Goedseels *et al*., 1986)

Coefficient of absorption of visible light: 0.96 (Goedseels *et al*., 1986)

Note: The air that was being heated up flows above and down absorber.

***2. Glazing: Emittance of glass:*** 0.82 (Goedseels et al., 1986)

Number of glass cover: One

Material: Glass of high iron-content (5 mm thick)

Gasket: U-shaped EPDM gasket

***3. Mounting: Orientation:*** North-south

Tilt: Latitude of Guangzhou city (23-30’ N)

***4. Sealant:*** Silicone sealant 5 mm thick

**c. Drying unit:**

***1. Drying system:*** Experimental cabinet tray-dryer, connected to the two solar air-heater

**Fig. 1** Small scale of the developed solar dryer

***2. Material:*** 1 mm thick sheet-iron insulated with fibre glass with aluminium foil, 3 cm thick

***3. Capacity:*** 6 kg of fresh product

Note: The load of the dryer was fitted to the properties of the product. The capacity of the dryer, calculated as quotient out of the load of fresh material and the drying time, was 6 kg/ drying round distributed as 2 kg for each layer.

***4. Ventilation:*** Type: Genuin exhaust unidirectional linked type APB25C (Axial fan)

Power: 36 W

Flow rate: 12.6 $m^3 min^{-1}$

Efficiency test:

The basic method of measuring collector performance was to expose operating collector to solar radiation and measured the fluid temperatures and the fluid flow rate. In addition, radiation on the collector, ambient temperature and wind speeds were also recorded. Thus two types of information were available: data on the thermal output and data on the condition producing that thermal performance. These data permit the characterization of collector by parameters that indicate how the collector absorbs energy and how it loosed energy to the surrounding.

The ASHRAE (The American Society of Heating, Refrigerating, and Air conditioning Engineers) standard indicates a test method for air collectors. Measurements may be made either outdoors or indoors (Duffie and Beckman, 1980).

The thermal performance of a solar collector was determined by establishing an efficiency curve from the instantaneous efficiencies obtained for combination values of incident solar radiation, ambient temperature, and average temperature of the air flowing through the collector (Goswami, 1986).

To investigate effects of environmental and operating parameters on the performance of the dryer various measuring devices were employed. The data were recorded by a programmable acquisition system including microprocessor control, recorded data at ten minutes intervals.

During winter season (Dec. 2000), the dryer was manually loaded with the product to be dried in the morning and the fan was started at 9:00 a.m. and it was stopped at 4:30 p.m. The fan was started again in the next morning and the process was repeated until final moisture of 5 % (w.b.) for bulb onion was reached.

**Table 1** Weather conditions and energy for the experiments

| Parameter | Value |
|---|---|
| Average ambient temperature, ºC | 22.10 |
| Solar radiation on horizontal surface, W $m^{-2}$ | 330.87 |
| Input solar energy, MJ | 73.90 |
| Useful energy, MJ | 43.20 |

**Table 2** Performance of the developed dryer under different weathering conditions

| Parameter | Clear day | Partial cloudy | Cloudy day |
|---|---|---|---|
| Air flow, $m^3$ $s^{-1}$ | 0.05 | 0.05 | 0.05 |
| Air temperature increase, ºC | 11.80 | 10.20 | 2.90 |
| Energy collected, MJ $day^{-1}$ | 20.80 | 18.00 | 3.40 |
| Available radiation during time of experiment, MJ $day^{-1}$ | 35.05 | 29.68 | 7.33 |
| System efficiency, percentage | 57.60 | 57.80 | 48.70 |

## Results and Discussions

**Efficiency Test Results:**

Climatic variables influence the performance of solar-heat collectors themselves as well as the energy requirements they serve. The variables are principally wind, temperature, precipitation, thermal radiation from the surroundings, and, especially, radiation from the sun (Brewer *et al.* 1981).

**Table 1** represents weather conditions and energy situations for the experiments. The drying air temperatures ranged between 21.7 ºC and 39.2 ºC and on average 30.1 ºC, with airflow rate of 72.7 $m^3$/(h.$m^2$. coll.surface), relative humidity 59.3 % on average

The performance of many collectors is sensitive to air speed over the collector in the range of 0-3 m $s^{-1}$. In order to maximize the reproductability of results, collectors should be mounted such that air with a mean speed between 3 and 8 m $s^{-1}$ will freely pass over the aperture (Gillett and Moon 1985). For given experiments the average wind speed was between 0.5-2.5 m $s^{-1}$ measured in the plane of the collectors at a distance of 50 mm from the surface of the cover (Gillett and Moon 1985). Due to the fact that this wind speed was less than that was recommended, therefore it might effect the thermal performance of the developed solar dryer.

In **Fig. 2** there were difference in the range of 1.7-16.1 ºC during 9:00 a.m. to 4:30 p.m. between ambient air and drying cabinet inlet air temperatures, which identify that there were temperature rises produced by the developed solar dryer and it was consider being high compare to conditions produce that difference. Also atmospheric dust and moisture, air pollution can affects the performance of solar energy system.

**Fig. 2** Solar system temperatures over time

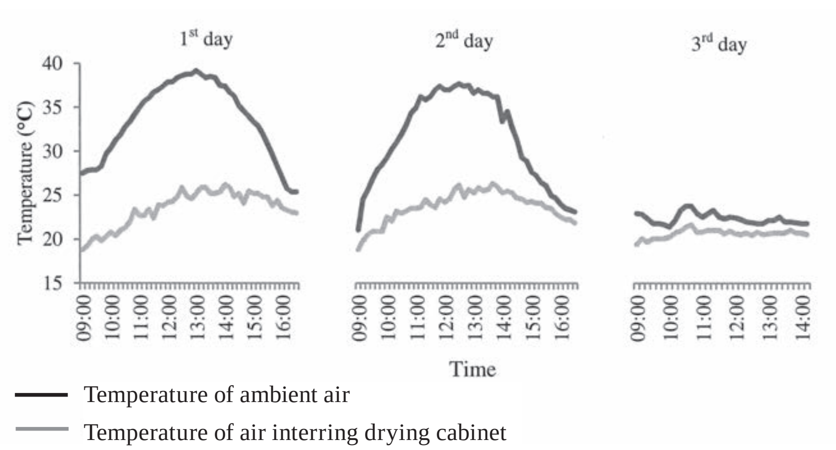


**Table 2** illustrates that the temperature inside the drying cabinet remains considerably higher than the ambient air temperature. Even in cloudy days, the solar dryer could maintain higher temperature and lower humidity. Rain does not seriously affect solar collectors, although it does imply the absence of sunshine, which decreases insolation on the plane of collectors and directly affects the quantity of energy would collect.

For given experiments, the collection efficiency for the main solar collector and the solar dryer were calculated. The average collection efficiency of the developed dryer was 54.7 %; the slope (U) of the curve was overall heat loss coefficient of the collectors, which were equal to 28.467 W $m^{-2}$ º$C^{-1}$ for the main collector and 23.474 W $m^{-2}$ º$C^{-1}$ for the dryer. This thermal coefficient is important quantity in evaluating the performance of a flat-plate collector and should, ideally, be as small as possible. These

**Table 3** The Parameters of the test on the product drying

| Parameter | Value |
|---|---|
| Total water removed ($W_s$), kg $H_2O$ | 4.926 |
| Drying rate ($u$), %M.C. $h^{-1}$ | 3.9 |
| Heat consumption($q_r$), kJ $kg^{-1}$ $H_2O$ | 10,061.3 |
| Dehydration intensity ($W_{ds}$), kg $H_2O$ $m^{-2}$ $day^{-1}$ | 1.074 |
| Drying intensity ($G_{ds}$), kg wet product $m^{-2}$ $day^{-1}$ | 1.308 |
| Electricity consumption ($q_j$), kWh $kg^{-1}$ $H_2O$ | 0.147 |
| Total energy consumption ($q$), kJ $kg^{-1}$ $H_2O$ | 10 590.5 |
| System drying efficiency ($\eta_d$), percentage | 24.2 |

**Table 4** Annual cost of useful energy of 11.258 MWh $yr^1$ delivered by solar collectors

| Parameter | Value | | |
|---|---|---|---|
| Gross collector's area ($m^2$) | 2.25 | | |
| Cost of collector (\$ $m^{-2}$) | 211.111 | | |
| Capital investment,(\$) | 475 | | |
| Salvage value, (\$) | 47.5 | | |
| | *n* | | |
| | 10 | 20 | 30 |
| Capital recovery factor | 0.163 | 0.117 | 0.106 |
| Salvage fund factor | 0.063 | 0.017 | 0.006 |
| First annual cost, \$ | 77.425 | 55.575 | 50.35 |
| Annual salvage value, \$ | 2.993 | 0.808 | 0.285 |
| Maintenance cost, \$ | 7.743 | 5.558 | 5.035 |
| Annual running fuel cost, \$ | 4.903 | 4.903 | 4.903 |
| Annual cost, \$ | 87.078 | 65.228 | 60.003 |
| Cost of 1 kWh of useful energy, \$ | 0.008 | 0.006 | 0.005 |

\$: U.S. Dollar

values may consider higher than what was expected. This may be due to the effect of low wind speed over the collector's cover, the present of clouds, and the sun was at the farthest point from the site, i.e. winter solstice (Dec. 21). Also some condensation was reported in the inner side of glass cover of the main collector, which reduced the energy that might reach the absorber plate. It was clear that the present of an assistant collector made improvement in collection efficiency of the solar system.

For evaluating the drying properties of the developed solar dryer, the performance parameters of the developed solar dryer are shown in **Table 3**. The results indicate that the numerical values of the heat consumption $q_r$, the mechanical consumption $q_j$, and the drying thermal efficiency of the solar dryer $\eta_d$ are satisfactory. In the total energy consumption $q$, only $q_j$ is commercial energy. Therefore, a large amount of commercial energy could be saved if solar dryer replaced the artificial dryer. The system drying efficiency for natural convection dryers values of 10-15 % are typical whereas for forced convection dryers higher values of 20-30 % can be expected (Commonwealth Science Council 1985), therefore, for given developed dryer the numerical value of system drying efficiency $\eta_d$ is satisfactory.

**A Techno-feasibility study:**

The calculation of the cost of useful energy delivered by the solar system is tabulated in **Table 4**, which is economically satisfactory. Since the annual delivered useful energy by the developed solar dryer is evaluated to be 11,257.84 kWh $yr^1$, therefore the annual quantity of the product that can be dried by the developed solar dryer assumed to be 4610.51 kg wet product/ yr.

Solar energy technology has been developed to a point where it can replace most of the fossil fuels or fossil fuel-derived energy in agriculture. In many applications it is already economical, and it is a matter of time before it becomes economical for other applications (Goswami. 1986).

## Conculsions and Recommendations

The drying air temperatures ranged between 21.7 ºC and 39.2 ºC and on average 30.1 ºC, with airflow rate of 72.7 $m^3$/ ($h.m^2$.coll.surface), relative humidity 59.3 % on average, and temperature rises of 1.7 ºC and 16.1 ºC. For those temperatures, the average collection efficiency was about 54.7 %.

Temperature inside the solar chamber remains considerably higher than the ambient. Even in cloudy days, the solar dryer can absorb intermittent sunlight and diffuse radiation, and maintains higher temperature and lower humidity.

The simple construction of the solar dryer enables manufactory either by small-scale industries or by farmers using locally available materials.

Recommended Future Work: A large-scale project must be setup, and will help assess in a more accurate way the economic feasibility of such an installation.

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# Energy Requirement for Irrigation Pumps in Allahabad District, Uttar Pradesh (India)

by
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## Abstract

A survey was conducted in six blocks of Allahabad district to assess the energy requirement for irrigation pumps. Around 26 villages of six blocks have been covered. The survey revealed that the pump sets were 8 to 12 HP, which was much higher than their requirement of 3 to 7 HP for irrigation. The energy requirement for each block was much higher than the actual energy required. The survey revealed that the pumping systems adopted by the farmers were inefficient and consumed more energy at the field level. The overall results showed that awareness among the farmers about the huge wastage should be made, which would help them in selection of proper size irrigation pump sets.

## Introduction

The heart of most irrigation systems is a pump. To make an irrigation system as efficient as possible, the pump must be selected to match the requirements of the water source, the water piping system and the irrigation equipment. Pumps used for irrigation in this region include centrifugal, deep well turbine and submersible. The energy required to pump irrigation water for crop production is measured in terms of fuel use or electric power use. Energy use depends on the amount of water pumped and on the fuel or electric power required to pump each unit of water. Before selection of irrigation pumps, a careful and complete inventory of the conditions under which the pump will operate must take place. The inventory must include:

1. The source of water (well, river, pond)
2. The required pumping flow rate
3. The total suction head
4. The total dynamic head

There usually is no choice when it comes to the source of the water; it is either surface water or well. Water and availability will be determined by the local geology and hydrologic conditions. However, the flow rate and total dynamic head will be determined by the type of irrigation system, the distance from the water source and the size of the piping system.

In India, 178 m ha out of 328 m ha total geological area is under cultivation. Creation of irrigation facilities are the basic need for development of agriculture and creation of employment opportunities in rural areas. Out of the 139 m ha ultimate irrigation potential, 82 m ha has been utilized for irrigation through major, medium and minor irrigation projects. Centrifugal pump sets are the most commonly used water lifting device for irrigation (Taneja *et al.*, 1986). There were about 8.7 million diesel pump sets and 15 million electric pump sets at the end of 2002. More then 70 percent were centrifugal pumps.

The energy used for irrigation is quite significant. An estimate indicates that ground water pumping requires more then 16 × 109 kWh of electricity and about 2,000 million liters of diesel oil annually. After 1951, the average annual growth rate of diesel pump sets was 0.13 million and the electric pump sets was 0.25 million. It was estimated that 23.7 million pump sets consumed about 60.90 billion kWh of electricity and 6 billion liters of diesel. About 90 percent of electric and diesel pump sets owned by the farmers were in the last three categories of energy consumption, indicating huge wastage of energy (Patel, 1999). It has been estimated that the overall efficiency of irrigation pump sets is 12.7 % for diesel operated and 325 for electric pump sets. Energy consumption in the existing pump sets is high due to low system efficiency. Larson and Fegmeir (1978) analyzed the energy input in irrigation crop production and reported that irrigation requirement maximum energy of 73.7 percent with ground water source and 13.4 percent with surface water supplied. Singh and Mittal (1985) reported that of the energy requirements for cultivation of major crops in Panjab, irrigation conserved maximum energy in all crops. Singh *et al*. (1997) investigated the energy requirement for production of rice in different states of the country. The energy requirements varied from 7,777 MJ/ha for Madhya Pradesh to 103,104 MJ/ha for Tamil Nadu. The variation in energy requirements in different states could be attributed mainly to irrigation requirements and quantity of fertilizer applied. About 90 % of total energy required in rice cultivation in Tamil Nadu was the electricity used in irrigation. However, in Panjab, rice cultivation required 32,892 MJ/ha of energy. Nearly 50 % of it was used for irrigation and about 30% was used for fertilizer and chemicals. Rice cultivation required 8,645 to 17,427 MJ/ha energy in West Bangal, 12,658 MJ/ha in Utter Pradesh and 8,784 to 11,330 MJ/ha in Orissa. In the same studies it was found that the total energy requirement for wheat was 18,881 MJ/ha in Panjab, 84,496 MJ/ha in Madhya Pradesh, 14,000 MJ/ha in West Bengal and 17,482 MJ/ha in Utter Pradesh. The variation in energy input was due to variation in fertilizer input depending upon the availability and purchasing power of farmers. Ramachandra and Nagarathna (2001) found that water and the associated average daily energy requirement depended on the area irrigated, type of crop, sources of water, total period of irrigation and irrigation efficiency.

## Materials and Methods

The survey was conducted in 26 villages and fewer than six blocks of Allahabad district on assessment of energy requirement for irrigation pumps. Detailed information was collected that related to work of the farmers like name of farmer, name of block, name of village, size of holding, type of pump used by farmers (fuel pump/energy pump) pump hp and required calculated parameters.

**Depth of Irrigation**

The depth of irrigation was calculated on the basis of moisture holding capacity of the soil in the crop root zone, in its different layers and the soil moisture extraction pattern of the crop in its root depth.

*Net irrigation depth (NID) = Aw × 0.5*

(Considering 50 % of moisture depletion)

where

Aw: Available soil water

NID: Net irrigation depth (cm)

**Discharge Capacity of Pump Based on Crop Requirement**

The pump discharge should meet the peak demand of water for the selected cropping pattern. The rate of pumping depends on the area under different crops, the water requirement of the crops, rotation period and the duration the pump is operated each day.

**Irrigation Interval**

The well yield utilization pattern was estimated based on operating hours of pumps, area to irrigate, type of crop grown and soil parameter by the formula:

$q = (27.78 \times A) / (H \times I)$

Where

q: Discharge rate (lps)

A: Area irrigated (ha)

D: depth of irrigation

I: Irrigation interval (days)

H: Pump operating hours (h/day)

**Water Horse Power (Whp)**

Water horse power was calculated by formula given below:

$WHP = (q \times H) / (75 \times 0.5)$

where

q = Discharge rate (lps)

H = Total head (m)

**System Efficiency**

The system efficiency was calculated by formula given below:

$\eta = (WHP \times 100) / IHP$

Where

η = System efficiency

IHP = Input horse power (hp)

**Energy Index**

Energy index was defined as the consumption of electricity or diesel per unit of irrigation work for an ideal or desired level of electrical consumption in an efficient pumping system. Energy index of the pump sets was calculated by using the equation:

$EI = 27.78\ P / (q \times H)$

where

EI = Energy index

q = Discharge rate l/s

H = Total head, m

P = Power consumption, kW

## Result and Discussion

**Classification of Farmer According to Land Holding**

The area to be surveyed was divided according to land holding of the farmer. It is shown in **Table 1** for farmers having <1, 1-2, 2-4,

**Table 1** Category of farmers according to land holding

| Land holding, ha | Category | No. of farmers | % |
|---|---|---|---|
| < 1 | Marginal | 7 | 7.4 |
| 1-2 | Small | 17 | 17.89 |
| 2-4 | Medium | 52 | 54.74 |
| > 4 | Large | 21 | 22.10 |

and > 4 hectare land holding. The categories were marginal, small, medium and large farmers.

**Cropping Pattern**

The maximum discharge that the farmer needed was computed, knowing the cropping pattern adopted by him. Paddy was the major crop during kharif season following wheat in the Rabi season. The other crops taken during kharif season were maize and sorghum while mustard, pea, potato and gram are taken in Rabi season.

**Power Consumption of Pumps**

The power consumption of the pumps for the six blocks was evaluated and compared between the required hp and the utilized hp for various blocks of Allahabad district. The tabular representation of results is shown in appendix **Table 2**. It clearly indicated that the variation between the average required power and average utilized power was maximum.

**System Efficiency of Pump Sets**

The number of farmers of each block, according to system efficiency, is shown in **Table 2**. Jasra and Karchhana block had more farmers in the range of 30-50 %. This showed that there was more energy loss in pump sets in this area. Farmers having a system efficiency range of 50-70 % were more in the Shankargarh and Chaka block. It showed that proper adoption of the required hp pump sets would decrease the wastage of energy. Farmers having system efficiency within range of 70-90 % was more in Chaka block.

**Energy Requirement for Irrigation Based on the Pumps**

The energy requirement for irrigation for various blocks was estimated based on the pumps. The calculation was done with the discharge information, WHP of pump, crop grown and available area. The energy utilization for irrigation for all blocks was higher than the actual energy used for irrigation. The tabular representation showed the energy utilization for irrigation. It showed that the difference was lowest in Chaka block (165,508.672 MJ/ha) and highest in the Meja block (415,114.995 MJ/ha). The higher energy utilization was due to lack of technical knowledge in irrigation. Farmers could reduce this excess energy by adopting the scientific approaches of water application such as irrigation scheduling (crop water requirement approach, pan evaporation replenishment and soil moisture deficit) and a pressurized irrigation system such as drip and micro-sprinkler.

**Energy Index of Various Blocks**

Energy index of various blocks was estimated based on pumps. The calculation of energy index included discharge, pumps power and head of the established pumps. The statically data present in appendix **Table 2**, shows that the energy index was maximum in Jasra block as compared to other blocks. The energy index ranged from 0.9 to 1.5 for Chaka and Koraon block, while other blocks had EI more than 1.5. The rectification measure in agriculture pumping systems can result in reduction in energy index and increase in system efficiency for other blocks.

## Conclusion

It was concluded that maximum percentage, i.e. about 54.74 % of medium farmers, had 2-4 hectare land holding. Paddy was the major crop during Kharif season following wheat in the Rabi season. It led to the conclusion that the pumping system adopted by the farmers was inefficient and consumed more energy at the field level. It necessitated the development of energy efficient pumping systems such as a model that would combine the standard components in irrigation pumps and their subsequent testing and evaluation. Proper extension work is needed to help the farmers select a pump size suitable for their land size and cropping pattern.

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**Table 2** Number of farmer for each block according to system efficiency, Power and Energy

| Number of farmers blocks wise | System efficiency, % | | | Power, HP | | Energy, MJ/ha | | Energy index |
|---|---|---|---|---|---|---|---|---|
| | 30-50 | 50-70 | 70-90 | Required | Utilized | Required | Utilized | |
| Chaka | 2 | 9 | 7 | 5.03 | 9.61 | 267820.98 | 433,329.66 | 0.98 |
| Jasra | 11 | 1 | 3 | 2.2 | 9.36 | 71,909.44 | 348,704.78 | 1.69 |
| Karchhana | 9 | 6 | 0 | 4.16 | 9.43 | 137,632.05 | 439,664.01 | 1.57 |
| Koraon | 6 | 7 | 2 | 3.96 | 9.57 | 147,963.03 | 380,586.21 | 1.51 |
| Meja | 7 | 6 | 2 | 3.79 | 9.73 | 171,555.56 | 586,670.55 | 1.64 |
| Shankargarh | 2 | 12 | 5 | 3.85 | 9.86 | 174,786.30 | 505,992.54 | 1.65 |

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# EVENT CALENDAR

### ◆ AG CONNECT Expo 2013
*January 29-31, 2013,* Kansas City, Missouri, UA
http://agconnect.com/

### ◆ AGROmash Expo 2013
*January 30th-February 2nd, 2013,* Budapest, HUNGARY
Agricultural machinery exhibition held in Hungary every year.
http://agromashexpo.hu/?nyelv=1

### ◆ 48th National Farm Machinery Show
*February 13-16, 2013,* Louisville, Kentucky, USA
Nation's largest indoor farm machinery show.
http://www.farmmachineryshow.org/generalinfo.aspx

### ◆ International Conference on Agricultural Engineering in Oman
—New Technologies for Sustainable Agricultural Production and Food Security—
*February 24-26, 2013,* Sultan Qaboos University, OMAN
http://www.agengineeingconf.com
Many well-known agricultural experts such as Dr. B. A. Stout of CIGR and Dr. Shujun Li of AAAE are invited as keynote speakers. English will be the official language in the conference.

