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EDITORIAL

This year, many parts of the world suffered from drought, and this gave a negative effect to agricultural production. Especially, the drought in the central western part of the U.S. was said to be the worst in half a century. The production of corn decreased, and made its price higher; up to 8 USD per one bushel. The price of corn has been rising from the time people started using it as the ingredient of bio-ethanol. As a matter of course, the growing demand of bio-ethanol eventually increased the price of ingredients, such as corn and wheat.

In such a situation, the global population is still growing and people are forced to control it by countermeasures such as the one-child policy in China. Regardless of the growing demand for food, the farmland on earth is limited. Up until today, the growth of agricultural production mostly relied on the improvement of land productivity. Over it, agricultural mechanization casts a long shadow. Agricultural machinery will optimize the farm work for more timely and precise work, which will improve the land productivity.

Regarding agricultural production, water is absolutely imperative. The use of underground water has been increasing recently as an alternative to rainwater. Underground water plays a crucial role especially during drought. However, according to recent research, 3.5 times the amount of water saved up underground seems to be used. We are still not sure just how much total water is underground, but the result of this research obviously warns against the overuse of water. For example, the upper stream area of the Ganges River uses about 50 times more water than it saved. Even in the High-plains area of the U.S., about 9 times more water is used. In the Southern Caspian Sea area, a horrifying record of 98 times more water is said to be used. As well as promoting agricultural mechanization, water-saving technology must be improved for the future.

Recently, I attended a symposium held by the Japanese Society of Agricultural Informatics. From agricultural machinery to breeding, the researchers introduced the current situation of various agricultural informatics research. As you can see from the brand new agricultural machinery made in developed countries, the biggest keyword today is "Informatization". To use the agricultural machinery and its information efficiently, technologies such as the internet and smartphones are spread broadly. Compared to 20 years ago, incredibly fast information transmission capacity is realized in newly developed internet technology. A tractor is a moving power source, and you can't do any farmwork without implements. The R&D of implements that best fit the region, the crop, and the operation is crucial. To accelerate the R&D, improvement of informatics technology is definitely needful. By using the new IT, diffusion of appropriate agricultural machinery to farmers will be done far more smoothly than before.

To prevent global warming, R&D and industrialization of renewable energies such as bio-ethanol is promoted in many areas around the world. Recently, in the U.S., a huge factory to produce bio-ethanol was built. They can produce bio-ethanol from the leaf of corn, instead of the fruit. If this technology spreads among countries, more corn can be used as food, thus, ease up the rapid growth of the price.

During the symposium, there was a presentation about exchanging information between plant body and co-existing microbes. Thinking of new agricultural mechanization, it is very profitable to, also, think about how to handle microbes. Japan is at the head of the list, and some countries are researching producing oil from algae. Plenty of oil and high protein forage can be made from algae. According to research in Japan, it may be possible to produce more than 800,000 U.S. dollars per one hectare of algae. Cultivating the ingredients, not only from the ground, but from the sea will surely help to solve the energy problem around us.

There is much unbelievable research done around the world. We should make good use of those newly developed technologies to produce new agricultural machinery. The most important point is for the people around the world to cooperate with each other to make a better world. Conflicts still arise in many areas of this planet, but those involved in agricultural machinery should communicate and cooperate with each other for the new future.

Yoshisuke Kishida
Chief Editor

October, 2012

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Developing a Solar Heating System for a Sweet Colour Pepper Greenhouse

by
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Abstract

The objective of the present study was to evaluate the effect of a solar heating system on the microclimatic conditions of a sweet colour pepper greenhouse during the winter season of 2009-2010. The use of the solar energy system for greenhouse heating in winter and cold days helped to save fossil fuels and conserve the green farm environment. It also enhanced the quality of greenhouse products, reduced production costs and limited the release of greenhouse gases. Inside and outside air temperatures, solar radiation flux incident, and relative humidity of inside and outside air for the last five years were collected and used to calculate the total night time heat loss from the greenhouse. Using these data the solar collector area and collector configuration were calculated so that the optimal surface area of was adequate to heat the greenhouse sweet colour pepper crop. The thermal performance analysis was experimentally determined by measuring the temperature increase at various water inlet temperatures and intensity of solar radiation, under clear sky conditions. A complete solar heating system (two solar collectors and storage tank) was utilised for heating 300 litres of water. The daily average overall thermal efficiencies of the solar collector and the storage system during the experimental period were 71.6 % and 91.3 %, respectively. Over a 181-day season the solar heating system collected 3,813 kWh of energy or 70.5 % of the total heat energy used to heat the greenhouse. This percentage could be increased by reducing heat losses from the greenhouse. Due to the microclimatic conditions of the greenhouse being at or near the desired level, the sweet colour pepper had optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield.

Introduction

Greenhouse development and expansion for off-season growing of vegetables and flowers since the first two-thirds of the twentieth century have been based on plentiful and relatively low fuel cost. The greenhouse industry has been considered as one of the fastest growing agricultural sectors in Egypt mainly because of its favorable climatic conditions during winter season. This sector creates important employment opportunities and benefits throughout the processing and marketing stages of greenhouse products. The industry is also very important for creating a demand for sub-sectors that provide inputs for greenhouse production such as seeds, organic fertilisers, bio-pesticides and glazing materials. The total greenhouse area has increased from 4.8 feddan in 1980 to more than 40,000 feddan in 2005, with 32,000 feddan plastic tunnels. This area has been in operation for high cash crops production (sweet colour pepper, beans, cucumber, tomatoes, and cantaloupe).

Because of large heating loads and relatively high prices of fossil fuels (100-150 $/barrel), alternative energy sources for greenhouse has gained utmost interest. Some of the important alternative sources of energy are; solar collectors, heat pumps, and thermal energy storage systems using phase change materials. As solar energy is available only during the daylight, its application requires efficient thermal energy storage. Therefore, the excess heat collected during the daylight is stored for later use at nighttime. Heating of a greenhouse is an essential requirement for proper growth and development of winter growing crops (Tiwari, 2003). Thermal heating of greenhouses have been studied by several researchers in employing different passive methods as well as active modes (Jain and Tiwari, 2003; Özturk and Bascetincelik, 2003; Abdellatif *et al.*, 2007; Benli and Drmus, 2009; and Lu Aye *et al.*, 2010). Among the active heating modes, a solar thermal system is one of the most practical and appropriate means for reducing the operating costs in a greenhouse. If heating pipes are galvanized or painted with aluminized paint, heat delivery rates will be approximately 15 % less than from black pipe (ANSI/ASAE, 2003).

In this research work, emphasis has given to solar thermal systems. Solar energy is non-polluting and offer significant protection of the environment. Therefore, solar thermal systems should be employed whenever possible in order to achieve a sustainable future. The solar energy collected by solar thermal systems is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at nighttime and/or cloudy days (Sayigh, 2001; Kalogirou, 2003).

The main objectives of the present study were: (1) to determine the actual surface area of solar collector suited for heating the greenhouse; (2) to evaluate the thermal performance analysis of the solar heating system; and (3) to investigate the possibility of utilising the solar thermal system for heating the sweet colour pepper greenhouses during the winter season of 2009-2010.

Materials and Methods

Design

The climatic conditions of the northern delta of Egypt (data of the last five years) were: the ambient air temperature at night time during winter lowered to 7.2 ºC, optimal air temperature for vegetable crops 18 ºC, overall heat loss coefficient for glazing material of fibreglass reinforced plastic 6.2 W/m^2. ºK, ambient air relative humidity 60 %, and solar radiation 6.686 kWh/m^2. day. Under these conditions, the greenhouse with 32 m^2 floor area (eave height 3.25 m, gable height 1.02 m, rafter angle 27º, total width 4.0 m, total length 8.0 m, and volume 87.68 m3) required a 300 litre water tank at 60 ºC. A mathematical computer model was developed to determine the actual surface area of solar collectors required to provide hot water for heating the greenhouse according to the total heat energy supplied. This required 4 m^2 of solar collector and a minimum flow rate of 12 litres per minute if the operating of solar heating is over a nine hour period. The heating operated over a five month season from November to April (the end of the heating operation depended on the atmospheric conditions in the particular year). The latitude and longitude angles of the site (University of Mansoura, Egypt) were, respectively, 31.045 ºN and 31.365 ºE, and 19.45 m above sea level. The meteorological data of site is given in **Table 1**.

Table 1 Meteorological details of the site

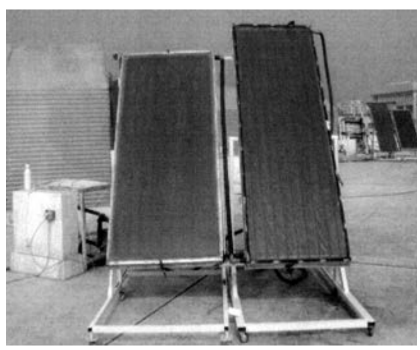
Location	Mansoura University, Egypt
Latitude angle	31º2'42"N
Longitude angle	31º21'54"E
Experimental period	November 2009 to April 2010
Average annual sunshine hours	1,209 h
Sunshine hours of experimental period	1,600 h
Daily average solar radiation	7.351 kWh/m^2/day
Maximum daily solar radiation	9.180 kWh/m^2/day
Minimum daily solar radiation	1.805 kWh/m^2/day
Mean water temperature at the beginning of each day	25 ºC

Solar Collector Area and Arrangement

Two solar collectors, each having a surface area of 2.0 m^2, and constructed of copper pipes with a black absorbing surface, were connected with a 32.0 m^2 sweet colour pepper greenhouse (**Fig. 1**). These solar collectors were arranged in one bank in a series array. The solar heating system is of the recycling flow system where the water is continually cycled through the solar collectors. The operating fluid (water) was continually pumped to pass through the solar collectors under clear sky conditions. After passing through the solar collectors, it was stored in a 300 liters insulated storage tank. The water pump was switched on and off manually on sunny days from 1st November 2009 until 20th April 2010. The flow rate of the operating fluid (12 l/min.) was adjusted and controlled every day using a control valve and a measuring cylinder with stop clock.

The thermal performance analysis of the solar collectors was experimentally determined by measuring the temperature increase at various water inlet temperatures, mass flow rate, and solar energy available under clear sky conditions. Using this data the solar collector area and configuration were calculated so that the water temperature at the end of day reached to over 60 ºC when the solar radiation was a maximum. Under steady-state conditions, the overall thermal efficiency (ηo) could be measured and determined using

Fig. 1 Solar collectors array, the first one is 2.0 m high and 1.0 m wide giving a net surface area of 2.0 m^2, the second is 2.4 m high and 0.85 m wide giving a net surface area of 2.04 m^2



the system analysis of Duffie and Beckman (1991); Kalogirou (2004); and ASHREA (2005) as follows:

$$\eta_o = \{F_R A_c [R (\tau\alpha) - U_o (T_{fi} - T_a)] / R A_c\} \times 100, \% \quad (1)$$

where F_R, A_c, R, $(\tau\alpha)$, U_o, T_{fi}, and T_a, respectively, were the heat removal factor, collectors surface area (m^2), solar radiation on a tilted surface (W/m^2), optical efficiency, overall heat transfer coefficient ($W/m^2.\ ^oK$), inlet water temperature (ºK) and ambient air temperature (ºK). The normalized temperature rise (D_T) of the solar collector was computed from the following relationship.

$$D_T = (T_{fi} - T_a) / R,\ ^oK\ m^2/W \quad (2)$$

Overall Design and Installation

The solar collectors were mounted individually on a movable frame outside the greenhouse at an optimum tilt angle and continually facing due south. The collectors were adjusted manually to change the orientation and tilt angle once each hour, so that at that time the angle of incidence of the surface of the solar collector and the sun's rays was set at zero. The site was protected from the prevailing north-westerly winds by the greenhouse, but was not shaded from the sun. The storage tank was equipped with a supplementary electric heater (2.5 kWh). The auxiliary heater was used when the stored solar energy was insufficient to provide the requirements of the heat energy supply. To provide and maintain positively a temperature of 16-18 ºC at night time during cold winter months, the greenhouse was equipped with a heat exchanger using parallel flow system in order to utilize the stored energy from the storage tank for heating the indoor air of the greenhouse (**Fig. 2**). The heat exchanger was located on an iron stand to be above the floor surface by 35 cm (the coldest zone inside the greenhouse). The heated water from the insulated storage tank (heated by solar energy during the daylight) was pumped to circulate through the heat exchanger. It was controlled by an on-off controller to initiate heating at 16 ºC and interrupt it at 18 ºC (environmental control board with differential thermostat).

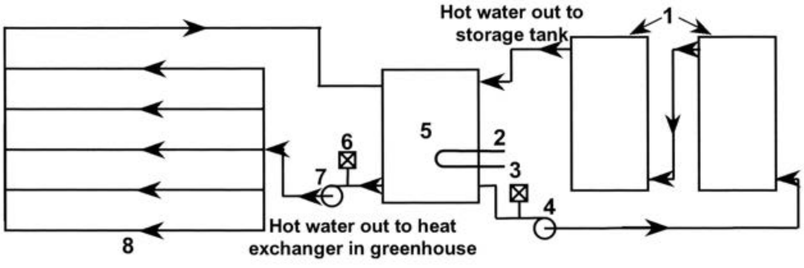
Measurements and Data Acquisition Unit

The solar radiation, air temperature, air relative humidity, and wind speed and direction were measured and recorded using the meteorological station, which installed just above the solar collectors and greenhouse. Disk solarimeters were installed on the top frame of the solar collectors in order to measure the solar radiation flux incident on a tilted surface. A 12 channel data-logger was also used for taking and storing reading from the different sensors (thermocouples type K) situated at different location of the solar collectors and the storage tank. Another data-logger was also used for taking and storing reading from the different sensors located at different situation of the sweet colour pepper greenhouse. The recorded data were stored in the memory for output to a printer or to a computer for storage on disk. The time interval for data recording was 60 min with data acquisition every one minute for integrated measurements. The calibration of all sensors and the logger was completed successfully at the beginning of the experimental work.

Cultivation and Watering Systems

A pots system was used as an agriculture system for sweet colour pepper. The greenhouse was equipped by 60 plastic pots arranged in five rows (each row had twelve pots). Drip irrigation system was used for watering the pots. A 200 liter scaled plastic water supply tank was located inside the greenhouse 1 m above the ground surface in order to provide adequate hydrostatic pressure for maximum use rate of water. Twelve drippers (long-bath GR 4 liter/hr discharge) were uniformly alternately distributed with 48 cm dripper spacing throughout each row of plants inside the greenhouse. Two trays of sweet colour pepper seedlings (Bravo-Enze Zaden, C.V) were used. Sixty five of seedlings with on average of six rear leaves were planted in the pots inside the greenhouse on 2nd October 2009.

Fig. 2 Schematic diagram of solar heating system included



1) solar collectors, 2) auxiliary electrical heater, 3) water flow control, 4) water pump for solar collectors, 5) storage tank, 6) flow control, 7) water pump for heating, and (8) heat exchanger

Results and Discussion

Thermal Performance

The solar collectors have been operating satisfactorily for six months without any malfunction, except for a small leaking in a rubber connection between the collectors and water pump after the water had reached to 70 ºC. Water temperatures have been monitored for six months beginning in November 2009, and the monthly average solar energy contribution is shown in **Fig. 3**. During the experimental period, there were 1,209 hours of bright sunshine of which 1,025 hours (84.78 %) were recorded and used in the thermal performance analysis and applications, slightly lower than average due to clouds. Although on day to day figures, the correlation between sunshine hours and solar energy collected was poor, agreement was good on a monthly average basis **Fig. 3**. The discrepancies between months rise was due to the number of bright sunshine hours, solar altitude angles, water temperature in the storage tank at the beginning of each day, and number of operating hours.

The thermal performance analysis of the solar collectors was mainly determined by its overall thermal efficiency in converting solar energy into stored heat energy. A comparison between the daily average total solar radiation and total solar energy collected was made (**Fig. 4**). The correlation between the solar energy collected (21.066 kWh) and the available solar radiation (29.405 kWh) was in agreement (91.03 %) except that the solar collectors appeared to be more efficient in February than in other months because the heat energy stored during daylight was consumed at night time. This was also due to the water temperature in the storage tank at the beginning of each day throughout the month being lower than the indoor air temperature. As the temperature difference between the absorber surface and the water passing through the solar collectors were increased, the heat transfer rate between the absorber surface and the water was increased. The regression analysis showed that the slope of the regression equation was almost equal to the daily average overall thermal efficiency (71.25 %) of the solar collectors during the experimental period (**Fig. 4**).

The overall thermal efficiency was the ratio of the solar energy collected by the solar collectors to the solar energy available. The daily average overall thermal efficiency of the solar collectors during the experimental period was 71.64 %, consequently, 28.36 % of the solar energy available was lost. The overall thermal efficiency (η_o) was correlated with the normalized temperature rise (D_T) as shown in **Fig. 5**. It revealed a high correlation ($r = 0.951$ with $p > 0.001$) between these parameters.

Heat Energy Provided

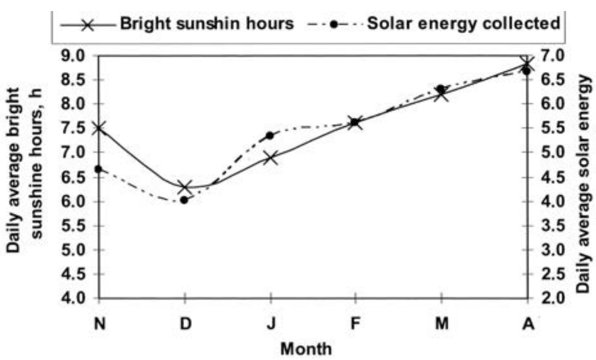
During the 181 day heating season the solar collectors collected 3,813 kWh. The daily average heat energy provided by the solar collectors during this period is given in **Table 2** where it is compared with total heat energy requirements for providing and maintaining optimal level of indoor air temperature. During the heating period the solar energy collected was 21.066 kWh of which 19.200 kWh was stored in the storage tank. This stored heat energy provided 70.5 % of the daily total heat energy required. The potential savings form solar power was not fully realized for three main reasons: first, little solar power was collected in the first two hours after sunrise and the last before sunset due to low solar altitude angle and water temperature in the storage tank. As the heat energy stored in the storage tank was not continually consumed at night time, at the beginning of some days more than two hours of sunshine were lost.

Secondly, throughout the heating season, the auxiliary electrical heater was switched on at the end of each day when the water temperature in the storage tank was lower than 60 ºC. Therefore, some of this heat energy dissipated into the indoor air in spite of its temperature higher than the set point temperature (16 ºC). This point of action resulted in extra loss of heat energy from inside to the outside atmosphere. This heat energy was ignored in computing the percentage of heat energy supplied by the solar heating system. This loss could be eliminated by installing an automatic control to switch on the auxiliary heater when the heat energy in the water tank was insufficient to pro-

Table 2 Daily average total heat energy normally required (kWh) during heating season (181 days)

Energy	Heat energy, kWh per day	Providing of total, %
Solar energy		
Total useful heat energy collected	21.066	-
Total heat energy stored in the storage tank	19.200	70.5
Electrical energy		
Total electrical energy used by water pump (4)	2.141	7.9
Total electrical energy used by water pump (7)	1.115	4.1
Total electrical energy used by electrical heater	4.778	17.5
Total energy actually used by greenhouse	**27.234**	**100**

Fig. 3. Daily average solar energy collected by solar collectors and daily average sunshine hours during the experimental period



vide the desired level temperature of indoor air.

Thirdly, during the coldest month (January) the outside air temperature at night time lowered to 7.3 ºC for the majority of nights and resulted in great heat energy loss. As the heat energy supplied into the greenhouse reside in the task of adding heat at the rate at which it is lost, accordingly, there were 7.397 kWh of electrical energy added to the water in the storage tank during this month. Therefore, a moveable thermal curtain should horizontally be spread at a height of 2.25 m above the floor surface at night time to reduce heat losses during this period. About a 40 % saving in heat energy supply can be achieved in this way. During the daylight, the thermal curtain can be withdrawn, but a 4 % light loss due to the rolled-up material is produced (Critten and Bailet, 2002). A moveable baffle should also be used to close the outside surface area of the cooling pads at the end of daylight to minimize the heat losses due to infiltration of cold air.

In spite of these heat energy losses solar power provided a significant proportion of the total heat energy required for heating the greenhouse.

Microclimatic Conditions

The air temperature inside the greenhouse was compared with the outside air temperature as an important measure of the effectiveness of heating system. The fluctuations of air temperature surrounding the crops played an important role for their growth rate, development, and productivity. Fluctuation changes in air temperature, caused by the on-off control board, were evidently observed inside the greenhouse. A temperature gradient developed along the centerline of the greenhouse and its value varied with time during each heating cycle. The nightly average air temperature inside the greenhouse varied between 15.9 ºC and 19.2 ºC, whereas, the outside air temperature ranged from 10.5 ºC to 16.6 ºC.

The highest air temperature inside the greenhouse (18.2 ºC) during January (coldest month) was 19.00 h, just two hours after sunset. The air temperature (18.2 ºC) was from the heat energy stored during the daylight; therefore, the heating process was not used over this hour. The lowest air temperature inside the greenhouse (15.9 ºC) was also recorded during January at 06.00h just prior to sunrise. The lowest air temperature inside the greenhouse occurred due to three reasons. Firstly, the majority of heat energy stored in the storage tank during daylight (from solar energy system) and supplementary heat energy added after that (from auxiliary electrical heater) was consumed during the heating cycles at night time. Secondly, the air temperature difference between the set point and the outside was 7.5 ºC, consequently greatest amount of heat energy was lost at that time. Thirdly, the fiberglass cover was able to keep the air temperature inside the greenhouse greater than that of the outside. Under these circumstances, the heating system provided a heating effect of 8.4 ºC.

The air relative humidity inside the greenhouse ranged from 61.3 to 75.8 %, whereas the outside air relative humidity was in the range of 33.5 to 68.5 %. The nightly average indoor air relative humidity was 71.7 %. However, the nightly average outside air relative humidity was 54.5 %. The cyclic variations in air relative humidity mainly occurred at the peak of the heating cycle in the greenhouse. The air relative humidity inside the greenhouse was decreased by 5.9 % at the peak of each heating cycle, whereas at the end of the cooling down it was increased by 8.1 %. Most protected cropping grow best within a fairly restricted range, typically 60 % to 80 % air relative humidity at night time for many varieties (Ozturk and Bascetincelik, 2003). High air relative humidity is the main response

Fig. 4 Solar energy collected (useful to storage) versus solar energy available during the experimental period

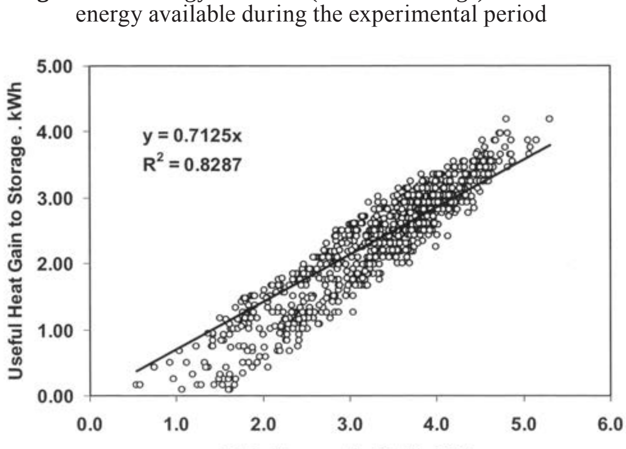
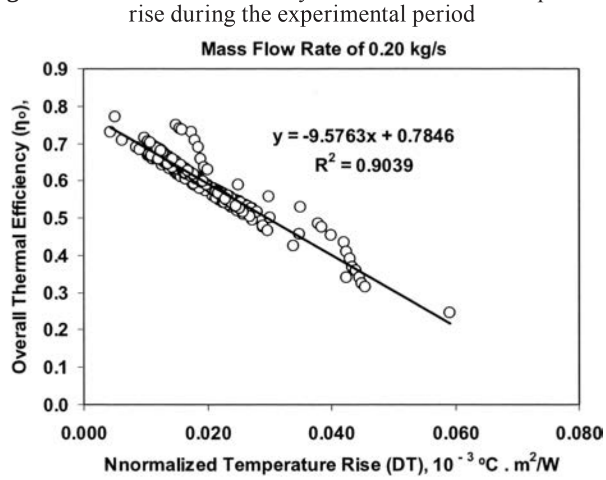


Fig. 5 Overall thermal efficiency versus normalized temperature rise during the experimental period



of pathogenic organisms. Most pathogenic spores cannot germinate at air relative humidity below 85 %. Low air relative humidity increases the evaporation demand on the plant to the extent that moisture stress can occur, even when there is an ample supply of water to the roots. Normal plant growth inside the greenhouse generally occurs at air relative humidity from 30 to 80 % (Hanan, 1998).