### ◆ Agritech Astana 2013
*March 13-15, 2013*, World Trade Centre (WTC) Complex, ASTANA
http://www.tntexpo.kz/agritek_as.php?lang=en

### ◆ Agrotech Kielce
*March 13-16, 2013,* Kielce, POLAND
http://expopl.all.biz/ja/expo-agrotech-7713

### ◆ AGRO EXPO Bucovina
—Agricultural machinery exhibition—
*March 22th-24th, 2013,* City Gallery, Suceava, ROMANIA
http://www.agro-expo.ro/en/

### ◆ 2013 AMC Conference
—The 28th annual Agricultural Machinery Conference—
*May 6–8, 2013,* Waterloo, Iowa, USA
http://www.amc-online.org/About.html

### ◆ XI International Controlled & Modified Atmosphere Reserch Conference
*June 3–7, 2013,* Trani, ITALY
http://www.ishs.org/news

### ◆ Suprofruit 2013
—12th International Workshop on Sustainable Plant Protection Techniques in Fruit Growing—
*June 28–30, 2013,* Valencia, SPAIN
http://www.suprofruit2013.org.es/

### ◆ CIOSTA xxxv
—(commission internationale de l'organisation scientifique du travail en agriculture) from effective to inteligent agriculture and forestry—
*July 3–5, 2013*, Aarhus, DENMARK

### ◆ ICSAEF 2013
—International Conference on Sustainable Agriculture, Environment and Forestry—
*July 08-09, 2013,* London, UK
http://www.waset.org/conferences/2013/london/icsaef/index.php

### ◆ ECPA
—9th European Conference on Precision Agriculture—
the auspices of the International Society of Precision Agriculture (ISPA) and the Universitat de Lleida (UdL)
*July 07-11, 2013,* Catalonia, SPAIN
http://www.ecpa2013.udl.cat/index.html

*(to be continued to p.84)*

# Performance of a Modified Commercially Available Wheat Thresher for Threshing Lentil (*Lens Culinaris*)

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## Abstract

Grains of legumes are considerably affected due to mechanical handling. Traditional threshing practices and operations are labour consuming and expensive. Timeliness is an important factor in grain production systems due to weather hazards. Lentil (*Lens Culinaris*) is an important pulse crop which has considerable potential for adoption by farmers provided some of the major operations such as threshing are mechanized. The present study was aimed at optimizing important operational and crop parameters influencing threshing of lentil. Peripheral speed of cylinder and crop feed rate were independent parameters and grain breakage, cleaning efficiency and threshing efficiency were the dependent parameters. Cylinder speed of 21.9 m/s and feed rate of 10.5 q/h resulted in optimum threshing efficiency, cleaning efficiency, grain damage and non-collectable losses of 99.45 %, 99.28 %, 0.98 % and 0.60 %, respectively.

## Introduction

Pulses are an important and integral ingredient of rich protein diet for humans but, in India, the availability of pulses per person in the country has been declining and prices are sky-rocketing. Per capita pulses consumption declined by over 53 % from 27.3 kg/year in 1958-59 to 12.7 kg/year in 2009 (*Anonymous*, 2010). Various pulses such as green gram, black gram and horse gram are harvested at a proper stage of physiological maturity when the grain moisture content is relatively higher to avoid losses during harvesting, handling and transportation. The crop, after harvesting, is dried in the sun to obtain 8 to 10 percent grain moisture content for threshing. One of the main hurdles in promotion and adoption of pulses by farmers is lack of mechanization of various farming operations. Lentil is one such crop which has considerable potential for adoption at a large scale by farmers provided some of the major operations such as threshing are mechanized.

At present, farmers in India thresh lentil either manually or by using a stationary combine harvester. The manual process is tedious and laborious, whereas feeding the precut crop to a stationary combine harvestor is also tedious and laborious. An attempt has been made by different researchers to evaluate the existing paddy and wheat threshers for pulse crop by incorporating necessary modifications. Tandon (1981) conducted trials on peg tooth and rasp bar type threshing cylinders for black gram and found that threshing efficiency as well as invisible grain damage were inversely proportional to concave clearance and grain-straw ratio, but directly proportional to cylinder speed. Singhal and Thierstein (1987) reported that a thresher with rasp bar and spike tooth type cylinders, primarily designed for threshing paddy, were quite safe for pulses, but several modifications were required to be carried out for effective threshing of common pulses. Anwar and Gupta (1990) evaluated the performance of an axial flow thresher (AGAD model C) to thresh the gram crop. The percent damage and threshing efficiency decreased with increase in concave clearance. Various studies revealed that, even though different threshers were tested for different crops, neither of the studies was related to threshing of the lentil crop. Keeping in view the limitation of threshability and the shortcoming of traditional methods, it was decided to develop a thresher for lentil which could be used for other crops as well.

## Materials and Methods

**Commercial Thresher**

A commercially available spike

tooth type thresher (**Fig. 1**) powered with an electric motor was selected and modified for use on lentil. This machine was used for wheat threshing on large scale in India. The overall dimensions of the thresher were *1765 × 1065 × 1570* mm. The main components of the thresher were main frame, threshing cylinder, concave, cylinder casing, aspirator I and II and a reciprocating sieve system. Brief specifications of the machine are given in **Table 1**. A typical cylinder concave clearance of 15 mm and cylinder 36 spikes are used for threshing wheat. The spikes consisted of 16 mm diameter studs. Aspirators (I and II) utilized centrifugal separation system and comprised of 3 to 4 blades. Aspirator-I separated the major chunk of chaff falling over the upper sieve directly below the concave. Aspirator-II carried out the second stage of cleaning. It picked up chaff from the screen just prior to discharge of grain from the main outlet. Reciprocating sieve system consisted of a replaceable set of sieve and screen mounted on an oscillating frame. The amplitude of oscillations could be varied. The upper sieve separated the chaff bigger than the grains, whereas the lower sieve separated the dust and particles smaller than the grain, thus, helping in delivery of clean grain at the main outlet. The thresher was provided with four cast iron wheels for easy transportation and with a stand on which to mount the motor. Such a thresher also had a provision for attaching a universal shaft powered by the tractor PTO and an attachment for transportation on the 3-point linkage of the tractor.

## Modifications for Threshing Lentil

Generally, 36 spikes were provided on the threshing cylinder for threshing wheat. However, only six spikes were provided on the threshing cylinder in 6 rows; one in each row for threshing lentil. The arrangement of spikes on the cylinder

**Table 1** Brief specification of commercially available spike tooth type thresher

| Particulars | Dimensions (mm)/ Details |
|---|---|
| Type of thresher | Spike tooth type |
| Overall dimension: | |
| a) Length, mm | 1,765 |
| b) Width, mm | 1,065 |
| c) Height, mm | 1,570 |
| Crops for which thresher is adoptable | Wheat/ Lentil |
| Power required | 7.5 hp |
| Concave clearance, mm | 25 |
| Diameter of cylinder, mm | 562 |
| Length of cylinder, mm | 334 |
| Description of threshing elements on cylinder | |
| a) No. of rows | 6 |
| b) No. of spike in a row | 6/1 |
| c) Total spikes | 36/6 |
| d) Type of spike | 16 mm diameter studs |
| e) Arrangement of spikes | Helical |
| Aspirator I & II | |
| a) Type of aspirator | Centrifugal |
| b) No of blades | 4 & 3 |

**Table 2** Modifications on wheat thresher used for threshing lentil

| Particulars | | |
|---|---|---|
| Crops for threshing | Wheat | Lentil |
| Concave clearance, mm | 15 | 25 |
| Description of threshing elements on cylinder | | |
| a) No. of spike in a row | 6 | 1 |
| b) Total no. of spike | 36 | 6 |

**Table 3** Specifications of independent parameters used for evaluation

| Description | Level | Values | | | |
|---|---|---|---|---|---|
| Peripheral speed (PS), m/s | 4 | 18.2 | 20.1 | 21.9 | 23.7 |
| Feed rate (F), q/h | 3 | 7.5 | 9.0 | 10.5 | |

**Fig. 1** Views of commercially available wheat thresher used for threshing Lentil

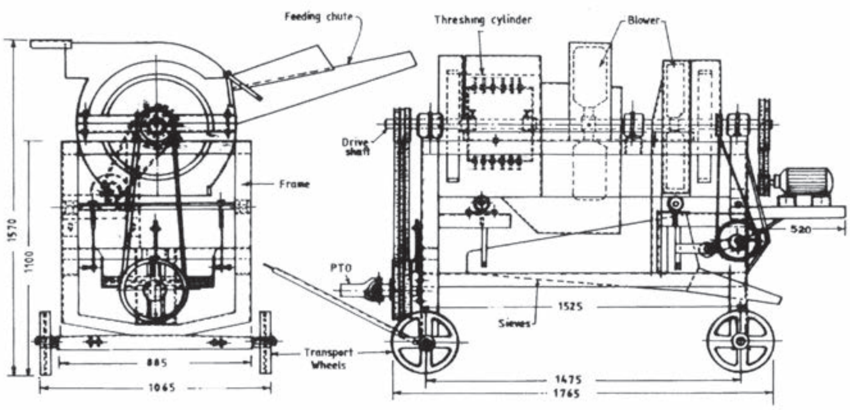


**Table 4** Field performance of modified wheat thresher on lentil

| Peripheral speed, m/s | | Feed rate, q/h | | Out-put, kg/h | Breakage, % | Total non collectable losses, % | Cleaning efficiency, % | Threshing efficiency, % |
|---|---|---|---|---|---|---|---|---|
| PS1 | 18.2 | F1 | 7.5 | 284.90 | 0.77 | 0.55 | 99.12 | 99.35 |
| PS2 | 20.1 | F1 | 7.5 | 284.63 | 0.98 | 0.65 | 99.29 | 99.40 |
| PS3 | 21.9 | F1 | 7.5 | 284.68 | 1.07 | 0.86 | 99.49 | 99.61 |
| PS4 | 23.7 | F1 | 7.5 | 284.07 | 1.74 | 0.95 | 99.86 | 99.85 |
| PS1 | 18.2 | F2 | 9.0 | 341.54 | 0.75 | 0.50 | 98.10 | 99.24 |
| PS2 | 20.1 | F2 | 9.0 | 341.87 | 0.97 | 0.59 | 99.06 | 99.33 |
| PS3 | 21.9 | F2 | 9.0 | 341.73 | 1.00 | 0.76 | 99.39 | 99.59 |
| PS4 | 23.7 | F2 | 9.0 | 341.70 | 1.69 | 0.89 | 99.80 | 99.79 |
| PS1 | 18.2 | F3 | 10.5 | 398.52 | 0.57 | 0.45 | 98.05 | 99.17 |
| PS2 | 20.1 | F3 | 10.5 | 398.04 | 0.77 | 0.41 | 98.52 | 99.10 |
| PS3 | 21.9 | F3 | 10.5 | 398.07 | 0.98 | 0.60 | 99.28 | 99.45 |
| PS4 | 23.7 | F3 | 10.5 | 398.13 | 1.64 | 0.80 | 99.07 | 99.73 |

periphery was helical. Similarly, concave clearance was increased from 15 to 25 mm by reducing the length of spikes. Various modifications incorporated on a typical spike-tooth type wheat thresher for lentil are shown in **Table 2**.

## Crop

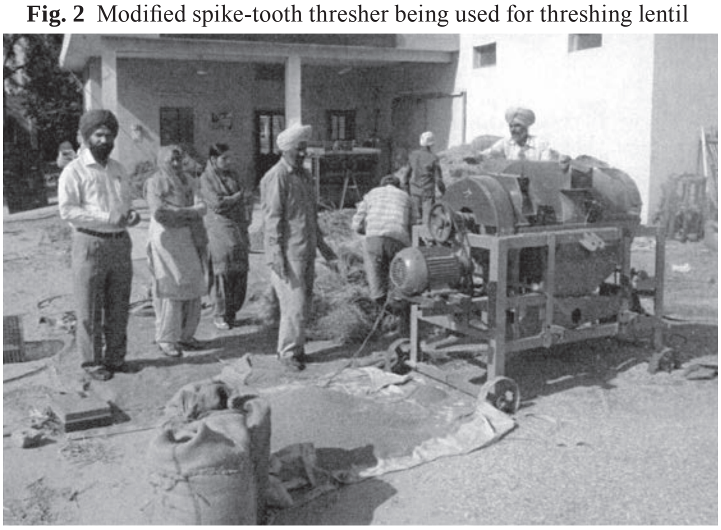
Lentil LL-699 variety, grown with standard agronomic practice as laid down in Package of Practices for Rabi crops (*Anonymous*, 2008 and *Anonymous*, 2009) at Punjab Agricultural University, Ludhiana, Punjab, India during Rabi 2008-09 and 2009-10, was used for the study. After attaining optimum grain maturity (majority of the pods turned brown) with grain moisture content of 18-20 %, the crop was harvested manually, in the month of March-April.

## Evaluation Procedure

The performance tests of lentil threshing were conducted at four levels of cylinder peripheral speed, three levels of crop feed rates and three replications. This was used in a completely randomized design (CRD) of a $4 \times 3 \times 3$ factorial experiment with three replications in each treatment and comparison between treatment means was considered significance with a difference (LSD) at the 5 % level. The peripheral speeds of 18.2, 20.1, 21.9 and 23.7 m/s were considered for this experiment and were attained with a set of driver and driven pulley of different sizes. Three levels of feed rates of 7.5, 9.0 and 10.5 q/h were considered for the experiment and were attained by varying the time of feeding the crop in the cylinder. The cylinder and concave clearance was 25 mm. Four levels of peripheral speed (18.2, 20.1, 21.9 and 23.7 m/s) and three levels of feed rate (7.5, 9.0 and 10.5 q/h) were the independent variables.

The effect of the both independent parameters on grain damage, non-collectable losses, cleaning efficiency and threshing efficiency was studied. The thresher was operated by a 7.5 hp, 3-phase electric motor. A tachometer was used for recording speed. The crop was weighted on a weighing balance. The grains collected for determining losses were weighed on an electronic balance.

**Fig. 2** Modified spike-tooth thresher being used for threshing lentil



## Plan of Experimentation

The mature dried crop was harvested 2-3 days prior to threshing and was manually fed into the thresher. Bundles of 10 kg were formed. These 10 kg bundles were fed to the thresher and the respective time period was noted. The outputs of these tests were noted and expressed in q/h. The samples were taken from the grain outlet for determining the percent unthreshed, broken percentage and cleanliness of the grains. Sieve overflow was collected and re-threshed

**Table 5** Factor means of independent variables on dependent variables

| Parameters | Level | Breakage, % | Non-Collectable Losses, % | Cleaning Efficiency, % | Threshing Efficiency, % |
|---|---|---|---|---|---|
| Peripheral Speed (PS), m/s | 18.2 | 0.696 | 0.503 | 98.42 | 99.25 |
| | 20.1 | 0.907 | 0.551 | 98.96 | 99.28 |
| | 21.9 | 1.014 | 0.741 | 99.38 | 99.55 |
| | 23.7 | 1.690 | 0.883 | 99.57 | 99.79 |
| Feed Rate (F), q/h | 7.5 | 1.138 | 0.756 | 99.44 | 99.55 |
| | 9.0 | 1.104 | 0.687 | 99.09 | 99.49 |
| | 10.5 | 0.988 | 0.567 | 98.73 | 99.36 |

at the end of experiment. The straw was also collected for one minute from the aspirator outlets and the grain recovered from this outlet was termed as non-collectable loss. The un-threshed grains from the grain outlet were separated, weighed and expressed as threshing efficiency. The unwanted material from clean grains was separated, weighed and expressed as cleaning efficiency.

## Results and Discussion

**Breakage**

The effect of four levels of peripheral speeds and three levels of feed rates was studied on grain breakage (**Table 4**). Average grain breakage was 1.08 %. The data were statistically analyzed (**Table 5**). Factor means clearly indicated that breakage was directly related to the peripheral speed and inversely related to feed rate. In other words, with the increase in the peripheral speed, breakage of grains increased and it decreased with the increase in feed rate. The effect of peripheral speed was significant at the 5 % level of confidence (**Tables 5** and **6**). However, the effect of feed rate on breakage and their interaction was non-significant. The percent breakage ranged from 0.57 to 1.74. Minimum breakage of 0.57 % was observed at lower peripheral speed (PS1) and higher feed rate (10.5 q/h), while breakage was the maximum at higher peripheral speed (PS4) and lower feed rate (7.5 q/h). Breakage was maximum at higher peripheral

**Table 6** ANOVA for the lentil threshing by modified wheat thresher

| Source of Variation | d.f. | Breakage, % | Non-collectable loss, % | Cleaning efficiency, % | Threshing Efficiency, % |
|---|---|---|---|---|---|
| PS | 3 | 62.58* | 24.90* | 27.18* | 98.05* |
| F | 2 | 2.83 | 9.87* | 17.94* | 16.62* |
| PS × F | 6 | 0.26 | 0.47 | 2.25 | 1.44 |
| Error | 24 | | | | |

* Indicate significant at 5 % level of confidence

**Fig. 3** Effect of peripheral speed and feed rate on grain breakage while threshing Lentil useing modified commercially available spike tooth type thresher

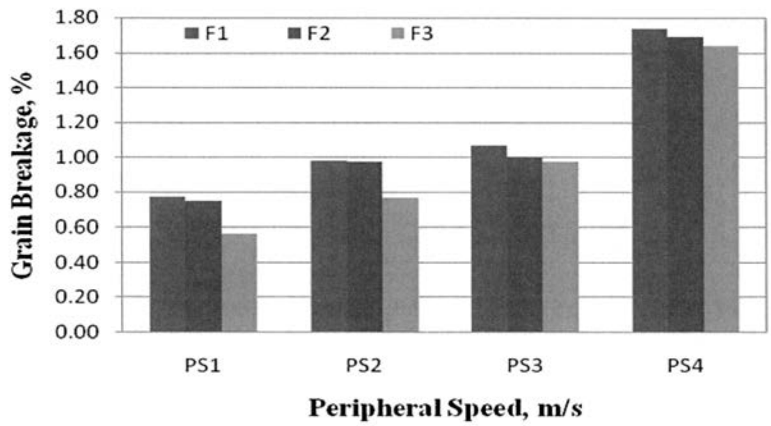
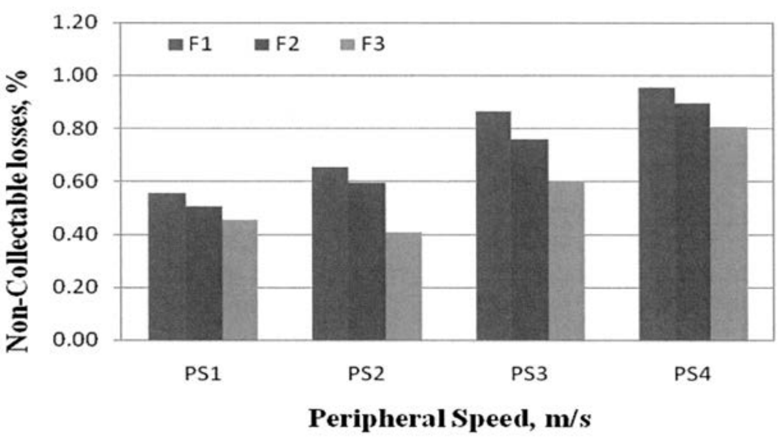



**Fig. 4** Effect of peripheral speed and feed rate on non-collectable losses while threshing Lentil useing modified commercially available spike tooth type thresher



speed due to the higher combined effect of impact and rubbing force (Neeraj and Singh, 1998). The breakage was also more at lower feed rate due to higher impact of threshing members. The percent breakage at different peripheral speeds and feed rates is shown in **Fig. 3**.

### Non-collectable Losses

Non-collectable losses are those which cannot be collected and are the seed losses from aspirators. The effect of four levels of peripheral speeds and three levels of feed rates were studied on non-collectable losses (**Table 4**). The percent non-collectable losses at different peripheral speeds and feed rates are shown in **Fig. 4**. Average non-collectable losses were 0.67 %. The data was statistically analyzed (**Tables 5** and **6**). The effect of peripheral speed and feed rate was significant at the 5 % level of confidence. However, interaction of peripheral speed and feed rate was non-significant. Factor means clearly indicated that non-collectable losses were directly related to the peripheral speed (with the increase in peripheral speed, the non-collectable losses also increased). Also, these were inversely proportional to feed rate (with increase in feed rate, the non-collectable losses decreased). The minimum non-collectable losses (0.41 %) were at PS2F3 and the maximum (0.95 %) at PS4F1. Non-collectable losses increased with the increase in peripheral speed because as the peripheral speed of the threshing cylinder increased, percent broken grains also increased. Simultaneously, aspirator speed increased since the aspirator was mounted on the same shaft, thus, leading to higher non-collectable losses. Further, non-collectable losses decreased with the increase in feed rate because percent broken grains and chances of their removal were reduced at higher feed rates.

**Fig. 5** Effect of peripheral speed and feed rate on cleaning efficiency while threshing Lentil useing modified commercially available spike tooth type thresher

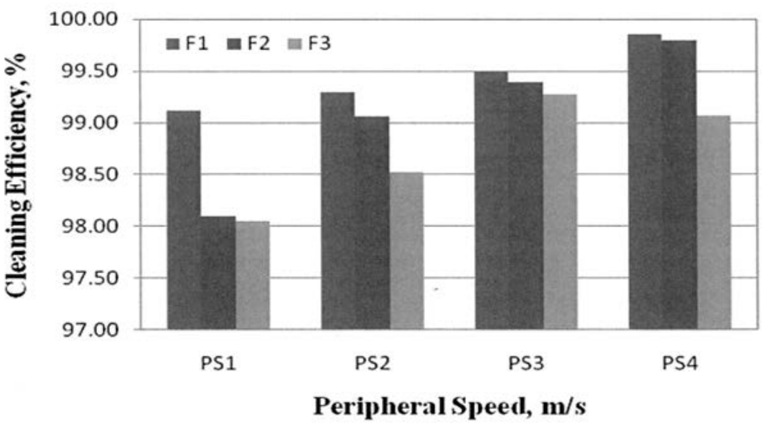
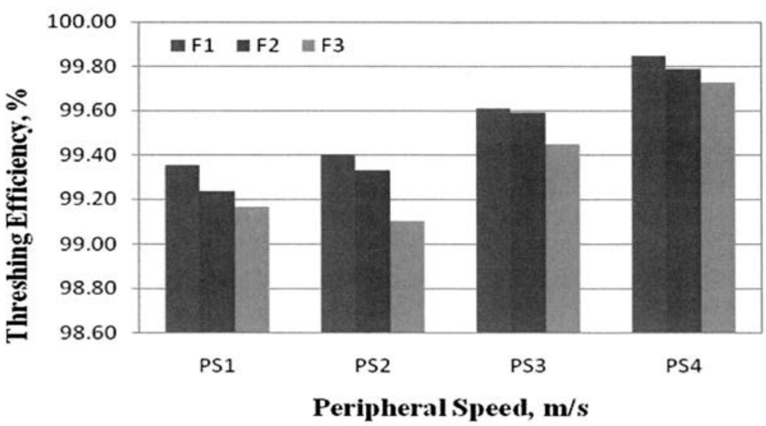



**Fig. 6** Effect of peripheral speed and feed rate on threshing efficiency while threshing Lentil useing modified commercially available spike tooth type thresher




### Cleaning Efficiency

The effect of four levels of peripheral speed and three levels of feed rate on cleaning efficiency (**Table 4**) was studied. Overall average of cleaning efficiency was 99.08 %. The data for cleaning efficiency was also statistically analyzed. Effect of peripheral speed and feed rate was significant (**Tables 5** and **6**) at the 5 % level of confidence. However, interaction of peripheral speed and feed rate was non-significant. Percent cleaning efficiency ranged from 98.05 at PS1F3 to 99.86 at PS4F1, respectively. Cleaning efficiency was directly related to the peripheral speed (with the increase in the peripheral speed the cleaning efficiency increased and it decreased with the increase in feed rate). The cleaning efficiency increased with increase in peripheral speed since the threshing cylinder and aspirators were mounted on the common shaft. Hence, increase in the speed of the threshing cylinder increased the separation. Further, cleaning efficiency decreased with the increase in feed rate since the amount of material available for separation increased at higher feed rates. The values of percent cleaning efficiency have been plotted in **Fig. 5**.