The nightly average water vapour pressure (VPD) during the experimental period was 0.67 kPa. Lower vapour pressure deficit, means the air surrounding the plant is at or near saturation, so the air cannot accept moisture from the leaf in this high air relative humidity condition. When the air vapour pressure deficit is too low (VPD < 0.43 kPa) at air relative humidity too high (RH > 85 %) and air temperature very low (Ta < 15 ºC), the water may condense out of the air onto leaves, fruits, and other plant parts. This can provide a medium for fungal growth and disease.

In cases where the VPD alternates between too high and too low, fruit quality can be adversely affected by "shrink cracks" in the skin as the turgor; pressure alternately expands and contracts the water-filled cells in the fruit. This condition can significantly downgrade the quality of vegetable crops. Several studies (Pringer and Ling, 2004; Argus, 2009) that explored disease pathogen survival at different climate levels revealed two critical values of air vapour pressure deficit. The studies showed that fungal pathogens survive best below vapour pressure deficit of 0.43 kPa.

The air temperature (16.4 ºC), relative humidity (71.7 %), and vapour pressure deficit (0.67 kPa) within the greenhouse were at or around the desired level particularly during the cold winter season when the sweet colour pepper plants were grown. The weekly averages increasing rate in number of leaves inside the greenhouse was 11.4 leaf/plant. As the number of leaves increased, the green surface area increased, and the biochemical reactions were, thus, increased making the photosynthesis process more active. The weekly average stem length of sweet colour pepper plants was 5.9 cm. As the indoor air temperature was reduced lower than 15 ºC, slower growth rate, longer internodes, thinner xylem, and smaller rate of fruit set occurred. Due to these reasons discussed previously, the average number of fruit being seated on the plants was 19.4 fruit/plant. Therefore, the total fresh yield of sweet colour pepper crop was 188.8 kg (5.9 kg/m^2).

Economic Considerations

The cost of the solar heating system included the auxiliary heater, water pumps, storage tank, control board, and heat exchanger that in 2009 was approximately $US 1,033 (LE 5,800). The cost of the adapted greenhouse included the ventilating and cooling systems, and fiberglass cover was approximately $US 2673 (LE 15,000). The life of the solar heating system and adapted greenhouse was almost 20 years. At the time the estimated return on capital was 27.4 % per annum. Since then, power costs have risen and the system is achieving a return of about 64 %. The economic benefit of renewable energy utilization in agricultural applications is still marginal due to the unrealistically low price tariff for electricity power, as the government financially supports this power. However, renewable energy systems can have a beneficial impact on the environmental, economic, and political issues of the world.

Conclusion

The primary objectives of this solar heating system are to increase the solar radiation converted into stored thermal energy and to investigate effective uses of that stored energy for heating sweet colour pepper greenhouse. A solar water heating system has been developed and installed on the roof of the Agricultural Engineering Department, University of Mansoura, besides an experimentally greenhouse. The system has operated satisfactorily for over six months.

The solar collectors, which are continuously orientated and tilted to maintain an incident solar angle of zero from sunrise to sunset will allow maximum values of both the absorptance of the absorber surface and the transmittance of the glass cover to be reached. The overall thermal efficiency and heat losses are mainly affected by the water inlet temperature and ambient air temperature.

Over the period November 2009 to April 2010, the solar heating system collected 3,813 kWh (13.73 GJ) of solar power. During the six months heating period the solar heating system provided 19.200 kWh per day on average or 70.5 % of the power required by the greenhouse.

The microclimatic circumstances within the adapted greenhouse were at or around the desired level during the daylight (26.8 ºC) and at night (16.4 ºC) particularly at the critical period (from 02.00 to 06.00 h) during the winter season, optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield were achieved. The nightly average vapour pressure deficit (0.67 kPa) was at the optimal level during the experimental period. The economics of such a system remains marginal at present Egypt power prices, although changes in power costs may drastically alter the situation.

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Tractor Drawn Raised Bed Seed Drill Under Vertisol

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Abstract

A tractor drawn (TD) raised bed seed drill machine was designed and developed. A computer aided design package for adoption of raised bed technology for farmers in black cotton soil conditions was utilized. The machine was evaluated and compared with the performance of a zero till drill and conventional practices at Jawaharlal Nehru Agricultural University farms as well as at a farmer's field for chickpea sowing. The total time and cost required for making raised bed and sowing operations by the raised bed planter was 1.21 h/ha and Rs.358.60/ha. This was 16.44 percent less time than conventional practices of wheat cultivation but was 28.83 percent more time than zero till drill practices. The average yield from the tractor raised bed seed drill was 1,482.7 kg/ha. Conventional practices and tractor drawn zero till drill were 1,139.2 kg/ha and 1,211 kg/ha, respectively. The soil conditions were better for the T.D. raised bed seed cum fertilizer drill (SCFD).

Intoduction

Raised bed was introduced to the rice-wheat system of the IGP in the mid 1990s. The benefits overcame the water logging and improved soil structure on the cropping soil in the high rainfall zone as compared to the conventional seed drill. Improved soil structure, proper aeration and proper drainage of soil led to high yield. It was adopted for growing high value crops that were susceptible to water logging stresses such as maize, cotton, wheat, and chickpea. The raised bed system facilitated irrigation through the furrow. In order to effect further sowing in irrigation water the system also allowed alternate or skip furrow irrigation. Furrow irrigation in raised bed systems was a rational water sowing technology that reduced soil erosion and saved irrigation water.

Soil is a complex medium but we can simply think of it as a combination of solid mineral and organic particles for air and water storage and movement. The air and water occupying these "empty" spaces are both vital. Seeds require oxygen and water to germinate. For healthy plant and root development roots must have oxygen in order to take up essential components of photosynthesis. The process responsible for building plant structures and soil nutrients must be in solution before roots can absorb them.

In the past many raised beds have been designed by scientist that gave good results in light soil. However, the performance was not up to the mark of satisfying the problems arising in the penetration and slope of the bed. A modified raised bed gave better results under the heavy soil conditions. The yield for the items to be measured; performance, working capacity, field efficiency and power requirement were tested in comparison with the conventional seed drill.

Methods and Materials

The machine consists of a 4 tine, 2 raised bed furrow openers along with the covering devices and seed-cum-fertilizer drill. The machine was designed with an Auto CAD 2006 Computer graphic package. The conceptual and orthographic design views of the raised bed furrow openers as well as isometric and orthographic design views of the machine are given in **Figs. 1** and **2**. The overall specifications of the machine are given in **Table 1**.

The raised bed type furrow opener (**Fig. 1**) consisted of furrow openers, a tine, a shovel, a boot and tubes for seed and fertilizer. The furrow openers were 87 cm long while the width of the bed-maker was 1.20 cm. Point shear was 40 cm long and 7 cm wide at a distance of two wings that were provided with the furrower to open the opposite end. Triangular furrows with 40 cm top width and depth were each made with this shaper. However, the bed width and furrow depth were adjustable. The tines were made of flat mild steel flat having a width of 55 to 75 mm and thickness of 15 to 18 mm. Boot and tube were made of mild steel with a minimum thickness of 1.8 to 2.0 mm and shovel material was high carbon steel having minimum carbon content of 0.5 %. The shovel was heat-treated with minimum hardness in the range of 350 to 450 HB. Thickness of the shovel was 3.0 to 4.0 mm. The furrow opener tines were made of mild steel while the shoe or shovel of the opener were made of wear resistant high carbon steel (0.5 to 0.6 % C, 0.65 % S and 0.05 % P). **Fig. 2** shows complete drawing views of the raised bed seed cum fertilizer drill.

The minimum diameter of seed and fertilizer tubes were 50 mm and were so placed that the centre to centre distance between seed and fertilizer tubes were a minimum of 50 mm. The lower tip of the fertilizer tubes was 10 mm below the tip of the seed tubes and were a minimum of 25 mm above the lowest point of the boot.

The performance of the tractor drawn raised bed seed drill was evaluated in 2.5 ha fields at JNKVV farms and a local farmer's field with vertisol soil after the harvesting of paddy crops. The machine performance was compared with the conventional practices and zero tillage drill for wheat cultivation. A 20 × 15 meter plot was used for each treatment. There were 5 replications for each treatment. Details of the treatments are given below:

Fig. 1 Isometric and orthographic diagram of furrower

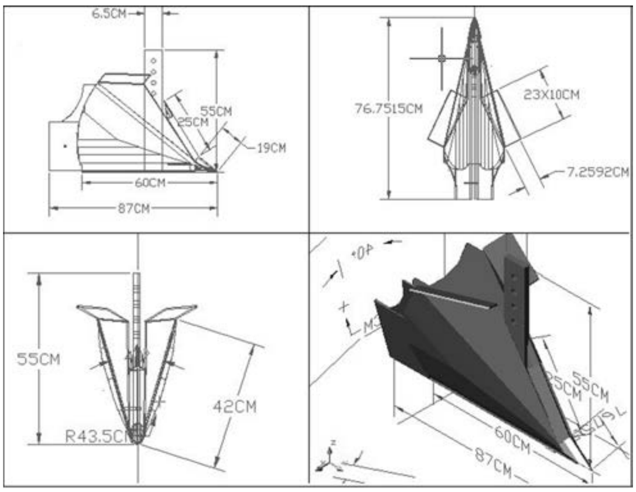
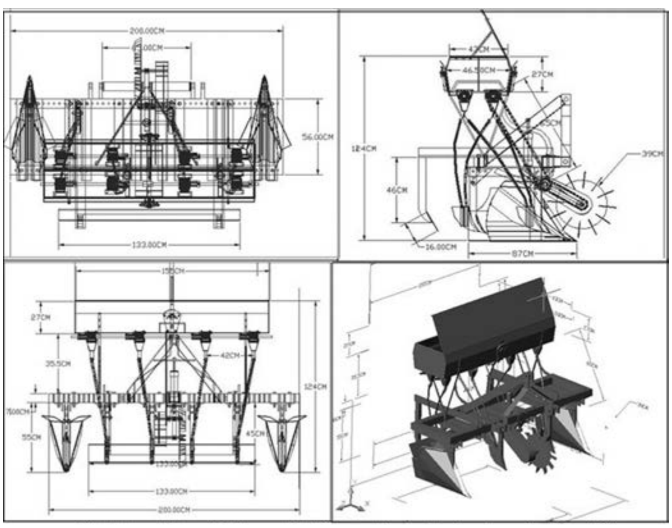


Fig. 2 Isometric and orthographic diagram of raised bed seed cum fertilizer drill



- T_1 = Tractor Drawn cultivator × 1 + Disc harrow × 1 + seed drill × 1.
- T_2 = Tractor drawn zero till seed cum-fertilizer drill.
- T_3 = Tractor drawn raised bed seed drill.

The performance was evaluated on the basis of field capacity, time required for tillage and sowing, cost of operations and yield. The soil physical parameters were also measured before and after the tillage operations. The JNKVV raised bed seed cum fertilizer drill was used for the sowing operation under the black cotton soil for the chickpea crop in a tilled field after harvesting of the paddy.

Results and Discussion

Table 2 shows the average performance results of all three systems for the last two years under vertisols. Maximum time was with T_1 at 11.65 h/ha and minimum was T_2 with 5.06 h/ha followed by T_3 with 10.37 h/ha. This meant that conventional practices required 43.43 % more time than T_2 and 10.09 % less than T_3, when the sowing was conducted just after the harvesting of the paddy crop. T_1 and T_3 took extra time for the first irrigation, the

Table 1 Specification of Tractor Drawn raised bed seed drill

Particulars	Size
Length, mm	2,000
Width, mm	560
Height, mm	1,024
Seed Metering Mechanism	Fluted roller type
Fertilizer Metering Mechanism	Gravity feed or corrugated roller type
Power transmission	Through chain & sprocket
Furrow openers	Duck foot shovel type
No. of Furrow openers	4
Size of feed shaft, mm	16-18
Size (diameter) and no. of flutes	42.07 (approx.) & 9
Diameter of fluted roller, mm	42.07 (approx.)
Size of fertilizer shaft, mm	20-22.5
Ground wheel diameter, mm	390-450

tillage operation and then sowing operations. The total days required for tillage and sowing operations by T_1 and T_3 treatments was between 12 to 15 days, while T_2 (tillage and sowing operations were conducted simultaneously) required 2 days just after the harvesting of the paddy.

The field capacity was measured for each treatment (**Table 2**) but it was not compared due to the different width of implements and the number of operations for each system. The cost of operation was minimum for T_2 with Rs. 411.84 /ha. For T_3 and T_1 it was Rs. 1,057.44 and Rs. 1,148.28 /ha, respectively, which included cost of seed and fertilizer also. The cost of operation was minimum with T_2 because this treatment (zero till drill) completed the tillage and sowing operations simultaneously at a shallow depth, and did not turn the soils and stubbles under the paddy harvested fields. Treatment T_1 required a higher number of operations as well as time. Treatment T_1 also required one to two more irrigations, which increased the production cost of chickpea.

The draft requirement was highest 3.45 kN for raised plant SCFD (T_3). Draft required for conventional seed cum fertilizer drill was lowest (2.45 kN). It may have been due to smooth movement of seed drill in firm soil. The energy requirement for different treatments was calculated in **Table 2**. Treatment T_1 required highest energy of 27.11 kWh/ha, whereas the zero till seed cum fertilizer drill required lowest energy of 6.84 kWh/ha. The main reason might have been due to the field preparation before sowing that represented 77.36 % of the energy. Only 22.63 % energy was contributed by the raised bed seed cum fertilizer drill. Over all, zero till seed cum fertilizer drill alone required highest energy for sowing operation alone. So, the developed machine required less energy with complete preparation of bed and furrow at the time of sowing itself. The cost of operation for the zero SCFD was highest compared to others due to its less annual use. The conventional seed drill required Rs.349.42 per ha with lowest cost of operation of sowing including the tractor. It might have been due to the lowest purchasing cost of the machine. The developed machine required only Rs. 9/ha extra from the conventional drill and it made the ridge and furrow that may need additional cost in the traditional method. The performance of the raised bed seed cum fertilizer drill was evaluated under direct sowing of chickpea crops. The machine performance was measured by the depth of sowing, width of tiling and sowing, time required for sowing for chickpea crop, field capacity, field efficiency, draft and fuel consumption. Whereas, for the changes in soil parameters, the moisture content, cone index and bulk density were measured before and after the operations. Then, lastly, the field and other agronomic parameters like germination percentage, plant height and viability percentage were measured for better comparison of combined machine performance as compared to conventional practice.

Table 3 shows that the viability percentage of the seed was 95.5

Table 2 Performance results of different machines

Particulars	Treatment 1			Treatment 2	Treatment 3		
	Cultivator × 1	Disc harrow × 2	Seed drill × 1	Zero Till seed cum fertilizer drill × 1	Cultivator × 1	Disc harrow × 2	Raised bed seed cum fertilizer drill × 1
Date of test							
Topography of soil	Plain	Plain	Plain	Plain	Plain	Plain	Plain
Type of soil	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
Plot size, hectare	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Av. Moisture content of soil, %	24.37	23.12	22.13	19.23			
Av. Depth of cut, cm	11.89	8.0	9.13	5.0	12.00	8.0	8.6
Av. Width of operation, cm	189	210	185	126.0			
Av. Speed of operation, km/h	6.0	6.20	5.68	4.00	6.0	6.20	5.20
Duration of test, h/ha		11.65		5.06		10.37	
Field capacity, ha/h	0.48	0.34	0.47	0.52	0.48	0.34	0.82
Theoretical field capacity, ha	0.594	0.510	0.66	0.72	0.594	0.514	0.95
Field efficiency, %	80.3	80.69	72	72.22	80.0	80.61	86.77
Draft, kN	6.42	5.39	2.45	3.2	6.42	5.39	3.45
Total energy, kWh/ha		26.32		6.84		27.11	
Fuel consumption, lit/ha		19.29		7.69		18.45	
Cost of operation, Rs./h	377.06 Rs.1,148.28		421.80	349.42	411.84	377.06 1,057.44	421.80
Total yield, q/ha		11.39		12.11		14.82	

SCFD = Seed cum fertilizer drill

percent, whereas germination percentage was highest for T_3 (87.5 %) followed by T_1 (82.05 %) and T_2 (77.50 %). The lowest germination percent was with zero till seed cum fertilizer drill due to spoilage of seed by high moisture percentage in the field. Plant population was highest (70 no/m^2) for conventional seed drill as the row spacing was closer as compared to the raised bed SCFD (T_3). As in T_2, (zero till SCFD) the germination was poor and plant population was also lowest (62 no/m^2). The plant growth was better in T_3 as compared to other treatments. Plant height, number of branches per plant, number of pods per plant as well as test weight of 100 seeds were highest for T_3 as compared to others. Due to better growth T_3 had highest yield (1,482.7 kg/ha). The yield was significantly higher 1,482.7 kg/ha (α = 5 %) for treatment T_3 (Cultivator × 1 + Disc harrow × 2 + Raised bed SCFD) whereas, it was lowest for treatment T_1 (Cultivator × 1 + Disc harrow × 2 + Conventional SCFD) with 1,139.20 kg/ha having a CD of 1,21.67. The yield for zero till seed cum fertilizer drill was 1,211.00 kg/ha, though it was at par with the conventional SCFD. The yield loss might have been due to higher population for conventional SCFD due to poor germination for zero till SCFD. **Fig. 3** shows the operating view and field crop conditions.

Fig. 3 Operational view of T. D. raised bed planter and crop view

Conclusion

These are the conclusion were drawn from the results.

1. Testing results shows that combine machine raised bed seed cum fertilizer drill gave better trouble free performance than the other conventional sowing operations.
2. The depth of penetration of bund former was reported as 22 cm, which was satisfactory enough for furrow irrigation as well as raised bed cultivation and shape of bed was trapezoidal.
3. Yield was significantly higher (1,482.7 kg/ha) for treatment T_3 and was lowest for treatment T_1 with 1,139.20 kg/ha with a CD of 121.67. The yield for zero till seed cum fertilizer drill T_2 was 1,211.00 kg/ha, though it was at par to the conventional method. The viability percentage of the seed was 95.5 percent, whereas germination percentage was highest for T_3 (87.5 %) followed by T_1 (82.05 %) and T_2 (77.5 %). Other benefits of treatment T_3 were easy weeding operation, more germination and better drainage.

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Table 3 Viability percentage, germination percent, biometrics of plants for different treatments

Treatment	Name of operations	Viability percent of seed, %	Germination percentage, %	Plant population no/m^2	Plant height, cm	No of branch per plant (avg. of 10 plants)	No of pod per plant	Weight of 100 grains	Yield, kg/ha
T_1	Cultivator × 1 + Disc harrow × 2 + Conventional SCFD	95.5	87.5	70	25.5	8.3	25	14.5	1,139.2
T_2	Zero till SCFD	95.5	77.5	62	27.5	10.5	34	16	1,211
T_3	Cultivator × 1+ Disc harrow × 2 + Raised bed SCFD	95.5	82.05	64	32	13.5	45	17	1,482.7

Decomposition of Raw Material Waste in Sugarcane Fields: Impact on Manorial Value of Soil Environment

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Abstract

Decomposition of sugarcane trash (dried leaves of cane) placed on the soil surface or buried inside the soil with or with amendment was studied under field conditions. Normally, this precious material is burnt in the field to facilitate subsequent cultural operations in a succeeding ratoon crop or planting/sowing of another crop. There is a need to change this evil practice. Researches have proven that chopped trash is decomposed quickly, if buried/mixed in soil simultaneously with the use of certain amendments/fungal culture. At a minimum level of assessment, it is capable of adding 14 kg N, 63 kg P_2O_5 and 32 kg K_2O per hectare. It ultimately leads to the formation of a highly colloidal, very slow degradable compound known as humus. Formation of this compound is capable of improving the physical and chemical properties of soil. The present study was conducted as a possible alternative method for the current practice of open air burning of post harvest sugarcane residue and thereby polluting the environment. A mechanical device to incorporate residue was developed, which chops trash into 1 to 2 cm long bits. Eight tons of trash per hectare were incorporated into the soil with two doses of N (75 kg and 150 kg), and aztobacter (10^4 No). Soil samples were drawn periodically at 0 (before giving treatment), 90, 180, 270 and 360 days of incubation. Trash with 8 t/ha with aztobactor and N 75 kg/ha gave significant improvement to the physical properties of the soil.

Introduction

Sugarcane trash (dried leaves of cane) left over in the field after harvest (**Fig. 1**), is a potential source of organic matter. At a minimum level of assessment, it is capable of adding 14 kg N, 63 kg P_2O_5 and 32 kg K_2O per hectare. It is usually burnt in situ so as to facilitate the subsequent cultural operations. Burning (**Fig. 2**) of trash not only robs the soil of the important nutrients which are essential for sustaining soil health, but also is an environment pollution hazard. It is reported that burning of post harvest sugarcane residue causes a loss of 80 to 95 percent of the dry matter and other nutrients. Under these circumstances there is an urgent need that the available nutrients in the trash should be recycled back in to the soil. Since 8-10 tonnes of trash/ha, are available and has very low bulk density, collecting trash from the harvested cane field and converting it in to compost is not an economically viable proposition. Further, the way trash is spread in the field after harvesting makes it rather impossible to handle manually. The only alternative left for the cane farmers is the availability of a simple equipment, which in a single pass could pickup the trash from an uneven spread trash , chop it into small bits and ultimately get it buried or mixed in the soil with microbial activity for quick decomposition.

Further, there should be a provision for the application of amendment to enhance decomposition rate. Trash in itself contains very little readily available nutrients, and is not easily decomposed by microorganism owing to high carbon nitrogen ratio and also being cellulosic in nature. In order to enhance the rate of decomposition of trash in the field itself and make it more useful to plants by achieving a narrower carbon and nitrogen ratio, nitrogen supplementation is also practiced. Trash can be most beneficially used either as a mulch or through in-situ incorporation in soil. It conserves soil moisture, modulates soil temperature and improves soil fertility and productivity. Organic matter loss is higher from buried trash than the trash applied on the surface. Trash placed inside the soil looses organic matter at higher rates than surface applied trash.

Materials and Method

In situ incorporation of sugarcane raw material waste (dry trash) in the field for the experiment was conducted at Indian Institute of Sugarcane Research main farm, Lucknow, Uttar Pradesh, India geographically. Lucknow is located between the parallels of 26º 5´ N latitude and 80º 6´ E longitude. The experimental site was about 123.50 m above mean sea level. Soil with chopped cane trash 8 t/ha alone, with Azotobacter and two nitrogen doses of 75 kg and 100 kg of urea was used. The chemical composition of trash is given in **Table 1**. Trash was incorporated with the help mechanical equipment, which was mounted with the tractor and was operated by PTO shaft. The system picks up trash, passes it on to the chopping unit where trash was chopped into small bits which ultimately was mixed up and buried under the soil with the help of a pair of discs provided at the rear end. Provision was also made for applying chemical/other substances for quick decomposition of trash.

To start with, burning of trash may be avoided in select areas where insects and pests are not a major problem and this precious material can be put to effective use either as a mulch to conserve soil moisture or as organic matter, thereby improving the soil health. **Fig. 3** shows the developed equipment.

Soil samples (**Table 2**) were drawn periodically at 0 (before giving treatment), 90, 180, 270 and 360 days of incubation and analysis. They were collected from 0-15 cm in all the field experiments. The samples were air dried and passed through a 2-mm sieve. Analysis work was carried out in the laboratories of Indian Institute of sugarcane Research Lucknow. Analytical methods of U.S. Salinity Laboratory Staff (1954) were followed or otherwise mentioned. All the calculations were made on oven dried soil weight basis. Soil pH was determined by pH meter having combination electrodes after calibrating with buffer solutions of pH 7.0 and 9.0 (Systronic). The electrical conductivity of soil was measured at 25 ºC in the soil and water saturated suspension

Table 1 Sugar-cane trash ash analysis

Ash mineral analysis	Dry Trash
P_2O_2, g/kg	0.42
K_2O, g/kg	1.24
CaO, g/kg	4.62
MgO, g/kg	2,014
Fe_2O_3, g/kg	1.15
Al_2O_3, g/kg	4.2
CuO, mg/kg	< 0.06
ZnO, mg/kg	12
MN_2O, mg/kg	168
NA_2O_3, mg/kg	97

Table 2 Physico-chemical, available macro and micronutrients and characteristics of the experimental soil

Characteristic	Value Surface Soil (0-15 cm)
pH	7.76
Electrical Conductivity (E.C.) $ds\text{-}m^{-1}$	0.25
Organic Carbon, %	0.52
Carbon and Nitrogen Ratio	34
Available N, kg/ha	275.97
Available P_2O_5, kg/ha	42.86
Available K_2O, kg/ha	229.68
Available Fe, mg/kg	38.40
Available Mn, mg/kg	8.80
Available Zn, mg/kg	0.84
Available Cu, mg/kg	1.90

Fig. 1 Dry trash on the field

Fig. 2 Trash burning in the field

Fig. 3 Sugarcane trash in corporation equipment in operation

ratio of 1 : 2.5 by glass electrode conductivity meter (Systronic) (Jackson, 1973). Organic carbon was determined by Walkley and Black (1956) rapid titration or wet oxidation method. The data collected on the soils was subjected to analysis of variance (ANOVA) as identified by Steel and Torrie, 1960.