### Threshing Efficiency

The effect of four levels of peripheral speeds and three levels of feed rates on threshing efficiency (**Table 4**) was studied. Average threshing efficiency was 99.47 %. The data were statistically analyzed (**Tables 5** and **6**). The effect of peripheral speed and feed rate was significant at the 5 % level of confidence. However, interaction of peripheral speed and feed rate was non-significant. Minimum threshing efficiency (99.10 %) was observed at peripheral speed PS2 and feed rate F3, while maximum threshing efficiency (99.85 %) was observed at peripheral speed PS4 and feed rate F1. Threshing efficiency was directly proportional to peripheral speed. However, it was negatively correlated with the feed rate. The values of percent threshing efficiency at different peripheral speeds and feed rates have been plotted in **Fig. 6**.

**Optimum Values of Independent Variables**

The effect of peripheral speed and feed rate on dependent variables (grain breakage, non-collectable losses, cleaning efficiency and threshing efficiency) were studied. To obtain optimum combination of parameters the criteria adopted was that the threshing efficiency should be the maximum, percent breakage should be minimum, non-collectable losses should be minimum and cleaning efficiency should be maximum.

Perusal of **Table 4** revealed that threshing efficiency was more than 99 % for all treatment combinations, therefore, any combination could be selected.

Breakage was less than 1 % for feed rate F3 for all the peripheral speeds except PS4. Similarly, breakage was below 1 % for PS1F1, PS2F1, PS1F2 and PS2F2. Therefore, any combination from these would lead to optimum performance.

Further perusal of table 4 revealed that non-collectable loss was less than 1 % for all treatment combinations. Hence, it can be ignored for calculation of optimum combination of operational parameters.

Amongst combinations selected based on percent breakage, the cleaning efficiency was maximum at PS2F1 (99.29 %) and PS3F3 (99.28 %). Enhanced feed rate made little difference in the cleaning efficiency. Hence, the recommended treatment combination was PS3F3. At the selected treatment combination peripheral speed was 21.9 m/s and feed rate was 10.5 q/h. The percent grain damage was 0.98, percent non- collectable losses were 0.60, percent cleaning efficiency was 98.28 and percent threshing efficiency was 99.45.

## Conclusions

1. Peripheral speed and feed rate play an important role in affecting threshing efficiency, cleaning efficiency and breakage of lentil crop. Threshing was almost complete during all trials of peripheral speed and feed rate.
2. The percent grain breakage was higher for higher peripheral speed and lower for higher feed rate.
3. The non-collectable losses were below 1 % for all combinations.
4. The percent cleaning efficiency ranged from 98.05 to 99.86.
5. Amongst combinations selected based on percent grain breakage and cleaning efficiency the recommended treatment combination was PS3F3.
6. For threshing of lentil with a modified commercially available wheat thresher the peripheral speed of 21.9 m/s and feed rate of 10.5 q/h was optimum. At this combination the percent grain damage was 0.98, percent non-collectable losses were 0.60, percent cleaning efficiency was 98.28 and percent threshing efficiency was 99.45.

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■■

**Table 7** Optimum values of independent parameters

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| Peripheral speed (PS), m/s | 21.9 | Non-collectable losses, % | 0.60 |
| Feed rate (F), q/h | 10.5 | Cleaning efficiency, % | 99.28 |
| Grain damage, % | 0.98 | Threshing efficiency, % | 99.45 |

# Modification and Performance Characteristics of a New Prototype for Cleaning Seed Cotton

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## Abstract

The present investigation was conducted in October, 2007 at the Rice Mechanization Center, Meet El-Deeba, Kafr El-Sheikh governorate. The modified prototype was fabricated at a small workshop in Kafr El-Sheikh city. The experimental results revealed that the seed cotton extractor (prototype) performance after modification was better than that before. Seed cotton waste was minimized by 14 % and 32.58 % for the prototype before and after modification, respectively. Also, cotton trash content was reduced by 8.87 and 35.75 % for the prototype before and after modification, respectively. Its productivity was increased by 92.19 % and 109.15 % before and after modification, respectively. Also, the prototype productivity was increased by 28.24 % when the feed rate was increased from 0.60 to 0.75 Mg/h. At all the investigated feed rates, the modified prototype had higher values of cleaning efficiency. The increment in cleaning efficiency was of 21.22 % by raising feed rate from 0.60 to 0.75Mg/h. The prototype energy requirements were minimized by 42.59 and 47.02 % before and after modification, respectively. Cotton moisture content was reduced by 31.80 % when the drying air temperature increased by 11.63 %. Total cost requirements for the modified prototype were slightly smaller by 0.66 %. Whereas, criterion function cost was smaller for the modified prototype by 16.77 % than before modification as seed cotton losses were effectively minimized after modification. The characteristics of cotton fiber quality were highly enhanced and strongly influenced by the investigated variables for the modified prototype than before modification.

## Introduction

Cotton is considered as the most strategic crop in the world. In addition, it is the most exported crop in Egypt because of its high quality and lint properties. The cultivated area of cotton in Egypt, has decreased in the last two decades from about one to one-half million feddans (GAGS, in Arabic 2006). The increased cost of production and competition with other crops, especially the manual picking operation that has a high labor requirement, were the main reasons for the reduction of the area of the cotton crop. To minimize the production cost, mechanical picking must be practiced. But, the mechanically picked seed cotton has a large amount of accompanied impurities that must be cleaned directly before further processing. So, by using the mechanically picked seed cotton, followed by a pre-cleaning process, the total production cost can be rapidly decreased (El-Yamani, 2007). In spite of this, mechanically picked seed cotton contains substantial quantities of trash that must be removed in the early stages of ginning to promote efficient drying, trouble free gin-stand operation and satisfactory lint grades. Cylinder type cleaners are generally employed for removing leaf material and other fine particulates. An extractor-type machine is used for removing large trash such as burs and sticks (Gillum and Armijo, 1997). Stick machines (separating sticks from the mechanically picked seed cotton) are commonly utilized, at commercial cotton gins, for removing large vegetative trash components in mechanically harvested cotton. These machines extract burs and sticks from the cotton by utilizing the centrifugal forces created by rotating saw cylinders and the stripping action of round grids positioned about the circumference of each cylinder (Baker and Laird, 1986). A multi-stage extractor was designed and located at the most convenient position in the seed cotton cleaning system. Laboratory studies indicated that the designed machine was substantially more efficient in removing burs and sticks from stripper cotton than that of the conventional system that was composed of two successive extractors. Cleaned seed cotton by the multistage extractor contained about one-half of trash as compared with that cleaned by conventional machinery (Baker and Lalor, 1990). The identification and technical performance evaluation of some biobased products was presented and subjected. These are potential alternatives to the petroleum-based floor strippers. Two sets of experiments were performed. The first set of experiments involved laboratory scale experiments using different cleaning products and techniques. The second set of experiments involved pre-field tests conducted on a typical floor in the Toxic Use Reduction Institute laboratory. All experiments employed the standard operating procedures under different experimental conditions varying the temperature, soaking time, cleaning media (abrasive pads or cotton cloth) and the concentration of products. The cleaning efficiency for each of the biobased or green products was based on the gravimetric analysis of the coupons. Performance of concentrated potential biobased floor strippers was in the range of 50 to 99 % (Ephraim *et al*., 2008). The model combination of the gin-lint cleaner was improved by adding a solid wrapped brush between the gin saws and primary cleaning cylinder and adding cleaning bars around the gin saw. The cleaning efficiency of the experimental machine was better than that of the standard saw-type lint cleaner. Also, lint quality properties of length and nap count tended to be better for cotton processed through the improved machine (Hughs *et al*., 1984). A full-size prototype coupled lint cleaner on a small scale using first and second pick, and stripper-harvested upland cottons on a large scale was built and tested. For both tests, the ginned and cleaned fiber from the coupled lint cleaner had significantly less trash and higher grades, longer fiber and fewer short fibers and higher cleaning rates with less fiber breakage. The higher cleaning efficiency of the coupled lint cleaner was more pronounced for the trashier counts but was significant even for cleaned cotton (Hughs *et al*., 1990). The seed cotton cleaning system included both large trash and small extracting. A limited system of trash cleaning components was out performed based only on the extraction of large trash. The more extensive systems produced cleaner lint than that produced by the limited system. Seed cotton cleaning level did not, however, significantly affect fiber or yarn quality (Baker *et al*., 1994). The self-cotton cleaning leading to the stain discoloration was quantified to assess the photo-activity of the clusters prepared under different experimental conditions. This process showed promise for the total removal of stains containing persistent colored pigments on the cotton fibers (Bozzia *et al*., 2005). Cotton cleaning efficiency was increased by decreasing moisture content, but whenever the moisture was decreased to a great extent, the mechanical motion of detergents damaged the cotton fiber and seed during cleaning. Therefore, the decrease of moisture in the cotton to be cleaned, should be the amount that does not affect the cleaning efficiency (Youssef, in Arabic, 1992). Drying seed cotton in most gins expose it to the drying air for a very short period of time (10 to 20s), which is normally assumed to transfer insignificant amounts of moisture from the seed. Indeed, lint near the center of clumps may be hardly dried at all and the exterior fibers may be over dried. This article will be concerned with the equilibrium moisture content of cotton. The up take of water by fibers is critical to textile manufactures (Abemathy *et al*., 1999). Most textile fibers are hygroscopic. They have the ability of water absorption or giving it to surrounding air. Crude cotton absorbs moisture from the air faster when in high humidity air and so its mass is increased quantitatively. Seed cotton wastage and the extracted trash were gradually increased as the cleaning cylinder speed was also increased (El Awady *et al*., 2005). The essential aim of the current study was to modify some parts in the seed cotton extractor with the purpose of raising its productivity and cleaning efficiency. The specific objectives were directed to the following two points:

a) To specify the optimum operating conditions of prototype before and after modification and
b) To minimize the energy requirements of prototype and its criterion function cost.

## Materials and Methods

**Experimental Prototype:**

A new pre-cleaning prototype of seed cotton extractor was locally manufactured, by El-Yamani (2007), to be suitable for cleaning the Egyptian cotton varieties (extra-long staple) from the accompanied impurities after mechanical picking. Those impurities such as motes, undeveloped ovules, sticks, flowers, branch parts, green leaves, burs, dust, sand, grass and rocks. Extracting the impurities from seed cotton heaps, using the new prototype, was achieved through three successive stages as follows. The first stage was to feed seed cotton mixed with impurities to the extractor by the mechanical loader. In this stage, a pre-cleaning of seed cotton occurred through conveying by mechanical loader. Some of fine and large impurities were extracted and removed through a specific screen beneath the mechanical loader. The second stage was to get rid of fine impurities (small trash) by means of four impact drums. The third stage was to remove large impurities and the rest of fine impurities. Three doffing and saw drums were involved in this stage that rotated in the opposite direction to that of the bristles. Through the second and third stages, the extracted impurities were collected and separated away through a specific hose and conveyed out of the prototype by means of a trash auger. The prototype was operated by the PTO of a 65 HP tractor. A detailed description of the prototype construction is presented by El-Yamani (2007). A sketch of the seed cotton extractor before modification is illustrated in **Fig. 1**.

**Suggested Modification:**

A sketch of the modified prototype is shown in **Fig. 2**. Four main parts in the prototype could be modified. The mechanical loader of the cotton heap was equipped with a specific drying unit for reducing the moisture content of seed cotton. The drying unit was mainly constructed to facilitate extraction of seed cotton from the accompanied impurities and hence raised the cleaning efficiency in the following stages of the prototype. Three 5 kW electrical heaters were involved in the drying unit to obtain different levels of drying air temperature. A 25 cm fan was fixed above the electrical heaters for delivering the heated air across the screen to meet the raw seed cotton heap during its feeding. The mechanical loader broke the cotton heap into crumbs during its feeding to allow the heated airflow to be increased. This process increased the cotton - heated air contact time and facilitated extracting the accompanied impurities from the cotton heap. The maximum heated air velocity of 10 m/s was used, beyond which it will overcome the cotton feeding upward. From the primary trials, it was found that the higher the heated air velocity the lower the cotton moisture content and the higher cleaning efficiency of the extracted seed cotton. The drying air velocity was constant at 10 m/s for all treatments. The drying unit was provided with an insulator to minimize heat dissipation. The number of impact drums was reduced from four to three. From the preliminary experiments, it was determined that the majority of fine impurities (small trash) were extracted with only three impact drums. But the number of saw and doffing brush drums was increased to four drums instead of three. This

**Fig. 1** A geometrical drawing of the seed cotton extractor before modication (El-Yamani, 2007)

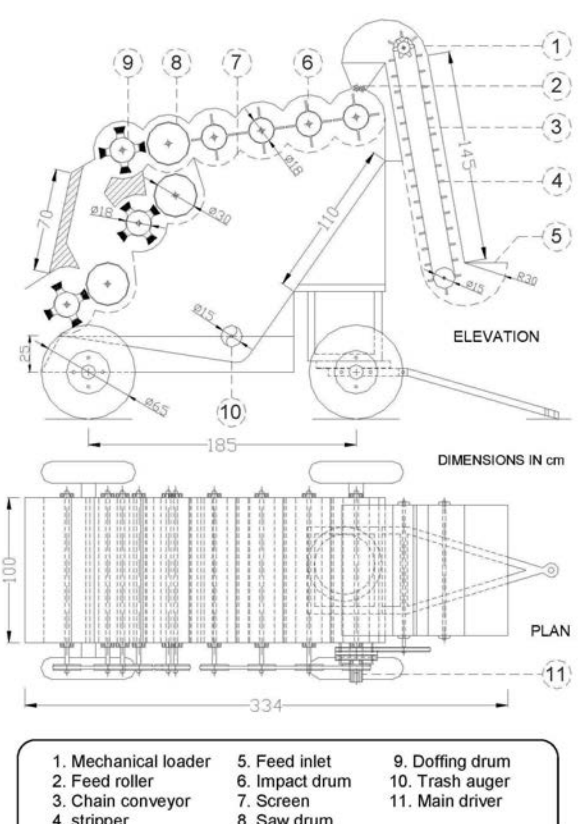
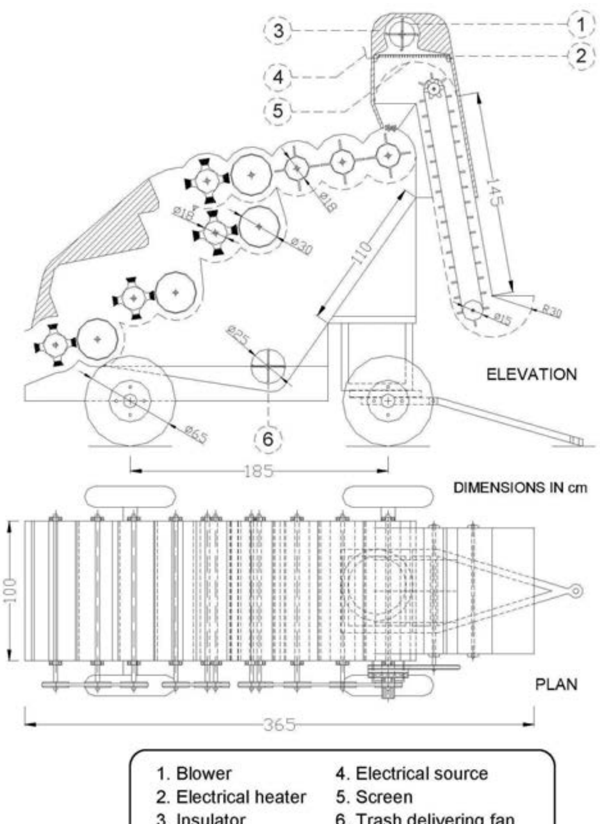



**Fig. 2** A geometrical drawing of the seed cotton extractor after modication



was because primary tests showed that those drums had high effectiveness in extracting the large impurities and the rest of fine ones. A trash auger was replaced with a fan to facilitate delivering of impurities out of the prototype. This accomplished the process in the lowest possible time.

**Investigated Variables:**

Three levels of seed cotton heap moisture content (6.31, 5.16 and 4.40 % d.b.) were studied before modifying the prototype. These values were obtained by drying the seed cotton heap inside a separate drying unit directly after mechanical picking. After modifying the prototype, three different drying air temperatures of 318.15 K (45 ºC), 338.15 K (65 ºC) and 355.15 K (82 ºC) were employed. The initial moisture content of the seed cotton heap that entered the modified prototype was constant at 13 % d.b. directly after picking for all investigated treatments. Three levels of saw drum speed of 5.97, 6.73 and 7.47 m/s were selected and investigated before and after modifying the prototype. Three different feed rates (0.30, 0.45 and 0.60 Mg/h) were used before modification and three others (0.39, 0.54 and 0.75 Mg/h) were used for the modified prototype.

**Instrumentation:**

Cotton moisture content was determined by the oven method. Two J-type thermocouples and a digital thermometer (Model: HH-26J-USA) were employed to recording drying air temperature inside the modified prototype. Drying air velocity was measured by means of a hot-wire type anemometer (Model: SATO-SK-73D). A tachometer (Model: 3632) was used to measure saw drum speed in rpm. This was converted into linear velocity in m/s. The current strength and potential difference were measured using an ammeter and voltmeter, respectively. Readings of amperes and volts were monitored before and during each treatment. Some empirical equations were developed to characterize the prototype performance.

**Measuring Procedures:**

Seed cotton trash content was determined by means of a fractionator instrument with a sample of 150 g. It was determined as a percentage of trash content using the formula of Youssef, in Arabic (1992):

*Trash content, %* $= \Sigma T_w / W_0$ ........ (1)

where;

$\Sigma T_w$ is the sum of trash content masses, g and

$W_o$ is the total mass of original sample, g.

Trash content output was collected, massed and re-separated into fiber and fiber foreign matter. The percentage of cotton wastage was calculated based on the collected cotton fiber in the sample to the total mass of sample.

Cleaning efficiency was calculated according to the equation of Mangialardi (1986):

*Cleaning efficiency, %* $= \{(Y_1 - Y_2) / Y_1\} \times 100$ ......................... (2)

where;

$Y_1$ is the total foreign matter content of specimen before extracting, % and

$Y_2$ is the total foreign matter content of specimen after extracting, %.

The amount of power required for operating the electric heater has been calculated according to Lockwood and Dunstan (1971):

*Electric heater power, kW* $= 1 / 1000\ (I \times V \times \eta_h)$ .................. (3)

where;

$I$ is the current strength, ampere;

$V$ is the potential difference, volt and

$\eta_h$ is the heater efficiency (assumed to be 85 %).

The power consumption requirements were calculated according to the formula of Embaby (1985):

*power consumption, kW* $= (FC \times p_f \times LCV \times 427 \times \eta_m \times \eta_{th}) / 3600 \times 75 \times 1.36$ ................................ (4)

where;

$FC$ is the fuel consumption, l/h;

$p_f$ is the fuel density (0.85 kg/l);

$LCV$ is the lower calorific value of fuel (10,000 kCal/kg);

427 is the thermo-mechanical equivalent, kg.m/kCal;

$\eta_m$ is the engine mechanical efficiency, (assumed to be 80 %) and

$\eta_{th}$ is the engine thermal efficiency, (35-40 % for diesel engine).

*Total power consumption, kW = Electric heater power, kW + Power requirements consumption, kW* ................................. (5)

*Specificenergy, kW. h / Mg = Total power consumption (kW) / Prototype productivity (Mg / h)* .. (6)

Total cost requirements of prototype, LE/h: including fixed and operating costs. Declining balance method was used to determine the depreciation (Hunt, 1983).

*Criterion Function Cost, LE/Mg = Unit operating cost, LE/Mg + Losses cost, LE/Mg* ............... (7)

*Unit operating cost, LE/Mg = Prototypecost (LE/h) / Productivity (Mg/h)* .......................... (8)

*Losses cost, LE/Mg = value of cotton wastage + the amount of lowering of seed cotton price determined by reduction in seed cotton grade* ........................... (9)

**Laboratory Tests:**

The cotton technology characteristics were determined at the Cotton Research Institute, Giza, Egypt. The fiber properties were determined under the standard conditions of 65 ± 2 % relative humidity and 294 ± 1K ambient air temperature. Fiber quality properties were analyzed after cleaning as follows: A digital fibrograph (Model-630) was used to determine the 2.5 and 50 % span fiber length (mm) according to May and Bridges (1995). Uniformity ratio was determined by the formula of Prakash (1962):

*Uniformity ratio, % = (50 % span fiber length / 2.5 % span fiber length) × 100* ....................... (10)

where it was expressed in uniformity quantity between short and long fiber length. HVI 9,000 instrument according to ASTM (D-1684-96) was used to estimate lint color (reflectance "*Rd*", % and yellowness "*+b*", unit from 5 to 17). Seed cotton strength (*g/tex*) was measured using stelometer instrument according to ASTM, designated D-1445-75, 1984. This instrument gave elongation reading and, hence, cotton length and strength could be determined using the formula of Nomeir, in Arabic (1996):

$$Strength\ for\ lengthunit,\ \% = 1.5 \times (W_c / W_s) \times 100 \quad (11)$$

Where;
$W_c$ is the cutting mass, kg and
$W_s$ is the total mass of sample, mg.

## Results and Discussion

A preliminary procedure was done to analyze the experimental data and determine the optimum operating conditions of the seed cotton extractor before and after modification. It was noticed that, for all the operating conditions of the prototype before modification, the optimum operating conditions were coincided with the cotton moisture content of about 5.16 % d.b. While the optimum was at a drying air temperature of 338.15 K for the modified prototype. The trash content and cotton wastage reached their lowest values at 5.16 % d.b. fiber moisture content and 338.15 K drying air temperature. Also, at these levels, both cleaning efficiency and productivity were maximized and the unit energy was minimized. Therefore, performance of the investigated prototype was characterized only by these optimum operating conditions.

**Prototype Performance:**

**Fig. 3** shows the relationship between saw drum speed and both of cotton trash content and seed cotton wastage at moisture content of 5.16 % d.b. and different feed rates before modification. The optimum operating conditions of the prototype were obtained at a saw drum speed of 6.73 m/s and feed rate of 0.45 Mg/h. In general, seed cotton wastage was inversely proportional to feed rate and directly proportional to saw drum speed. Cotton trash content was directly proportional to feed rate and inversely proportional to saw drum speed. At constant saw drum speed of 6.73 m/s, seed cotton wastage was decreased from 1.57 to 1.35 % (−14 %) and cotton trash content was increased from 3.63 to 4.77 % (+31.4 %) by increasing feed rate from 0.30 to 0.60 Mg/h. On the other hand, at a constant feed rate of 0.45 Mg/h, seed cotton wastage increased from 1.31 to 1.59 % (+21.37 %) and cotton trash content decreased from 4.51 to 4.11 % (−8.87 %) by increasing saw drum speed from 5.97 to 7.47 m/s. The effect of saw drum speed on both of cotton trash content and seed cotton wastage at different feed rates and drying air temperature of 338.15 K after modification is illustrated in **Fig. 4**. The optimum operating conditions of the prototype were

**Fig. 3** Relationship between saw drum speed and both of trash content and cotton wastage at different feed rates and moisture content of about 5.16 % d.b. before modification

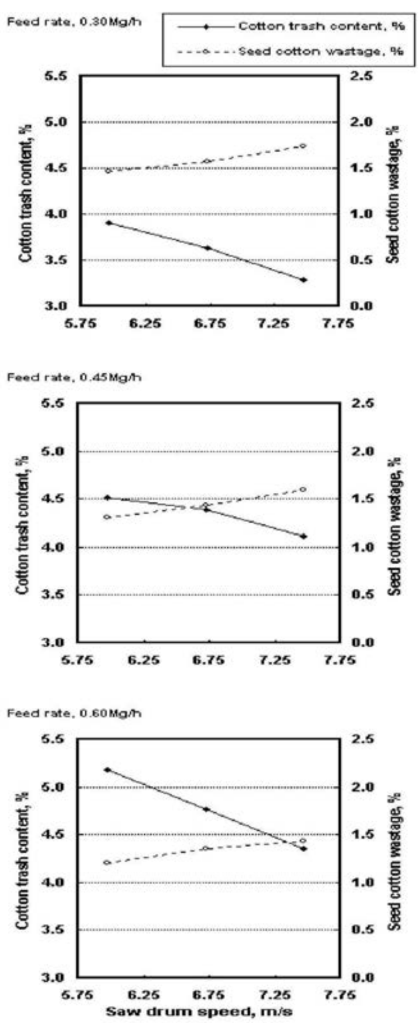
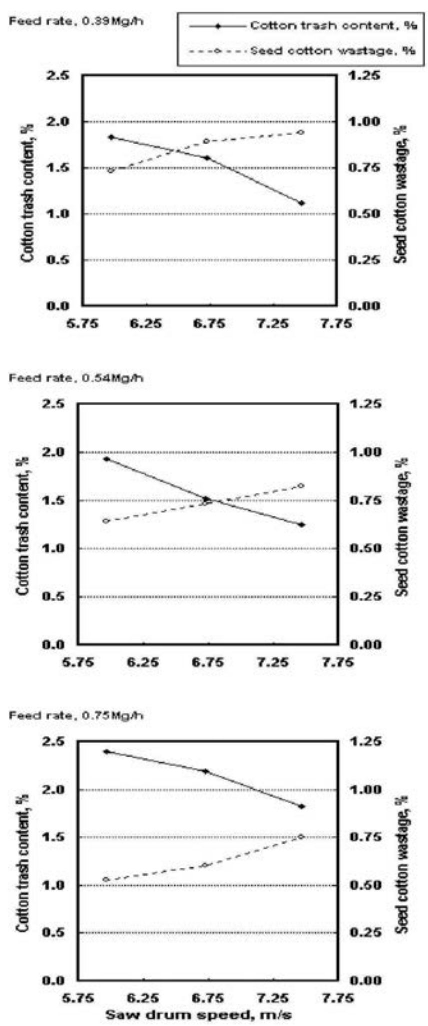



**Fig. 4** Relationship between saw drum speed and both of trash content and cotton wastage at different feed rates and drying air temperature of 338.15K after modification



obtained at saw drum speed of 6.73 m/s and feed rate of 0.54 Mg/h. The trend of data obtained was almost the same as that before modification. But, after modification, the values of cotton trash content and seed cotton wastage were greatly less than that before modification. Also, the values of feed rates obtained after modification were higher than that before. At constant saw drum speed of 6.73 m/s, seed cotton wastage decreased from 0.89 to 0.60 % (−32.58 %) and cotton trash content increased from 1.61 to 2.19 % (+36 %) by raising feed rate from 0.39 to 0.75 Mg/h. Meanwhile, at constant feed rate of 0.54 Mg/h, seed cotton wastage increased from 0.64 to 0.82 % (+28.13 %) and cotton trash content reduced from 1.93 to 1.24 % (−35.75 %) by increasing saw drum speed from 5.97 to 7.47 m/s. As a conclusion, from **Figs. 3** and **4**, seed cotton wastage reduced by 14 and 32.58 % for the prototype before and after modification, respectively. Cotton trash content was reduced by 8.87 and 35.75 % for the prototype before and after modification, respectively.

**Prototype Productivity:**

**Fig. 5** illustrates the relationship between feed rate and productivity of the prototype at a saw drum speed of 6.73 m/s, cotton moisture content of 5.16 % d.b. and drying air temperature of 338.15 K. Generally, the prototype productivity was directly proportional to feed rate. At a constant saw drum speed of 6.73 m/s before modification, the prototype productivity increased from 0.269 to 0.517 Mg/h (+92.19 %) by increasing feed rate from 0.30 to 0.60 Mg/h. While after modification, it increased from 0.317 to 0.663 Mg/h (+109.15 %) by increasing feed rate from 0.39 to 0.75 Mg/h. Moreover, the values of prototype productivity after modification were higher than that before modification at all investigated feed rates. It can be concluded that the prototype productivity was raised by 92.19 and 109.15 % before and after modification, respectively, by changing feed rate within the applied range. Also, by increasing feed rate from 0.60 to 0.75 Mg/h, the prototype productivity was raised from 0.517 to 0.663 Mg/h (+28.24 %).

**Prototype Cleaning Efficiency:**

The relationship between feed rate and cleaning efficiency of the prototype at saw drum speed of 6.73 m/s, cotton moisture content of 5.16 % d.b. and drying air temperature of 338.15 K is depicted in **Fig. 6**. In general, prototype cleaning efficiency was inversely proportional to feed rate. At constant saw drum speed of 6.73 m/s before modification, the prototype cleaning efficiency decreased from 78.1 to 74.0 % (−5.25 %) by increasing feed rate from 0.30 to 0.60 Mg/h. While, after modification, it reduced from 93.5 to 89.7 % (−4.06 %) by increasing feed rate from 0.39 to 0.75 Mg/h. In addition, at all the investigated feed rates, the prototype had higher values of cleaning efficiency after modification than that before. Briefly, the prototype cleaning efficiency was reduced by 5.25 and 4.06 % before and after modification, respectively, by changing feed rate within the investigated range. Moreover, it increased from 74.0 to 89.7 % (+21.22 %) by raising feed rate from

**Fig. 5** Relationship between feed rate and extractor productivity at saw drum speed of 6.73 m/s, moisture content of about 5.16% D.b. and drying air temperature of 338.15 k

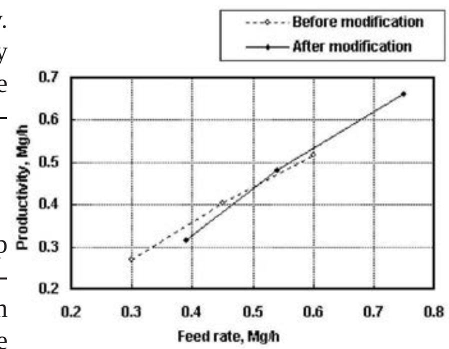



**Fig. 6** Relationship between feed rate and extractor cleaning efficiency at saw drum speed of 6.73 m/s, moisture content of about 5.16 % d.b. and drying air temperature of 338.15 k

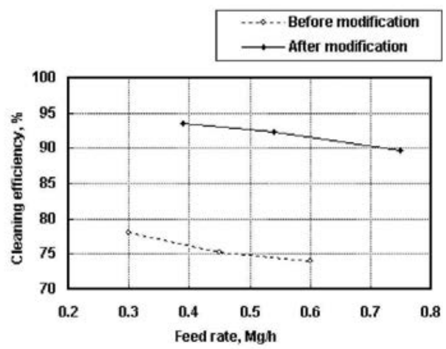



**Fig. 7** Relationship between feed rate and extractor unit energy at saw drum speed of 6.73 m/s, moisture content of about 5.16 % d.b. and drying air temperature of 338.15 k

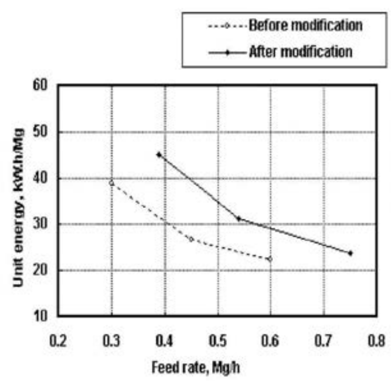



**Fig. 8** Relationship between drying air temperature and cotton moisture content at feed rate of 0.54 Mg/h and saw drum speed of 6.73 m/s after modification

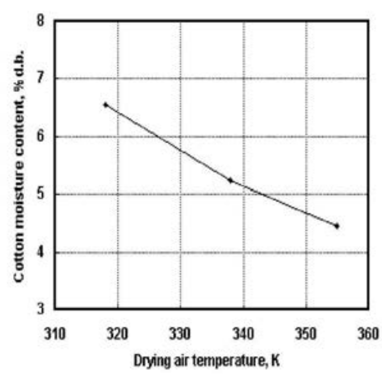


**Table 1** Standard deviation values of cotton moisture content entering the prototype before modification and the exiting ones after modification

| Initial moisture content of cotton entering the prototype before modification, % d.b. | Final moisture content of cotton exiting the prototype after modification, % d.b. (drying air temperature, K) | Mean, % d.b. | Standard deviation of the initial and final moisture content, % d.b. |
|---|---|---|---|
| 6.31 | 6.54 (318.15) | 6.43 | 0.1626 |
| 5.16 | 5.23 (338.15) | 5.20 | 0.0495 |
| 4.40 | 4.46 (355.15) | 4.43 | 0.0424 |

0.60 to 0.75 Mg/h.

**Prototype Energy Requirements:**

**Fig. 7** shows the effect of feed rate on unit energy at saw drum speed of 6.73 m/s, cotton moisture content of 5.16 % d.b. and drying air temperature of 338.15 K. Unit energy values were decreased by increasing feed rate for the prototype before and after modification. At a constant saw drum speed of 6.73 m/s before modification, the unit energy of prototype was decreased from 38.81 to 22.28 kWh/Mg (−42.59 %) by increasing feed rate from 0.30 to 0.60 Mg/h. But after modification, it was minimized from 45.07 to 23.88 kWh/Mg (−47.02 %) by increasing feed rate from 0.39 to 0.75 Mg/h. The unit energy values were higher for the modified prototype than that before. In short, the prototype unit energy was minimized by 42.59 and 47.02 % before and after modification, respectively, by changing feed rate within the investigated range. Moreover, it was raised from 22.28 to 23.88 kWh/Mg (+7.18 %) by increasing feed rate from 0.60 to 0.75 Mg/h.

**Drying Air Temperature:**

**Fig. 8** depicts the relationship between drying air temperature and cotton moisture content after modification at feed rate of 0.54 Mg/h and saw drum speed of 6.73 m/s. In general, cotton moisture content was inversely proportional to the drying air temperature. The moisture content of seed cotton was reduced from 6.54 to 4.46 % d.b. (−31.80 %) by increasing drying air temperature from 318.15 to 355.15 K (+11.63 %). This meant that the designed drying air temperatures play an important role in reducing the cotton moisture content, and consequently enhance cleaning efficiency and finally the cleaning process will be intensified. **Table 1** shows the standard deviation values of cotton moisture content entering the prototype before modification and the exiting ones after modification. Values of cotton moisture content exiting the modified prototype under the effect of drying air temperature were very close to those entering before modification. As the standard deviation was decreased from 0.1626 to 0.0424 % d.b. (−73.92 %), the average moisture content was reduced from 6.425 to 4.430 % d.b. (−31.05 %). It can be concluded that drying seed cotton immediately before cleaning and extracting improved the cleaning efficiency and minimized energy requirements. Therefore, there was no need to dry seed cotton separately after picking as the modified prototype saved this supplemental process and, hence, the unit cost could be minimized.

**Table 2** Estimation of the prototype cost

| Item | Tractor | Prototype before modification | Prototype after modification |
|---|---|---|---|
| No. of years (used before) | 9 | 1 | 1 |
| Remaining value, LE | 4,632.3 | 5,780 | 6,936 |
| Fixed cost, LE/year: | - | - | - |
| a) Depreciation | 694.81 | 1,120 | 1,224 |
| b) Interest on investment, housing, taxes and insurance | 639.25 | 797.6 | 957.17 |
| Total fixed cost, LE/year | 1,334 | 1,917.6 | 2,181.17 |
| Operating hours per year | 1,000 | 700 | 700 |
| Operating cost, LE/year: | - | - | - |
| a) Repairs and maintenance | 1,000 | 400 | 480 |
| b) Fuel + lubrication | 7,500 | 100 | 135 |
| c) Electric current | - | - | 475 |
| d) Labor | 2100 | 3,750 | 2,775 |
| Total operating cost, LE/year | 10,600 | 4,250 | 3,865 |
| Total cost, LE/year | 11,934 | 6,167.6 | 6,046.17 |
| Prototype cost before modification, LE/h | (11,934 + 6,167.6)/700 = 25.86 | | |
| Prototype cost after modification, LE/h | (11,934 +6,046.17)/700 = 25.69 | | |

**Total Cost Requirements:**

A detailed estimation of the prototype cost before and after modification is given in **Table 2**. The overall cost requirements for the prototype before and after modification are listed in **Table 3**. For the modified extractor, their values were slightly smaller (−0.66 %) than that before modification. The lowest values of total cost were of 25.86 and 25.69 LE/h for the prototype before and after modification, respectively.

**Table 3** The economical cost for producing one megagram seed cotton at the optimum operating conditions

| Prototype | Feed rate, Mg/h | Saw drum speed, m/s | MC, % d.b. | Drying air temperature, K | Product-ivity, Mg/h | Total cost requirements, LE/h | Criterion cost, LE/Mg |
|---|---|---|---|---|---|---|---|
| Before modification | 0.45 | 6.73 | 5.16 | - | 0.403 | 25.86 | 64.17 |
| After modification | 0.54 | 6.73 | - | 338.15 | 0.481 | 25.69 | 53.41 |

**Table 4** Quality characteristics of the extracted seed cotton before and after modification of prototype

| Prototype | M.C., %d.b. | Drying air temp., K | Feed rate, Mg/h | 2.5 % span fiber length, mm | | | 50 % span fiber length, mm | | | Fiber length uniformity ratio, % | | | Fiber strength, g/tex | | | Color reflectance (Rd), % | | | Color yellowness (+b), unit | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 5.97 m/s | 6.73 m/s | 7.47 m/s | 5.97 m/s | 6.73 m/s | 7.47 m/s | 5.97 m/s | 6.73 m/s | 7.47 m/s | 5.97 m/s | 6.73 m/s | 7.47 m/s | 5.97 m/s | 6.73 m/s | 7.47 m/s | 5.97 m/s | 6.73 m/s | 7.47 m/s |
| Before modification | 6.31 | - | 0.30 | 31.3 | 31.1 | 30.8 | 14.6 | 14.3 | 14.0 | 46.6 | 45.9 | 45.4 | 28.3 | 28.1 | 27.7 | 71.3 | 71.6 | 72.0 | 9.0 | 9.4 | 9.7 |
| | | | 0.45 | 31.6 | 31.4 | 31.2 | 14.8 | 14.5 | 14.3 | 46.8 | 46.2 | 45.8 | 28.6 | 28.3 | 28.0 | 70.6 | 70.9 | 71.5 | 8.7 | 9.1 | 9.4 |
| | | | 0.60 | 31.9 | 31.7 | 31.5 | 15.2 | 14.9 | 14.6 | 47.6 | 47.0 | 46.3 | 28.9 | 28.7 | 28.4 | 70.2 | 70.7 | 71.2 | 8.4 | 8.6 | 9.2 |
| | 5.16 | - | 0.30 | 31.1 | 30.8 | 30.5 | 14.4 | 14.0 | 13.8 | 46.3 | 45.5 | 45.2 | 28.1 | 27.9 | 27.5 | 72.1 | 72.5 | 72.8 | 8.8 | 9.1 | 9.5 |
| | | | 0.45 | 31.4 | 31.2 | 30.9 | 14.6 | 14.3 | 14.1 | 46.5 | 45.8 | 45.6 | 28.4 | 28.1 | 27.9 | 71.7 | 72.2 | 72.6 | 8.5 | 8.7 | 9.1 |
| | | | 0.60 | 31.6 | 31.5 | 31.3 | 15.0 | 14.8 | 14.4 | 47.4 | 46.9 | 46.0 | 28.6 | 27.9 | 27.6 | 71.4 | 71.9 | 72.3 | 8.3 | 8.5 | 8.9 |
| | 4.40 | - | 0.30 | 30.9 | 30.6 | 30.3 | 14.2 | 13.9 | 13.6 | 45.9 | 45.4 | 44.9 | 27.5 | 27.3 | 27.0 | 73.2 | 73.6 | 73.9 | 8.5 | 8.8 | 9.3 |
| | | | 0.45 | 31.2 | 30.8 | 30.7 | 14.4 | 14.1 | 13.9 | 46.1 | 45.7 | 45.3 | 27.8 | 27.5 | 27.4 | 72.7 | 73.1 | 73.5 | 8.2 | 8.4 | 9.0 |
| | | | 0.60 | 31.3 | 31.1 | 30.9 | 14.7 | 14.5 | 14.2 | 47.3 | 46.6 | 45.6 | 28.1 | 27.8 | 27.5 | 72.3 | 72.6 | 73.0 | 8.1 | 8.3 | 8.7 |
| After modification | - | 318.15 | 0.39 | 31.9 | 31.6 | 31.3 | 14.9 | 14.7 | 14.5 | 47.1 | 46.9 | 46.6 | 27.6 | 27.3 | 27.1 | 73.1 | 73.8 | 74.2 | 8.4 | 8.8 | 9.2 |
| | | | 0.54 | 32.3 | 31.9 | 31.6 | 15.2 | 15.0 | 14.7 | 47.6 | 47.3 | 46.7 | 27.9 | 27.7 | 27.4 | 72.3 | 73.2 | 73.7 | 8.1 | 8.5 | 8.9 |
| | | | 0.75 | 32.6 | 32.4 | 31.8 | 15.6 | 15.4 | 15.8 | 48.4 | 48.2 | 48.1 | 28.3 | 28.0 | 27.8 | 71.9 | 72.5 | 73.1 | 7.9 | 8.2 | 8.6 |
| | - | 338.15 | 0.39 | 31.4 | 31.2 | 31.1 | 14.6 | 14.5 | 14.4 | 46.5 | 46.4 | 46.3 | 27.3 | 27.0 | 26.7 | 74.3 | 74.9 | 75.3 | 8.2 | 8.5 | 8.9 |
| | | | 0.54 | 32.2 | 32.0 | 31.3 | 15.0 | 14.9 | 14.8 | 46.6 | 46.5 | 46.4 | 27.7 | 27.5 | 27.2 | 73.6 | 74.1 | 74.7 | 7.8 | 8.1 | 8.5 |
| | | | 0.75 | 32.5 | 32.3 | 31.6 | 15.3 | 15.1 | 15.0 | 47.0 | 46.7 | 46.6 | 28.0 | 27.8 | 27.4 | 73.0 | 73.5 | 73.9 | 7.6 | 7.9 | 8.4 |
| | - | 355.15 | 0.39 | 31.2 | 31.1 | 30.8 | 14.4 | 14.2 | 14.0 | 46.1 | 45.6 | 45.4 | 27.2 | 26.8 | 26.5 | 75.1 | 75.5 | 76.1 | 7.9 | 8.2 | 8.5 |
| | | | 0.54 | 32.0 | 31.7 | 31.2 | 14.8 | 14.7 | 14.6 | 46.3 | 46.1 | 46.0 | 27.5 | 27.2 | 26.9 | 74.4 | 74.9 | 75.3 | 7.5 | 7.8 | 8.1 |
| | | | 0.75 | 32.4 | 32.1 | 31.5 | 15.1 | 15.0 | 14.9 | 46.6 | 46.4 | 46.3 | 27.8 | 27.5 | 27.1 | 73.9 | 74.5 | 74.9 | 7.2 | 7.5 | 7.7 |

This may be because the fixed and operating cost parameters are nearly alike. However, the total cost was of 25.86 LE/h before modification at a feed rate of 0.45 Mg/h, saw drum speed of 6.73 m/s and cotton moisture content of 5.16 % d.b. Whereas, after modification the value was of 25.69 LE/h at a feed rate of 0.54 Mg/h, saw drum speed of 6.73 m/s and drying air temperature of 338.15 K. This meant that the prototype had its lowest cost only under the optimum operating conditions.

**Criterion Function Cost:**

**Table 3** indicates the values of criterion function cost for the prototype before and after modification. Criterion function cost includes both machinery operating cost (unit cost) and cost due to seed cotton losses (losses cost). However, the criterion function cost was essentially determined to specify the most economic prototype. Its value was smaller for the modified prototype by 16.77 % than that before modification as seed cotton losses were minimized after modification. Moreover, the lowest values of criterion function cost were obtained at the optimum operating conditions. Its value was of 64.17 LE/Mg before modification at feed rate of 0.45 Mg/h, saw drum speed of 6.73 m/s and cotton moisture content of 5.16 % d.b. Meanwhile, after modification its value was of 53.41 LE/Mg at feed rate of 0.54 Mg/h, saw drum speed of 6.73 m/s and drying air temperature of 338.15 K.