Results and Discussion

It was observed from (**Fig. 4**) that there appeared to be a tendency for pH to decrease with trash application but the change was hardily measurable at the end of incubation. It was further decreased with the addition of N. The decrease in pH might have been due to release of weak organic acid formed upon trash decomposition. A similar decrease in pH upon addition of composed agricultural waste was observed (Yadav *et al.* 1999). Trash alone or with N increased electrical conductivity of the soil very slightly due to stabilization of salt present in the soil by organic acid formed during the trash decomposition. It was also observed that the organic carbon content in the soil increased

Fig. 4 Impact of sugar industrial raw material waste (Trash) on physical properties of the soil environment

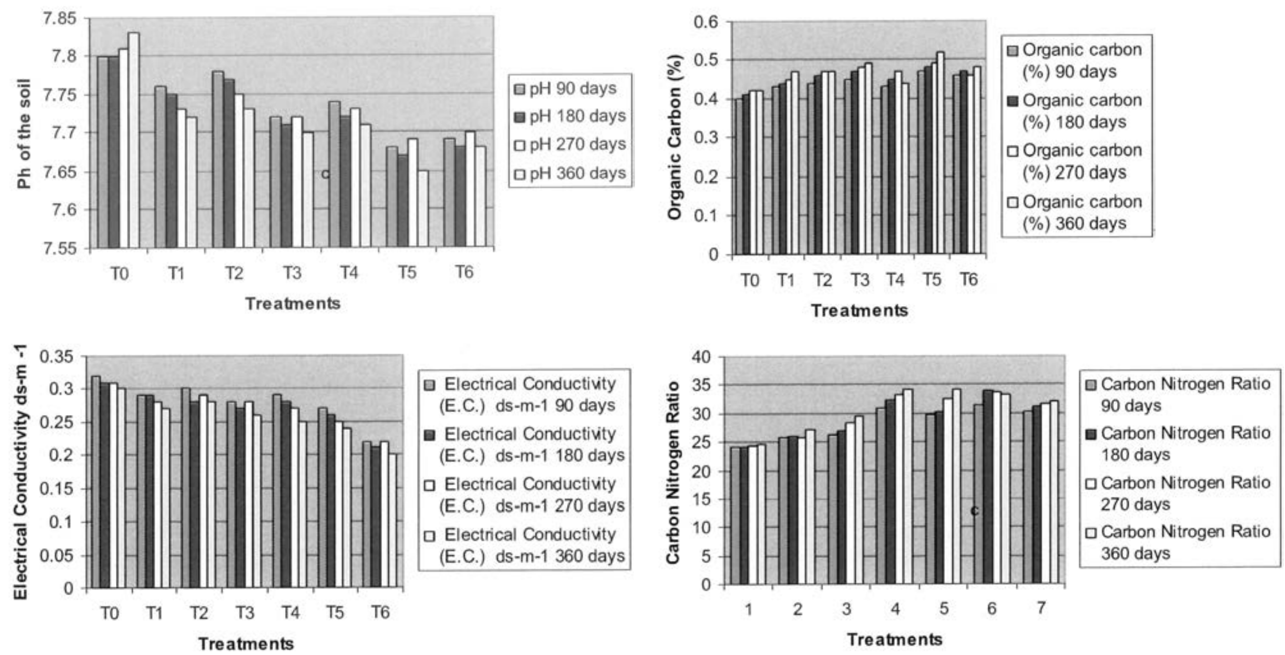
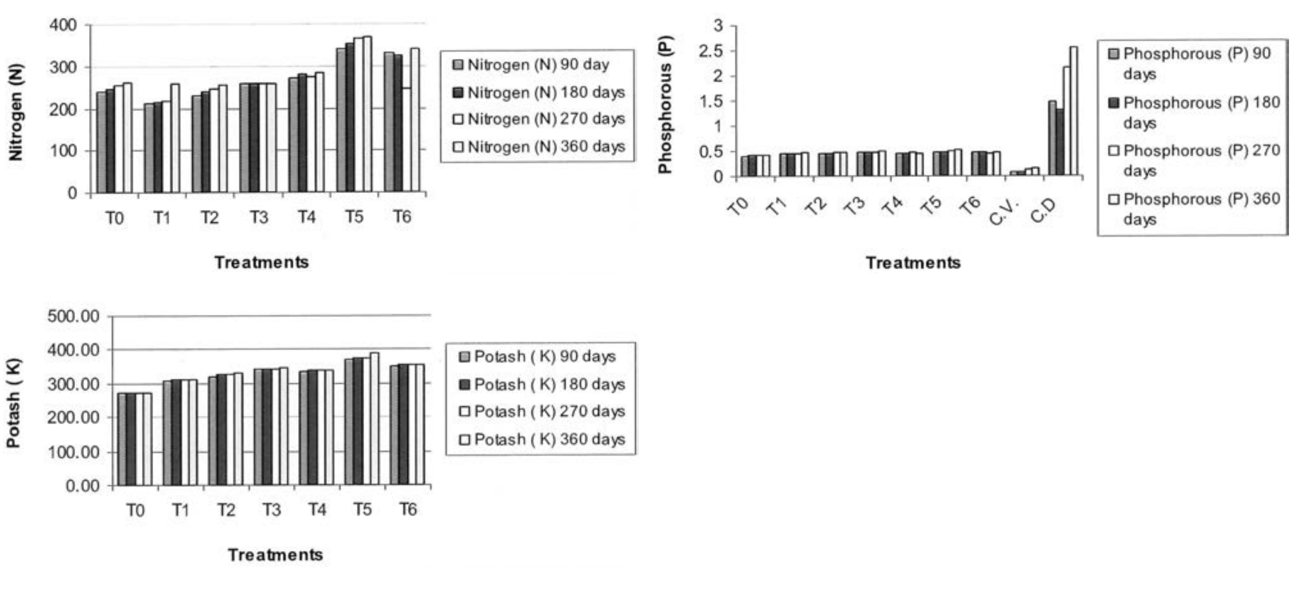


Fig. 5 Impact of sugar industrial row material waste (Trash) on Macro nutrient of the soil environment



significantly upon the decomposition of trash with time. Decomposition was more rapid with N. The maximum increase in organic carbon was reported with eight t/ha with aztobactor and N 75 kg/ha. The increase in organic carbon content in the soil might have been humidification. Similar observation was reported by (Singh and Yadav *et al.* 1999). Trash alone or with nitrogen increased the electrical conductivity or salt content of soils slightly due to the solubilization of salts present and the organic acids formed during decomposition of trash.

The means of days and treatments of incubation in the soil showed that available macro nutrients (**Fig. 5**) increased slightly with time; the control upon the decomposition of trash alone or with treatment. This might have been due to immobilization of soil N by the bacteria responsible for trash decomposition. The increase in available nitrogen in the soil was due to partial relies of nitrogen present in the trash. Similar observations have been made by the by (Singh and Yadav, 1986). The micronutrients increased significantly with time. The control upon the decomposition of trash alone or with treatment (**Fig. 6**) showed that addition of nitrogen helped in releasing micronutrients from the trash by hastening trash decomposition

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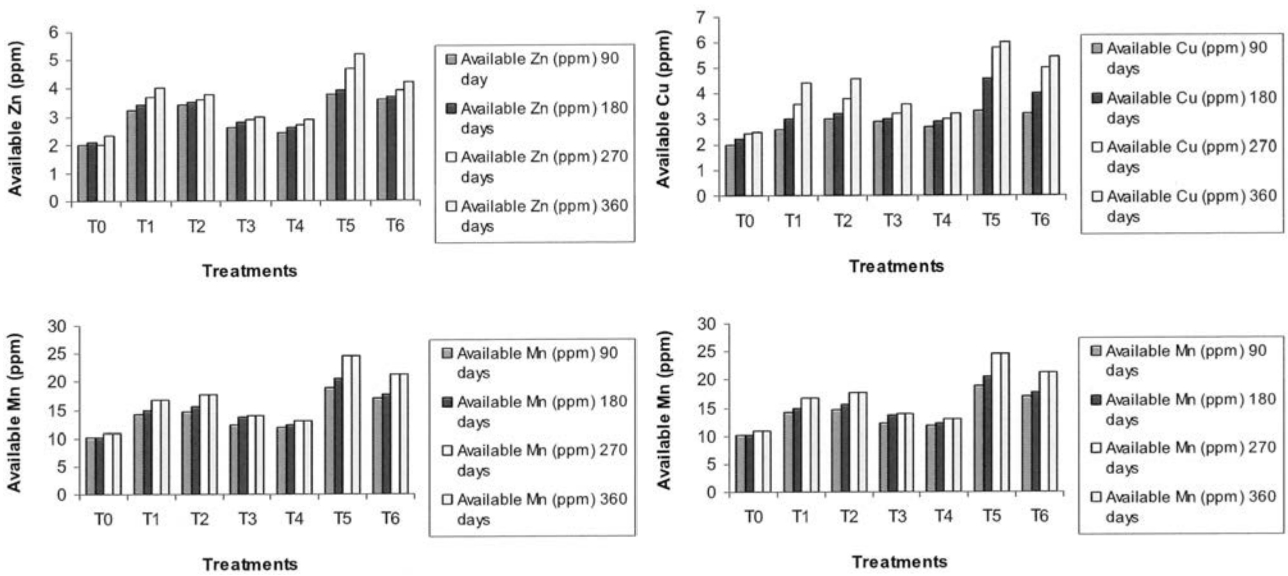
Fig. 6 Impact of sugar industrial row material waste (Trash) on Micro nutrient of the soil environment



The Extent and Nature of Tractorization in India: An Overview of the Past and Current Status and Future Trends

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Abstract

Mechanization is an unavoidable imperative to increase the productivity for the majority of farmers in India. The timeliness of operations has assumed greater significance in obtaining optimal yields from different crops, which has been possible by way of mechanization. The small size of holdings of the farmers is the main constraint of mechanization. The quantum of power available for the farming sector rose from 45.29 million kW in 1971-72 to over 170 million kW in 2000-01. Correspondingly, power intensity on the Indian farm increased from 0.2 kW/ha to 1.50 kW/ha on the basis of net-cropped area. The tractor density in India is about 11 tractors per thousand hectares as against 27 tractors per thousand hectares in USA. The world average including under-developed countries is 19 tractors per thousand hectares. The growth of the tractor manufacturing industry has been very rapid starting with 881 tractors in 1960-61 to above 310,000 tractors in the year 2005. The 31-40 HP tractor has the maximum share (51 percent) followed by 21-30 HP (18 percent) and above 40 HP (32 percent) in 2006. However, in recent years, the trend has shifted towards higher HP (above 40 HP) which growth has increased 24 percent in FY03 to 32 percent in FY06. There are currently 14 players in the tractor industry producing 60 models. However, about 90 percent of the market was covered by the top 5-6 players only. Mahindra & Mahindra is the leading player in the industry with 30 percent share while other players like TAFE + Eicher, PTL, Sonalika and Escorts enjoy a market share of 23, 11, 11 and 10 percent, respectively. Mahindra & Mahindra has a significant share in the southern and eastern markets. The 93 percent of sales of 264,790 tractors during 2005-06 were concentrated in 12 major states, namely, 16 percent in UP, 10 percent in Rajasthan, 9 percent each in Madhya Pradesh (MP) and Gujarat and Karnataka, 8 percent in Andhra Pradesh (AP), 7 percent each in Maharashtra and Tamil Nadu, 6 percent in Haryana, 5 percent in Punjab, 4 percent in Bihar and 3 percent in Orissa. The tractor penetration levels are not uniform throughout the country. The medium horse power category tractors, 31-40 HP, are the most popular in the country and the fastest growing segment. In the India subcontinent, tractor penetration is higher in Punjab and Haryana regions.

Introduction

The Indian geographical area is 329.3 m ha. India is number one in terms of irrigated land area (57 m ha), second in arable land (162 m ha) and seventh in total land area (297 m ha) (Anonymous, 2006b). The country food grain production has increased from 51 million tonnes (in 1951) to 230 million tonnes (2007-08) with surplus for export. Thus, the biggest challenge before the agriculture sector of India is to meet the growing demand for food to feed the increasing population. The ICAR, in its vision 2020 document, has projected the demand of food grains at about 293.6 million tonnes by 2020 (Anonymous, 2006d). Since the cultivated area cannot be increased, the increased production will be possible only by increased productivity and increased intensity of cropping. The cropping intensity is stagnating at 1.35, which could be increased with increase in irrigation and mechanization (Singh, 1998 and 2000). To increase food production, the productivity of the land and labour need to be increased substantially. This will require increasing the mechanization level (i.e. modern technologies) and better management of food production systems (Singh, 2000). The application of agricultural machinery has been increased from time to time by new or improved implements. Improved machinery has changed the face of farmers from Bakhars to rotavators, Persian wheel to drip and micro sprinkler system, cone dibblers to pneumatic planters, sickles to combine harvesters, sieve to color sorters, and kolhus to solvent extraction plants and hand mill to roller flour mills (Srivastava, 2005). The growth in adoption of agricultural machinery in the country has been possible due to increase the demand of new machinery by large farmers. Continuous effort is made by industry to produce or make available to farmers the new precise machinery (Anonymous, 2006a). The intensified mechanization in Indian agriculture for smaller holding famers can meet the production need of the explosive population. Therefore, in this paper, a study was made to overview of tractorization in India with respect to penetration, density, market shares of the current status and future trends.

Table 1 Fragmented holding pattern

Farmers holding	FY* 91 (percent)	Percent of land holding
Marginal (< 1 ha)	59.3	15.0
Small (1-2 ha)	18.7	17.4
Semi-medium (2-4 ha)	13.3	23.2
Medium (4-10 ha)	7.1	27.0
Large (> 10 ha)	1.6	17.3
All holding	100	100

*FY-Financial year

Distribution of Holding Size in the Farmers

It is important to understand the state of the agricultural sector. Though we have a large portion of our land irrigated, mechanization is virtually non-existence. This is because of the fragmented nature of land holdings in India. Land holdings of less than 1 to 4 ha is 56 percent of the total land holdings in India (**Table 1**). Large scale holdings of more than 10 ha accounted for just 10 percent of total land holdings (Singh, 1998 and 2000). Average productivity per hectare has remained stagnant and arable land has been on the decline due to increasing urbanization.

Land holding is one of the major reasons of low adoption of mechanical power and machinery by Indian farmers. However, some small farmers have also started owning tractors due to the opportunity of custom hiring. The small holding size of the farmers stands in the way of mechanization. The majority of small cultivators are poor farmers who are not in a position to purchase the costly machinery and tractors.

Constraint of Mechanization in Low Holding Size Farmer

Farm mechanization has been helpful to bring about a significant improvement in agricultural productivity. Thus, there is strong need for mechanization of agricultural operations for fragmented holdings. The timeliness of operations has assumed greater significant in obtaining optimal yields from different crops, which has been possible by way of mechanization. The small size of holdings of the farmers is the main constraint of mechanization. Lack of effective government policies and also non availability of cheap implements and tractors are also the main reason for low mechanization. Lack of proper knowledge of farmers to purchase farm machinery as well as to operate and maintain properly leads to wrong choices and makes it uneconomical. The economical condition of the majority of farmers is not good so that they are not in a position to purchase the costly tractors and implements. There is no such system to purchase farmers produces at a good price or policies to establish a processing plant region-wise so that farmers can get a better price. If they could, they would be more excited about purchasing the latest developed machinery. Research development and testing of farm machinery and equipment suitable to small farms (such as sugarcane planter and cotton picker) is necessary particularly for dry farming for operations such as paddy transplanting, sugarcane and fodder harvesting and spraying tall plants (fruit, forest, cotton and sugarcane).

Projection of Tractor Volume by National Commission on Agriculture (Nca) in 1971

The mechanization is an unavoidable imperative to increase the productivity for a majority of farmers in India who have small holdings (< 4 ha). The question is how small should farmers go for a small tractor. The tractors in India are out of reach for the majority of farmers. Barely two percent of the 115 million farmers own a tractor, according to the 1995-96 agricultural censuses. Two percent of farmers possessing tractors do not own one third of the arable land. First, most farmers possessing tractors are rich and have large land holdings. Second, tractors are available for hire. The hiring rates vary from region to region and also with the nature of work. But small farmers are unable to reap such benefits. For them, a low-priced, small tractor of 15-24 horsepower (HP) would be ideal. This need was recognized as early as 1970 when the National Commission on Agriculture (NCA) was set up. After a five-year study, NCA submitted a long report in 1976 that recommended the type and quantity of tractors India should have by 2000: 2.08 million tractors and power tillers (a farm machine, with two wheels, to till the soil) below 15 HP, 0.12 million medium tractors of 35 HP and 80,000 65 HP tractors, which taken together would total 2.28 million. This policy argued that 2.08 million tractors and power tillers below 15 HP were needed for small and medium farmers. Besides, they are considered more suitable for paddy cultivation in the country's dominant food grain crop than medium (25-40 HP) and heavy (above 40 HP) tractors. At the turn of the century, India had about 2.67 million tractors, which was more than NCA's projections. But category wise, the numbers went awry: about 1.47 million tractors were in the 31-40 HP range, 0.65 million were of 40 HP and above and 0.68 million were of 30 HP and less. Only a part of the 0.68 million tractors below 30 HP would constitute small tractors for which NCA had projected a figure of over 2 million. Such a large gap was shocking and reveals the perfunctory approach of the government to small farmers. The quantity of power tillers sold was merely 70,000. The agricultural engineering community, in general, and the Indian tractor industry, in particular, were responsible for throwing NCA's calculations off balance. Instead of a small tractor, they came up with medium to heavy tractors, which benefited only the large farmers. As a result, tractors are concentrated in a few states, which were the main beneficiaries of the Green Revolution such as Punjab, Haryana and parts of Uttar Pradesh. Big tractors, like big cars, have become status symbols. This is partly why the tiny state of Punjab has maximum tractors. Tractors also work best when the time for agricultural work is limited. About 65 percent of our cultivable area consists of dry farming or rainfed farming. If we are unable to do seedbed preparation and sowing in a timely manner, given the receding soil moisture, yields are less.

Power Utilization Pattern

In 1951, when the country was in its formative years after centuries of colonial rule, there were only 8,635 tractors in use and all of them were imported. Production of tractors commenced during 1961-62, turning out 880 of them (Mondal, 2008). This figure peaked to over 262,000 in 1999-2000. The sale of tractors in 2003-04 was 172,000 (Anonymous, 2006c). The quantum of power available for the farming sector rose

Fig. 1 Unit power consumption pattern over the year

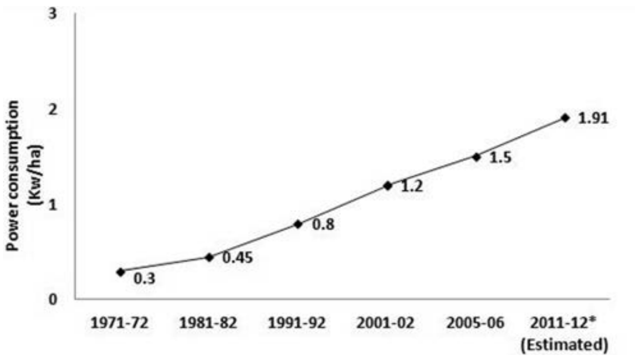


Fig. 2 Change in power utilization pattern over the year

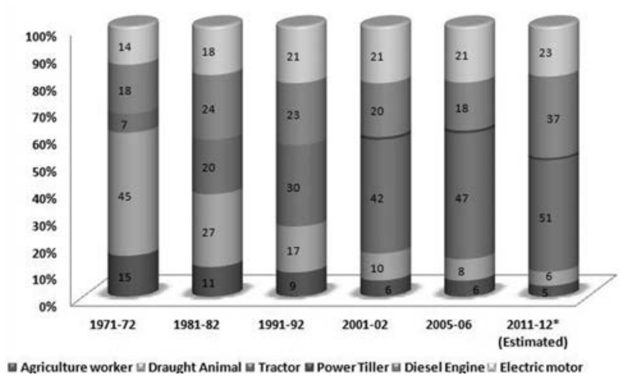


Table 2 Farm power availability and average productivity of food grain in India 2001

Name of state	Power avail-ability	Food Grain productivi-ty (kg/ha)
Punjab	3.50	4,032
Haryana	2.25	3,088
Uttar Pradesh	1.75	2,105
Andhra Pradesh	1.60	1,995
Uttaranchal	1.60	1,712
West Bengal	1.25	2,217
Tamil Nadu	0.90	2,262
Karnataka	0.80	1,406
Kerala	0.80	2,162
Assam	0.80	1443
Bihar	0.80	1,622
Gujarat	0.80	1,169
Madhya Pradesh	0.80	907
Himachal Pradesh	0.70	1,500
Maharashtra	0.70	757
Rajasthan	0.65	884
Jharkhand	0.60	1,095
Jammu & Kashmir	0.60	1,050
Orissa	0.60	799
Chhattisgarh	0.60	799
All India	1.35	1,723

(Source: Srivastava, 2005)

from 45.29 million kW in 1971-1972 to over 170 million kW in 2000-01. Correspondingly, power intensity on the Indian farm increased from 0.2 kW/ha to 1.50 kW/ha (Singh, 2006) on the basis of net-cropped area (**Fig. 1**). The state of Punjab has the highest average farm-power intensity of 3.5 kW/ha (Srivastava, 2005) and also has the highest productivity levels (**Table 2**). The farm power input per unit cultivated land in India (1.50 kW/ha) is still very low compared to South Korea of 7 kW/ha, Japan 14 kW/ha and USA 6 kW/ha (Singh, 1999). During the same period, contribution of animate power reduced from 60 percent of the total farm power to less than 17 percent and mechanical and electrical power sources increased from 40 percent to over 83 percent (**Fig. 2**). It is also seen that the adoption of mechanical and electrical power was higher for stationary applications than for traction required for field operations. Power for traction (tractors and power tillers) increased from 8.46 percent to 32.85 percent, indicating that more and more power-operated equipment was coming into use (Singh, 1999). Human power continues to be a significant component for digging, clod breaking, sowing, interculture, harvesting, threshing, cleaning, and grading for which traditional tools and implements have evolved over time in different parts of the country. The small and marginal farmers rely on draught animals for field operations, transport and agro-processing. The extent of area under the command of draught animals is about 57 percent. The need to achieve timeliness of field operations and effective utilization of inputs has resulted in the development of appropriate machinery, which also reduces drudgery.