**Quality Characteristics of Seed Cotton:**

The quality characteristics of the extracted seed cotton for the prototype before and after modification are listed in **Table 4**. It was obvious that the fiber span length, fiber length uniformity ratio and fiber strength were directly proportional to both of feed rate and cotton moisture content and inversely proportional to both of saw drum speed and drying air temperature. Conversely, the color reflectance and yellowness are directly proportional to both saw drum speed and drying air temperature and inversely proportional to both feed rate and cotton moisture content. At the optimum operating conditions of 6.73 m/s saw drum speed, 5.16 % d.b.

**Table 5** Multiple linear regression equation describing the cleaning process of the seed cotton extractor

| Indicator | Before modification | | | | | After modification | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $a_o$ | Regression coefficients | | | $R^2$ | $a_o$ | Regression coefficients | | | $R^2$ |
| | | $b_1$ | $b_2$ | $b_3$ | | | $b_1$ | $b_2$ | $b_3$ | |
| Productivity, Mg/h | +0.0352 | +0.0149 | +0.8159 | −0.0126 | 0.9945 | +0.3074 | −0.0008 | +0.9917 | −0.0155 | 0.9967 |
| Cleaning efficiency, % | +77.6642 | −1.9552 | −13.7037 | +2.2433 | 0.9338 | +41.6782 | +0.1205 | −10.841 | +2.3100 | 0.9624 |
| Specific energy, kW.h/Mg | +34.8650 | +0.9159 | −54.2963 | +2.0514 | 0.9308 | +66.3770 | −0.0540 | −56.830 | +2.4849 | 0.9216 |
| Total cost, LE/h | +5.7877 | +1.1274 | +12.9852 | +1.1311 | 0.9553 | +36.1907 | −0.0766 | +9.2015 | +1.5604 | 0.9634 |
| Criterion cost, LE/Mg | +81.2030 | +0.2537 | −111.759 | +5.1780 | 0.9533 | +98.7946 | −0.0626 | −99.252 | +5.3041 | 0.9235 |

cotton moisture content and 0.45 Mg/h feed rate before modification and 338.15 K drying air temperature and 0.54 Mg/h feed rate after modification, both fiber length uniformity ratio and color reflectance were increased by 1.53 and 2.63 % for the modified prototype than that before modification, respectively. Contrariwise, both fiber strength and color yellowness were decreased by 2.14 and 6.90 % for the modified prototype than that before modification, respectively. The maximum values of 2.5 and 50 % fiber span length, fiber length uniformity ratio and fiber strength were of 31.9 mm, 15.2 mm, 47.6 % and 28.9 g/tex, respectively, for the prototype before modification at a feed rate of 0.60 Mg/h, cotton moisture content of 6.31 % d.b. and saw drum speed of 5.97 m/s. While, they were 32.6 mm, 15.6 mm, 48.4 % and 28.3 g/tex, respectively, for the modified prototype at a feed rate of 0.75 Mg/h, drying air temperature of 318.15 K and saw drum speed of 5.97 m/s. On the other hand, the lowest values of color reflectance were 70.2 and 71.9 % for the prototype before and after modification, respectively, at a feed rate of 0.60 and 0.75 Mg/h and moisture content of 6.31 % d.b. and drying air temperature of 318.15 K, respectively. Meanwhile, the lowest values of color yellowness were 8.1 and 7.2 units for the prototype before and after modification, respectively at a feed rate of 0.60 and 0.75 Mg/h and moisture content of 4.40 % d.b. and drying air temperature of 355.15 K, respectively. In short, the cotton fiber technology characteristics were highly improved and strongly influenced by the investigated variables for the modified prototype than that before modification. A multiple linear regression equation was developed. It had the following formula:

$$E = a_o + b_1M + b_2F + b_3S \quad (12)$$

where;

$E$ is the efficiency indicator of prototype, %;

$M$ is the cotton moisture content (% d.b.) or drying air temperature (K);

$F$ is the feed rate, Mg/h;

$S$ is the saw drum speed, m/s;

$a_o$ is the Y-intercept and

$b_1$, $b_2$ and $b_3$ is the regression coefficients.

Values of the predicted regression coefficients and its determination coefficients ($R^2$) are listed in **Table 5**.

## Conclusion

**The Specific Conclusions are:**

The optimum operating conditions of the prototype were specified as follows: feed rate of 0.45 and 0.54 mg/h before and after modification, respectively; cotton moisture of 5.16 % d.b. before modification and drying air temperature of 338.15 K after modification; and saw drum speed of 6.73 m/s. Moreover, performance of the modified prototype was better than that before at all operating conditions.

The prototype productivity was increased from 0.403 to 0.481 Mg/h and its cleaning efficiency was raised from 75.2 to 92.4 % after modification. The total cost for producing one megagram of seed cotton was reduced from 64.17 to 53.41 LE and total losses were minimized from 1.43 to 0.73 % after modification. The specific consumed energy was increased from 26.76 to 31.37 kWh/Mg because of adding a drying unit to the modified prototype.

The cotton fiber technology characteristics were better for the modified prototype. Values of 2.5 and 50 % fiber span length, fiber length uniformity and color reflectance were higher for the modified prototype. Both fiber strength and color yellowness were slightly smaller for the modified prototype than that before modification.

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# NEWS

## Prof Gajendra Singh, Prof. Nalavade and Mr Balachandra Babu attend Club of Bologna meeting in Italy

The meeting of the Club of Bologna was held during 10-11 November 2012 in Italy. The Club was established in 1988 for the study of strategies for the development of agricultural mechanization worldwide, taking into consideration technical, economic and social advances and changes in agriculture on an international level. The club has 16 members on its Management Committee and 85 full members from 40 countries from all over the world. Prof. Singh, well known as a co-editor of AMA, has been a full member since 1991 and member of the Management Committee since 1995. Main topic discussed this year was "How far is robotics in our future agriculture?, and what is ready to be transferred in the next years?" Main speakers were from Italy, Denmark, France, Germany, Japan and USA.

The main event is an international exhibition of farm equipment (EIMA) organized by UNACOMA. FICCI sponsored about 20 persons (mainly manufacturers) from India to visit the EIMA in Bologna. Mr Balachandra Babu of M/S. FARM IMPLEMENTS (INDIA) PVT. LTD., Chennai was elected as a new full member of the Club. Mr Babu is Vice President of the "All India Agricultural Machinery Manufacturers Association".

The Club organized the "Giuseppe Pellizzi International Best PhD Prize2012" in Agricultural Mechanization. Most of the contestants were from Europe and U.K. There was only one entry from Asia, Mr Parish Navalade of India. At present he is working as Assistant Professor at IIT Kharagpur. He did his PhD at Asian Institute of Technology (AIT), Thailand. He was awarded the third prize. The Club paid his air travel and local expenses in addition to cash prize of Euro 600.

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# Pedal Operated Integrated Potato Peeler and Slicer

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## Abstract

For the processing of potatoes, removal of the peel is an important unit operation. Hence, a pedal operated integrated potato peeler and slicer was designed and developed. The main parts of the integrated machine were peeling drum, water spraying unit, slicing unit, a piston to transfer the peeled potato from peeler to slicer and a power transmission system. The peeling drum, with protrusion on the inside surface, rotated and detached the peel from the potatoes by abrasion. The water spraying unit washed the potatoes and, simultaneously, the peel was removed from the drum through the peripheral clearance of the drum along with the flow of water. The miter gears, transmission shafts and chain drives were significant parts of the machine. The machine worked at 45 rpm with a 65 kg/hr capacity.

## Introduction

Potato (*Solanum Tuberosum L.*), the third most important staple crop in the world, is a widely consumed vegetable in India. The production of potatoes in India was 40,476.30 thousand metric tonnes in 2010-2011 from a total area of 1893.90 thousand hectare (Anonymous, 2011). Potato is the only crop that can make an impact on the highly populated Indian nation for feeding the people. India ranks fourth in area and third in global potato production. It produces around 8 % of the world's total produce (Anonymous, 2011). Between 1960 and 2000, potato production increased by almost 85 percent, partly in response to growing demand from higher-income urban populations. Since 1990, per capita consumption rose from around 12 kg to 17 kg a year. Uttar Pradesh was the largest producer of potatoes for India with 108.09 lakh tonnes production from an area of 5.27 lakh hectares. Production of potatoes in Uttarakhand was 5.12 lakh tonnes from an area 2.51 lakh hectares. (Directorate of Economics & Statistics, Government of India, 2008-09). The other major producers were West Bengal, Bihar, Punjab, MP, Gujarat and Assam.

Regarding the consumption pattern, India has a huge population to feed and that's why it has a large demand for this crop. As a result, there is a very small quantity of the potatoes left for the export, making India's share in world export negligible (Anonymous, 2011).

Annual post harvest losses of potatoes vary from 5 to 40 % mainly due to inadequate storage facilities in rural areas. Hence, the farmers are forced to sell potatoes at a very low price. Therefore, a need was felt to design equipment for farmers to process potatoes at a small scale level that can process the potato and convert the potato into a form which could be stored for further use.

The potato chip is a very popular snack food in India. For making chips, the important preparatory operations are washing and peeling. Hand peeling is traditional in India and is tedious and time consuming. Moreover, the loss of flesh is very high. However, the potato processing industry uses lye peeling. In the lye peeling process, a heat ring is formed below the surface of the potato due to tissue damage and polyphenol enzyme activity that deteriorates the quality of the chips. It is not recommended for making the chips. Therefore, keeping the above fact in mind, the Department of Post Harvest Process and Food Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar designed and developed a pedal operated integrated potato peeler and slicer unit. The present study was undertaken with the following objectives: to design and develop a pedal operated integrated potato peeler and slicer.

## Material and Methods

An integrated pedal operated potato peeler and slicer of 65 kg/hr capacity was designed and developed (**Fig. 1**). The machine was fabricated in the development laboratory of the Department of Post Harvest Process and Food Engineering, College of Technology. The main components of the unit were (1) peeling section, (2) slicing section and (3) power transmission system. The design of various components of the integrated unit was mainly based on the functional and structural strength and was checked mathematically. Different sizes of potatoes were put into the peeling section manually. The peeling was done at 45 rpm speed and, thereafter, with the help of a piston mechanism, peeled potatoes were transferred to the slicing unit. A provision was made to transmit the power by pedal. The power was transmitted to the main shaft, through a bevel (miter) gear shaft, chain and sprocket drive.

***Frame***

The angle iron frame of the machine was fabricated in a rectangular shape to provide the strength and firmness to the machine. The frame size was 555 mm long, 390 mm wide and 620 mm high. The unit was fabricated with mild steel 33 × 30 × 2 mm angle iron (**Fig. 2**). The frame was strong enough to bear the load of the other components.

***Design of bevel gear:***

A set of bevel gears was required, with a shaft angle of 90 degrees, to transmit the human power to the peeling drum. Face width, circle diameter, pitch diameter and number of teeth on each pinion and gear, along with various standards/proportionate dimensions, were essential for drawing and fabrication of the gears. All the following design parameters were calculated as per the method given by Sharma and Agarwal (1996) and Omre (1999).

1. The transmitted load was calculated as,
   $T = hp \times 4500 / 2\pi \times ND$ ...... (1)
   where
   $N$- rpm of pinion
   $hp$- human power, watts
   $d$- pitch diameter of gear, m
2. The pitch cone angle (δ) is shown below
   a. For pinion
   $\tan\delta_1 = \sin\alpha_1 / (i + \cos\alpha_1)$ .... (2)
   where,
   $\alpha_1$ - shaft angle for gear, degrees
   $i$- transmission ratio
   b. For gear
   $\delta_2 = \alpha_1 - \delta_2$
3. Number of teeth (N)
   a. For pinion
   $N_p = 15 / i + 1$ ........................ (3)
   Where i = 1
   b. For gear
   $N_g = N_p \times i$ ............................ (4)
4. Pitch circle diameter (d)
   a. For pinion
   $d_p = N_p \times m$ .......................... (5)
   where
   $m$- module for the gears, mm
   b. For gear
   $d_g = N_g \times m$
5. Cone distance (R)
   $R = d_p / 2\sin\delta_1$ ....................... (6)
6. Face width (f)
   $f = Np \times m / 6\sin\delta_1$ ............... (7)
7. Middle circle diameter ($d_m$) of pinion and gear
   a. For pinion

**Fig. 1** Integrated pedal operated potato peeler and slicer

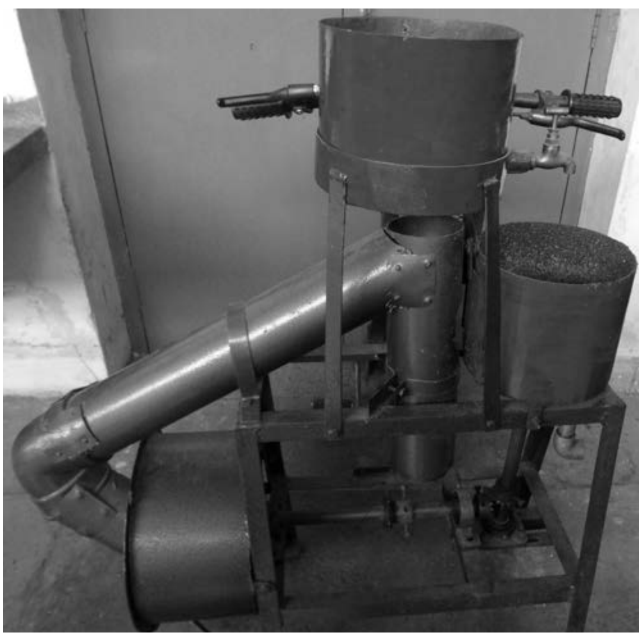
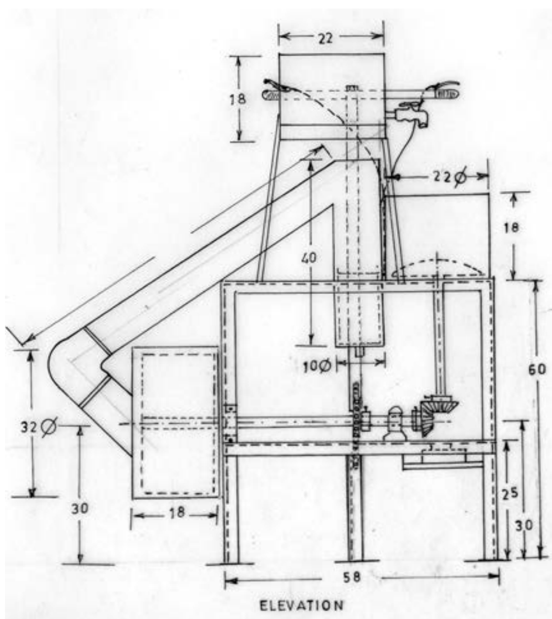


**Fig. 2** Schematic diagram of pedal operated integrated machine



$d_{mp} = d_p - f\, Sin\delta_1$ ....................(8)

b. For gear

$d_{mg} = d_p - f\, Sin\delta_1$ ..................(9)

8. Normal pitch ($p_n$) of pinion is given by

$P_n = [\pi \times d_p / N_p]\, Cos\sigma_m$...... (10)

where

$\sigma_m$ = pitch cone angle, °

9. Tip circle diameter ($d_{tc}$)

a. For pinion

$D_{tcp} = dp + 2m\, Cos\, \delta_1$............ (11)

b. For gear

$D_{tcg} = d_g + 2m\, Cos\delta_2$ ........... (12)

10. Virtual number of teeth ($t_v$)

a. For pinion, $T_{vp}$

$T_{vp} = N_p / Cos\delta_1$.................... (13)

For gear, $T_{vg}$

$T_{vg} = N_s / Cos\delta_2$.................... (14)

11. Tip clearance (c)

$c = 0.2 \times m$.......................... (15)

12. Whole depth (h)

$h = 2.2 \times m$ ......................... (16)

13. Addendum (ha)

$ha = m$ .................................. (17)

14. Dedendum (hd)

$hd = 1.25 \times m$...................... (18)

15. Addendum angle ($\theta_a$)

$tan\, \theta_a = m/R$ ........................ (19)

16. Dedendum angle ($\theta_d$)

$tan\, \theta_d = 125 \times m/R$ ...............(20)

17. Crown height (ch)

a. For pinion

$ch_p = (d_g / 2) - m\, sin\delta_1$........ (21)

b. For gear

$Ch_g = d_p / 2 - m\, Sin\delta_2$.........(22)

18. Back cone distance ($R_b$)

a. For pinion

$R_{bp} = R\, tan\delta_1$ .......................(23)

b. For gear

$R_{bg} = R\, tan\delta_2$ .......................(24)

19. Outside diameter ($O_d$)

a. For pinion

$Od_p = d_p + 2h_a\, Cos\theta_a$ ..........(25)

b. For gear

$Od_g = d_g + 2 \times h_d \times Cos\theta_d$..(26)

The dimensions of the gear and pinion were checked as per design calculation. **Fig. 3** shows the forces acting on a bevel gear tooth.

***Bending stress***

Bending stresses for the gears were calculated using modified Lewise Equation as shown below:

$F_t = F_b\, f\, m\, Y\, (1 - f/R)\, C_v$........(27)

where

$F_t$- tangential force acting on the pinion, Newton

$F_b$- bending stress of the material, Gpa

$f$- face width of gear, cm

$m$- module of gear, mm

$Y$- form factor for gear

$R$- cone distance for gears, cm

$C_v$- velocity factor

Tangential force ($F_t$)

$F_t = 2T / d_{mp}$ ............................(28)

$Y = \pi\, (0.154 - 0.912/N_g)$.........(29)

$C_v = 3 / (3 + V)$.......................(30)

where

$V$- pitch line velocity of pinion, m/s

***Dynamic load***

Beam strength ($F_b$) was calculated as:

$F_b = f\, m\, Y\, f_{ef}\, (1 - f/R)$............. (31)

The maximum instantaneous dynamic load ($F_d$)

$F_d = F_t / C_v$ ..............................(32)

**Transmission Shafts**

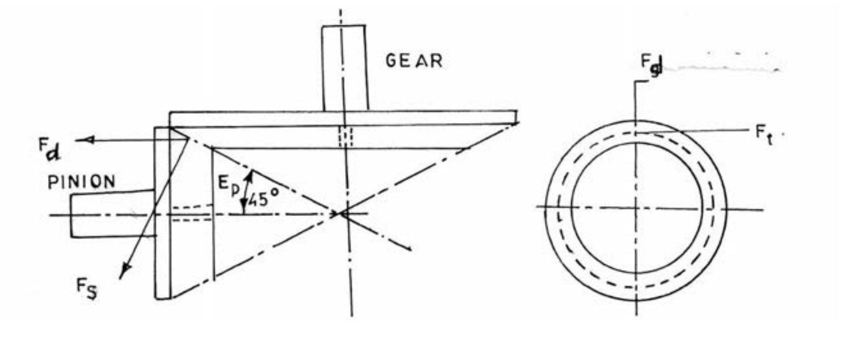
***Pinion Shafts***

The torque to be transmitted by humans may be found as follows

$T = (hp \times 4500) / 2\pi N$............ (33)

where

**Fig. 3** Forces on bevel gear




N- number of rpm of shaft

*Design torque* $(T_d) = K_s \times T$...(34)

The shear stress relationship for the solid shaft was modified as

$K_s \times T = f_s \times \pi d^3/16$ ................(35)

Axial load on the shaft ($F_{ax}$), N

$F_{ax} = T \times N /(9.55 \times 10)^{-6}$.......(36)

*Moment of inertia* $(I) = (\pi \times d)^4 / 64$ .............................................(37)

where

$d$- diameter of shaft, mm

*Bending moment* $(M_b) = (E \times I) / r$. .............................................(38)

where

$E$- modulus of elasticity for MS shaft, N/m$^2$

*Bending stress for the solid shaft* $(\sigma_b) = (32 \times M) / (\pi \times d)^3$..... (39)

**Design of Chain and Sprocket**

As the speed of the pinion was not very high, the chain velocity would be low. Therefore, a roller chain was selected for transmitting the power to the peeler and slicer through bevel gear.

*Velocity ratio* $(V_r) = N_1 / N_2$....(40)

where

$N_1$- speed of large sprocket, rpm

$N_2$- speed of small sprocket, rpm

*Chain pitch* $P = C / 40$ ........... (41)

where

$C$ is the centre to centre distance between two sprockets, mm

*Chain speed* $(V) = pnz / (60 \times 1000)$ .............................................(42)

where

$p$- pitch of the roller chain, mm

$n$- Speed of pinion, rpm and z- number of teeth of pinion

Total circumferential/driving force acting on chain, N

$F = (2\pi \times 1000 \times T) / zp$........ (43)

Chain tension due to centrifugal force of inertia ($F_c$) per unit chain length was neglected due to low speed of chain.

*Tension due to sagging* $F_f = K_f \times W \times C$.................................(44)

$K_f$- chain drive coefficient

$C$- centre to centre distance between two sprockets

W-average weight N/m

Total load on driving side (Tight side) of the chain, N

**Table 1** Specification of pedal operated integrated potato peeler and slicer

| Particulars | Specifications |
|---|---|
| Length, mm | 960 |
| Width, mm | 990 |
| Height, mm | 1,110 |
| Weight, kg | 80 |
| No. of persons | 01 |
| Estimated cost, Rs | 12,000.00 |
| Capacity, kg/hr | 65 |
| Efficiency, % | 88.5 |

**Table 2** Energy consumption in different potato peeling and slicing methods

| Name of the machine | Capacity, kg/hr | Efficiency, % | Energy, MJ/q |
|---|---|---|---|
| Mannual peeling and slicing | 8 | 85 % | 24.5 |
| Hand operated peeler and slicer | 60 | 90 % | 6.54 |
| Pedal operated integrated peeler and slicer | 65 | 88.5 % | 3.02 |

$F_0 = F + F_f$ ...............................(45)

The pedal operated integrated potato peeler cum slicer was compared with traditional peeler and slicer.

The man-hours were transferred into energy equivalents by using the following relationship from Wahid *et al.* (2003).

One man-hour = 1.96 MJ

## Results and Discussion

The data presented in **Table 1** showed the brief specifications of the pedal operated integrated potato peeler and slicer. A comparative study of the integrated unit was done with a manual and hand operated peeler and slicer (**Table 2**).

The integrated unit saved 88 % and 54 % energy consumption as compared to manual and hand operated peeler and slicer, respectively. The pedal operated integrated peeling and slicing machine was more economical because it had very high capacity; reduced the manpower in comparison with the hand operated machine as well as the manual. Also, the pedal and hand operated units peeled potatoes in uniform layers with a smooth surface and losses in weight were more with in comparison to the conventional knife.

## Conclusion

A pedal operated integrated potato peeler and slicer was designed and developed. The dimensions of the unit were 960 × 990 × 1,110 mm and the weight of unit was 80 kg. It could be operated by a single person. Its capacity and efficiency was 65 kg/hr and 88.5 %, respectively. The integrated unit saved 88 % and 54 % energy consumption as compared to manual peeling-slicing and the hand operated peeler-slicer unit, respectively.