Tractor Density

The most important long-term driver is the tractor density (number of tractors per thousand hectares) in the country. The tractor density in India is much lower than the rest of the world. The tractor density in India is about 11 tractors / thousand hectares as compared to 27 tractors / thousand hectares in USA and the world average, including under-developed countries, is 19 tractors / thousand hectares (**Table 3**). India's gross cropped area is next only to United States of America and Russia and, along with fragmented land holdings, has helped India to become the largest tractor market in the world. But it drops to eighth position in terms of total tractors in use in the country. When compared to international figures, it is only three percent of the total tractors

Table 3 Indian tractor density

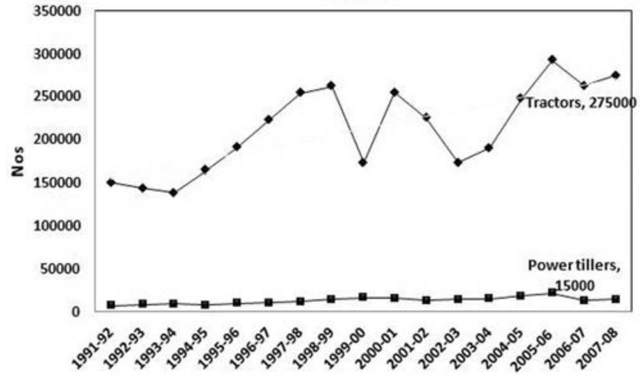
Description	Units	World total/ average	India	India rank
Arable Land	M ha	1,444	170	2
Irrigated Area	M ha	249.6	45.8	2
Tractors In Use	Tractors /000 hectares	27	10.5	8

Table 4 Year-wise production and sale of tractors and power tillers

Year	Production		Sale	
	Tractors	Power tillers	Tractors	Power tillers
1991-92	151,759	7,580	150,582	7,528
1992-93	147,016	3,648	144,330	8,642
1993-94	137,352	9,034	138,796	9,446
1994-95	164,029	8,334	164,841	8,376
1995-96	191,329	10,147	191,329	10,147
1996-97	222,769	11,000	222,769	11,000
1997-98	260,815	12,200	254,279	12,200
1998-99	261,609	14,480	262,351	14,880
1999-00	278,556	16,891	173,181	16,891
2000-01	255,690	16,081	254,825	16,018
2001-02	219,620	13,563	225,280	13,563
2002-03	166,889	14,613	173,098	14,613
2003-04	190,687	15,665	190,336	15,665
2004-05	249,077	18,985	247,693	18,985
2005-06	296,080	22,303	292,908	22,303
2006-07	264,146	13,375	263,146	13,375
2007-08	278,000	15,000	275,000	15,000

(Source: Tractor Manufacturers Association, 2003-07)

Fig. 3 Growth of tractors and power tillers over the years in domestic market



used all over the world. It is to be noted that, while the overall automobile industry is facing recession, the tractor industry is growing at 9 percent. About 20 percent of world tractor production is carried out in our country only. The arable land in India is high and is 12 percent of the total arable land in the world. The tractor market in India is about Rs 6,000 crore. On an average around 400,000 tractors are produced and their sale is 260,000. Uttar Pradesh state is the largest tractor market in our country. One out of every four tractors is being purchased here. Indian tractor market has to be viewed considering its position in the world with respect to key parameters as given below:

Indian Tractor Production and Market —Current Status

The production of irrigation pumps and diesel engines started during the 1930s. The manufacture of tractors and power tillers started in 1960. Tractors came to India through imports and later on were indigenously manufactured with the help of foreign collaborations. The manufacturing process started in 1961-62. Indian tractor industry is relatively young but now has become the largest market worldwide. The growth of the tractor manufacturing industry has been very rapid, starting with 881 tractors to above 310,000 tractors in the year 2005. The sale of tractors in 2003-2004 was 172,000 (**Table 4** and **Fig. 3**). India is largest manufacturer of tractors in world with an estimated 275,000 units being produced in the last financial year. India has emerged as the leading producers of wheel tractors accounting for about one third of the global production and more than 50 percent of tractors greater than 60 HP.

The 93 percent of sales of 264,790 tractors during 2005-06 were concentrated (Jain, 2006) in 12 major states, namely, 16 percent in Uttar Pradesh, 10 percent in Rajasthan, 9 percent each in Madhya Pradesh, Gujarat and Karnataka, 8 percent in Andhra Pradesh, 7 percent each in Maharashtra and Tamil Nadu, 6 percent in Haryana, 5 percent in Punjab, 4 percent Bihar and 3 percent in Orissa (**Table 5** and **Fig. 4**). Total population of tractors (based on sale data) should be 3.85 million at end of March 2008. The share of eastern states, namely Bihar, Orissa, West Bengal and Assam had been consistently low at 7-9 percent due to various socio-economic, agro-climatic and other reasons. The credit availability to the farmers in this area has been another major reason for the slow growth in the eastern states. Tractor sales in Maharashtra, Tamil Nadu, Karnataka and Andhra Pradesh have been showing consistent growth since mid 1980's. This region is expected to contribute more than 30 percent to the tractor industry in this decade. This expectation is based on the fact that the farmers in this southern region have been adopting high value case crops and latest crop production / management practices. After a drop in sales in 2006-07 sales have risen in 2007-08.

The tractor penetration level in India is very low as compared to the world standards. Also the penetration levels are also not uniform throughout the country. The medium horsepower category tractors, 31-40 HP, are the most popular in the country and the fastest growing segment (Jain, 2006). If we compare states within the India subcontinent, tractor penetration is higher in regions like Haryana and Punjab at 90 tractors per 1,000 ha. This indicates the huge potential for increase in sale of tractors in other states. In fact, most of the manufacturers consider that future growth would primarily be led by volumes from Eastern and Central Uttar Pradesh, Madhya Pradesh, Bihar, Maharashtra, Andhra Pradesh and other southern states. Keeping in mind the existing land holding pattern as per government statistics, land holdings

Table 5 State-wise sale of tractors in India 2005-06 (%)

Name of state	Sale of tractor
Uttar Pradesh	16
Rajasthan	10
Madhya Pradesh	9
Gujarat	9
Karnataka	9
Andhra Pradesh	8
Maharashtra	7
Tamil Nadu	7
Haryana	6
Punjab	5
Bihar	4
Orissa	3
Others	7
Exports	12

(Source: Tractor Manufacturers Association [TMA], 2003-06)

Fig. 4 Sale of tractors as per state wise (%)

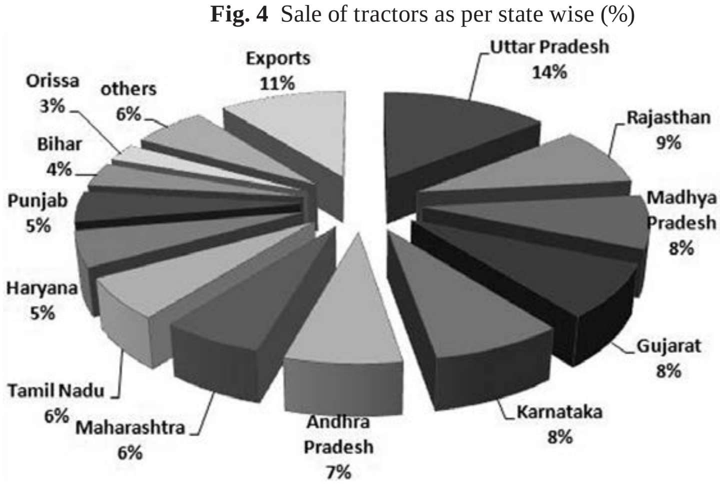


Fig. 5 HP Segment wise tractor share

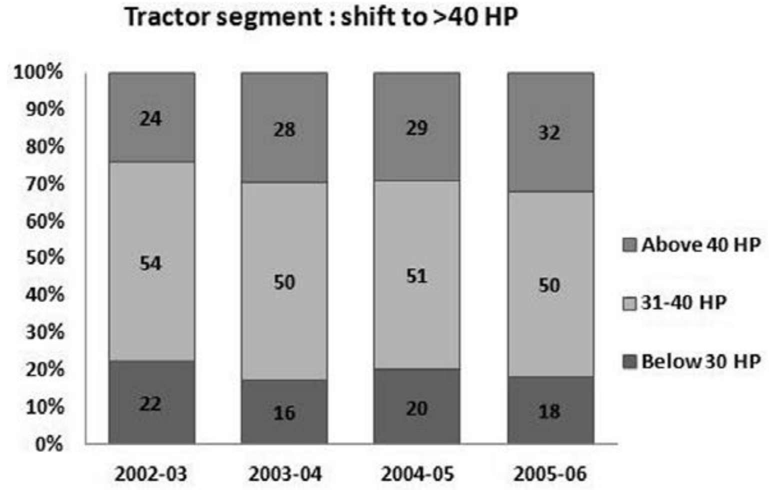


Fig. 6 Tractor HP segment as manufacture wise

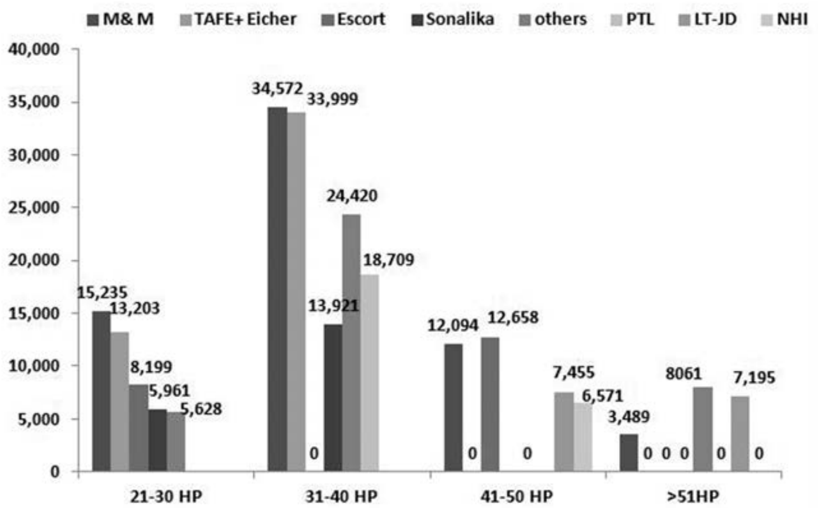
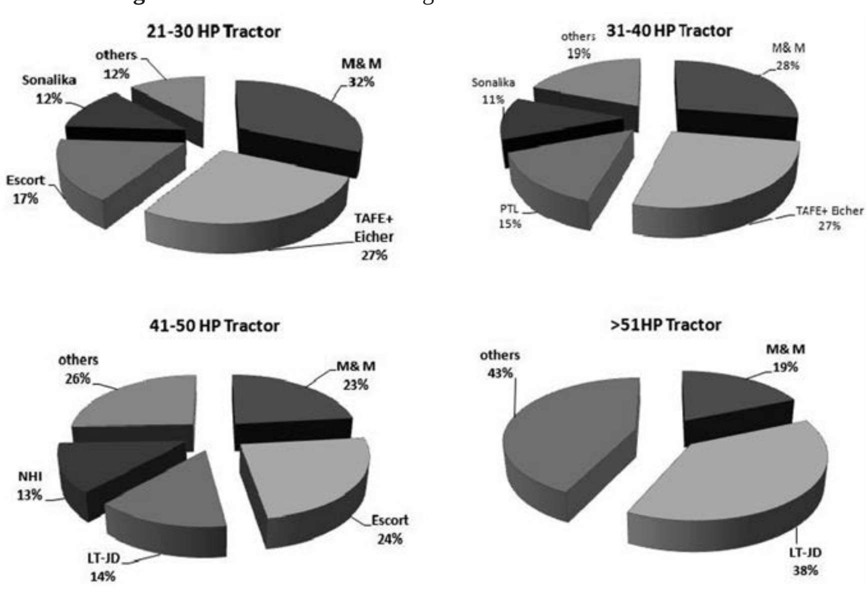


Fig. 7 Market share with HP segment of different manufacture



greater than 4 ha accounted for 44 percent of total land holdings in the country. Even if half of them go for mechanization, industry volumes could double in the long run.

The power tiller production was also started in 1960 and today production has reach up to 17,000 units (**Table 4**). However, the demand of the power tiller has not grown that fast. There are mainly 2 manufacturers of power tillers in the country producing about 6 models that range from 8-12 HP. In addition, , there are 4 other manufacturers who are importing and selling Chinese power tillers in the country. The major sales of power tillers are in the States of West Bengal, Tamil Nadu, Karnataka, Assam, Kerala, Orissa and Maharashtra (Anonymous. 2007).

This report gives an insight into the tractor industry in India, discussing its inception and growth. It analyzes the current scenario of tractors in India, industry size, domestic and exports trends and India's share in global market. Lastly, it discusses the players in the industry and profiles the top players.

Segment Wise Tractor Share in Indian Market

HP wise segment analysis revealed that the Indian tractor market share is divided in three categories as less than 30 HP, 31-40 HP and above 40 HP tractors. The 31-40 HP tractors had a maximum share of 51 percent followed by 21-30 HP (18 percent) and above 40 HP (32 percent) in 2006 (Jain, 2006). However, in recent years, the trend has moved towards higher HP (above 40 HP) where growth increased from 24 percent in FY03 to 32 percent in FY06 (**Fig. 5**). Above 40 HP tractors had highest market share and decreased from 54 percent in FY03 to 50 percent in FY06. Below 30HP and the segment between 31-40 HP may follow more or less similar patterns (i.e. 22 percent in FY03 to 18 percent in FY06). A typical Indian

Table 6 Major Tractor Players with their share

Tractors manufacturer	Sale nos. (2005-06)	Market share (percent)
Mahindra & Mahindra	85,028	29
TAFE (MF+EICHER)	66,667	23
International tractors Ltd (Sonalika)	32,017	11
Punjab tractors Ltd (PTL)	31,396	11
Escorts	28,297	10
John Deere	19,951	7
New Holland (CNH)	13,214	5
HMT	7,900	3
Force Motors	4,461	1.5
Mahindra Gujarat tractors Ltd	2,749	0.90
VST (Mitsubishi)	1,228	0.40
Total	292,908	100

(Source: Tractor Manufacturers Association, 2004-07)

tractor is about 30-35 HP whereas, the ones used in the USA for agricultural purposes are more than 150 HP. The Mahindra & Mahindra and TAFE have the widest portfolio with presence across all segments of tractors (**Figs. 6** and **7**). LT-JD and NHI have a significant share of the >40 HP tractors.

Make Wise Share in Domestic Market

There are currently 14 players in the industry producing 60 models. However, about 90 percent of the market is shared among the top 5-6 players only. Mahindra & Mahindra is the leading player in the industry with 30 percent share, while other players like TAFE+ Eicher, PTL, Sonalika and Escorts enjoys a market share of 23, 11, 11 and 10 percent, respectively (**Table 6**). The Mahindra & Mahindra has a significant share in the southern and eastern markets. The TAFE has increased its market share by 6 percent with acquisition of Eicher in May 05. L & T-John Deere is export focused accounting for 47 percent of total exports (65 percent).

Monsoon season is a key driver for sales of tractors. A series of good or bad monsoon can affect the sales. In recent years the industry has registered a good growth in sales, both domestic as well as exports. This is also partly because of the initiative of the government to boost the agriculture and agricultural machinery industry.

Export —Current and Future Status

The import was stopped in 1976 India. The export was started in 80's, mainly in African countries. During 1990's, export of tractors grew from a few hundred to about 3,000 annually. Indian tractors and agricultural machinery are gaining acceptance in international markets. Tractor exports from India grew continuously over the past five years by 31 percent CAGR. The exported tractors were 28,118 in 2005-06 (Jain, 2006). Tractor exports rose from US $78 million in FY01, to US $235 million in FY05. Sizeable quantities were exported to Africa, the Middle East, Asia, South America and other nations. Major markets are USA, SAARC countries, Turkey, Malaysia and parts of Eastern Europe. Exports were expected to reach a level of 60,000 tractors per annum by 2010-11.

Conclusions

The mechanization / tractorization are the only way to achieve the ICAR projected the demand of food grains to about 293.6 million tonnes by 2020 to feed our explosive populations. The increased production will be possible only by increased productivity and increased intensity of cropping. India is largest producer of tractors in the world since it was started from 880 tractors in 1960 to 310,000 tractors in 2005-06. The 31-40 HP tractors has maximum share 51 percent but, in recent years, the trend has been shifted towards higher HP (above 40 HP) which growth has increased 24 percent in FY03 to 32 percent in FY06. The tractor density in India is about 11 as compared to the world average, including under-developed countries, of 19 tractors per thousand hectares. The Mahindra & Mahindra has a significant share in the southern and eastern markets with a total of 30 percent while other players have less market share like TAFE + Eicher (23 percent), Escorts (10 percent) and PTL (11 percent) and Sonalika (11 percent). Tractor penetration in states within the India sub-continent is higher in regions like Haryana and Punjab at 90 tractors per 1000 ha. This indicates the huge potential for increase in sale of tractors in other states. In fact, most of the manufacturers consider that future growth would primarily be led by volumes from Eastern and Central UP, MP, Bihar, Maharashtra, AP and other southern states. Tractor exports from India grew continuously over the past five years by 31 percent CAGR. The significant quantities of tractors of different sizes are exported to Africa, the Middle East, Asia, South

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America and other nations. Major markets are USA, SAARC countries, Turkey, Malaysia and parts of Eastern Europe. The tractor penetration levels are also not uniform throughout the country.

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■■

NEWS

◇ Dr. Radhey Lal Kushwaha Achieves "Kishida International Award"

In recognition of his distinguished leadership in improving the living conditions in rural communities of developing countries, Dr. Radhey Lal Kushwaha was chosen as the recipient of the 2012 Kishida International Award. The Award Ceremony was held on 1st of August, 2012 at "Award Luncheon", during ASABE Annual International Meeting 2012.

Kishida International Award serves to "recognize outstanding contributions to engineering mechanization-technological related programs of education, research, developments, consultation or technology transfer outside United States." It was initiated in 1978, and the award is endowed by Shin-Norinsha Co., Ltd., publisher of "*Agricultural Mechanization in Asia, Africa, and Latin America*", and Kishida family, in honor of Yoshikuni Kishida, founder of the firm.

Dr. Kushwaha is Professor Emeritus at the University of Saskatchewan, as well as the fellow of ASABE (American Society of Agricultural and Biological Engineers) and CSBE(Canadian Society for Bioengineering). He contributed globally as a teacher, researcher, and technocrat in soil dynamics and small scale machinery. He has been a member of ASABE for 46 years, and provided leadership in forging the cooperative agreement between the Indian Society of Agricultural Engineers and ASABE.

Abstracted from the booklet "ASABE 2012 Annual International Meeting" Award Luncheon.

Design, Development and Performance Evaluation of a Foot Operated Maize Cob Sheller

by

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Abstract

The conventional methods of maize shelling are very laborious and time consuming. A low cost and highly efficient foot operated maize sheller was designed, developed and evaluated for its performance and techno-economic feasibility in comparison to three existing methods of shelling. Average output of 24.27 kg/h and shelling efficiency of 97.32 % were obtained. Maximum detachment of grains with minimum damage of 5.15 % were observed at a moisture content of 16-18 %. The designed maize sheller was techno-economically feasible with an operating cost of $1.24 / qtl. as compared to $1.68, 2.45 and 3.71 per quintal for the beating method, horizontal maize sheller and octagonal maize sheller, respectively. The net present value, benefit cost ratio, break-even point and pay back period were $ 60, 2.07, 8.75 q and 4 months, respectively, of the designed sheller.

Introduction

Maize (Zea mays) is one of the important cereals of the world and provides more human food than any other cereal that is high yielding, easy to process and readily digested with low production cost. It is the largest cereal crop of Jammu and Kashmir that is grown in the high rainfall area with good drainage. The total production of maize in J&K during 2006-07 was 4,869 thousand quintals in 0.33 m ha area, thus, giving an average yield of 15.05 qtl /ha (Anonymous, 2007). Maize improvement schemes have recently entered a new phase marked by the introduction of more sophisticated breeding techniques, cultivation practices, use of high yielding varieties and improvement and better utilization of the available seeding, harvesting and threshing / shelling equipment. Improved implements and machines with higher increased capacity would permit the farmer to perform the operations timely, thereby minimizing the loss of grain and maintaining the quality of produce (Dixit and Khan, 2007).

The maize crop is usually harvested at about 18-20 % kernel moisture content (wet basis) and then the crop is dried to a moisture content of 13-17 % (w.b.) followed by dehusking. Shelling of maize is one of the important post harvest operations and is very tedious and time consuming. It is based on the principle that when some impact or pounding is given on the cob, the grains are separated from cobs. The strength of the bond between the grain and the cob depends upon various crop factors; viz. type of crop, variety of crop, ripening phase of grain and moisture content of grain. Most of the farmers use the conventional method of maize shelling that is extraction of grain from the cob with the fingers or beating with a stick. This is slow and labour consuming. Ergonomically, these methods of maize shelling create drudgery to the users. The shelling of maize by rubbing or by pressing requires more energy and effort and output capacity is less. Although beating action leads to increased shelling capacity in comparison to rubbing or pressing the grain damage is much more significant, and leads to increased loss of grain during storage. In addition, small hand tools often made by local artisans are sometimes used to shell maize. The shelling capacity of these hand tools is very low while drudgery is very high (Solanki *et al*., 2006). Some motor driven (mechanical) shellers developed by many institutions across the country have been very effective due to increased capacity. These shellers have been unacceptable for the hilly region due to non availability of power, low land holdings, high initial cost and lack of technical know-how by the farmers. Grain cracking during shelling is also a potential hazard. It affects the subsequent separating and cleaning processes and is a major factor accounting for the overall quality of the harvest. The grain damage and cob break up decreased significantly with later harvest date (Akubo, 2002).

The constraints of existing maize shelling methods were low shelling capacity, increased body discomfort, higher grain damage, high initial cost and non availability of power. This identified the need for the design and development of a low cost maize sheller with increased capacity and less drudgery. Agriculturists also recognized the need for more expeditious and efficient methods such as using improved, small stationary power operated mechanisms. Considering the above facts, a low cost foot operated maize cob sheller was designed and developed to improve shelling capacity and reduce body discomfort and grain damage.

Materials and Methods

The study was carried out in the Division of Agricultural Engineering, SKUAST-K, Shalimar, Srinagar during 2009-10. The prototype was designed to minimize the efforts required and drudgery of operator for shelling maize cob. The detailed design of the prototype was as follows:

Design of the sheller: A sheller was designed to increase shelling capacity and minimize effort and drudgery.

By using the Cambel (1990) equation from Sharma and Jain (2008)

H.P. = 0.35-0.092 log t

where t is time in minutes

For 4 hour continuous work, H.P. developed by man is

$H.P. = 0.35-0.092 \log (4 \times 60) = 0.13$

Also, $H.P. = Push\ (kg) \times speed\ (m/sec) / 75$

Speed of the larger pulley = 40 rpm

$\therefore$ *Linear speed of pulley* $= (\pi D N_b / 60) = [(\pi \times 0.15 \times 40) / 60] = 0.314$ *m/sec*

Push = 31.05 kg

Also, $H.P. = 2\pi NT / 4500$

$\therefore 0.13 = 2\pi \times 40 \times T / 4500$

$T_b = 2.32$ *kg-m* $= 232$ *kg-cm*

Where,

N_b = r.p.m. of larger pulley

D = diameter of larger pulley (15 cm)

T_b = torque on larger pulley

Design of Shaft on which the Larger Pulley was Mounted

Torque on shaft $T_b = (T_1 - T_2) \times r_1$

Torque on larger pulley = 232 kg-cm

T_1 =Tension in tight side of belt (kg)

T_2 = Tension in slack side of belt (kg)

r_1 =Radius of larger pulley (r_1 = 7.5 cm)

Therefore,

$(T_1 - T_2) = T_b / r_1$

$T_1 - T_2 = 30.93$ *kg* .... (1)

Also

$T_1 / T_2 \times e^{\mu e \theta}$ .... (2)

$\mu_e = 2\mu / \sin \beta$

Where,

μ = Coefficient of friction (0.3 for rubber belts)

θ =Angle of contact in radians

β = Groove angle of pulley, 38º.

Therefore,

$\mu_e = (2 \times 0.3) / \sin 38^o = 0.974$

$\theta = \pi - 2 \sin^{-1} [(D_1 - D_2) / 2C]$

Where,

D_1 = Diameter of larger pulley (15 cm) and D_2 = Diameter of smaller pulley (7.11 cm)

C = Centre to centre distance between two pulleys (50.8 cm)

$\theta = \pi - 2 \sin^{-1} [(15 - 7.11) / (2 \times 50.8)]$

θ = 8.68º = 2.99 radian

Putting the values in **Eqn. 2**.

$T_1 / T_2 = e^{0.974 \times 2.99}$

$T1 / T_2 = 18.40$ *or* $T_1 = 18.40T_2$

Putting this value in **Eqn. 1** we have

T_2 = 1.77 kg

T_1 = 32.70 kg

Therefore,

$T_1 + T_2 = 34.47$ *kg*

Maximum banding moment on the shaft on which larger pulley is mounted is

$M_b = (T_1 + T_2) \times$ overhang distance

$M_b = 34.47 \times 6 = 203.86$ *kg-cm*

Also, torque on larger pulley = 232 kg-cm

Therefore, equivalent torque (T_e) is given by

$T_e = \sqrt{T_b^2 + M_b^2}$

$T_e = \sqrt{(232)^2 + (206.86)^2} = 310.8$ *kg-cm*

Take factor of safety = 3

$T_e = 310.8 \times 3 = 932.4$ *kg-cm*

Also,

$T_e = (\pi / 16) \times F_s \times d_g^2$

where,

F_s = allowable stress (F_s = 550 kg/cm^2)

d_g = diameter of shaft on which larger pulley is mounted

$932.4 = (\pi / 16) \times 550 \times d_g^3$

$d_g = 2.05$ *cm* $= 20$ *mm*

Therefore, diameter of shaft on which larger pulley is mounted is 20 mm.