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# Development of Power Operated Curry Leaf (*Murraya Koenigii*) Stripper



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## Abstract

Curry leaf (*Murraya Koenigii*) is used as a leafy spice in Indian cuisine for its characteristic flavour and is reported to have a lot of medicinal values. It is one of the prime ingredients in masala and pickle industries in raw/dried or powdered form. These products have large demand in both domestic and international markets. The primary requirement to obtain the curry leaves is to strip the leaflets from the stem. At present this operation is being carried out manually in unhygienic conditions. To reduce the drudgery of the human labour and to increase the output capacity, a power operated curry leaf stripper has been developed to strip out the leaflets from the branch. The equipment comprises four major components viz., power source, pulling mechanism, stripping mechanism and collecting tray. With this device, an operator can safely strip 36-44 kg of curry leaflets per hour. The saving in labour and cost over conventional method is to the tune of 80 percent and 60 percent, respectively. An Indian patent no 1146/MUM/2008 has been assigned for the equipment and the equipment has been commercialized


## Introduction

Curry leaf (*Murraya Koenigii*) is a shrub or small tree native to India (**Fig. 1**). It is used as a leafy spice in Indian cuisine for its characteristic flavour and is reported to have a lot of medicinal values. Curry leaf is cultivated on a commercial scale in the southern provinces of India. The leaves have 66.3 percent moisture, protein 6.1 percent, carbohydrate 16 percent, fibre 6.4 percent, phosphorus 600 mg, iron 0.93 mg and ß- carotene (Vit. A) 7.56 mg. (Shankaracharya and Natarajan, 1971). Fresh curry leaves on steam distillation yield 2.5 percent volatile oil, which is used as a fixative in soap industry (Lathan Kumar *et al.*, 2003). The antioxidant and anticarcinogenic effect of curry leaves have been studied and it has been reported that the curry leaves have a high potential as a reducer of the toxicity of carcinogen (Khanum *et al.*, 2000; Palaniswamy, 2001).The leaves of the plant are employed extensively as flavourant in curries like 'dal', 'South Indian Sambar', 'rasam' and 'chutneys'. Powdered curry leaf with mature coconut kernel and spices forms an excellent preserve. Curry leaf is used in traditional medicine, like ayurvedic and unani medicine. The plant is credited with tonic, stomachic and carminative properties. The undiluted essential oil exhibits strong antibacterial and antifungal activity when tested on microorganisms. Crude leaf extracts of curry leaf plant are reported to possess antibacterial activity. It has a potential role in the treatment of diabetes.

The curry leaves have good export potential besides internal consumption. The leaves rapidly lose

**Fig. 1** Curry leaf (*Murraya Koenigii*) field

their moisture and get wilted. They retain their flavor even after drying and hence these are marketed both in fresh and dried forms. The dried curry leaves find its application as an ingredient in masala powders. It is one of the prime ingredients in masala and pickle industries in raw, dried or powdered form. These products have large demand in both domestic and international market.

The existing method of stripping the curry leaf from the harvested leaflets is done manually with bare hands by labour in an unhygienic way and there is every possible risk of contamination in handling. Further, since the product is being used in the export market both as fresh product and in the powder/ masala industries, there is also the possibility of contamination being carried over to the processed product in the food chain. It is highly laborious to strip the leaflets manually with hands just after harvesting, as it needs more force ( Ravindra Naik *et al*., 2008). The power operated curry leaf stripper developed would overcome the difficulties encountered in this operation.

## Material and Methods

### Material

Curry leaf varieties Sen Kaampa, Dharwad-1 and Dharwad-2 which were procured from curry leaf farmers of Karaimadai (District) of Tamil Nadu, were used for evaluation.

***Concept of mechanical stripper:***

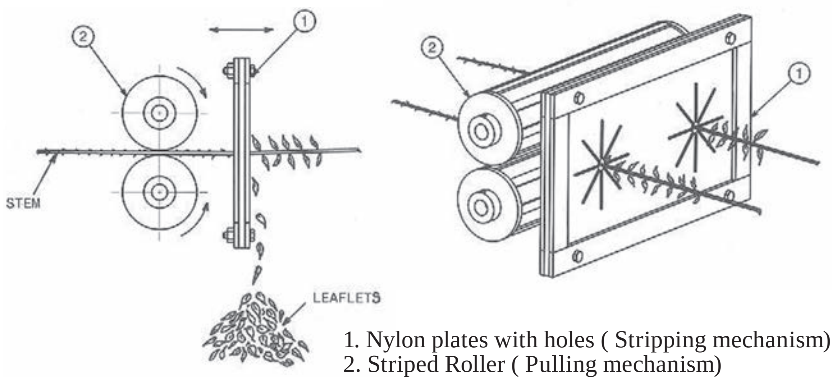
The concept of mechanical stripper is given in **Fig. 2**. The stripping of the curry leaflets from the petioles is done manually by holding the bottom of the petiole in the left hand and by gripping leaflets together between two fingers of the right hand and gliding down the fingers from bottom of petiole to its tip. In a similar way, the stripping mechanism has been developed which could carry out the function of gripping and holding the leaflets, while the branch with petioles is pulled through by a pair of striped roller (Stripping mechanism) which revolve in opposite direction. The leaflets are striped by reciprocating motion of nylon plate with holes (stripping mechanism). By the simultaneous action of gripping of leaflets while pulling of the branch and stripping, the leaflets are stripped from the petioles of the branch. The striped leaflets are collected in the tray placed below the machine so that the hygienic condition is maintained, thereby avoiding contamination.

Details of the power operated curry leaf stripper: To reduce the human labour and to increase the output capacity, a power operated curry leaf stripper has been designed and developed (**Fig. 3**). The main components of the equipment are pulling mechanism, stripping mechanism, collecting tray and power source

**Stripping Mechanism**

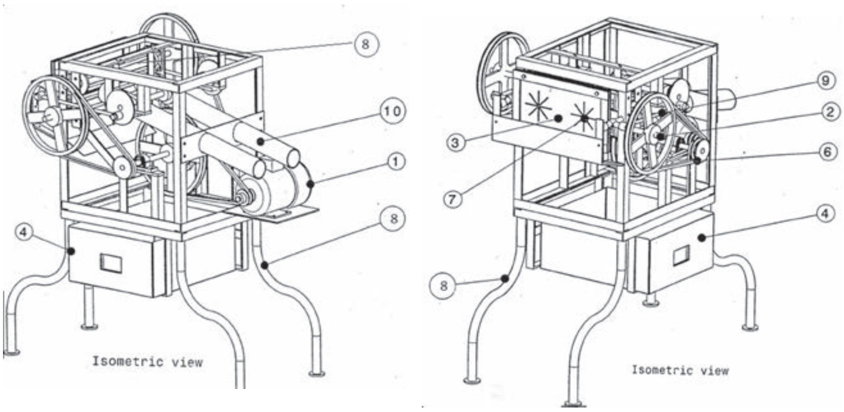
The curry leaf branches are fed in to the stripping mechanism, which is made of nylon plate. The nylon plate fixed vertically in the front has two tapered holes at the centre. The plate is also provided with a set of eight slots placed radially from the periphery of the central hole. The slots are of 50 mm length, and 5 mm height and at 45º angle from the central hole to enable the petiole to pass through it. A MS pipe that acts as a baffle is provided behind the nylon stripper plate. The lower end of curry leaf branch, which is fed in to the stripping mechanism first, is

**Fig. 2** Concept of mechanical stripping of curry leaf




1. Nylon plates with holes ( Stripping mechanism)
2. Striped Roller ( Pulling mechanism)

**Fig. 3** Isometric view of Power operated Curry leaf stripper




1. Power source- Motor; 2. Pulling mechanism; 3. Stripping mechanism; 4. Collecting tray; 5. Striped rollers; 6. Power transmission system; 7. Nylon plates with holes; 8. Stand; 9. Reciprocating rocker arm; 10. Stem outlet pipe

pulled inside the system by the pulling mechanism.

### Pulling Mechanism

It is a set of striped rollers made of mild steel (MS) used as pulling rollers. The stripes (8 no.) made of MS, give better grip to hold the curry leaf branch subjected to stripping mechanism. The rollers rotate in opposite direction to each other. The speed of the rollers has been optimized to 60 rpm and the drive is obtained by using series of belt and pulley drives. The pulling mechanism is fitted just behind the stripping mechanism. The rollers in the pulling mechanism draw the stem through them from the rear side of the stripping plate as the curry leaf is inserted through the holes in the stripper plate. Simultaneously the stripping mechanism is subjected to a reciprocating motion through a pair of rocker arms of 400 mm in length, which is operated with the help of a cam. The stripping mechanism strips curry leaflets from the petioles of the branch. The nylon plate provided in the stripping mechanism facilitates easy stripping by 2 persons. The nylon plate reciprocates by to and fro motion (with a stroke length of 55 mm) holding the branch to be stripped, enabling the stripping process when the stem passes through the hole and pulled by the pair of rollers. During the backward motion of the stripper mechanism, a small vibration is generated when the stripper plate hits the MS pipe acting as a baffle. This vibration partially helps in the release and dropping of the clogged leaflets in the nylon plate in to the collection tray below. The stripped stem passes through the two stem Outlet pipes made of Plastic. The outlet pipes are provided such that the stripped stem does not come in contact with the driving mechanism and are positioned in such a way that the stripped stem is collected behind the equipment. Thus the curry leaf branch to be stripped is subjected to pulling and stripping action simultaneously resulting in stripping of the leaflets from the petiole of the branch.

**Table 1** Performance of power operated curry leaf stripper

| Parameters | Range | Mean |
|---|---|---|
| Output capacity/ feed/ inlet, kg/h | 18-22 | 20 |
| Total capacity of the equipment, kg/h | 36-4 | 40 |
| Stripping efficiency (including petiole), % | 97.5-99.05 | 98.46 |
| Stripping efficiency (without petiole), % | 88.5-91.10 | 90.2 |

### Collecting Tray

The stripped leaflets are collected in to the collecting tray. The MS/plastic collecting tray is provided below the equipment. The stripped leaflets fall on an inclined sheet placed at an angle 450 to the horizontal and get collected in the tray. The collection tray can be easily slide in and out from the equipment.

### Power Source

Single-phase one hp electric motor is used as power source to operate the pulling rollers and the stripping mechanism. Energy used by the equipment was recorded by using wattmeter

The cost economics of the developed curry leaf stripper was analysed as per Regional Network for Agricultural Machinery Test code for Farm Machinery (RNAM, 1983)

## Results and Discussion

### Evaluation of the Equipment

The equipment was fabricated at the Research centre of Central Institute of Agricultural Engineering - Regional Centre, Coimbatore, India (**Fig. 4**). Long duration evaluation of the equipment was also carried out (**Fig. 5**). The output capacity of the equipment when two operators are using the equipment ranged from 36-44 kg of fresh leaves. The stripping efficiency with petioles and without petiole was to the tune of 98.46 and 90.2 percent respectively (**Table 1**).

### Extent of Damage to Striped Curry Leaf

The striped leaves were grouped in to five groups based on the extent of damage to the leaves (based on visual

**Fig. 4** Power operated curry leaf stripper


**Fig. 5** Evaluation of power operated curry leaf stripper

observation). The details of the extent of damage are given in **Fig. 6**. From the figure, it is seen that the curry leaf obtained without leaf damage was about 85 percent . Further, the extent of damage from 0-3, 3-5, 5-10 and more than 10 percent were 6, 4, 3 and 2 percent, respectively.

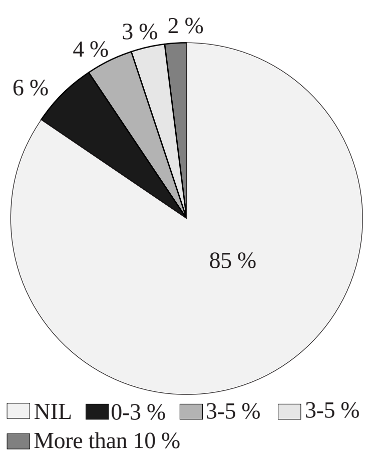
### Energy Consumed for Operation of Equipment

The equipment was connected with the wattmeter (0-1000 W) and the energy required was recorded. It was found that the energy required to operate the machine was in the range of 285-300 W, whereas the energy required for stripping the curry leaves was very low (15-20 W).The stripped curry leaves could be used either for culinary industry or can be packaged and sold in the market .There is no loss reported in the nutrition due to the stripping action by the equipment.

### Cost Economics of Curry Leaf Stripping

The cost of stripping one kg of fresh curry leaf using the stripper has been worked out to be Rs.3.50 per kg whereas the manual stripping was found to be Rs.9.0 per kg. Hence the percentage savings in cost was found to be about 60percent using the stripper and the percentage saving of labour was 80 percent. An Indian patent no 1146/MUM/2008 has been assignment to the equipment and the equipment has been commercialized

**Fig. 6** Extent of damage of curry leaf stripped using power operated curry leaf striper




## Conclusion

Curry leaf (Murraya Koenigii) is used as a leafy spice in Indian cuisine for its characteristic flavour and is reported to have a lot of medicinal values. The curry leaves are to be striped from the stem for making use in masala and pickle industries in raw. At present this operation is being carried out manually in unhygienic conditions. To reduce the drudgery of the human labour and to increase the output capacity, a power operated curry leaf stripper has been developed. The capacity of the equipment is 36-44 kg of curry leaflets per hour with a saving in labour and cost over conventional method is to a tune of 80 percent and 60 percent, respectively.


### Acknowledgement

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# Agricultural Mechanization in Sub Saharan Africa for a Better Tomorrow

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## Abstract

Progress in agricultural mechanization in sub-Saharan Africa (SSA) has stagnated more recently than in the last three decades. This is one of the major causes that leads to declined agricultural production per capita and reduced self-sufficiency in major cereal crops. When can we have mechanized agriculture in SSA to meet the long-time demand of African farmers?

The purpose of this paper is to discuss what enabling environment is required to boost agricultural mechanization in SSA. It reviews the issues of agricultural mechanization in SSA in the late 20th century. The recent new economic situation in SSA and other favourable factors are described. It analyses the causes of failure in agricultural mechanization for small scale farmers, then identifies some possible counter measures with enabling environment that promote agricultural mechanization. One of the key issues is how to promote sound competitiveness of the private sector through Private-Public Partnership (PPP). The role of the public sector in promoting PPP in agricultural mechanization is discussed along with development of the partners' role. The time has come. The paper concludes that agricultural mechanization would be boosted under current favourable economic situations in SSA by achieving an enabling environment in each country.

## Overview of Agricultural Mechanization in Africa

**Brief History and Situation of Agricultural Mechanization**

In sub-Saharan Africa (SSA), compared to other world regions, tractor use remains almost negligible. As an index of mechanization, the number of tractors in use in selected countries is shown in **Table 1**. In Asia, tractor use over the same period has increased tenfold. The poor states in SSA have an extremely low number of tractors per 1,000 hectares (ha) of arable land. There were two tractors per 1,000 ha of farm land in 1980, but this reduced to 1.3 in 2003. By comparison, in Asia and the Pacific Region there were 7.8 in 1980 and this rose to 14.9 by 2003.

After independence of many African countries in the 1960's, tractor mechanization was intensively promoted as part of large-scale agricultural schemes. On the other hand, farming was Africanized and farms were distributed to individual farmers. To meet the new demand by small scale farmers, animal draft power was spread as an intermedi-

**Table 1** Tractors in use in selected countries (units)

| Country | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|
| China | 73,021 | 126,440 | 346,786 | 747,900 | 861,364 | 824,113 | 685,202 | 989,143 | 1,410,647 | 2,063,528 |
| India | 48,000 | 100,000 | 227,668 | 382,869 | 607,773 | 988,070 | 1,354,864 | 2,091,000 | 2,789,000 | 3,149,000 |
| Egypt | 14,500 | 17,300 | 21,500 | 36,000 | 51,856 | 57,000 | 89,080 | 86,255 | 98,051 | 102,584 |
| Côte d'Ivoire | 705 | 1,412 | 2,150 | 3,700 | 4,300 | 4,830 | 5,330 | 8,400 | 9,280 | 9,400 |
| Nigeria | 1,000 | 2,900 | 5,650 | 8,400 | 11,150 | 13,900 | 16,650 | 19,400 | 23,000 | 24,800 |
| Kenya | 5,729 | 7,247 | 6,013 | 6,546 | 9,000 | 10,000 | 11,200 | 12,200 | 13,420 | 14,000 |
| Tanzania | 16,750 | 17,000 | 13,600 | 10,000 | 8,000 | 7,365 | 7,525 | 16,300 | 21,500 | 21,500 |
| Uganda | 579 | 1,280 | 1,731 | - | - | - | - | - | - | - |

Source: FAOSTAT website, 2010

ate technology that is suited to SSA. However, it was popularized in a few countries such as Ethiopia and animal power remained in limited use in most SSA. The unpredictable droughts and the epidemics of animal diseases hit many parts of Africa and prevented farmers from using animal power. Intermediate technology was not able to meet the demand of a majority of small scale farmers.

To promote tractor use among relatively small scale farmers, tractor hiring schemes were operated as a government service. However, most governments failed to operate tractor hire services. Identified causes included technical problems, management failures under bureaucracy, shortage of public financial support, low incentives for operators under public service, and low machinery productivity. Kaul (1991) pointed out that their beneficial effects could be offset as a consequence of distorted mechanization policies, which usually benefited the capital intensive large scale farms. Tractor hiring schemes were privatized in several countries in the 1980's and 1990's as a part of structural adjustments.

**Past Interventions and Experiences**

Besides many private sector initiatives, there have been a lot of government interventions and donor supported projects and pilot activities implemented to mobilize agricultural mechanization in SSA. These past actions and experiences included:

- Subsidized delivery of machinery and equipment to farmers
- Importation of agricultural tools, implements and powered machines with tax exemptions
- Promotion of tractor hiring services
- Repair and maintenance by machine dealers and entrepreneurs
- Research and development of machines with locally available materials
- Development and production of simple tools and machines
- Education and training of engineers, technicians, extension workers, operators and farmers
- Provision of commercial financing and soft loans
- Regulatory work and standardiza-

Chinese power tiller

CMC Nairobi


Reaper test

Rice miller

tion

Some of the above worked well in a specific place and time, but didn't achieve the expected goal. Many factors complexly relate to each other and any single action was not able to attain agricultural mechanization. For example, donors and political leaders directly delivered agricultural machines to farmers with no payment. This action distorted the market and the private sector and the market shrunk with lost competitiveness. This also caused a negative influence on machine ownership by farmers. These obstructing factors should be removed by the initiative of the public sector.

**Constraints to Agricultural Mechanization in SSA**

Africa Rice Centre (Africa Rice) invited representatives of rice stakeholders in St. Louis, Senegal in June 2011 to develop a roadmap for boosting agricultural mechanization in the SSA. Based on the constraints faced by key stakeholders in mechanization, factors to promote agricultural mechanization were discussed. Some of the constraints identified in the workshop are listed below.

- Low purchasing power of farmers and less availability of low cost agricultural machinery
- Limited access to agricultural credit for farmers and local fabricators
- Low utilization of machinery and low volume of business resulting from a poor cash flow
- Lack of suitable machinery packages for main agricultural operations
- Poor quality tools, equipment and machinery
- High local production cost due to imported materials
- Unstable spare parts supply and post sales service
- Limited human resources such as trained operators and mechanics for farm machinery
- Inadequate business knowledge and poor technical knowledge in agricultural machinery
- Few private sector led programs based on a clear mechanization policy and strategy

Farmers in SSA may face these constraints simultaneously and straggle to get and operate machinery on their farms in most cases. These constraints may not be removed unless agricultural machinery stakeholders find a new approach and a framework suitable for contemporary SSA.

## Lessons from Agricultural Mechanization in SSA

**Pre-Conditions to Start Mechanization**

The stagnation of mechanization has been experienced in many SSA countries. The causes may differ from place to place and from time to time. There is no single model of mechanization that can be applied to all SSA countries. The conditions for mechanization are not the same and may not be favourable in specific places. However, there are several empirically known pre-conditions to start agricultural mechanization.

The first one is profitability. When the farm operations are mechanized, farmers should have more profit than before. Mechanization is costly and fixed cost is especially too much to recover for many cases. This may not be applied only for farm operations, but also for non-agricultural activities. When machines are introduced, farmers expect less time required in the farm. It is, however, not easy to transfer the time saved by mechanization from farm work to other value added activities or money making work.

Secondly, technical feasibility is assured. All countries try to stimulate the use of agricultural mechanization technologies, but selection of machinery is sometimes not adequate. One of the examples is rubber wheeled tractors used in swampy conditions. It cannot perform its maximum capacity under inappropriate conditions.

Thirdly, the machinery supply chain is functional. All stakeholders in the machinery supply chain should get enough margin to sustain their business activities. If a link of the supply chain is broken the business model is no longer functional. The cost should be recovered within the supply chain and all stakeholders should have some margin from mechanization to sustain their business. Therefore, the total volume of potential market and business is critical to determine their profitability.

Fourthly, business risk is minimal to promote foreign investment. It is important to have a concrete policy to promote agricultural mechanization because it requires a long term perspective and continuous commitment from the government. The political and social stability is one of the indicators of country risk and SSA countries are required to show its stability in terms of sustainable economic performance. Economic change is always a risk for investors, but political and social risk should be avoided by maintaining peace and order.

**Agricultural Mechanization Policy**

Almost all countries in SSA have an agricultural mechanization policy or strategy. It is, however, not always implemented very well. This is due to weak commitment of the government in terms of limited budgetary allocation, limited human resources to implement the programs and a poor monitoring system among others. A more critical constraint is the difficulty of investment in agricultural mechanization caused by less profitability of farming in SSA. It is not easy to sell a small amount of cash crops in rural areas. Also, the price drops with a larger supply of products when the crops are harvested in the best cropping season.

There is a myth that agricultural mechanization increases unemployment of farm workers who have no other income source in rural areas. This prevents boosting of agricultural mechanization in developing countries. The argument is made that mechanization provides more employment opportunities in the value chain by having more quality products. However, it is not so easy to have high added values in remote places from the market. The government has a challenge to reserve enough budgetary requirements for agricultural mechanization, because most policies and strategies, if not all, are formulated by the ministry of agriculture and the ministry of finance is not involved in its development process.

The government of Uganda implemented its Development Strategy and Investment Plan (DSIP) and the Agricultural Technology and Agribusiness Advisory Services (ATTAS) was one of the key programs to support farmers by the research and extension linkage. The Agricultural Mechanization Taskforce was formed in 2012 to cover the thematic area of "Labour-Saving Technologies and Mechanization" to boost agricultural production and productivity. That was one of 12 strategic commodities and selected thematic areas in the non-ATAAS as a part of DSIP. The Agricultural Mechanization Taskforce has regularly met and conducted analytical work on agricultural mechanization. It held a wider stakeholder workshop that included line ministries, private sectors and farmers, and submitted a report including proposals of projects (MAAIF a, 2012 and MAAIF b, 2012).

Within each country, farming systems are diversified and the mechanization level is not uniform. Policy planners of each country are required to consider situations of smallholder farmers, although large commercial farming is the main driving force for agricultural mechanization if people are aiming at reduction of rural poverty. This approach requires careful studies, not only on farm machinery, but also on standardization of agricultural machinery for each country, in addition to provisions for subsidies and tax exemptions, and agricultural mechanization training centres for extension workers, technicians and farmers. Based on the studies through dialogue among stakeholders, the natural and human resources and socio-economic situation should be well incorporated when the policy and strategy are formulated.

**Table 2** List of machinery for domestic production

| Under production | Produced in 3 years | Produced in 10 years | Produced over 10 years |
|---|---|---|---|
| Mould board plough<br>Chisel plough<br>Rice weeder<br>Rice thresher<br>Paddy cleaner<br>Small trailer | Chisel plough<br>Treadle pump | Disc plough<br>Planter<br>Rice huller | Rice destoner<br>Rice grader<br>Paddy separator<br>Paddy dryer<br>Dehusker<br>Reaper |

## Technical Problems Experienced in SSA

Agricultural machinery should work in more unstable conditions that accepts crops and agricultural products that have irregular shape and hardness or under variable conditions. In SSA farm operations should be done under tough conditions such as high temperature and fine dust. It is necessary to overcome such technical difficulties such as durability requirement when agricultural mechanization is considered. Farm management is a more important aspect when agricultural mechanization is planned for the individual farmer. Diverse people create diverse types and models of farm tools and machines to meet their own need. Standardization may not always be useful for end users if off standard hoes are regulated and demolished from the market. In the market economy, de facto standards should be employed to reflect actual user needs for sound mechanization. To improve compatibility of farm machinery, it is necessary for the government to apply regulatory actions to standardize the design of machine elements, especially for safe use of agricultural machinery. It is the manufacturers' responsibility to reflect farmer needs to their products including after sales services.

**Table 2** shows a list of machinery to be produced in Uganda (MAAIF c, 2012). Locally produced machines are categorised into four; namely, machinery under domestic production, machinery to be produced within three years, machinery to be produced within 10 years, and machinery to be produced over 10 years. Some machines are produced after purchase order in the country. It is necessary for farmers to buy machines when needed. It is a big challenge for local manufacturers to always make machines to available in the market.

There is a research and development institute for agricultural mechanization in most SSA countries to respond to the demand of local farmer needs. These institutions try to come up with original designs suited for their recipient farmers. However, it is more efficient to modify designs developed by international organizations such as the International Rice Research Institute (IRRI) and AfricaRice. They have developed relatively simple machines designed for smallholder farmers. However, these developed machines are not always appropriate for all farmers in SSA because conditions of machine use are quite different and the support services after sales are weak in some countries. It is necessary to have a more efficient framework under international

**Table 3** Personnel and training needs for domestic machinery production

| | R & D | Raw materials | Manufacturing / Outsourcing | Assembling | Testing |
|---|---|---|---|---|---|
| Personnel | Engineers | Metallurgists | Mechanical Engineers, Electrical Engineers, Technicians, Artisans | Mechanics, Technicians | Engineers, Machine operators |
| Training areas needed | CAD Design and modeling | - | Advanced welding , fabrication, Blacksmith and foundry / Advanced machining | - | Test procedures, standards |

**Table 4** Personnel required in support services for wider use of agricultural machinery

| | Certification | Marketing | Delivery System | Maintenance & Support |
|---|---|---|---|---|
| Personnel | Legal Advisors | Economist, Marketing Officer, Sales Engineers | Rural networking of dealers | Service Engineers, Mechanics, Technicians, Blacksmiths |
| Training areas needed | - | Sales and marketing | Entrepreneurship, machinery repair and maintenance | Farm machinery repair and maintenance |

organizations to develop machines because agricultural engineers in developing countries are one of the most endangered resources.

It is critical to have enough skilled and qualified personnel in the agricultural machinery supply chain to promote appropriate agricultural mechanization. The rice mechanization taskforce team of Uganda suggests that the human resource in **Table 3** and **Table 4** are able to fill the gap to empower local resources to be mobilized (MAAIF c, 2012). It also identifies necessary training to build capacity of human resources in the process of upper-stream of the agricultural machinery supply chain (**Table 3**) and in the support services for wider use of agricultural machinery (**Table 4**). Higher education receives higher priority in the agricultural engineering sector but more people are required at the technician level to mobilize the functions of the sector. University education is paying too much emphasis on theoretical aspects in some SSA countries. It may be required to obtain a degree, but a paper or theses can't solve the problems that farmers face, unless it is implemented as development program or project.

### Utilization of Agricultural Machinery

Promotion of agricultural mechanization is associated with improvement of farming practices that are suitable for mechanized farming. It is necessary to reduce production cost by using agricultural machinery. However, it may require farmers to change farming practices by mechanization, and it may also cause conflicts with conservative farmers. Land consolidation is one of the important issues to improve efficiency of machinery use in SSA where there are many small farmers and scattered small fields exist. However, it may not be possible unless land registration is completed to assure farmers of their land titles.

Machinery is expensive for the majority of smallholder farmers and is not affordable unless they share the use of machines. Alternatively group ownership of machinery was encouraged by the government to mechanize farming in SSA. It is well known that group ownership failed in most cases if not all. It is necessary to distinguish group ownership and group use of machinery. When a farmer is the owner and the operator of machinery, it is much easier to operate and manage machines than when machines are shared by a group of farmers. Individual ownership may not be the best choice in SSA, because it is less cost effective and each farmer may not have enough capacity to manage agricultural machinery. The most important issue is to improve access to agricultural machinery, but not necessarily to increase ownership on machines and equipment.

## New Era for Agricultural Mechanization

### Favourable Changes in African Economy

The economy in Africa has been steadily growing except for some socially unstable countries since the beginning of the 21st century. **Fig. 1** shows that direct investment inward flow is rapidly growing except for Northern Africa where it experienced disturbance by Arab Spring. Western Africa and Eastern Africa showed about 5 times increase in the volume of inward direct investment without major fluctuation. This is a clear indication of steady growth of African economy.

The world trends in agricultural mechanization show that economic growth and mechanization have strong correlations. The countries with steady economic growth in Asia have achieved agricultural mechanization, although their mechanization level has not been so different from the SSA situation when they started mechanization several decades ago. It is time to shift from subsistence agriculture to commercial agriculture and from hand tools to agricultural machinery.

**Table 5** shows the real Gross Domestic Products (GDP) growth rate of Africa and some selected

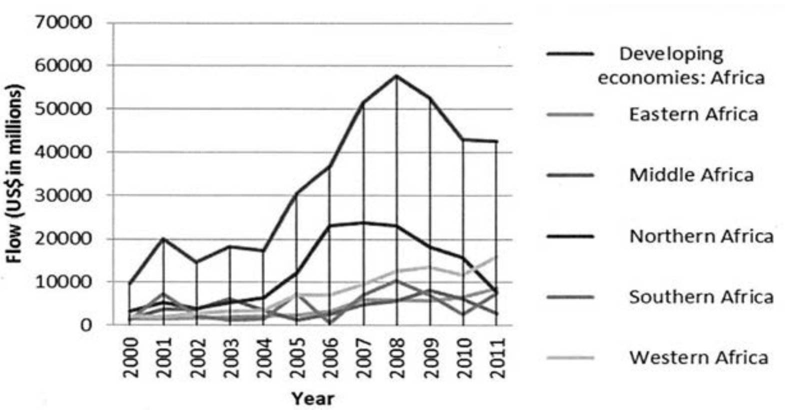
**Table 5** Real GDP Growth Rates (%), 2003-2013

| Fiscal Year* | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 (e) | 2012 (p) | 2013 (p) | Ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kenya | 2.9 | 5.1 | 5.9 | 6.3 | 7.0 | 1.5 | 2.6 | 5.6 | 4.5 | 5.2 | 5.5 | 4.7 |
| Tanzania | 6.9 | 7.8 | 7.4 | 6.7 | 7.1 | 7.4 | 6.0 | 7.0 | 6.4 | 6.8 | 7.1 | 7.0 |
| Uganda | 6.2 | 5.8 | 10.0 | 7.0 | 8.1 | 10.4 | 4.2 | 6.1 | 4.1 | 4.5 | 4.9 | 6.5 |
| Africa | 5.3 | 6.1 | 5.9 | 6.2 | 6.5 | 5.5 | 3.1 | 5.0 | 3.4 | 4.5 | 4.8 | 5.1 |

Note: Fiscal year July (n-1)/June (n), Fiscal year (e) is estimation and Fiscal Year (p) is prediction.
Sources: African Economic Outlook (African Development Bank Statistics Department, Various domestic authorities and AfDB estimates)

countries in East Africa (African Economic Outlook, 2012). Over the period from 2003 to 2013, the average GDP growth rate was 5.1% for Africa. Tanzania reached its average growth rate of 7.0% without dropping to less than 6.0%. The stable and consistent GDP was one of the major reasons for steady inward flow of foreign direct investment. It is considered that the business environment in Africa is changed by globalization of economy and Africa is now providing firm business opportunities.

**Fig. 1** Inward foreign direct investment flows annual, 2000-2011

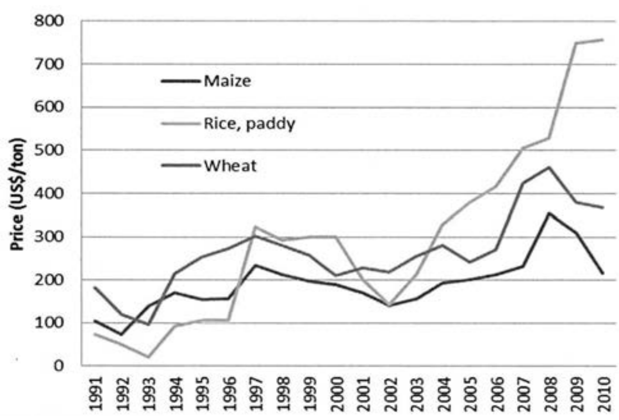



Source: UNCTAD-STAT, Inward and outward foreign direct investment flows, annual, 1970-2011

## World Food Security and African Agriculture

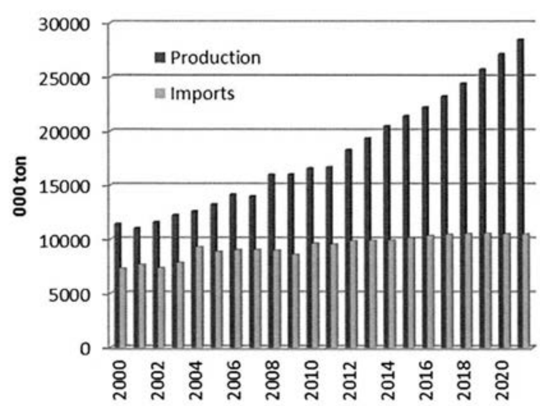
In the first decade of the twenty first century, there was a food price hike due to world food crisis. It provided more incentives to African farmers to produce more crops, because it had more returns when new land was opened and fertilizer use was increased. **Fig. 2** shows the outlook of prices of three agricultural commodities; namely maize, rice and wheat in Kenya. After the food crisis of 2007 and 2008, the price of some crops reduced. However, it is believed that the price of rice and other grains in the international markets will stay at high levels in the foreseeable future through a combination of factors such as increased demands and changing consumption patterns in countries with growing economies, competition from production of bio-fuels from grains, and possible effects of

**Fig. 2** Producer price for major cereal crops in Kenya, 1991-2010




Source: FAO STAT 2012
http://faostat.fao.org/site/703/DesktopDefault.aspx?PageID=703#ancor

**Fig. 3** Rice production and imports in sub-Saharan Africa




*The unit is kt (for Biofuels in millions of litres)
Source: OECD-FAO Agricultural Outlook 2012-2021
http://stats.oecd.org/viewhtml.aspx?QueryId=36357&vh=0000&vf=0&l&il=blank&lang=en

climate change.

African farmers are more interested in cash income from farming rather than food production. Most of African countries import food because they cannot produce food to meet their domestic demand due to growing population and economy. On the other hand, the growing economies such as China and India are critically important in stabilizing the agricultural commodity price in the international market. The price will remain high for some years. This situation creates a crisis for food importing African countries to pay a lot of foreign exchange to meet the food demand in each country. However, only Africa can save the increasing world population by providing food to the world. It can be a driving force to have more African farmers seek food production and agricultural income. Another effect of high food prices is that they generate more agricultural income to farmers and producers, and enhances more investments in agriculture, especially in agricultural mechanization. The increase in food price also increased labour cost and it led to agricultural mechanization rapidly; although the increase in oil price accelerated cost of agricultural inputs and farming practices.

The major cereals traded in the world markets are wheat, corn, and rice. Wheat and corn are widely traded with annual trading amounts estimated to be 130 million tonnes and 90 million tonnes, respectively, while rice is mainly produced and consumed in Asia with a thin market of 30 million tonnes per year. African countries are major importers of rice with a consumption and importation rapidly increasing at the level of 14 million tonnes and 6 million tonnes in milled rice. The rice production in SSA is continuously being increased while rice import is maintained at around 10 million tonnes in paddy as shown in **Fig. 3**.

For sustainable agricultural growth, investment in the agriculture sector is inevitable. Eyo (2008) reported a Nigerian study that microeconomic policies reduce inflation, increase foreign private investment in agriculture, introduce favourable exchange rates, make agricultural credit have significant effect on agricultural output growth that would be invaluable in fortifying government expenditure in the sector and ensure agricultural output growth.

In Asia increased rice production has been achieved through an increase in the yield per unit of land, whereas in Africa the expansion in cultivated land is the primary factor in the increase of total output. It can be said that among the staple food crops, rice represents Africa's best opportunity for reduction of imports. Increase in the yield will be required if there are constraints to shift the land use from traditional crops to rice. Any increases in local production will replace rice imports purchased with foreign exchange, and it will be reinvested in agriculture with reserved foreign exchange from importing rice.

**Globalisation of the Agricultural Machinery Industry**

There was a significant influence in production of agricultural machinery, including tractors, after starting globalization of the economy. Tractor manufacturing companies of developed countries in Europe started to shift their manufacturing factories from their original countries to Eastern Europe or Latin American countries considering global markets. Japanese manufacturers started to produce tractors and other equipment in Asian countries. China and India produced agricultural machinery for domestic use and for export, starting from collaboration with foreign origin manufacturers. Since then, they have continued their efforts to domestically produce machinery by improving product quality to be competitive in the international market.

The agricultural machinery production was expanded to emerging countries in the last two decades. If these growing countries continue to supply cheap machines to the world market, the availability of agricultural machinery will be expanded to other developing countries. On the one hand, SSA countries can mechanize their farming with less initial investment, and be a driving force to promote mechanization. On the other hand, developing countries in SSA are forced to import machines from emerging countries unless they build their capability to manufacture agricultural machinery with less production cost.

**Supports from International Organizations**

Sector wide support in the agricultural engineering sector from international organizations has been reduced since agricultural mechanization is removed from mainstream of international agricultural development issues. However, more people have given attention to agricultural mechanization in international communities considering favorable internal and external conditions surrounding African agriculture.

The Food and Agriculture Organization (FAO) has been a catalyst to promote agricultural mechanization in developing countries. Several SSA countries are supported in formulating mechanization strategies. Bishop (2005) published a guide for preparing an agricultural mechanization strategy under FAO. Key stakeholders for preparation were listed to promote sound mechanization, and special attention was paid to the roles of government and the private sector. Sims *et al.* (2006) used a word of "enabling environment" as conditions to be provided by government for a largely self-sustaining development of the agricultural engineering sector. Mrema *et al.* (2008) urged African leaders to install essential mechanization supply systems and support services responding to economic demand. Sims and Kienzle (2009) indicated with diagrams that all stakeholders in farm machinery supply chain need to make a profit enabling the supply chain to be sustainable. FAO and United Nations Industrial Development Organization (UNIDO) conducted a round table meeting of experts in Arusha, Tanzania in 2009, and the meeting made recommendations to facilitate support of both public and private sector investment flows into the development of agricultural mechanization in Africa. UNIDO and FAO co-hosted a parallel conference on "Creating a competitive edge through agricultural mechanization and post-harvest technology in developing countries" in the International Conference of Agricultural Engineering in Valencia, Spain in 2012, and UNIDO proposed establishment of a regional agricultural machinery center in Africa (Jenane and Samarakoon, 2012).

The Coalition of African Rice Development (CARD) is an initiative to double Africa's rice production to 28 million tons by 2018. In Asia, increased rice production has been achieved through an increase in the yield per unit of land, whereas, in Africa the expansion of cultivated area is the primary factor for increase in rice production. Agricultural mechanization is one of the most important agendas to double rice production by having timely operations both in upland, lowland and irrigated land. CARD considers that mechanization should not be occurred only for rice, but machinery should be highly utilized with other crops, for on and off farm use. CARD selected seven pilot countries (Cameroon, Madagascar, Mali, Rwanda, Senegal, Tanzania, and Uganda) for agricultural mechanization in its process and organized its workshops two times in Nairobi in 2012 as a CARD process.

## Enabling Environment to Promote Agricultural Mechanization

**Creation of Enabling Environment**

Creating enabling environment for agricultural machinery supply chain is the most necessary action to promote sound and intensified mechanization in SSA. Mrema *et al.* (2008) stated minimum features of enabling environments and urged African governments to foster the development of mechanization with high priority actions such as improving rural infrastructure, strengthening agricultural support services, expanding the supply and effective demand, providing direct support to companies involved in machinery supply and hiring services, reducing or absorbing transactions and information costs for mechanization services, promoting collaboration for

**Table 6** Check list of enabling environment to promote agricultural machinery after-sales services

| Actors on supply chain | Check list –what they have to do | Check list –enabling environment needed | Check list –enabling environment that government can provide |
|---|---|---|---|
| International makers and Importing Agents | • Quality assurance (At least 2-year warranty on tractors and farm engines, and 1-year warranty on equipment)<br>• Assurance of spare parts supply (At least 5-year supply for tractors and 3-year supply for equipment) | • Import subsidies for warrantied machines, equipment and spares<br>• Avail loans for purchasing machines with warranty | • Agreement with international manufacturers, importing agents or dealers on warranty, and its disclosure and monitoring (MAAIF)<br>• Avail government loans for equipment with warranty (MAAIF)<br>• Tax incentives such as reduced import tariffs for machinery and spare parts with warranty (MOFEP, URA) |
| Dealers | • First-time free maintenance service of imported machines<br>• Stocks of standard spare parts<br>• Operator training on purchase | • Government support for Preventive maintenance<br>• Avail loans for shops dealing spare parts<br>• Availability of skilled technicians | • Support forming agricultural machinery dealers association (MAAIF)<br>• Avail government loans to spare parts dealers in remote trading centres (MAAIF)<br>• Provide training for technicians (MAAIF) |
| Domestic manufacturers | • Attach leaflet on safety use and maintenance of equipment<br>• Indication of manufacturer's contact | • Two step loans, Soft loans | • Certification of safety products (MAAIF, UNBS, MTIC)<br>• Avail government loans for equipment with safety certification (MAAIF) |

MAAIF: Ministry of Agriculture, Animal Industry and Fisheries MOFEP: Ministry of Finance and Economic Planning
URA: Uganda Revenue Authority UNBS: Uganda National Bureau of Standard
MTIC: Ministry of Trade, Industry and Cooperative

provision of mechanization services, removing or reducing import and sales taxes on agricultural machinery and equipment, and making risk management tools such as insurance widely available.

It is important for farmers to recover investment in agriculture by securing output markets. Due to a lack of basic infrastructure such as roads and bridges from farms to markets, it may prevent access to output markets as well as to agricultural inputs. Especially for inland locked countries, the border is an obstacle to import materials and export agricultural products unless cross-border collaboration is available. Stable electricity supply is another important infrastructure for agro-processors to have uniform high quality products.

From the aspect of international manufacturers, it is critical to have a certain number of machines to produce or export to meet the demand. Suppliers are obliged to provide services such as repairs and supply of spare parts after sales. It is expedient to export machines only to countries or regions with growing markets. Reduction of business risk is critical for foreign investors including agricultural machinery exporters. Transaction cost should be minimized. However some countries require many days to issue a Letter of Credit and to clear customs when importing machinery. These costs are added on the sales price, and farmers are forced to buy more expensive agricultural machinery. Also, availability of crop and other insurance provide suppliers secured margins if farmers can not get expected farm sales.

Provision of subsidies for agricultural machinery purchases could be a promoting factor to increase potential buyers. However, subsidy for vulnerable farmers is not always a right solution because they have no access to credits. It is more important to improve access to machinery use for small farmers who are a majority of African farmers. Available loans for beneficiary farmers with little collateral are necessary.

These priority measures are considered to have interactions and some actions produce an effect when other interventions are available. It may have conflicts among measures if the target is not the same. Many countries have reduced import tariffs for agricultural machinery, but it is a counter problem for local manufacturers if they fabricate similar products for domestic use. Local manufacturers have to compete with tax exempted imported machinery, and they may need to use taxed imported low materials such as steel products and machine elements. If the government promotes domestic production of agricultural machinery, balanced measures are necessary for local manufacturers. Thus, enabling the environment should be examined not only for its positive effects but also negative effects on other stakeholders.

The CARD rice mechanization taskforce team in Uganda worked on the list of stakeholders and their requirements for thematic actions for mechanization with necessary enabling environment and the role of government. **Table 6** shows an example of enabling environment to promote agricultural machinery after-sales service improvement.

**Private-Public Partnership in Mechanization**

As seen in many SSA countries, the use of tractors was enthusiastically spread through the Tractor Hire Scheme by national programmes in the 1960s and 1970s to expand food production and agricultural exports. The government hiring scheme was not successful in many countries, because full support from the government did not provide fair competitiveness. Private sector development was considered the key to boost agricultural mechanization under structural adjustment. Following the structural adjustment introduced in developing countries, many countries terminated government hiring service and the private sector has taken up the initiative. However, it is not easy to instantly shift its management from the government to private sector or farmers' group. The support from the government to ensure smooth transition to the private sector is not adequately provided. Bishop (2005) argues that the absence of an enabling policy environment curtails initiatives by would-be adopters, particularly given the weak state of agricultural profitability. For example, tractor owners are extremely vulnerable to the withdrawal of government support.

As a government there must be a clear policy on agricultural mechanization that promotes continuous private investment not only in agricultural machinery but also in agriculture as a sector. It includes legislative actions along with technical measures and economic interventions. It should eliminate unfavourable conditions as well as illegal actions that retard private investment in the sector. The policy should be based on long term vision for agricultural development and the strategy should be reviewed periodically to reflect socio-economic situation to maintain sound competitiveness in the sector.