We know,

$N_{big} \times D_{big} = N_{small} \times D_{small}$

$40 \times 6 \times 2.54 = N_{small} \times 2.8 \times 2.54$

$N_{small} = 85.7$ *r.p.m.*

$T_{big} \times N_{big} = T_{small} \times N_{small}$

$232 \times 40 = T_{small} \times 85.7$

$T_{small} = 108.2$ *kg-cm*

Thus, the torque in smaller pulley = *108.2 kg-cm*

$T_{small} = (T_3 - T_4) \times r$

$108.2 = (T_3 - T_4) \times (2.8 \times 2.54)$

$(T_3 - T_4) = 15.21$ *kg*

where,

T_{small} = torque on smaller pulley

T_3 = tension in tight side of belt (kg)

T_4 = tension in slack side of belt (kg)

Also, $T_3 / T_4 e^{\mu e\theta}$

Since the gears are mounted on the same shaft that is fitted to the smaller pulley, the gears rotate with the same speed as that of shaft.

r.p.m. of shaft fitted to smaller pulley = 85.7

∴ r.p.m. of gears mounted on same shaft = 85.7

$N_1 t_2 = N_2 t_1$

$\therefore N_1 / N_2 = t_2 / t_1$

or

$N_2 / N_1 = t_1 / T_2 = 1.6$

$N_2 = 1.6 \times N_1 = 1.6 \times 85.7 = 137.12$ r.p.m.

where,

t_1 = number of teeth of upper gear

t_2 = number of teeth of lower gear

N_1 = speed of lower gear in r.p.m.

N_2 = speed of upper gear in r.p.m.

Since r.p.m. of lower gear and pulley (smaller) is the same, the

torque on lower gear = 108.28 kg-cm

$\therefore N_2 / N_1 = t_1 / t_2$

$N_2 / N_1 = 1.6$ − *equation* ....(3)

Also,

$N_2 / N_1 = T_1 / T_2$ *equation* ....(4)

==>

$T_1 / T_2 = 1.6$ − *from equation*........ ....(3 & 4)

Now we know that torque on the lower gear (T_1) = 108.2 kg-cm

$\therefore T_2 = 108.2 / 1.6$

$T_2 = 67.675$ kg-cm

Since the upper gear is keyed to the sheller the sheller moves with the same speed as that of upper gear; i.e. (137.12 r.p.m.).

We know that

Torque = Force × perpendicular distance

∴ *Force* = 67.675 / 1.5

Force on the shaft on which the sheller is mounted = 45.15 kg

∴ *Torque on the sheller* = $f \times r_{sheller} = 45.15 \times 4 = 180$ kg-cm.

Based on the above design parameters, a prototype foot operated maize cob sheller was fabricated in the workshop (**Fig. 1**). The sheller consisted of frame, transmission system, shelling unit and cob container. The detailed technical specifications are given in **Table 1**.

Frame

The structure of the frame consisted of four 900 mm long vertical angle iron bars (40 × 40 × 5 mm) to maintain strength and to resist vibration and overturning. The overall dimensions of the frame were 850 × 450 × 900 mm to make it of cuboid shape. The dimensions of the frame were selected keeping in view the anthropometric measurements of the users.

Transmission system

The most common mode of using manual power is the upper limbs but pedalling with the legs requires less energy. Studies also indicated that at sub-maximal workload, arm exercise was performed at a greater physiological cost than leg exercise.

With the above analysis, a transmission system of the prototype was designed that consisted of a foot pedal, connecting rod, belt and pulley and a set of bevel gears (Sharma and Jain, 2008). The pedal was framed with circular iron bars welded in a rectangular shape (508 × 406.4 mm) with little curvature.

The system was designed to obtain the desired torque and speed at the shelling unit. Four set of bevel gears were mounted on a shaft and attached with each sheller. The shaft was supported on two ball bearings to minimize the friction. A small pulley of 71 mm was mounted on this shaft driven from another pulley of 150 mm by a V-belt. A connecting rod of 10 mm diameter with length of 406 mm was provided with one end attached to the pedal and the other end to the crankshaft on which the larger pulley was mounted. At the end of the crankshaft, a flywheel of mild steel was provided co-axially with the larger pulley to maintain the torque. The connecting rod converted the

Fig. 1 Front view of foot operated maize cob sheller

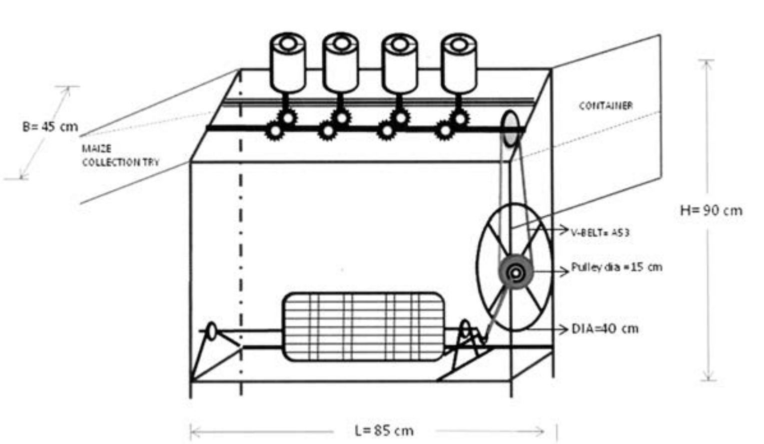


Fig. 2 Isometric view of maize sheller used in shelling unit of designed prototype

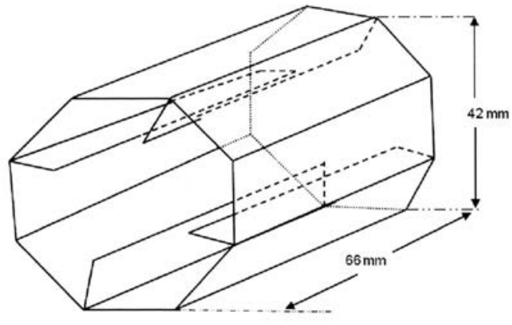


Table 1 Technical Specifications of foot operated maize cob sheller

Particulars	Specifications
Overall dimensions (L × B × H), mm	850 × 450 × 900
Weight of machine, kg	50
Power source	Manual
Type of machine	Foot operated
Drive Mechanism	Belt & Pulley and Gears drive
Shelling unit	Octagonal tubular maize cob sheller
Shelling capacity, qtl/h	24.27
Shelling efficiency, %	97.32
Grain damage, %	5.21
Labour requirement, man-h/qtl	4.12
Energy requirement, MJ/qtl	8.09
Cost of shelling, $/ q	1.24
Break Even point, qtl	8.75
Cost-Benefit Ratio	2.07
Pay back period, months	4
Approx. cost of the machine, $	60

reciprocating motion of the pedal to rotary motion of the crank shaft.

Cob Container

A cob container (46 × 41 × 15 mm), made of mild steel sheet, was provided on one side of the machine to hold the maize cobs for easy removal by the users.

Shelling Unit

The most important component of the prototype, the shelling unit, consisted of octagonal mild steel shellers having tapered fins on the inner side (**Fig. 2**). The shellers were supported on a rectangular G.I. pipe with a square cross section (31.75 × 31.75 mm). The supporting rectangular G.I. pipe was connected with the frame assembly. The rotary power was transmitted to each of the shellers through a set of bevel gears at the bottom. The cobs were hand held by the operator and feed to the sheller. The to and fro motion of the shellers helped in detaching the grains from the cob. The detached grains from all the shellers discharged to the collecting bin through a common outlet provided at the end of the discharge unit of trapezoidal shape.

Performance Evaluation of Maize Cob Sheller

The foot operated maize cob sheller (**Fig. 3**) was evaluated at three different moisture levels of cobs (20-22, 18-20 and 16-18 %) and compared with three others maize shelling methods; viz. horizontal maize cob sheller, CIAE make octagonal maize cob sheller and beating (traditional) method of shelling (**Figs. 4-6**). Two persons were required for pedalling and inserting the cobs in four octagonal maize shelling units. Due to forward and backward twist, the grains from the cobs were detached. The tapered fins of the shellers provided a frictional force over the grain layers. Maize grains obtained after shelling were collected in a bin through an outlet.

The dependent variables; viz. shelling capacity, shelling efficiency, grain damage, labour requirement, cost of shelling and energy requirement were determined. The shelling capacity was observed by the quantity of shelled grain per unit time. The shelling efficiency was determined by the percent shelled grain with respect to total grain input. The grain damage was calculated by the ratio of the percent of broken or cracked grain to the total shelled grain. The cost of shelling for one quintal of maize was calculated from labour requirement by assuming the wages at $ 0.3/hr. For the developed foot operated maize cob sheller, other fixed and variable costs were also taken into account. The specific energy (MJ/kg) required for shelling was calculated by using the constant energy expen-

Fig. 3 Foot operated maize cob sheller in operation

Fig. 4 Horizontal maize cob sheller in operation

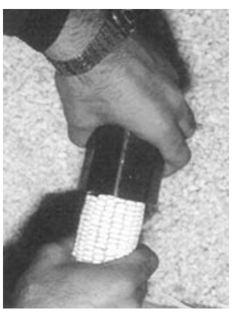


Fig. 5 CIAE make octagonal maize sheller

Fig. 6 Beating (traditional) method of maize shelling

Table 2 Comparative evaluation of shelling methods at different grain moisture content

Shelling Methods		Moisture content, %	Shelling capacity, kg/hr	Shelling efficiency, %	Grain damage, %	Labour requirement, man -hrs/qtl	Cost of shelling*, $/qtl	Energy requirement, MJ/qtl.
Foot operated maize cob sheller		20-22	23.2	96.33	5.31	4.31	1.29	8.50
		18-20	23.98	97.16	5.16	4.16	1.25	8.20
		16-18	25.64	98.47	5.15	3.89	1.17	7.70
	Mean		24.27	97.32	5.21	4.12	1.24	8.13
Horizontal maize cob sheller		20-22	10.15	80.64	6.05	9.85	2.96	19.30
		18-20	13.27	82.24	4.64	7.61	2.28	14.90
		16-18	14.13	87.11	4.13	7.08	2.12	13.90
	Mean		12.52	83.33	4.94	8.18	2.45	16.03
Octagonal tubular maize cob sheller		20-22	7.28	79.18	5.75	13.70	4.12	26.90
		18-20	7.96	80.16	4.87	12.61	3.78	24.70
		16-18	9.32	81.19	5.05	10.79	3.24	21.10
	Mean		8.19	80.18	5.22	12.37	3.72	24.23
Beating method of shelling		20-22	17.63	34.91	8.92	6.29	1.89	11.10
		18-20	18.49	35.97	7.42	5.40	1.62	10.60
		16-18	18.8	39.27	7.24	5.36	1.60	10.50
	Mean		18.31	36.72	7.86	5.68	1.70	10.73
	$C.D_{(0.05)}$		1.456	2.67	2.81	1.10	0.33	2.00
	$S.E._m$		0.70	1.29	1.35	0.53	0.16	0.90

*1.0 $= Rs. 50

diture value of 1.96 MJ for an adult man working for 1 hour.

In order to determine the techno-economic feasibility of the prototype, Cost-Benefit ratio (CBR), Break-Even Point (BEP), and Pay Back Period (PBP) were calculated. The CBR was calculated from annual cost (fixed cost + variable cost) for shelling and annual benefit (shelling capacity × working hours × 0.03) assuming a shelling charges of $ 0.03/kg. The BEP was calculated by the following formula.

BEP (kg) = (FC) / [SF-VC/(H × SC)]

F.C = Total fixed cost

V.C = Total variable cost

S.C = Shelling capacity kg/hr

S.F = Shelling charges, $/kg

H =Annual working hours

The PBP is an indicative factor of how many working hours the purchaser / owner of the machine will require to regain his initial investment.

PBP = I.C. × H / ANI, where I.C. = Initial cost ($),

ANI = Annual Net Income ($),

H = working hours.

The data were statically analysed using randomized block design and Mini-tab Software.

Results and Discussion

Shelling Capacity

The highest shelling capacity (25.64 kg/hr) was recorded in the foot operated maize cob sheller at a moisture content of 16-18 % while the lowest capacity (7.28 kg/hr) was at an octagonal tubular maize sheller at 20-22 % moisture content. Data presented in **Table 2** clearly indicated that that the shelling capacity was significantly differed

Fig. 7 Influence of moisture content and shelling methods on shelling capacity

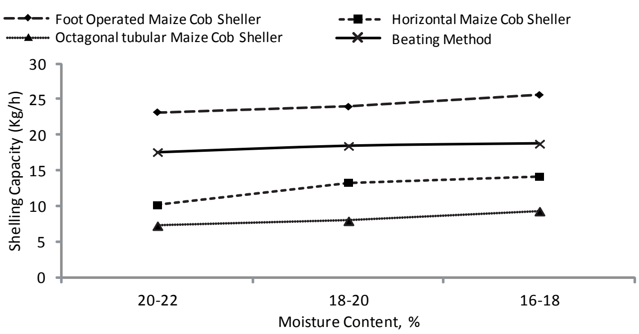
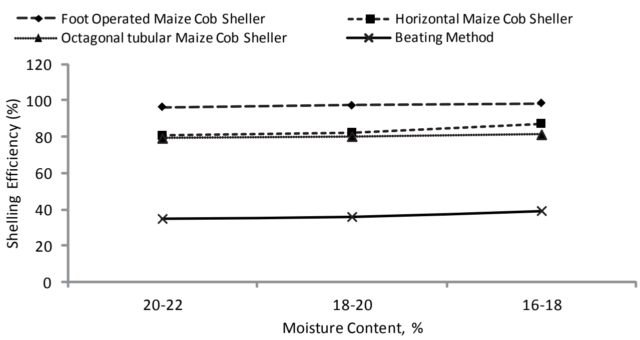


Fig. 8 Influence of moisture content and shelling methods on shelling efficiency



among all the shelling methods. **Fig. 7** shows that the shelling capacity increased with the decrease in moisture content in all the shelling methods. These results were supported by Nalbant (1990) and Testra (2009). The higher shelling capacity for the foot operated maize cob sheller was due to continuous operation of four shellers and less effort required for machine operation.

Shelling Efficiency

The maximum shelling efficiency of 98.47, 87.11, 81.19 and 39.27 % was at 16-18 % moisture content in the foot operated, horizontal maize sheller, octagonal and beating methods, respectively. The lowest shelling efficiency in the beating method could be attributed to unequal / non-uniform distribution of forces. As shown in **Fig. 8**, the lower shelling efficiency at higher moisture content (20-22 %) in all shelling methods might have been due to a strong bond between grains and cobs.

Grain Damage

Grain damage was significantly influenced by the moisture content and methods of shelling. The minimum grain damage (4.13 %) was in the horizontal maize sheller at 16-18 % moisture content, while the maximum damage (8.92 %) was in beating method at 20-22 %.

However, grain damage occurring in the foot operated sheller (5.15 %) was statistically at par with horizontal cob sheller at 16-18 %. The highest grain damage observed in the beating method was due to greater impact force on the maize cobs to detach grains.

The increased grain damage at higher moisture content was due to more plastic and less compressive strength of maize grain. Moreover, there seemed to be a direct relationship between grain damage and moisture content; i.e. the higher the moisture content the higher the grain damage (**Fig. 9**). The results confirmed the findings of Nital *et al.* (1992), Nalbant (1990), Singh (1977) and Johnson *et al.* (1963).

Energy Requirement and cost of shelling

The data presented in **Table 2** revealed that the foot operated maize cob sheller required less energy as compared to other shelling methods. The lowest energy requirement of 7.70 MJ/qtl was in the foot operated sheller at 16-18 % moisture content, while the highest energy requirement of 26.90 MJ/qtl was in the octagonal maize sheller at grain moisture content 20-22 % (**Fig. 10**). This significant variation in energy requirement was due to easy operation and less effort required in the designed prototype with high shelling capacity.

The cost of shelling per quintal was also lowest in the foot operated sheller ($1.17) followed by the beating method ($1.60), horizontal maize sheller ($2.12) and octagonal maize sheller ($3.23) at 16-18 % grain moisture content (**Fig. 11**). This showed that the cost of shelling had negative correlation with grain moisture content.

Economic Analysis

Economic evaluation was based on undiscounted measures such as cost per qtl of shelled maize and a break even point and discounted measures such as pay back period, benefit?cost ratio and internal rate of return. The cost of shelling could be reduced up to 8.8, 98.3 and 200 % when compared with beating, horizontal maize sheller and octagonal sheller, respectively. The foot operated maize sheller's net present value, benefit cost ratio and break-

Fig. 10 Influence of moisture content and shelling methods on energy requirement

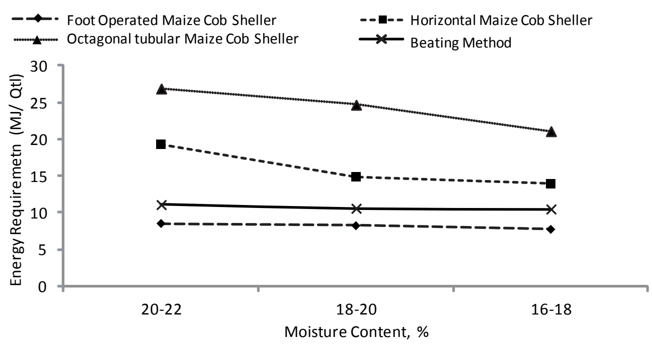


Fig. 9 Influence of moisture content and shelling methods on grain damage

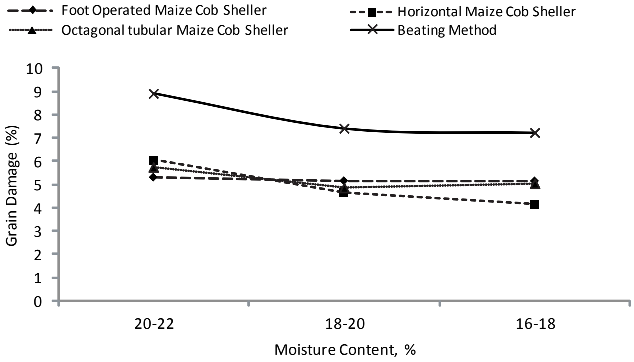
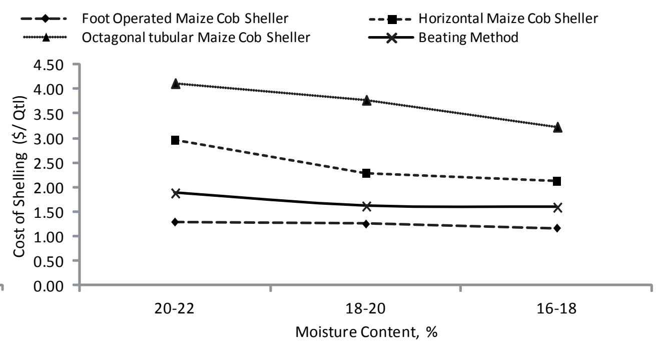


Fig. 11 Influence of moisture content and shelling methods on cost of shelling



even point were $ 60, 2.07 and 8.75 q, respectively. Considering the above parameters and a productivity unit of 40-60 q/ha, the designed prototype was suitable for the peasants having a minimum land holding of 0.15 hectare, which was quite possible in hilly regions. The pay back period of the designed foot-operated maize-cob sheller was only 4 months, pointing that foot-operated maize-cob sheller can be used successfully for commercial purpose. Another added value of the new prototype was its simple construction, ergonomically designed and low investment cost. With its simple construction and low value, the prototype could be easily fabricated at small workshops at the village level and have good prospects for application in the state.

Conclusion

- The designed prototype had higher capacity (24.27 qtl/hr) with higher shelling efficiency (97.32 %) and lower grain damage (5.31 %) than the existing methods of shelling.
- The maximum shelling efficiency of 98.47, 87.11, 81.19 and 39.27 % was recorded at lower grain moisture content of 16-18 % in the foot operated, horizontal maize sheller, octagonal and beating methods, respectively.
- The cost of shelling ($1.17/qtl) was lowest in foot operated sheller and could be reduced by about 8.8, 98.3 and 200 % when compared with beating, horizontal maize sheller and octagonal sheller, respectively.
- The foot operated maize sheller's net present value, benefit cost ratio, break-even point and pay back period were $60, 2.07, 8.75 q and 4 months, respectively.
- The designed prototype was simple in construction, energy efficient, economically viable and easy in operation with good prospects for application at the farm level in Jammu & Kashmir state.

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Effect of Speed on Wear Characteristics of Surface Treated Cultivator Shovels in Sandy Loam Soil

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Abstract

In agricultural machines, wear is the most rapid and common form of damage. This is responsible for most of the idle time and maintenance, apart from heavy expenditure on repair and spare parts. Wear studies were conducted on cultivator shovels coated with EWAC 1002 ET surface hardening powder (Tungsten carbide base). The tests were conducted under controlled soil bin conditions in sandy loam soil at 9-12% moisture content for 100 hours at three different speeds of 0.7, 1.0 and 1.3 m/s. Gravimetric wear in each shovel was recorded at an interval of 20 h. Wear rate increased by 29.41 % with increase in speed from 0.7 to 1.3 m/s.

Key words: Cultivator, gravimetric wear, shovel, sandy loam, speed and wear rate.

Introduction

Nowadays agriculture is considered as an industry. Technology has contributed in a big way to farm mechanization. Many improved tools, equipment and farm implements are in use in agriculture.

All the digging parts of tillers, seeding and excavating machines are exposed to abrasive wear. Abrasive wear occurs when the hard particles such as sand, stone pieces or hard materials slide or roll over a surface with certain pressure. In agricultural machines, wear is the most rapid and common form of damage. This is responsible for most of the idle time and maintenance, apart from heavy expenditure on repair and spare parts.

The reversible shovels wear out rapidly for a tractor drawn cultivator, sometimes in only one season. This results in high maintenance cost, frequent stoppage of work and loss of time during peak hours till replacement. The quality of work is affected adversely and energy is wasted by continuous use of blunt shovels.

Surface hardening can play a vital role to reduce wear. There are number of surface hardening methods such as hard facing with electrode, nitriding, carbonitriding and hard surfacing with oxy-acetylene thermal spraying of different metal alloy powder. It is not necessary to harden the whole surface of the tool since wear occurs only at the critical contact locations in the tool.

About 70 percent research in wear is carried out as accelerated wear tests under controlled conditions due to its slow occurrence in field conditions and the requirement of quick results (Bhusan and Gupta, 1991). Wear in the cultivator shovels depends on forward speed in sand (Kurchania, 1997). In view of the above, a study was undertaken on the abrasive wear of cultivator shovels coated with EWAC 1002 ET surface hardening powder at different forward speeds in sandy loam soil under controlled soil bin conditions.

Materials and Methods

Wear studies were conducted under controlled soil bin conditions (Chahar, 2006). A soil bin with an outer diameter of 5,520 mm and inner diameter of 3,490 mm was fabricated from MS sheets 1.63mm thick (**Fig. 1**). The soil bin was filled with a sandy loam soil up to 540 mm height. The working width of 1010 mm of the soil bin was used to operate the shovels in a circular path. DC variable speed shunt wound motor was coupled to a worm gear by a flange to reduce the rpm in the ratio of 5:1 and to transmit the power in a perpendicular direction. The vertical powered shaft of the gear was clamped to the horizontal beam. The outer end of the horizontal beam was supported by a pneumatic wheel. The rectangular tool frame was clamped on the horizontal beam such that the tool carriage could work in the soil bin. A compaction roller was also attached with tool frame to maintain the uniform compaction behind the tilled soil.

EWAC 1002 ET surface hardening powder (tungsten carbide base) was flame sprayed onto the shovel surface to bond by diffusion with the base metal. Shovels (**Fig. 2**) hardened with the powder coating with a hardness of 610 BHN were mounted on a tool frame. Initially shovels were weighed on an electronic balance of 10 mg sensitivity. Three sets of shovels were consecutively mounted on shanks and were operated at speeds of 0.7, 1.0 and 1.3 m/s. The depth of operation of shovels was kept constant at 100 mm. The moisture content of the soil was maintained in the range of 9 to 12 percent. The wear tests were conducted for 100 h and weight loss in the shovels was measured at an interval of 20 h. The shovels were thoroughly washed in water and dipped in dilute acetone solution before weighing. Cumulative average weight loss and wear rate were also calculated during the study.

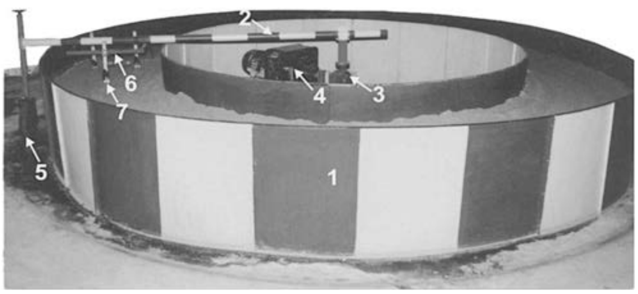
Results and Discussion

The weight of shovels reduced with the increase in working time, which resulted in increase in cumulative wear at all levels of forward speed (**Fig. 3**). This confirmed the findings of Singh and Thakur, 1989; Raval and Kaushal, 1990; Singh *et al*., 1993; Kurchania, 1997; and Mahapatra, 2002, who observed a linear relationship between cumulative wear and period of work.