Human resource development is an important role of the government. A long term perspective and intervention are needed to factionalize agricultural machinery supply chain to avail appropriate innovations to farmers. Technical issue is only a part of entire system and socio-economic issues should be recognized more importantly. It is necessary to form a multi-disciplinary team with inter-disciplinary persons, including the private sector, in order to tackle highly complex problems in agricultural mechanization. It is an important government role to provide a more productive environment to create new ideas and diverse solutions considering dynamic changes in the future.

To avail only high quality machines in the market is critically important if end users have difficulties in their selection when purchasing machinery. Testing and evaluation of machinery and equipment are one of the countermeasures. However, it may not be justifiable for some countries to establish a machinery testing centre to evaluate and certify them without an appropriate number of qualified staff. Rather, it is recommended to establish an information sharing mechanism such as a network for machinery certification. Information and Communication Technology (ICT) should be highly utilized for this purpose. Agricultural machinery database should be shared among organizations for machinery testing and evaluation at sub-regional or regional levels. Usually national standards are regulated by an independent organization under the government, and it may not directly be linked to agriculture related ministries. It is important to have collaboration among ministries concerned on agricultural mechanization especially for legislative issues.

More importantly, private sectors led actions on quality products that are demanded by end users. These must be internal control measures among manufacturers and dealers to oblige warranty of machinery and assurance of spare parts supply for a certain period of time. This is an example of internal enabling environment required for stakeholders in the supply chain.

### Synchronizing Donor Support and Government Programs to Promote PPP

Donor intervention to agricultural mechanization to a particular developing country was partially done and not always organized well. Especially technical design intervention was not adequate if private sector was not fully involved. Donors were used to provide grant aid for farmers as a subsidy to avail new machines. It may distort market economy to prevent sound promotion of agricultural mechanization. Donors are required to provide channels of private investors from developed countries to farm machinery industries and agricultural businesses.

Donor actions are always expecting positive results from development cooperation projects. Lessons prevail that unexpected negative impacts more or less appear after the projects. Negative impacts are difficult to anticipate because detailed previews or assessments are not fully employed to spend more budgets for cooperation activities. Another lesson is that each donor program has a different time scale to get the results. This creates difficulties in harmonizing the programs in the sector by the government of developing countries. One subsidized programme to procure farm machinery may cause difficulties of others to operate a pure competitive machinery supply. Donor coordination should be more seriously considered by paying more attention to thorough assessment on the effect of agricultural mechanization on rural society as well as supply chains. On the other hand, beneficiary countries should control and regulate donor programmes as well as governmental programmes. This may require legislative framework to implement donor programs under government programs. Without initiatives of the beneficiary countries, no programmes can be properly operated. Donor communities can find partnership when there is ownership of beneficiary countries.

However, there are two hindering aspects existing in the recent trend in developing countries; namely decentralized implementation of support programs for farmers and independence of separated line ministries. The individual local government does not have enough capacity to implement field programs as the central ministry intended. Newly established or separated ministry may not have enough capacity to operate programs with coordination among line ministries. Too many donors provide too many diversified support programs and projects. Many countries face under staffing in the government and it is difficult to handle all support programs in harmony. This implies that donor programs should have capacity building components where scarcity of human resource is observed.

### Uncertainty or Predictable Risks in Agricultural Mechanization in SSA

As it was mentioned above that agricultural mechanization in SSA has a plenty of constraints. Even if the price of agricultural commodities is preferable for farmers, it is not an advantage unless African farmers can earn from selling extra products. Many African farmers in rural areas are still subsistent producing various kinds of crops for food in small rainfed fields, and this restricts African farmers from getting income from agriculture.

The above mentioned favorable changes may not be continued in the future. Therefore the following has to be considered as predictable risks. Economic growth has been maintained for more than a decade but its sustainability is not assured. If the economy slows down, investment in African agriculture will be reduced. In addition, there must be an increase in jobless people and hiring service of agricultural machinery should compete with lowered labor cost. If the agricultural commodity price is reduced, there will not be reinvestment in agriculture. Once political or social disturbance occurs, direct foreign investment will shrink and support from donor partners will be reduced or halted for some time. Originally, agriculture is based on natural resources and effect of climate change provides more uncertainty to agriculture business.

Rural development is critical if smallholder farmers are targeted for agricultural mechanization. As it is mentioned above, participatory approach to vulnerable smallholder farmers is necessary to empower rural people. There must be a mechanism to include disadvantaged farmers in the target by forming a group to develop their capacity or a channel to build a partnership for development. It is a real responsibility of the government to improve human security of rural people.

## Conclusion

African farming has been considered subsistence and dominated by small scale famers. Agricultural mechanization has been slow to start in SSA because African farmers have no purchasing power for machinery with abundant labour force in the sector. This is only one side of the profile of African agriculture, and it has another face of the market oriented global agribusiness. African farmers and traders have started heavier investment in the sector, although it may not be at an adequate level to generate sustained growth in productivity and income. Incentives for private investment in agricultural innovations are greatly enhanced by two factors, namely, secured output markets and the level of costs incurred while investing in innovations. Small holder farmers are lacking market access and they often are forced to employ low-input and low-output subsistence agriculture. Technology success in Africa depends on assured output markets. African markets have been integrating to the global market and agricultural mechanization has more reality than before. It is the right time to revitalize agricultural mechanization programs to enhance agricultural production and re-investment in agriculture.

As an investment in agriculture in SSA increased market scale of agricultural machinery is also enlarged. The demand of farmers and the motivation of suppliers are consistent under the current circumstances. Many pre-conditions to promote mechanization can be met by actively solid investment in agriculture that is supported by the recent firm economic growth in SSA and constantly high crop prices in the world market. It can create a situation that is profitable for all stakeholders in the machinery supply chain; namely farmers, machine owners, machine operators, machine suppliers, and manufacturers. This can happen firmly if the government sector leads PPP to promote agricultural mechanization.

A policy and strategy for agricultural mechanization developed by the agriculture related ministry are not always implemented as planned. This should be endorsed by the finance ministry to obtain a budget to implement. It is more important to have legal support in the government if sustainability is considered. This also enables donor communities to synchronize their programs and projects under government programs. Agricultural mechanization should be well incorporated in the organic low on agriculture to legally support enabling environment to confirm smooth implementation of mechanization programs.

More attention should be paid to build capacity of human resources in the agricultural machinery supply chain. Promotion measures cannot be implemented smoothly without enough qualified government staff and personnel in the agricultural engineering sector. Many universities are changing their name of the department from agricultural engineering to food, bio, and other engineering related names. It is an indication of neglecting agricultural engineering needs. It is necessary to strengthen professional training programs to build capacity of agricultural engineers if they cannot have it in the university education system. Networking of agricultural engineering institutions using ICT is an alternative to supplement the gap.

African countries are disadvantaged more by global warming and climate change than other regions by suffering from the most severe consequences. The global financial depression seriously hampers efforts to encourage private enterprise to expand their activities in SSA, but Africa continues to have high GDP growth. Africa will face perilous challenges in the years ahead, but it is a region of vast promise and prosperity. Agricultural mechanization is the key to come out from the vicious circle of subsistence African agriculture under a favourable economic situation. It is hoped that agricultural mechanization vitalizes agriculture in SSA by achieving enabling environment in each country that leads to world food security and poverty reduction for a better tomorrow.

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# EVENT CALENDAR

◆ **SEAgIng SECH**
—vii congreso ib ricoéde agroingenieria y ciencias horticolas—
*August 26–29, 2013,* Madrid, SPAIN
http://www.sechaging-madrid2013.org

◆ **Agricontrol 2013**
—The 4th IFAC Conference on MO delling and Control in Agriculture, Horticulture and Post Harvest Industry—
*August 28–30, 2013,* Espoo, FINLAND
http://agricontrol2013.automaatioseura.com

◆ **5th International Conference**
—Trends in Agricultural Engineering—
*September 3– 6th, 2013,* Prague, CZECH REPUBLIC
http://www.conference.cz/tae2013/home.htm

◆ **Joint European Conference on Precision Livestock Farming**
*September 10–12, 2013,* Leuven, BELGIUM
http://agricontrol2013.automaatioseura.com

◆ **AGRITECHNICA 2013**
—World's leading international exhibition for agricultural machinery and equipment—
*November 12-16, 2013,* Hannover, GERMANY
http://www.agritechnica.com/home-en.html

◆ **ADAGENG 2014**
—12th International congress on mechanization & Energy in Agriculture—
*June 3–6, 2014,* Cappadocia, TURKIYE
http://www.adageng2014.com

◆ **ADAGENG 2014**
—12th International congress on mechanization & Energy in Agriculture—
*June 3–6, 2014,* Cappadocia, TURKIYE
http://www.adageng2014.com

◆ **DLG-Feldtage 2014**
—One of the largest agricultural machinery exhibition in Germany—
*June 17-19, 2014,* Hannover, GERMANY
http://www.dlg-feldtage.de/en.html

◆ **AgEng 2014 Zurich**
—Engineering for improving resource efficiency—
*July 6–10, 2014,* Zurich
http://www.AgEng2014.ch

◆ **18th World Congress of CIGR**
—International Commission of Agricultural and Biosystems Engineering—
*September 16–19, 2014,* Beijing, China
http://www.cigr2014.org

# Main Production of Agricultural Machinery Manufactures in Japan

by
Shin-Norinsha Co., Ltd.
1-12-3, Kanda Nishikicho, Chiyoda-ku, Tokyo, 101-0054 JAPAN

Introduced here are the main products of agri cultural machinery manufactures in Japan with a number of photographs. The products are developed and improved for both foreign and domestic makers. For further information please refer to the manufacturers listed in the directory.

■: Dimensions ●: Weight ▲: Engine

**ALPS KEIKI**
*Battery Tester* ***"SP1250BT"***
Applying "Kinetic Inward Resistance System" (patent), which estimates the ohmic value by looking at the displacement of current and tension in the battery while charging and discharging. ■L145×W280×H70mm ●800g

**ARIMITSU**
*Knapsack Power Mist Dusters*
**"SG-6020D"**
It can carry out fetilizer spreading and herbicide spraying from ridge between rice fields and it can spread/spray uniformly in a short time. ■L363×W520×H740mm ●10.1kg ▲49.4cc □Chemical tank: 20L.

**CANYCOM**
*Grass Cutter* ***"MK60"***
Engine directly connected to the transmission. Screw-drive mowing knife with no belt. ■L2080×W770×H1100mm ●150kg ▲5.7ps □Cutting: W700 ×H0-85mm (Variable)

**ISEKI**
*Tractor* ***"TJV95"***
High output and torque engine of 95ps equipped. Common rail type electronic fuel injection system applied. This tractor computerizes the fuel injection, and the user is able to choose from two types of engine output patterns “Output Priority Mode” and “Fuel Consumption Priority Mode”.

**ISEKI**
*Sub-Compact Tractor* ***"TXG237"***
Easy to jack up by applying full-open bonnet. A full flat floor with expanded floor space. HST with two pedals. Perfect lever alignment for efficient operation. ▲23ps

**ISEKI**
*Rice Transplanter* ***"PZ60-HGRTE18"***
The transplanting part can automatically rise, and rotate with no brake. “Rotating Seedling Case” and “Big Deck” are equipped, and it can handle winding plants seen in many Chinese markets. ▲16hp □Row: 6

**KAAZ**
*Backpack Brush Cutter*
***"VRS400(S)-TU43"***

KAAZ has manufactured brush cutters over 40 years. Our concept is "Made in Japan". ■Shaft: 26mm, Length of main pipe section: 1500mm ●10.6kg ▲2-stroke ▲ 42.7cc □Fuel tank: 0.9L

**KARUI**
*Chipper **"DraCom KDC-131B"***

Grind the branches in parks, bamboo woods, and fruit farms into useful woodchips and decrease the volume at the same time. ■L1800×W770×H1250 mm ●415kg ▲9.6kW □Max. branch: ø120mm □Processing Capacity: 800-1300kg/h

**KAWABE**
*Trencher for Multi-Crops **"NF-843"***

By forward movement you can plow to replace surface soil with subsoil. ■L2150×W800×H1090mm ●297kg ▲Water-cooled Diesel 8ps □Tire: 4.00×8AG □4 wheel driving vehicle with same Dia. tires. □Self propelled

**KOSHIN**
*Back Pack Type Engine Sprayer*
***"ES-15DX"***

PUMP □Type: Shingle differential Piston Pump □Max Pressure: 3.0MPa □Max.Suction Volume: 5.2L/min Engine □Type: Forced Air-cooled 2-stroke Gasoline Engine □Model: Koshin k25 ▲25.4cc

**KOWA**
*Chipper **"Green Shredder P-550"***

Best for saving the environment. Spiral blade enables efficient cutting with less sound. ■L1080×W695×H1050mm ●98kg ▲4.9PS/2000rpm □Max. branch: ø40mm □Processing Capacity: $4m^3/h$

**KUBOTA**
*Tractor **"L4708"***

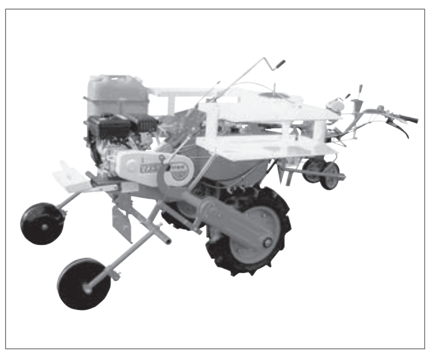
L4708, is a high performanced L-series tractor which can be operated in both paddy and dry field with high horse power and column shuttle specification. ▲47ps

**KUBOTA**
*Tractor **"M9540"***

M9540 is a high performanced M-series tractor which can be operated in dry field including land preparation with high mobility and low fuel consumption. ▲95ps

**KUBOTA**
*Combine **"DC-60"***

Compact & Efficient, maximizes productivity. It offers high speed operation with minimal grain loss and outstanding durability.



**MAMETORA**
*Vegetable Transplanter **"TP-4"***

This machine is available both pot and soil block in seeding transplanting. ■L217×W122×H106-130cm ●170kg ▲4.4ps/2000rpm, 126cc □Speed: 0.2-0.4m/s □Efficiency: 10a/1.5-2.0h □Rows: 1

■: Dimensions ●: Weight ▲: Engine

**MARUNAKA**
*Brush Cutter "**V282W/TJ45E**"*
■L1860×W690×H525mm ▲45.4cc □Driveshaft Housing: ø28mm □Driveshaft: ø8mm □Ergonomic Double Handle □2 stroke □OutPut: 1.4kW

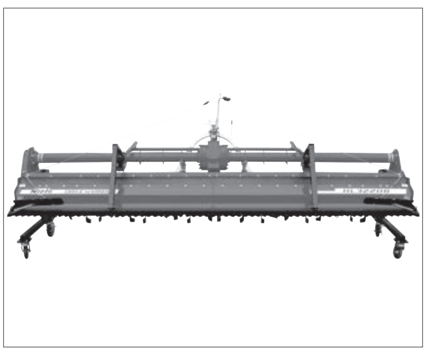
**MARUYAMA**
*Boom Sprayer "**BSA650LDE**"*
For crop management in rice paddy and field cultivation. ■L3940×W2150×H2400 /800mm (effective ground height) ●1145kg ▲15.4kW, 1123cc □Discharge Rate: 100L/min □Working Width: 9.9-15.9m

**MITSUBISHI**
*Tractor "**GCR1350**"*
■L4260×W2100×H2640mm ●5300kg ▲4-cycle, Water-cooled diesel 92.8kW/2200rpm, 4398cc □Crawler: W550×L2390mm □HST □PTO: 559, 793, 1040rpm

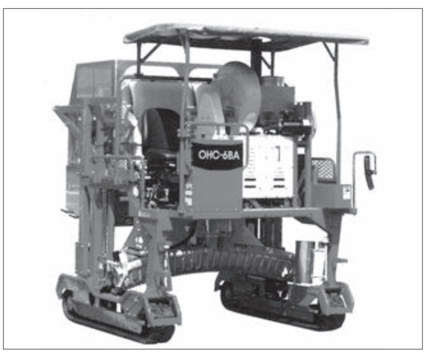
**MITSUBISHI**
*Tractor "**MT36**"*
Cover all aspects of Ground and Lawn care ■W1400×L3190×H2410mm ●1205kg ▲4-cycle, Water-cooled diesel 27ps/2600 rpm, 1662cc □Gear □Speed change: 8F-8R □Rear PTO rpm: 540/1000 □Tires: F7-16 R12.4-24 □Wheelbase: 1750mm □Ground clearance: 330mm

**MITSUBISHI**
*Rice Trans-Planter "**LV63**"*
■L3255×W2000×H1930mm □Ground height: 435mm ●696kg ▲Water cooled 4-cycle, OHC gasoline. 16.0ps/2800 rpm □HST □Rotary type □Rows: 6 □Width of stub: 11/12/14/16/18/21cm

**NEW DELTA**
*Blower "**NDBL 6500V**"*
High-power engine blower. The original blow-integrated fan case is supported by various users. ■ L355×W457×H457mm ●10.8kg ▲64.7cc □Fuel Tank: 2L □Rotating Speed: 6500rpm □Air Volume: 15.0m$^3$/min



**NIPLO**
*Rotary Harrow "**HL4020B**"*
High durability guaranteed by the double frame structure. Large spring-brake ploughs in the straws and residual stems beautifully. ■ L850×W4150×H1395mm ●575kg ▲70-100ps □Working Width: 391cm □Side drive

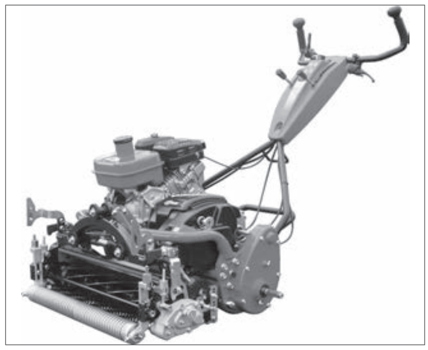



**OCHIAI**
*Riding Type Tea Picking Machine*
*"**OHC-6A**"*
Full working width cutter bar. Stepless speed control. ▲Water-cooled Diesel engine 28.4ps.

**OREC**
*Dehedral Levee Bush Cutter*
***"Wing Mower WM624A"***
■L1785×W830×H940mm ●61kg ▲4.3 hp □Handle load: 9kg □Speed change: F2, R1 □Driving wheels: F □Working Width: 600×H10-70mm (left roter adjustable in 4 levels) □4 bar knives

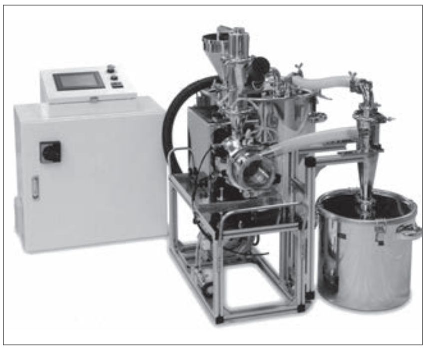
**SANEI**
*Poteto Harvester* ***"MINI·SS-11"***
Works remarkably on slope lands and small plantations!! ■L3800×W2250×H2280mm ●1200kg □Half mounted type □Adaptable Tractors: over 22.5kW (over 30PS) □Discharge Height: 855-2285mm

**SATAKE**
*Mill* ***"SRG30A"***
Rice Powder Food Responded Flouring Machine. Able to flour from small amount. ■W1950×D1000×H2896mm □Processing Ability: 30kg/h □Required power: 3-phase 200V 8.55kW



**SHIBAURA**
*Green Mower* ***"G-FLOW22"***
New concept greens mower with Offset Moving System + Floating Head. With the widest range of movement of the reel unit, G-FLOW22 gives you the best undulated ground contour following performance. ▲4.5ps □Cutting: W557mm □11 blades /height of cut: 2-30 mm

**SHIBAURA**
*Fairway Mower* ***"SR525"***
Ride-On 5-Gang Reel Fairway Mower with 38hp/45hp Shibaura Diesel Engine. ▲27.9(38) kW(hp) /33.6(45) kW(hp) □Width of cut: 2900 mm. □7 / 9 / 11 blades with height of cut 7-30 mm

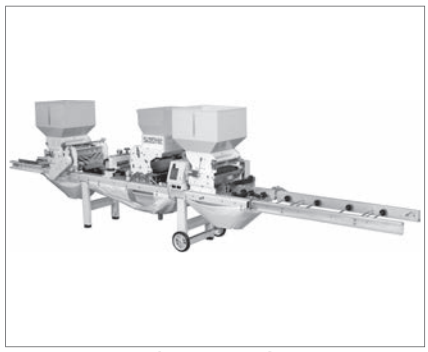


**SHIZUOKA**
*Mill* ***"SM150"***
Rice Powder Responded Flouring Machine. Finishes up in a fine powder form by swirling airflow crush system. ■L1010×W830×H700mm ●140kg □Processing Ability: 1-15 kg □Crushing Grain Size: 10-100μm

**STAR**
*Inline Baler/Wrapper* ***"TIB3000"***
High mobility and capacity. Exceed your imagination. Works efficient on grass, paddy and other fields. Cost-reduction work would be realized.■L465×W250×H180mm ●1690kg □Bale Size: 36×46cm(Cross) L30-120cm □Suitable Tractors: 26-59kW

**SUKIGARA**
*ABLE Potato Planter* ***"TAP-110M"***
Planting, ridging, ground cover laying in one operation.

**SUKIGARA**
*Three-Tine Light Cultivator*
■Length: 51cm ●8.5kg □Cultivator width: 18-30cm



**SUZUTEC**
*Seeder for Box Nursery* ***"THK2008"***
Full automatic seeding. You can just dial and control the seeding amount by the gram weights. Aluminium rails used to attain lighter bodies.

■: Dimensions ●: Weight ▲: Engine


**TIGER**
*Grader "**CRV-32A**"*
An excellent grader!. Liquid Crystal Panel. LED Handle. ■L1075×W505×H 1660mm □Height of the Elevator Pit: 960mm □Whole Rice Grain Outlet: 985mm □Processing Capacity 600-1920kg/h □Motor Power 100v/400w □Maximum Weighing Capacity: 80kg

**TOHNICHI**
*Torque Wrench "**QL**"*
The first click-type torque wrench made in Japan, 1956. A global standard structure of tightening a bolt. An alarm tells you the finish of tightening when it reaches the torque you've configured.

**YAMAMOTO**
*Vertical Rice Milling Machine "**XP-4000**"*
The rice milled by of the vertical rice milling machine evolves further. ■W1315×L2282×H2282mm ●2000kg □Required power: 58.2kW □Max capacity: 4.0t/h

# DIRECTORY

**Alps keiki**
Alps Electric Instruments Co., Ltd. ►http://www.alpskeiki.co.jp ►285 Takebusa, Shinnsyuushinmachi, Nagano-shi, Nagano-ken, 381-2411 Japan ►+81-26-262-2111

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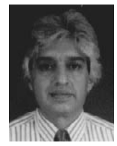
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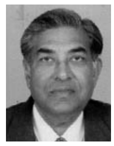
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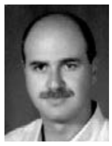
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