Average cumulative wear in shovels was 4.10, 4.60 and 5.29 g at the speeds of 0.7, 1.0 and 1.3 m/s, respectively. Maximum wear loss in shovels was at a speed of 1.3 m/s.

The wear rate increased by 11.76 percent as the forward speed increased from 0.7 m/s to 1.0 m/s (**Fig. 4**). Further increase in speed from 1 m/s to 1.3 m/s resulted in 15.78 percent increase in the wear rate. This might be due to the fact that at higher speed, the soil particles striking the surface of shovel develop increased the normal component of pressure at the points of contact on the surface. Therefore, the relationship between wear and forward speed became nonlinear. These results were in agreement with Singh, 1972, Moore and McLees, 1980 and Kurchania, 1997, who observed that the wear rate increased with increase in speed. The wear pattern of the shovels was also observed during the study. The shovels were found to wear out along the thickness. The maximum decrease in thickness was observed at the tip of the shovel. This might be due to the resultant of all the soil reactions

Fig. 1 General view of experimental setup



1. Soil bin 2. Horizontal beam 3. Worm gear unit 4. DC motor 5. Pneumatic wheel 6. Tool frame 7. Shovel

Fig. 2 Test shovels

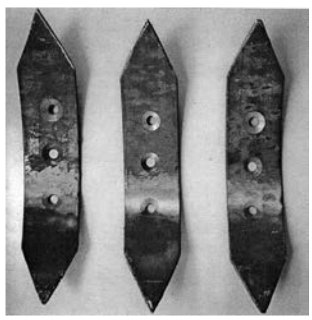


Fig. 3 Cumulative wear in shovels at different operating speed and time

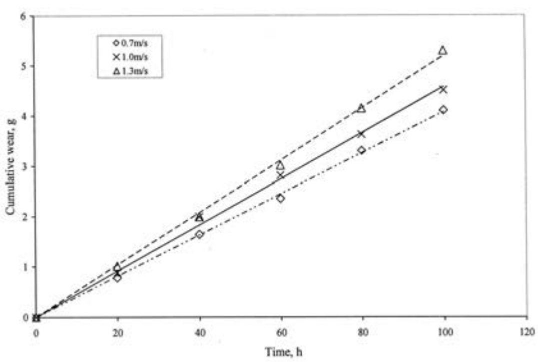
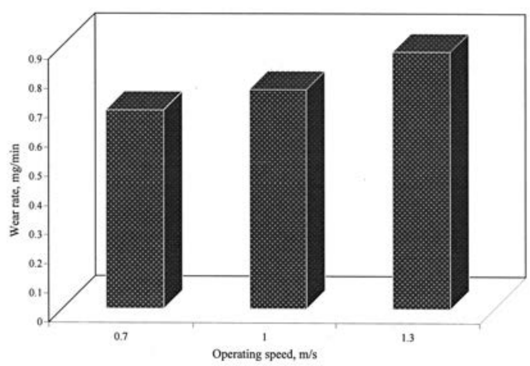


Fig. 4 Effect of speed on wear rate of shovels



acting around the tip of the shovel. The wear rate was directly proportional to the magnitude of confining stresses. The confining stresses increased with the depth of operation of the shovel. Therefore, the part of the shovel close to the soil surface would have minimum rate of wear. This result was in agreement with the findings of Singh and Thakur, 1989 who observed maximum wear at the tip of the shovel.

Conclusions

Based on the results, the following conclusions were drawn.

1. The cumulative wear of shovels increased with increase in operating time.
2. Wear in shovels increased with increase in forward speed.
3. The maximum wear occurred at the tip of the shovel along the thickness.

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■■

NEWS

◇ "PROJECTIONS OF AGRIBUSINESS" Brazil 2009/10 to 2019/20

The Brazilian agribusiness has great growth potential. The domestic market is expressive for every analyzed product, and the international market has presented sharp growth of the consumption.

Super populated countries will have difficulties to attend the demands due to the exhaustion of their farmlands. The difficulties of world stock renewal; the sharp consumption increase especially of grains such as corn, soybean and wheat; the ongoing urbanization process in the world brings favorable conditions to countries as Brazil, which have immense potential of production and available technology. The availability of natural resources in Brazil is competitiveness factor.

The most dynamic products of the Brazilian agribusiness must be the soybean, poultry meat, sugar, ethanol, cotton, soybean oil, and cellulose. These products indicate elevated growth potential of the production and of the exports for the following years.

The growth of the agricultural production in Brazil must happen based on the productivity. A strong growth of the total factor productivity as recent works have showed must be maintained. The results show a higher increase of the agriculture and livestock production than the increase of area. The projections announced by AGE and MAPA indicate that from 2010 to 2020, the average annual growth rate for the production of crops must be of 2.67 %, while the area must expand anuually at 0.45 %.

Although Brazil will present in the following years strong increase of the exports, the domestic market will be a strong growth factor. Of the increase forecasted in the following years in soybean and corn production, 52.0% and 80.0% respectively, will be directed to the domestic market. There will be, this way, a double pressure on the increase of the national production, due to the domestic market growth and to the exports of the country.

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A Pneumatic Powered Cotton Picker for Major Indian Cultivars and Compatibility to Women Operators

by

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Abstract

The traditional system of women's participation in cotton picking and the steady increase of female workers in Indian farms call for special attention in developing a cotton picker for reduction of drudgery. Mechanical harvesters are not feasible for Indian cotton varieties when agronomical practices and staggered blooming characteristics considering are considered, therefore, pneumatic principles were applied. A four wheel push type trolley was used to mount all the components for better maneuverability in field condition as well as better compatibility with women operators. Dimensions of the machine parameters, viz. pick-up pipe diameter, filter type, filter height, collection drum capacity, and aspirator speed were optimized through the build and test method. The effect of variations of the parameters on pressure, which directly induced picking force, was studied independently and in combination, and the best-suited parameters were selected through statistical analysis. The statistical analysis was used to optimized the cotton picker with a pick-up diameter of 50 mm, nylon mesh filter of 300 mm height, 50 l capacity collection drum and an aspirator speed of 3,500 rpm. The cost of picking with picker was Rs. 10.10 per kg of cotton (1 $ = Rs. 45). The savings in cost, time and energy, compared to conventional picking was 15.8, 67.5, and 66.6 percent, respectively. The break-even point and pay back period for the picker was 1,147 kg/annum and 2.30 year, respectively. The cotton picker addressed the women's requirement for cotton picking in Indian farms.

Introduction

Indian women workers are traditionally involved in picking cotton from bolls while men concentrate on the remaining activities of cotton cultivation. Interestingly, women constitute only 48 percent of total population in India; but 78 percent of economically active women in the country are engaged in agriculture compared to 63 percent of men. Women do approximately 65 percent of the farm manual labour. Among the total women workers, 32.9 percent are cultivators and 38.9 percent are agricultural labourers. Among the total men workers, 31.1 percent are cultivators and 20.8 percent are agricultural labourers. Emerging studies and data suggest that an increasing number of adult women in India are farmers. An analysis of the dynamics of agricultural workers in India identified that the percentage of women in the agricultural workforce was 35.1 in 1991, which rose to 39.0 by 2001, showing a clear trend of increased women participation in agriculture. It is also projected that their participation will touch 50 percent by the year 2020 (Census of India, 2001). As far as efficiency of work is concerned, it is reported that women labourers are more efficient than men with respect to rice transplanting (16 percent more), weeding in rice and wheat fields (7-8 percent more), picking of pearl millet (25 percent more), and 37 percent more in picking cotton. (Thakur, 1994; Nag, P. K. and Chatterjee, S. K. 1981). To plan the 129 million worker population of women in Indian farms by the year 2020, appropriate tools and equipment should be developed or modified to address their specific needs (Nawab Ali, 2005).

Cotton is an important commodity in the world economy which is essentially produced for its fibre. The Industrial Revolution and the invention of the cotton gin paved the way for the important place that cotton holds in the world today. Grown in more than one hundred countries, cotton is a heavily traded agricultural commodity, with over 150 countries involved in exports or imports of this universal textile raw material. The cotton crop was cultivated on 10.17 million ha with a production of 29.20 million bales at an average of 488 kg/ha during 2009-10 in the Indian subcontinent (Anon, 2010). Although India is currently first in area, second in yarn production, and third in raw cotton production in the world today (Anon, 2010), the entire cotton is hand picked by human labour involving about 1,565 man h/ha (Goyal, 1979). It is not only tedious work but also ten times costlier than irrigation and about twice that of weeding (Ahmed et.al 1985). In recent years labour shortages appear during the peak periods of cotton harvesting. Moreover, the cost of cotton production is excessively high, reducing the profit margin available to the farmer. Since the varieties used in our country require cotton picking at several stages, the use of mechanical cotton pickers is not feasible as in the case of defoliated picking method (Mathews and Tupper, 1965). Improvement in present cotton pickers will no doubt contribute to the solution of the above problems. However, complete solution is likely to come only through the use of some entirely different harvesting principle. A harvest method which does not require mechanical contact with the cotton bolls for removal from the bur would be desirable.

Considering the cultural and agronomical practices and staggered blooming characteristics of Indian cotton, mechanical harvesters are not considered suitable for Indian cultivars. That is, Indian varieties need cotton picking at several stages and the use of mechanical pickers is not feasible, which leads to the selective picking method (Bilanski *et al.*, 1962). The only alternate for these problems is focusing toward the pneumatic system of picking. Therefore, the feasible alternative is to design a pneumatic powered picker. The development of such unit would be the first step into the mechanization of cotton cultivation. Also, considering ergonomic limitations of the women operators, a trolley mounted cotton picker was developed at Tamil Nadu Agricultural University, Coimbatore.

This present paper describes the development of a women operated pneumatic powered cotton picker compatible with major Indian cotton varieties along with the performance results with a special emphasis to optimization of functional components.

Materials and Methods

Description of the Unit

A pneumatic powered cotton picker was developed to increase the maneuverability and reduce the drudgery so that it could be used by women labourers. The components were mounting on a trolley so that two women operators could conveniently pull the equipment in the field and execute picking operation by selective picking. The components were similarly optimized and the dimensions were determined. The components were the prime mover, aspirator, cotton filter, cotton collection drum, cotton pick-up pipe, and trolley. To suit the required power for designed capacity, a Honda 2.25 kW engine was selected from the market. The engine was petrol-start-kerosene run.. The crankshaft was directly coupled with the aspirator impeller. The power consumed by the aspirator of the cotton picker was calculated based on the pressure and velocity of flow of air. The aspirator was especially designed for the optimized value of suction force of the two inlet pick up hoses. The entire aspirator was mounted on a specially fabricated trolley with 150 mm clearance from the trolley platform. The poly propylene 50 litre capacity drum was mounted on the trolley platform with suitable frame. The top half of the drum was attached with the two tank nipples in diagonally opposite direction. These nipples were provided with 25 mm diameter pick-up hoses for collecting cotton. The bottom of the drum was cut open and fastened with a suction duct. The suction duct was connected to the drum with an air tight flange with suitable clip. The circular cotton filter was 100 mm diameter and 300 mm high and made from nylon mesh. It was attached inside the collection drum vertically on a suitable flange to restrict the entry of cotton inside the aspirator. To facilitate the user to cover the entire strip of the cotton field, two 5 m pick up hoses were optimized. Since the pick up hose was flexible, a 100 mm G.I. pipe nipple was provided at the tip of pick up hoses. The impeller eye was connected with the bottom of the collection drum by a 75 mm diameter air tight duct. The specifications of the trolley mounted cotton picker are given in **Table 1**. A handle was attached to the trolley front wheel axle for better maneuverability in turning. The unit is

Table 1 Specification of the unit

Parameters	Particulars
Overall dimensions (length × width × height), mm	520 × 400 × 1000
Engine power	2.25 kV (petrol start-kerosene run)
Type of aspirator	Axial flow type (Centrifugal fan)
Maximum speed of impeller, mm	3,500
Minimum speed of impeller, mm	2,000
Type of collection drum	Polypropylene container
Capacity of collection drum, l	50
Mounting pattern of collection drum	Vertical
Type of cotton filter	Nylon mesh
Mounting pattern of cotton filter	Vertical
Dimension of cotton filter, mm (dia × height)	100 × 300
Type of cotton pick-up pipe	PVC hose
Number of pick-up pipe and Diameter, mm	Two, 25
Number of operators	2 women

Fig. 1 Pneumatic cotton picker for women

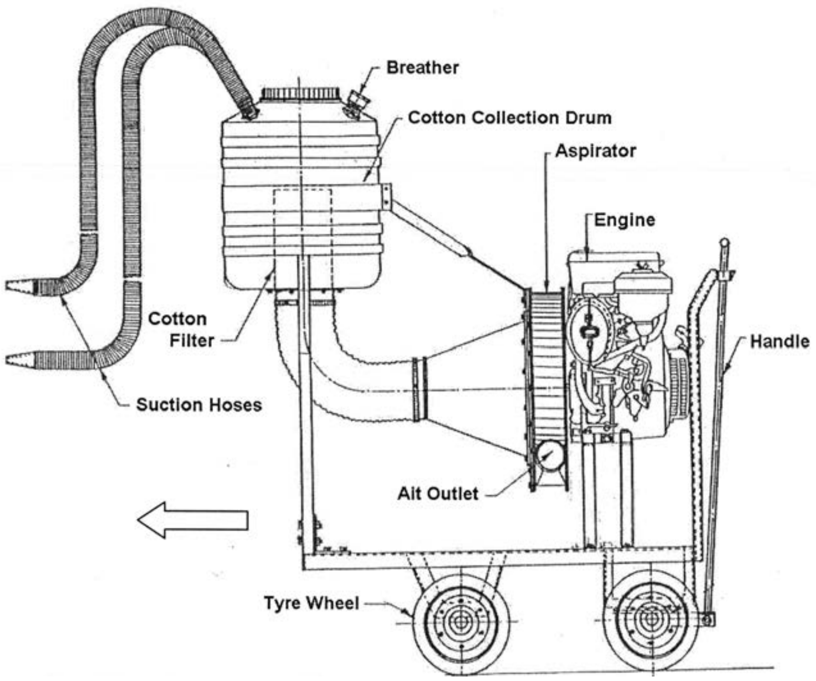


Fig. 2 Field operation of the unit by women

shown in **Fig. 1** and the operation of the unit is shown in **Fig. 2**.

Experimental Design

Optimization of the dimensions of the various components used in the prototype was achieved by with an experimental design: Factorial Randomized Block Design (FRBD). In this analysis four factors; pick up pipe diameter, filter type, filter height, and collection drum capacity were considered for the optimization. Three levels were considered for each factor chosen. The best combination of the dimensions of the various components was one that gave the maximum pressure. The analysis was repeated for the different speeds of the engine.

Optimization of Machine Components

It was essential to optimize the various machine and operational parameters; pick-up pipe diameter, filter type, filter height, collection drum capacity and aspirator speed that control the suction force. The engine was allowed to run steadily at different speeds and the pressure, as well as pressure head loss at the tip of suction pipe were measured with a U-tube monometer for different combinations of the above related parameters (Ananthakrishnan, 1996).

A light-weight PVC pipe was used as a pick-up pipe to reduce frictional resistance and weight of the unit. The velocity and pressure of air flowing through the suction pipe depended on the diameter of the suction pipe. Hence, the diameter of the suction pipe needed to be optimized with respect to the suction force of air required to be produced to affect the pneumatic picking of cotton. The pick-up pipe diameter was varied to study the suction force of air stream generated by the aspirator to optimize the pick-up pipe diameter. Three levels of pick-up pipe diameter, viz., 18 mm, 25 mm and 32 mm were adopted for the experiment. The PVC tank nipples were used to connect the pick-up pipes. A suitable screen was provided as a filter to restrict the entry of cotton into the aspirator and to allow the air alone to pass into the aspirator with less resistance between the collection tank and the aspirator. The net suction force depended on the type of screen adopted. The nylon mesh, aluminium perforated sheet, and G.I. mesh made filters were selected and the best one was optimized based on the suction force developed at the tip of the suction pipe. Three levels of filter height were used; 200 mm, 300 mm, and 400 mm. The variation in the filter heights was necessary to accommodate the varieties in the height of the collection drum. By measuring the suction force created at the tip of the suction pipe, the filter height was optimized for its best performance.

The capacity played a vital role in the suction force developed in the container and, hence, was essential to determine the optimum capacity of the container to be used as a collection drum. Three levels of collection drum capacity were used; 25 l, 50 l, and 100 l. The aspirator was the pivotal component of the picker, which created the pneumatic force that was used for suction of cotton from the boll. Though it had been concluded in many conventional applications that the aspirator speed was proportional to the suction force, it was felt essential to study the relationship of suction force with the speed of aspirator to find the optimum speed of aspirator to suit pneumatic picking of cotton. For this purpose, four levels of speed (2000, 2500, 3000, and 3500 rpm) were selected.

Field Evaluation of Picker

The picker was evaluated for its performance in the field. Twenty plots in which twenty varieties taken for this study were randomly distributed. The cotton picker was evaluated in each variety. Actual time of operation, time lost for unloading cotton, time lost in adjustment, fuel consumption and number of bolls left unpicked were observed during field trials (Williamson and Riley, 1961; Serikov *et al*., 1991).

Three replications of each variety (5 × 3 m plots) were randomly placed in the field. The operators were allowed to pick the cotton variety-wise by machine for a known period of time. The weight of the seed cotton picked by the machine was analyzed in comparison with manual picking. The same procedure was repeated during three pickings of cotton (first picking, second picking, and third picking). The picking efficiency for the twenty varieties with the cotton picker was also determined. The number of bolls in plots selected for determining field capacity including plots for replication was counted before and after picking. This procedure was repeated for all three pickings (first picking, second picking, and third picking). A fuel consumption meter was used for determining fuel consumption (Jesudas, 1994). It consisted of a measuring jar from which fuel was taken for the engine. Fuel consumption was measured by operating the cotton picker for a known time. The difference in volume of the fuel in the measuring jar gave the volume of fuel consumed. Trash content was estimated by a trash analyzer in which trash was separated when the cotton was fed through the inlet after ginning (Brashears, 1989; Mayfield, 1989; Smith and Dumas, 1982).

Results and Discussion

Optimization of Machine Components

The dimensions of machine parameters, viz. pick-up pipe diameter, filter type, filter height, collection drum capacity, and aspirator speed were varied. The effect of variations of said parameters on pressure, which directly induced picking force, were studied independently and in combination. The best-suited parameters were selected through statistical analysis (Nasritdinov and Mansurov, 1991).

The diameter of the pick-up pipe was varied in the range of 18 mm, 25 mm and 32 mm and the effect was studied with different aspirator speeds. From the statistical analysis (Factorial Completely Randomized Block Design), the variation in diameter showed positive correlation, and the maximum pressure was obtained in 25 mm diameter pick-up pipe. The improved pressure in the 25 mm diameter pick-up pipe may be due to drag coefficient during suction of seed cotton. In real action, the seed cotton is shrunk (squeezed) about half of its projected area due to suction force that matches with the 25 mm diameter pick-up pipe. For the 18 mm diameter pick-up pipe, entry becomes narrow and takes lot of time. For the 32 mm diameter pick-up pipe, the drag force was affected due to very large difference between shrunk seed cotton projected area, and pick-up pipe cross-sectional area, which makes atmospheric air enter and nullifies the effect on seed cotton.

There was a very strong correlation between the filter type and pressure in the pick-up pipe. The pressures with the nylon filter (0.0497 kg/cm^2) and GI mesh (0.0480 kg/cm^2) were almost the same. But, with the aluminum-perforated sheet, the pressure of 0.0401 kg/cm^2 was drastically affected. This variation among the filters might be due to the major variation in orifice configuration. Though the effect of nylon mesh filter and G.I. mesh filter were the same on pressure, the nylon mesh was selected because of its light weight and anti corrosive property for all the cotton pickers. It was evident that the nylon mesh filter was the best suited for the cotton picker. Three sets of filter heights were selected for each machine, i.e.

200, 300, and 400 mm. This variation among the filter heights was selected by considering the height of collection drum. The effect of filter heights on pressure was statistically significant. The maximum pressure could be obtained at a height of 300 mm. From the ANOVA (**Table 2**) it was evident that the filter height had significant effect on pressure. Further increase of the filter height above the particular height might have created undue losses in suction (turbulence effect) due to abstraction at the top of the collection drum for free flow of air. The variation in height had correlation with the pressure in the pick-up pipe. The 50 l capacity was optimized. It was evident that the speed of the aspirator had strong positive correlation with pressure in the pick-up pipe. The speeds selected for the study ranged from 2,000 to 3,500 rpm. These ranges of speed were selected in accordance with the prime mover. In general the pressure in the pick-up pipe increased with increase in the aspirator speed, and hence, the maximum speed of 3,500 rpm was optimized.

The combined effect was also studied. The interaction of the pick-up pipe diameter, filter type, filter height, collection drum capacity,

Table 2 ANOVA for optimization of machine components

SV	DF	SS	MS	F
Treatment	80	3,280,751.099	41,009.389	28.99**
D (D)	2	89,069.895	44,534.948	31.49**
H (H)	2	385,554.988	192,777.494	136.29**
F (F)	2	240,130.377	120,065.188	84.88**
C (C)	2	71,704.821	35,852.410	25.35**
D × H	4	33,174.216	8,293.554	5.86**
D × F	4	58,360.049	14,590.012	10.31**
D × C	4	25,275.494	6,318.873	4.47**
H × F	4	71,170.512	17,792.628	12.58**
H × C	4	148,952.457	37,238.114	26.33**
F × C	4	1,575,330.179	393,832.545	278.43**
D × H × F	8	76,421.228	9,552.654	6.75**
D × H × C	8	186,848.562	23,356.070	16.51**
D × F × C	8	90,625.784	11,328.223	8.01**
H × F × C	8	43,843.432	5,480.429	3.87**
D × H × F × C	16	184,289.105	11,518.069	8.14**
Error	243	343,713.750		
Total	323	3,624,464.849		

CV=5.6 %, **=Significant at 1% level, D=Pickup pipe diameter, H=Filter height, F=Filter type, C=Collection drum capacity

Table 3 Field capacity

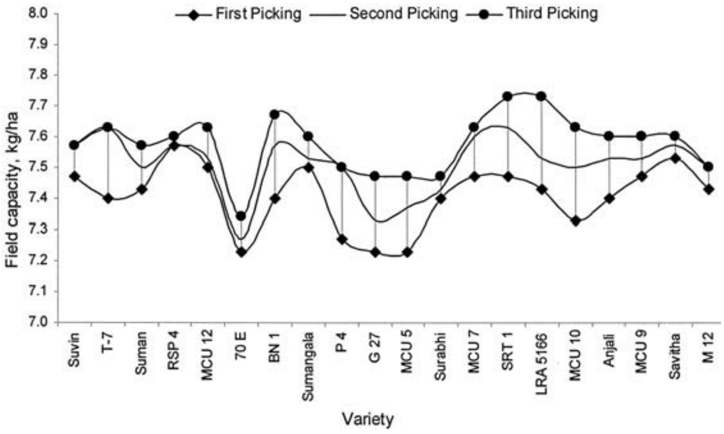
Variety	Filed capacity, kg/h							
	Machine picking				Manual picking			
	First picking	Second picking	Third picking	MEAN	First picking	Second picking	Third picking	MEAN
Suvin	7.47	7.57	7.57	7.54	1.33	1.40	1.47	1.40
T-7	7.40	7.63	7.63	7.55	1.37	1.37	1.40	1.38
Suman	7.43	7.50	7.57	7.50	1.43	1.57	1.70	1.57
RSP 4	7.57	7.57	7.60	7.58	1.53	1.60	1.63	1.59
MCU 12	7.50	7.53	7.63	7.55	1.57	1.60	6.73	1.63
70 E	7.23	7.27	7.34	7.28	1.33	1.40	1.43	1.39
BN 1	7.40	7.57	7.67	7.55	1.53	1.57	1.67	1.59
Sumangala	7.50	7.53	7.60	7.54	1.33	1.40	1.40	1.38
P 4	7.27	7.50	7.50	7.42	1.37	1.50	1.63	1.50
G 27	7.23	7.33	7.47	7.34	1.33	1.43	1.53	1.43
MCU 5	7.23	7.37	7.47	7.36	1.37	1.50	1.63	1.50
Surabhi	7.40	7.43	7.47	7.43	1.53	1.60	1.60	1.58
MCU 7	7.47	7.60	7.63	7.57	1.20	1.40	1.53	1.38
SRT 1	7.47	7.63	7.73	7.61	1.37	1.40	1.63	1.47
LRA 5166	7.43	7.53	7.73	7.56	1.47	1.53	1.57	1.52
MCU 10	7.33	7.50	7.63	7.49	1.43	1.47	1.47	1.46
Anjali	7.40	7.53	7.60	7.51	1.40	1.43	1.43	1.42
MCU 9	7.47	7.53	7.60	7.53	1.37	1.40	1.50	1.42
Savitha	7.53	7.57	7.60	7.57	1.50	1.60	1.70	1.60
M 12	7.43	7.50	7.50	7.48	1.27	1.43	5.80	1.50
Mean	7.06	7.16	7.22	7.15	1.34	1.41	1.50	1.42
SD	0.10	0.09	0.10	0.10	0.10	0.08	0.12	0.10

and aspirator speed had a significant effect on pressure. The combination of D_2 (25 mm), F_1 (nylon mesh), H_2 (300 mm) and C_1 (50 l) for speeds S_4 (3,500 rpm) gave a maximum pressure of 0.0585 kg/cm^2.

Field Evaluation of Cotton Picker

There was a significant difference in field capacity of machines in comparison with manual cotton picking. In general the increase in field capacity was about four times that of the cotton picker (with two women labourers). The field capacity increased with picking time. The third picking (7.06 + 0.1 kg/h) had more field capacity than the first picking (7.22 + 0.1 kg/h).The result was in accordance with the findings of earlier studies (Khan, 1981; Negwekar, *et al*., 1983; Sekongo, 1986 and Moholkar and Thombre, 1987). This might be due to the full maturity of cotton bolls during the third picking.

Fig. 3 Field capacity of cotton picker



The field capacity was highest in SRT 1 variety (7.61 + 0.13 kg/ha) followed by RSP 4 variety (7.58 + 0.02 kg/h) and lowest in 70E variety (7.28 + 0.06 kg/h) followed by G 27 variety (7.34 + 0.12 kg/h). It was apparent that there was no significant difference in man-hour requirement among the varieties by using cotton picker.

The maximum picking efficiency of 99.26 + 0.23 percent was observed with manual cotton picking. The picking efficiency was highest in MCU 9 variety (95.05 + 1.57 percent) and lowest in MCU-7 variety (90.66+0.09 percent). Also, picking efficiency increased with the time of picking. It was less in the first picking (87.33 + 0.68 percent) and more in third picking (88.42 + 1.18). This showed that the maturity aspect played a positive role in mechanized

Table 4 Picking efficiency

Variety	Picking efficiency, %							
	Machine picking				Manual picking			
	First picking	Second picking	Third picking	MEAN	First picking	Second picking	Third picking	MEAN
Suvin	91.33	91.97	93.13	92.14	99.70	99.70	99.70	99.70
T-7	92.50	93.13	94.40	93.34	99.50	99.50	99.57	99.52
Suman	92.13	92.14	92.33	92.20	99.27	99.33	99.43	99.34
RSP 4	92.00	92.30	93.43	92.58	99.33	99.67	99.67	99.56
MCU 12	92.33	92.73	92.87	92.64	99.23	99.27	99.33	99.28
70 E	91.30	91.57	91.73	91.53	99.18	99.20	99.33	99.24
BN 1	90.57	91.20	91.20	90.99	99.70	99.70	99.73	99.71
Sumangala	92.50	92.53	92.77	92.60	99.10	99.40	99.63	99.38
P 4	90.90	91.03	91.30	91.08	98.10	99.17	99.27	98.85
G 27	91.17	92.27	95.03	92.82	98.10	99.47	99.63	99.07
MCU 5	91.67	92.23	93.00	92.30	96.13	99.33	99.33	98.26
Surabhi	90.93	93.07	93.53	65.51	99.20	99.23	99.53	99.32
MCU 7	90.60	90.63	90.97	90.73	98.07	99.03	99.30	98.80
SRT 1	92.33	92.53	92.83	92.56	99.23	99.47	49.53	82.74
LRA 5166	91.53	91.90	92.10	91.84	98.93	99.03	99.57	99.18
MCU 10	91.00	91.40	91.40	91.27	99.23	99.37	99.43	99.34
Anjali	92.70	92.77	92.83	92.77	98.73	98.93	98.93	98.86
MCU 9	92.27	94.67	95.23	94.06	99.53	99.63	99.67	99.61
Savitha	92.17	92.33	92.60	92.37	99.37	99.40	99.67	99.48
M 12	91.27	92.60	92.90	92.26	99.23	99.37	99.47	99.36
Mean	91.66	92.25	92.78	92.23	98.943	99.36	96.986	98.43
SD	0.68	0.88	1.18	0.81	0.82	0.22	11.17	3.71

cotton harvesting. These results were in accordance with the findings of Tupper (1964).

Mean trash content in machine picking and manual picking was 10.63 + 1.18 and 3.77 + 0.91 percent, respectively. In comparison with manual picking, machine picking incorporated more trash as depicted in **Table 3**. Picking time also influenced the trash content in seed cotton significantly. The first picking registered minimum trash content (9.18 percent) followed by second picking (10.58 percent) with maximum trash content (12.13 percent) in the third picking (Kirk *et al.*, 1973). The fuel consumption of the picker was 0.75 l/h.

Economics

The economics of the cotton picker was analyzed as per the RNAM test code and procedure for harvesters. (Anon, 1995). The break-even point and the pay back period for the unit were also calculated (Ahmed, 1985). The cost of the picker was Rs.35,000. The cost of picking of cotton with picker was Rs. 10.10 per kg. The savings in cost compared to conventional picking was 15.8 percent for the trolley mounted cotton picker. The break-even point and pay back period for the picker were 1,147 kg/annum and 2.30 per year, respectively. Savings in time and energy compared to the conventional method was 67.5 and 66.6 percent for the picker, respectively.

Conclusion

Even though the manual picking had the highest picking efficiency on evaluation with other parameters, namely field capacity, cost of picking, break even point, pay back

Fig. 4 Trash content trends with respect to time of picking

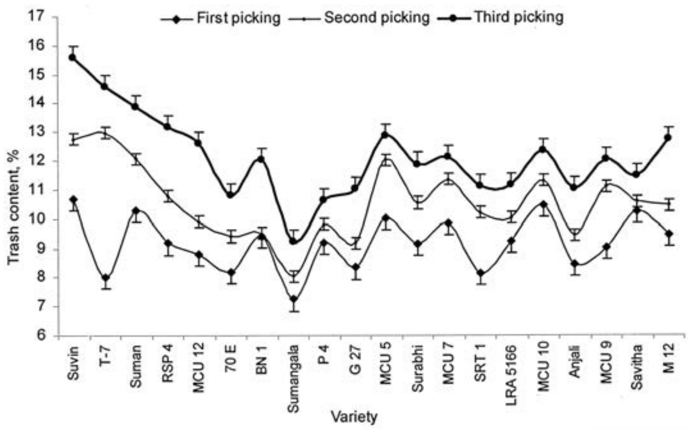


Table 5 Trash analysis

Variety	Trash content, percent							
	Machine picking				Manual picking			
	First picking	Second picking	Third picking	MEAN	First picking	Second picking	Third picking	MEAN
Suvin	10.7	12.76	15.61	13.02	3.01	5.81	6.87	5.23
T-7	8.02	12.98	14.57	11.86	1.58	4.73	5.94	4.08
Suman	10.31	12.07	13.89	12.09	1.37	3.98	6.34	3.90
RSP 4	9.18	10.79	13.19	11.05	2.11	5.76	6.31	4.73
MCU 12	8.79	9.91	12.61	10.44	2.06	5.34	5.78	4.39
70 E	8.21	9.42	10.81	9.48	1.02	4.06	5.19	3.42
BN 1	9.41	9.51	12.03	10.32	3.04	3.75	4.89	3.89
Sumangala	7.25	8.05	9.24	8.18	2.56	3.24	4.51	3.44
P 4	9.20	9.82	10.65	9.89	3.24	3.84	5.76	4.28
G 27	8.35	9.18	11.05	9.53	1.56	2.75	4.94	3.08
MCU 5	10.05	12.03	12.89	11.66	2.45	4.28	5.78	4.17
Surabhi	9.15	10.56	11.89	10.53	1.76	3.51	4.72	3.33
MCU 7	9.85	11.35	12.14	11.11	1.08	2.46	3.54	2.36
SRT 1	8.16	10.22	11.12	9.83	2.08	3.25	4.82	3.38
LRA 5166	9.23	10.04	11.17	10.15	3.04	4.05	4.67	3.92
MCU 10	10.46	11.31	12.36	11.38	1.24	3.49	6.71	3.81
Anjali	8.45	9.45	11.04	9.65	0.71	2.46	3.42	2.20
MCU 9	9.04	11.12	12.05	10.74	1.45	2.49	4.61	2.85
Savitha	10.25	10.59	11.48	10.77	2.16	3.92	6.08	4.05
M 12	9.45	10.45	12.76	10.89	2.73	5.62	6.38	4.91
Mean	9.18	10.58	12.13	10.63	2.01	3.94	5.36	3.77
SD	0.90	1.22	1.43	1.18	0.74	1.04	0.96	0.91

period, cost savings, time savings and energy savings, picking through the trolley mounted cotton picker was promising to address the need of ever increasing women's role in Indian farms.

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NEWS

Precision in Grain Yield Monitoring Technologies: A Review

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Abstract

Spatial variability in crop productivity is the result of soil variability at spatial scale. Assessing soil and crop infield variability is very crucial and the first step of precision agriculture. Spatial variability of all the determinants of crop yield should be well recognized, adequately quantified and properly located. In precision agriculture, after assessing the in-field variability, the same is taken care of through site-specific planting, site-specific nutrient and other input applications. To maximize economic return from agricultural production units, costs have to be minimized and benefits maximized. In this paper, an overview has been given about the past and current research toward the evaluation of currently available sensors used in combine harvesters for measuring grain yield. Sensors based on measurement of impact, volume and weight are available commercially.

Nomenclature

ha : hectare
Hz : Hertz
kg : kilogram
% : percent
i.e. : that is
sq m : square meter
I/O : input/output
GPS : Global Positioning System
RDS : Radio Data System

Introduction

Yield of a crop depends on a variety of natural factors such as soil and climate; agronomic practices such as sowing time, seed rate, irrigation and weed control; and the proper management such as crop sequence, precision and timeliness of the farm operations. Researchers (Samra *et al*., 1992) have documented significant spatial variation in wheat and rice yield within the Indo-Gangetic plains of India. It is important to measure the spatial variation of grain yield for the optimal crop management. One of the most important objectives of farmers is to get maximum output from his field with minimum inputs, i.e. maximizing economic return.

Yanai *et al*. (2001) and Inamura *et al*. (2004) have documented significant spatial variation in rice yield within a Japanese paddy field. It is important to measure the spatial variation of grain yield for the optimal crop management. Amongst the most important measures to minimize the spatial variation in rice productivity is making balanced use of soil nutrients. Recently the Indian government approved a Nutrient-Based Subsidy (NBS) regime for fertilizers that would help to increase agricultural productivity by promoting balanced fertilizer use. It is to enable precision agriculture that potentially will revolutionize agricultural yield, while being sustainable. The key is integrating the farming communities and the entire value chain together and, with this, the farmer will be the real beneficiary and the positive domino effect will be felt across the entire ecosystem to the end consumer. Monitoring crop yield is the most interesting operation of any farmer. Yield monitors for grain crops have started to be introduced in some developing as well as transitional countries. A yield monitor is a recent development in precision farming and agricultural machinery especially for developing countries that allows farmers to assess the yield variability in his field during harvesting of crop. There is a logical first step for those who want to begin practicing site-specific crop management or 'precision agriculture'. A yield monitor is one of the technologies acquired by growers in the adoption of precision agriculture (PA) practices.

Yield mapping can be defined as the measurement of the harvested crop over space and time and the summation of those in graphical form (Pierce, 1997). A yield monitor used in conjunction with a Global Positioning System (GPS) receiver records field and crop information during harvest and gives the user an accurate assessment of how yields vary within a field. Yield and quality information can be acquired during harvesting using the batch type yield monitoring system (Chosa *et al.*, 2004).

Mainly combine harvesters are used for the harvesting of wheat and rice in the northern part of India. In Punjab, the total area under combine harvesting for rice and wheat is 91 % and 82 % respectively (Gajri *et al.*, 2002). In India or in Punjab, yield is measured during marketing of harvested crop and as a gross yield of the land owned by the farmer. The present trend is to use high capacity machines on custom hiring basis. The marginal and small farms cannot enjoy the benefits of mechanization through individual ownership. Custom hiring of farm machinery and power, including combine harvester, is the only means by which they can reap the benefits of farm mechanization. About 90-95 % of the total 425 thousands combines operated in India are on custom hiring basis. A yield monitor can also be used to measure the yield of experimental research plots. By using the yield monitor in a combine harvester, charges for custom hiring may be charged by the operators on the weight basis rather than area basis used nowadays to collect the charges from the farmers.

An understanding of yield variations within or between fields has been used to evaluate growth and management history and this provides important information to determine site-specific management for the following year. Sites where lodging has been observed should have reduced amounts of fertilizer applied and sites where yield has been low should have increased amounts of fertilizer. Although we can understand yield variations through routine farm work, the yield monitoring combine is expected to play an important role in establishing site specific crop management and spreading related technology to farmers. Two types of yield monitors can be developed. One is batch type and other is continuous type. In concerns of developing countries like India where the size of the farms are not as big as in developed countries, a batch type yield monitors will be useful to measure the field yield. So there arises a need of a low cost yield monitoring system suited to Indian field conditions.

First of all, the review of a grain yield monitoring system for combines using weight type, volumetric type and impact-type flow sensors is described in this paper. Second, review of the error analysis on different yield monitors is proposed. Finally, an overview of commercially available yield monitors is presented in the paper.

Present Technologies for Yield Monitoring

Research on sensor technology for precision farming continues to escalate. Research involves the measurement of flow rate as well as different properties of grains. The placement of these sensors on the combine can be easily understood when looking at the different functions of the harvester. According to a United States Department of Agricultural (USDA) survey (Daberkow and McBride, 1998) of corn producing farms in 16 states of the United States of America (USA), about 9 % used some form of Precision Agriculture (PA) for corn production. This was equal to about 1/5th of the corn harvested in 1996. They also indicated that 545 of the Precision Agriculture adopters use a grain monitor. In Argentina there were about 560 yield monitors in 2001 and about 4 % of the grain and oil seed area was harvested with headers equipped with yield monitors (Lowenberg, 2003). Yield monitors are being used on some larger farm operations in Brazil and Mexico (Norton and Swinton, 2000). Informal reports indicate that about 800 yield monitors were used in Australia in the 2000 harvest. Some fifteen farmers used the yield monitoring system in South Africa during the 1999-2000 crop season (Wilhem, 2000).

Direct Methods

The grain yield monitor first became available in the early 1990's. The first adopters of this technology were typically universities, research institutes and technology hungry farmers. Today, nearly every grain combine manufacturer in the United State of America (USA) offers an optional, factory installed yield monitor. Further, a few third party companies have yield monitoring systems available to fit most late model combines. The yield information provided by these systems has become widely accepted for both agronomic management decisions and record keeping. Most commercial sensors rely on impact sensing for mass-flow measurement. In these sensors the impact force or moment, caused by the change in momentum of the grain flow, is measured. The plate can be flat or curved, or just a pair of fingers. These sensing devices are mounted at the top of the elevator. Initial yield monitor research was focused on mass flow sensor development. De Baerdemaeker *et al.* (1985) investigated an impact type flow meter which measured grain forces on a curved circular tube using a load cell near the top of a clean grain elevator. The force developed by the change in momentum of the grain was proportional to grain flow rate. The calibration of the sensor was influenced by the slope of the field and was dependent on material properties like moisture content, friction, and kernel size. This work was a precursor to the development of most of the yield monitoring systems used today.

In weighing of the grain bin (Colvin, 1990), mass flow equals the change of weight of the bin in time. As the grain bin has to be mechanically isolated from the harvester, the construction of the sensor is not easy. More problems are noticed when measuring on slopes. Moreover, accuracy is limited because the weighing cells have to be adapted for the weight of a full grain bin. In weighing of a pivoted auger (Wagner and Schrock, 1987) and weighing of an element at the bottom cross auger, the grain is measured as it travels through the bottom cross auger before it reaches the clean grain elevator. The manufacturer claims independence of crop type. The advantage of this system is the lower time delay, as the system measures at the first point where the grain is cleaned. In weighing of an elevator (Schrock *et al*., 1995), the conventional elevator, transporting the clean grain to the grain bin, is replaced by a triangular construction. The upper part is pivoted at one side and mounted on a load cell at the other side. The signal of this load cell and speed of the elevator sprocket wheel is used to predict the mass flow. As a combine is normally equipped with a linear elevator, it needs a strong modification to install this sensor. Another method in which a paddle wheel is rotated at a controlled speed to ensure that the region between adjacent paddles (cell) is filled with grain. This sensor is called the Claydon Yieldo meter, according to the inventor. Major problems are the discrete measurement (the wheel is not turning continuously), and the possible obstruction of the machine when the sensor is damaged. For example when the wheel is jammed, there is blockage to the grain flow through the elevator which results in damage to the elevator. Searchy *et al.* (1989) used the sensor to create a yield map, which resulted in an error of 7.1 % on total yield for a 1.3 ha field.

Volume of grain is measured when flowing through the sensor during a fixed time interval, or time is measured by a fixed volume of grain flowing through the sensor. To acquire accurate measurements, mass density has to be measured for each different field, or even different measurements on one field. By means of optic sensors (light emitter and detector), height of the grain on the elevator paddles is measured. Together with the conversion of volume to mass, the conversion of height to volume is a second drawback of this sensor. This sensor has been studied in different forms, depending on the configuration of the light emitter and detector. One possibility (Diekhans, 1985) is to place the emitter and detector aside from the elevator. This one-dimensional system has been studied by Strubbe *et al.* (1996). When tested at a transverse slope of 11 %, the difference between estimated and real volume approached 13 % at high flow rates. By using a two-dimensional system (placing two sensors at each side of the elevator) the results could be improved. To improve further, the grain should be spread more homogeneously on the paddles. By vibrating the machine, the grain surface is more flattened near the top of the elevator, but placement of the sensor is more difficult. Also, a better resolution of the emitter-detector system could improve the results. Reitz and Kutzbach (1992) describe a two-dimensional system with one emitter/detector pair aside of the elevator, and two at the backside parallel to the driving direction. By introducing the latter pair of sensors, the accuracy, when harvesting on a hillside, could be strongly improved.

Hummel *et al*. (1995) tested a similar sensor developed by Pfeiffer *et al.* (1993). Light emitted at one side of the elevator was captured at the other side by 4 photodiodes. When the calculated calibration model was validated on a different field, the error was maximal 4.5 % on a reference weight of 160 kg. The calibration curve was non-linear, and this deviation from linearity increased with moisture content. Chosa *et al.* (2002, 2003 and 2004) reported a grain yield monitoring system for head-feeding combines in Japan. This system used optical sensors installed in a grain tank to measure the grain flow and a load cell that was settled below the grain tank to measure the weight of tank, including the grains harvested. Chosa *et al.* (2003) proposed a method to correct the grain yield measured using a constant determined by the relative position between the harvested position and the grain flow measured position based on the experimental results.

Hindryckx and Missotten (1994) and Kutzbach and Schneider (1997) gave an overview of different devices for measuring grain yield. Mass or volumetric flow sensors were divided into four groups, depending on the principle of measurement. The basic principle of these measurements was the combination of a weight and speed. Frequently, the grain mass was measured by weighing machine components that transported the grain. In general, problems were noted with dependence on the moisture content and combined operation on slopes. These measuring devices were difficult to construct. Strubbe (1997) reduced this material dependency by changing the mounting of the plate based on measured moments at a specific angle. The signal to noise-level was substantially reduced. This improved system produced a maximum error of 5 % under all field conditions, independent of crop variety and moisture content. The calibration curve was linear, and had only to be determined once a season. When predicted values with this calibration were compared with the mass as measured with a load cell, the error was less than 0.5 % under normal harvesting conditions.

An intelligent yield monitor was developed for grain combine harvester by Minzan *et al.* (2005). The harvested crop was wheat, and the harvesting combine used to equip the monitor was JL1065, a typical machine with 4-meter swath width in northern China. The monitor could collect four analog signals, grain flow, grain moisture content, grain temperature, and header up/down signal, and two digital signals, ground speed and elevator speed. Two digital signals were sensed by Hall effect elements. The monitor could also synchronously receive Digital Global Positioning System (DGPS) signals. A liquid crystal display and a touch screen were integrated as an I/O interface. Field tests showed a linear relationship between actual yield and the output of the yield monitor. The error between measurement and prediction was less than 3 %. It is concluded that the developed intelligent yield monitor was practical. Michihisa *et al.* (2005) developed a grain yield monitor for head-feeding combines. It consisted of two grain flow sensors, a single kernel moisture sensor, an Real Time Kinematic (RTK) GPS and so on. A method to correct the time laged in the separation and cleaning section and the circulation of grain flow using a return flow sensor was adapted to obtain the accurate grain yield. The yield monitor was installed on a 4-row combine, and was tested in several hectares of paddy fields. In addition, a grain yield mapping software was developed for this monitor. A new crop mass flow sensing technology was proposed to reduce the effect of combine dynamic errors by Veal *et al.* (2010). This new sensor measured the flow of biomass through the feeder housing. Results were also compared with to yield data collected from an impact type mass flow sensor located in the clean grain elevator. The results indicated that biomass flow sensing at the feeder housing might complement existing technologies to improve yield monitor data quality.

Indirect Methods

The dielectric constant of the mixture of air and grain increased as the mass flow increased. However, the dielectric constant was not only dependent of the mass flow, but also on the moisture content and grain type. Separate calibrations were required for each grain type. The calibration curve was non-linear and partly dependent of the moisture content. The change of the dielectric properties of the material between two capacitor plates was measured (Stafford *et al.* 1991). It was proposed as a less invasive method of determining the corn yield variation within the field through the use of remote sensing methods (Diker *et al.*, 2002). Aerial images of a field were taken with a multispectral digital camera and these images were analysed using the red, green and near infrared bands. Both traditional yield monitor data and the remote sensing data indicated that the yield variability within the field increased beyond the area covered by the center pivot irrigation system used in the field. Both methods indicated that the center of the field was less variable. Wild *et al.* (2003) proposed another method to determine crop yields that did not involve mass flow measurement within a grain combine. Instead, this method was based on radar pulses. In the test setup, a radar pulse was sent through the material once the pulse struck a metal sheet. The returning signal intensity was recorded. The results of the test were promising, as the coefficient of determination relating the amount of crop to the signal strength was between 94 and 99 %.

Errors in Yield Sensing

The majority of modern yield monitors utilize force sensing of grain mass flow at the top of the clean grain elevator. This technology is simple to implement, relatively inexpensive to maintain and collects data in an efficient manner. Yield monitors are important tools because they provide a summary of yield variability across a field. By understanding the spatial variability in crop yield, a producer can determine the amount and placement of various inputs such as fertilizers, seed or herbicides. The accuracy of yield monitor data is critical to the development of quality yield maps that can be used in the decision making process (Birrell *et al.*, 1996). However yield monitoring is not a perfect technology and it has the potential to generate inaccurate maps as a result of systematic errors inherent with current mass flow sensing techniques.

The accuracy of yield sensing equipment has been a frequent topic of study and is well documented in journals and in conference proceedings. Early research activities were directed towards validating the performance of commercially available yield monitoring systems. Much of this work was focused on quantification of yield measurement errors. Blackmore and Marshall (1996) selected six common sources of error and ranked them according to how much they affect the yield monitor's accuracy. The six errors were incorrect swath width, time lag through the threshing mechanism, GPS error, grain surging within the transport system, grain loss, and sensor calibration. In order to correct or remove the erroneous data, an expert filter and interpolation techniques were adapted to generate the grain yield map. As the grain flow is influenced by the combine dynamics such as the time lags and smoothing processes of the header, threshing section, and separation section, the site-specific grain yield was different from the grain flow into the grain tank. Therefore, it was necessary to analyze the combine dynamics in order to correct the grain flow for the precise grain yield mapping.

Munoz and Colvin (1996) examined a yield monitor in the laboratory and discovered the instantaneous yield was within 10 % of the true continuous yield most of the time. However, it was noted that the values at low flows appeared to be overestimated. Stafford *et al.* (1997) predicted the errors associated with incorrect cutting width could be upwards of 10 %. Drummond *et al.* (1999) proposed a method of using vector analysis in ArcInfo to correct for swath width errors by determining if the area currently being harvested contained a portion of the area previously harvested, thus, reducing the effective cutting width. Wrong interpretation of the cutting width when using partial header resulted in error on measured area and incorrect yield. The header cut off error happened when the combine was not harvesting but area was being added because the system was not shut off (Menegatti and Molin, 2002). Failures on collecting data were found in several situations when the monitor should be recording.

Menegatti and Molin (2002) suggested that errors are usually caused by Global Positioning System (GPS), yield sensor, calibration, moisture sensor, errors related to the combine dynamics and errors related to the measured area. Yield monitors available in the market generate data that may be submitted to a filtering process to improve the quality of information. Fill time error was found in all beginnings and ends of rows. Its characteristic is a slow increase on yield measured as the combine is being filled up. Lag time error is a systematic displacement of the yield points led by wrong time delay in the yield monitor and was found in all data. Bad yield sensor calibration was a systematic error evidenced by a difference between monitor and the total weighed yield. Some errors occurred on specific monitors while others were present in all files. Filters werer proposed with specific routines for each equipment to eliminate errors.

Time lag or time delaywas a common source of error as the time required for grain to travel through the combine to reach the point of yield measurement was variable. This led to incorrect assignment of geographic coordinates to the yield data. Nolan *et al.* (1996) determined that the time delay was generally between 10 to 35 seconds (s) with an average delay of 15 s. Whelan and McBratney (1997) investigated the time lag issue in greater detail and determined that grain harvested at a given position does not reach the mass flow sensor at the same instance in time. Twenty percent of the grain impacted the mass flow sensor 7 s after entering the combine, but grain from this same position continued to impact the mass flow sensor as much as 25 s after the crop had been engaged.

AI-Mahasneh and Colvin (2000) showed that improved filtering techniques and yield algorithms by manufacturers played a major role in the increased quality and accuracy of yield maps. Birrell *et al.* (1996) used a first order system with zero hold to model grain flow through a combine to correct yield monitor data. They demonstrated that the model worked better than the time delay set by the manufacturer but found that the approach was susceptible to signal noise. Similarly a simple time shift of the yield data was proposed by Beal and Tian (2001). They defined a Surface to Area Ratio (SAR) of the yield map, which was minimized to determine the correct offset for generating yield maps. Beck *et al.* (2001) discussed the combination of a number of filtering strategies to develop an all purpose algorithm that can be used to quickly filter yield monitor data. These common filters included removal of unrealistic yield values, removal of unrealistic moisture contents and removal of inappropriate cycle distances.

Many researchers have proposed development of alternatives to the current force impetus devices. For example, Chaplin *et al.* (2003) measured the torque required to drive a modified clean grain elevator. The torque sensor was more responsive to changes in mass flow into the clean grain elevator than the mass flow sensor. However, both measurement devices failed to precisely measure flow rates at levels below 3 kg/s as the standard errors for both devices increased significantly at the lower flow rates (5 to 18 % for the torque sensor and 15 to 60 % for the impact plate sensor).

Arslan and Colvin (1998) tested the AgLeader 2000 yield monitor in a laboratory test stand. When the flow rate was kept constant during each test run, a correlation coefficient of 0.99 was achieved where the largest difference was 9.17 %. However, varying the flow rate during the test run seemed to cause the sensor to be less accurate. Minimum test run duration and flow rates (1.5 kg/s) were also required to achieve this accuracy. Potential extraneous noise signals were identified as the elevator paddles and chain. However, because the processing hardware for the grain flow sensor was sampling at 500 Hz and reporting averaged data at 1 Hz, the sampling rate was high enough to provide a reasonable digital approximation to the response of the grain sensor. Arslan and Colvin (2002) reviewed sources of error in yield maps under various categories. One category was sensor errors. The discussion of sensor errors was focused on accuracy of the overall sensing system, emphasizing primarily the importance of proper calibration for the expected operating range for the combine. Additionally, poor sensor response observed at low flow rates was attributed to the sensing system not being calibrated below 2 kg/s.

Burks *et al.* (2003) noted the instantaneous response of a GreenStar® sensor varied nearly 7 % around the mean for flow rates of 21.1 kg/s. Variation around the mean became high as flow rates increased. Possible explanations included material surging within the material handling system or within the clean grain elevator. The researchers also noted that "instantaneous flow rates may be less reliable further away from the calibration point."

Chaplin *et al.* (2003) employed a Grain Flow Plate (GFP) sensor and a torque transducer to measure grain flow through a combine in a laboratory experiment. Statistical analysis was performed on a 200 Hz signal that would ordinarily be processed by the algorithms in the yield monitor control unit. The yield monitor processing hardware was not used in this experiment. The researchers discovered that for a known grain flow into the combine and for a grain flow plate sensor, sensor precision for flow rates < 1 kg/s was ±60 % and that the error decreased significantly as flow rate increased to the capacity of the machine. Errors from a torque-based sensor were considerably smaller. This experiment represents one of the first attempts to examine the precision of yield sensors on combine harvesters. Performing a field study would be the next step in the evolution of this experiment. Kettle and Peterson (1998) reported that the accuracy of two Green Star yield monitoring systems mounted on two John Deere combines was affected by variation in grain feed rate and field slope. Results from this study indicated that yield estimates while harvesting up slopes (6 to 9 %) were on average 12.5 % less than reference measurements while down slope operation overestimated yields by an average of 36.8 %. They stated that good consistency in the errors measured existed and that a slope correction factor might provide a possible correction technique. They also concluded that the yield monitor's response to decreasing grain flow rates was non-linear, but exponentially making the manufacturer's calibration procedure inaccurate under low field conditions. Specifically, they observed errors of 4.6 % on normal flow rates on level land, compared to 5.7 % at half flow and 20.3 % at one third of the normal flow rate.

Kormann *et al.* (1998) compared different grain flow sensors, and summarized calibration errors of the various sensors used in several years of field tests. The error for the Claydon Yield-o-meter (with paddle wheel—commercialized by the Claas Company) varied between 6.40 and −8.48 % at a 95 % confidence interval. A significant portion of this error was caused by variation in mass density of the grain. A second volumetric sensor, the RDS Ceres II system, had a similar error, ranging between −7.02 and 6.85 %. The grain moisture content was a significant disturbance parameter. The range of the Massey Ferguson radiometric sensor was from −9.15 % to 7.15 % and for the AgLeader yield monitor −10.11 % to 5.67 %. Kornmann *et al.* (1998) also conducted laboratory tests with wheat (14 % moisture content). Again, four sensors were tested, but the Claydon (Claas) Yield-O-Meter was replaced by the Claas Quantimeter 2, an optical sensing system similar to the RDS sensor. In the first test, the error was measured at different mass flows. Five replications were made at each mass flow. The overall error range at a 95 % confidence interval for the RDS Ceres 2 sensor was 0 % to 2 % and −1.5 % to 2.5 % for the Claas quantimeter. The error was greater for the radiometric sensor and the AgLeader 2000 yield monitor, respectively (−3 %, 1.5 %) and (−4 %, 2 %). With those two sensors, the error increased significantly at low flow rates. The slope of the field was less of a factor using the Massey Ferguson radiometric sensor (total error between −2.5 % and 0.5 % at 95 % confidence interval). For the AgLeader 2000, the Quantimeter II and the Ceres 2 sensor the error ranges were (−4.5 % to −1.5 %), (−5.2 % to 3.2 %) and (−3 % to 9.2 %) respectively. The two volumetric sensors are clearly influenced by the slope. Improper calibration was another source of yield monitor error and resulted from using too few calibration data points, calibrating outside of the operating parameters or simply relying on data that were outdated; i.e. using last year's calibration. As manufacturers improved their products, it was imperative that producers take advantage of these newer more precise utilities.

Birrell *et al.* (1994) compared the Claydon sensor with an impact-based sensor, when used for yield mapping. The error on the total yield of a field was similar, but when looking more in detail on smaller surfaces, the signal of the Claydon sensor contained more noise. This was attributed to the discrete measurement method of the sensor. Unfortunately, the authors didn't publish any statistics about the accuracy of this device. The manufacturer of the sensor claims an accuracy of ± 1 % once the moisture content and density are determined correctly (Murphy *et al.* 1994). Stott *et al.* (1993) found an error of ± 10 % when volumetric flow was compared to weighing the contents of the grain bin.

Kettle and Peterson (1998) reported that an error of 5.1 % was encountered in both hillside and level-land operation. It was noted that the yield estimates from the yield monitor were 25 % higher than the weighed measurements for flows below the lower bound of the calibration for the yield monitor. Howard *et al.* (1993), also, determined the error to be 5 % with an alternate yield measurement system from field experiments. These studies did not investigate the response from the yield monitoring systems over small areas or short field transects.

The most common method of assessing yield monitor accuracy was to compare the accumulated mass of grain sensed by the yield monitor to the scaled weights of trucks hauling grain from the field. Many studies using this method have reported errors of 10 % (Grisso *et al.* 2002). There have been numerous efforts by researchers to document and elaborate on the various sources of errors that affect the accuracy of yield monitoring technology. Improper calibration is another source of yield monitor error and results from using too few calibration data points, calibrating outside operating parameters, or simply relying on outdated data (i.e. using last year's calibration). Grisso *et al.* (2002) also noted the importance of yield monitor calibration and that combine operational characteristics impact yield monitor accuracy. One of the most suspect error sources, but with poor quantification to date, is the effect of slope or topography on yield sensor accuracy. Study of calibration error was conducted by changing the amount of material entering the combine by altering the travel speed of the machine. The resulting wet weight calculated by the yield monitor was compared to the wet weight found using weigh scales after each load was unloaded from the combine. The results indicated the yield monitors had less than 4 % error in the calculated weight when the combine was operated at the calibration ground speed. But the error increased to more than 10 % when the machine was operated at speeds outside the calibration range.

The slope also affected mass flow sensor response. Combine pitch had a greater effect than roll on mass flow measurements (Fulton *et al*., 2009). Errors observed during roll tests (−3.45 % to 3.46 %) were considered small and were impractical to using predictive approaches as compared to higher errors (−6.41 % to 5.50 %) due to pitch.

Force sensors for mass flow rate measurement from various studies seemed to have been the best compromise of accuracy versus design constraints and cost. Most commercial yield monitors available today are based on force impetus sensors. Most types of force impetus sensors have been located within the clean grain elevator of the combine.

Commercial Systems

RDS Technology Limited produces a yield mapping system (Ceres) based on volumetric measurement. An emitter/detector system is mounted on the side wall of the clean grain elevator. This system was patented earlier (1982) by the Claas Company. The Claas quantimeter II is similar to the RDS sensor. The Greenstar yield mapping system of the John Deere Company uses an impact style mass flow sensor with a curved plate. The deflection of the plate is measured via a linear potentiometer. Case IH (Advanced Farming Systems) utilizes the impact sensor developed by AgLeader. This impact-type sensor has a flat plate on which the deflection is measured by strain gauges. The Deutz-Fahr Teris system uses the same sensor. The Grain-Trak yield measuring system by Micro-Trak uses two fingers to measure the impact force. With the Fieldstar precision farming system of Massey Ferguson a radiometric yield meter is used. However, in countries where the use of the radioactive radiation source is not allowed, an impact system with two measuring fingers can be used. Harvest Master registers grain flow by measuring the tension in the elevator chain. The idler wheel support is replaced with a load cell to measure the chain tension.

The performance of three of the major yield monitor manufacturers were evaluated through the harvest of wheat and oilseeds (PAMI, 1999). The three systems studied were the Case IH AFS system on a 2188 model combine, the John Deere Green star System on a 9610 combine and the Ag Leader PF 3000 system on a John Deere model 7720 combine. Specifically, each yield monitor was evaluated to determine the ability to measure the amount of grain harvested, GPS position accuracy and the entire unit function for indication of yield while harvesting through the field. In most cases the yield monitors obtained accurate levels of ±2 to 3 % based on accumulated load weights. With proper calibration, all three monitors recognized the magnitude of yield change in field tests. A point of error found was the yield change did not necessarily correspond with the input field yield probably due to variations in the actual time lag not accounted for by yield monitors.

Future Studies

There is the dire need of precision farming in India as the productivity of major crops is 30-50 % below the International averages. India's population is growing faster than its ability to produce rice and wheat. There is uneven scale of mechanization as Punjab is an over-tractorized state. Yield monitoring is the first and essential component to start any precision agriculture system because the data generated by yield monitor systems are used to study yield variability to evaluate the economic benefits of input alternatives and to determine the spatial distribution of inputs required within a field. In India or in Punjab, yield is measured during marketing of harvested crop and as a gross yield of the land owned by the farmer. As reviewed above, in advanced countries, high hp combines used for large farms are available with yield monitors fitted as standard equipment or a yield monitor can be installed separately as an accessory. However, these are difficult to apply to low hp combines directly because the sensor and system has usually been designed for those combines. Beside, the required accuracy of yield is different to that in India because of the difference in the field size. Mainly, combine harvesters are used for the harvesting of wheat and rice in the northern part of India. In Punjab, the total area under combine harvesting for rice and wheat is 91 % and 82 % respectively. Custom hiring operators may charge from the farmers on weight basis rather than area basis. Yield monitor can also be used to measure the yield of experimental research plots of the crops. The yield monitoring combine is expected to play an important role in establishing site specific crop management and spreading related technology to farmers. To spread the use of yield monitoring technology in the Indo-Gangetic plain and throughout India, it is necessary to develop an Indigenous yield monitoring technique for a low hp combine. A batch type yield monitor can be developed to measure the yield for minimum area to be treated; i.e. Kanal (500 sq m) in Indian Farming. The error associated due to swath width, time lag and GPS error can also be eliminated by this method.

Conclusions

Declining factors of productivity, mainly due to indiscriminate use of resources, is one of the major issues of sustainability of Indian Agriculture. Spatial variability in crop productivity is the resultant of soil variability on a spatial scale. Therefore, assessing soil and crop yield variability has been taken up with different approaches in the country. Assessment of the infield variability is very crucial and the first step of precision agriculture. In precision agriculture, after assessing the in-field variability, the same is taken care of through precision land leveling for managing landscape variability, variable rate technology, site-specific planting, site-specific nutrient and other input applications. Researchers have documented significant spatial variation in wheat and rice yield within Indo-Gangetic plains in India. It is important to measure the spatial variation of grain yield for the optimal crop management. Therefore, the grain yield monitor for head feeding combines has been developed to measure the spatial variation of grains.

The yield monitor system performs different functions to prepare yield maps by spatial measurement of yield through GPS. The yield monitor measures the amount of grain in the hopper by using a flow measuring device and other devices, such as a grain moisture sensor. The GPS determines the combine's location from a satellite radio signal. Together, data from the monitor and the GPS system is used to create a yield map for every location in the field. This map can then be used, along with other data, to make crop input and other decisions as a part of a Precision Farming system.

Mainly yield monitors are mass, volumetric flow and impact type depending on the principle of measurement. Critical points include ease of mounting on different types and models of combine harvesters, calibration and precision/accuracy and removal of obstructions to the normal threshing process even when the sensor is damaged. Six common sources of error, which affect yield monitor accuracy are incorrect swath width, time lag through the threshing mechanism, GPS error, grain surging within the transport system, grain loss, and sensor calibration.

Different types of yield monitors based upon the principles of measurements are available commercially. RDS Technology Limited produces a yield mapping system (Ceres) based on volumetric measurement. The Greenstar yield mapping system of the John Deere Company, CASE IH and Deutz-Fahr Teris use an impact style mass flow sensor with a curved plate. The Grain-Trak yield measuring system by Micro-Trak uses two fingers to measure the impact force. A radiometric yield meter is used with the Fieldstar precision farming system of Massey Ferguson. However, in countries where the use of the radioactive radiation source is not allowed, an impact system with two measuring fingers is used.

Need of Yield Monitoring Systems in India

1. Mainly combine harvesters are used for the harvesting of wheat and rice in the northern part of India.
2. In Punjab, the total area under combine harvesting for rice and wheat is 91 % and 82 % respectively
3. Custom hiring operators may charge from the farmers on weight basis rather than area basis.
4. Yield monitor can also be used to measure the yield of experiment research plots of the crops.
5. The yield monitoring combine is expected to play an important role in establishing site specific crop management and spreading related technology to farmers.
6. To spread the use yield monitoring technology in the Indo-Gangetic plain and throughout India, it is necessary to develop an original yield monitoring technique for a low hp combine.

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Feasibility of Axial Flow Propeller Pumps for the Kuttanad and Kole lands of Kerala, India

by

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Abstract

The Kuttanad and Kole lands of Kerala, India are low lying lands subjected to water logging during rainy season mainly due to inadequate drainage facilities. By early twentieth century, the Petti and Para system was introduced for the dewatering operations in these lands which revolutionized the drainage pumping of the areas. Different models of the Petti and Para system are available. However, the system is inefficient in terms of operation and maintenance and demands the requirements of highly efficient pumps for the dewatering operation.

Several types of pumps are available for dewatering, but the axial flow propeller pump ensures high discharge, low head pumping. A propeller pump develops pressure head by the propelling action of impeller blades on water. For the sustainable agriculture operations, the use of axial flow propeller pumps as against the traditional system should be promoted as it accounts for the energy and cost saving technology.

Introduction

The low lands of Kerala, especially Kuttanad and Kole lands, have specific requirements for drainage and other water management practices for supporting sustainable agriculture. During the monsoons, heavy rains flood the fields in these areas. Crops of low-lying areas remain under submerged conditions for several days and plants start wilting and ultimately get damaged. Dewatering the fields commences soon after the wet ploughing and the completion of repairs to the outer bunds. Extensive area of low lying lands in Kerala is subjected to water-logging during rainy season due to inadequate drainage facilities.

Introduction of the locally made propeller pump, known as the Petti and Para, had revolutionized the drainage pumping of the region in the early twentieth century. The Petti and Para is a traditional dewatering system manufactured by local blacksmiths and carpenters. It is a special pump driven by a heavy electric motor and discharges water with high flow rate, against low heads. The Petti and Para is conventionally designed by the local blacksmiths. The pump is connected to the motor using a long belt. The Petti and Para has high discharge capacity under low head conditions.

Several types of pumps are available for lifting irrigation and drainage water under different head and discharge conditions, such as centrifugal pump, turbine pump, submersible pump, mixed flow pump and propeller pump. The centrifugal pump is efficient above 4 m head and produces low-head discharge. Only propeller pumps are specifically suited for high discharge and low head conditions for drainage of water from rivers, canals and ponds. The feasibility of a low head, high discharge, low cost, improved energy efficient axial flow propeller pumps against the traditional Petti and Para system is studied and discussed.

Petti and Para —An Indigenously Developed Pumping Device

The dewatering of low lying lands is mainly done by means of the Petti and Para, a locally made crude form of axial flow dewatering propeller pump. This device was introduced in 1918 by George Brendon, a British engineer utilizing the locally available fabrication facility from black smithy and carpentry. The Petti and Para is cheap in its construction compared to other pumps. Most of the Petti and Para are operated by motors in the range between 25-100 HP, mostly by 50 HP motors. Though it meets the requirement for pumping, it is highly inefficient in terms of energy consumption. The farmers stick to the Petti and Para as they are provided with full subsidy on electricity by the State Government. The Petti and Para system is shown in **Fig. 1**.

Saji (1994) conducted studies on the effect of various parameters on the performance of the Petti and Para in a specially designed and constructed test bed at KAU, Vellanikkara. Tests were conducted by varying the number of blades on the impeller. For a 4 bladed impeller, the maximum efficiency obtained was 23.72 percent at 350 rpm against a head of 89.15cm and a discharge of 291.83 lps. Input power was 14.62 HP. For a 5 bladed impeller, maximum efficiency was 30.09 percent at 330 rpm with an input power of 13 HP. For a 6 bladed impeller, the maximum efficiency obtained was 18.98 percent at 305 rpm. He concluded that a 5 blade impeller was most suitable for a 15 HP Petti and Para with a working speed of 330 rpm.

Construction Details

A rotating impeller is housed inside a cylindrical wooden drum called Para. By the rotation of the impeller the hydro dynamically activated water flows axially upwards through the Para, takes a 900 turn and flows out through a horizontal rectangular wooden outlet called Petti. The impeller with shaft is suspended from a thrust bearing resting on a stand tube. The Petti is rigidly housed to the embankment made of bamboo and mud. The axial load on Petti is thus transferred to the basement. Vanes of the impeller are bolted to the shafts of the impeller. The major parts of the system, the 'Petti' and the 'Para', are shown in **Figs. 2a** and **2b**.

The impeller is made of cast iron and blades are made of mild steel. The number of blades on the impeller is three or four. A mild steel shaft of 100 mm diameter is used for the pumping unit. The power for driving the pump is from a three phase 50 HP induction motor through a belt drive. A rotor type thrust bearing is used to suspend the rotor. The Petti is made of tongue and grove wooden planks with a metal plate to make it water tight. The Para is made of wood and strengthened by mild steel rings. The dimensional details of the Petti and Para are given in **Table 1**.

The 'Para' is in the form of a cylindrical wooden drum and is made out of wooden planks, which are tongued and grooved so as to make the 'Para' water tight. The impeller is fixed to the shaft so that it is housed inside the top 'Para'. The inside of the top the 'Para' is lined with M.S. sheet where the impeller is positioned so that it protects the Para, that is made of wooden planks, from rupture in case of bearing failure.

The Para was originally made of wood and now of iron, and is made water-tight. A flat pulley is provided at the top of an iron shaft. The discharge pipe (the Petti) is made up

Table 1 Dimension of the Petti and Para

Petti	(cm)
L × B × H	480 × 108 × 44
Thickness of the wooden plank	9
Para	
Diameter	76
Height	115

of boat quality wood in rectangular shape. The top of the Para is fitted to the Petti. Thus, the water lifted by the rotation of the impeller (as shown in **Fig. 3a** rises up through the Para and flows across the bund through the Petti. Most of the Petti and Para are operated by motors in the range between 25 HP and 100 HP. The motors usually used are slip ring type, fitted with the outdated oil immersed starters. A flat quarter turn belt drive of about 20 cm width is used to take the power to the impeller shaft. The motor shaft is horizontal and that of impeller is vertical. Length of the belt drive is nearly 10 m. Para is vertically hung on a pair of rails mounted on a masonry structure. The bottom of

Fig. 2 Major parts: **2a** Petti; **2b** Para

Fig. 1 The Petti and Para in operation

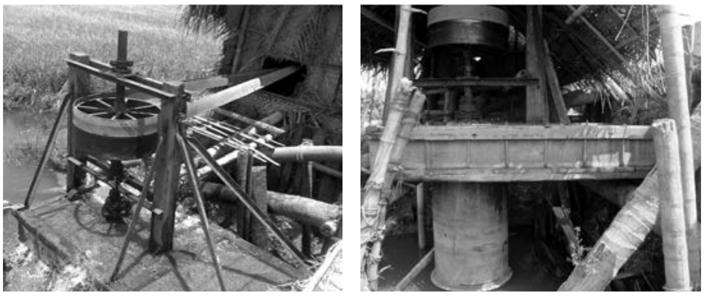


Fig. 3a The impellor; **3b** Butterfly valve

the Para is provided with a butterfly mild steel foot valve for restricting the backward flow as shown in **Fig. 3b**. The foot valve is seated perfectly over the M.S. ring without any leakage in order to avoid priming of the pump often. The views of a typical Petti and Para are shown in **Fig. 4**.

Specifications of the Petti and Para vary in Kuttanad and Thrissur-Ponnani type. The Kuttanad model is made of Anjili and Tharubagam timber while Thrissur model by Anjily Milal and Pongu. The Petti and Para are of four types depending upon the material of construction and are: (a) both made of wood, (b) Petti made of wood and Para made of iron, (3) Petti and Para made of iron with belt drive and (4) both Petti and Para are made of iron with direct drive.

Present Status

- Pump houses are temporary sheds, thatched roof, RCC or hollow block-light roofing.
- The condition of the system is leaky.
- Careless and improper routine maintenance.
- Aquatic weeds, foreign materials affect operation.
- Operates sometimes for 24 hrs daily, for more than 20 days continuously.
- Unsafe electrical connections, unergonomic pump house lay-out.
- Low efficiency –20 and 25 percent.
- Huge loss in electricity.

The problems faced by farmers are installation, operation, maintenance work below water level is a challenging job, risky life; difficulty in getting the device fabricated in time by local artisans; bulky and heavy-difficulty in transportation: metal and wood used are poor quality; minimum period of drainage for inundated rice crop is 26 hrs, and increase in total head to 3-4 m.

A preliminary study conducted revealed that the Petti and Para runs most inefficiently with heavy loss of power. Efforts are on to improve the efficiency and reduce power consumption. With the solid technical support from EMC, an NGO in Kuttanad, by name STARS, has prepared a project, which is funded by the Science and Society Division of DST, Govt. of India. Use of new materials and computer-aided design for upgrading the device is contemplated by the Centre.

The entire water from the waterlogged area is drained into the nearby sea for seed bed preparation for rice cultivation. The waterlogged lands have to be drained in the shortest possible time to initiate seed bed preparation. The short time available for seed bed preparation need adoption of high discharge low head pumps. The low head, high discharge, low cost improved energy efficient axial flow pumps may be provided at subsidized cost to famers to pump out the flood waters from the fields to save their crop during heavy monsoon rains.

Propeller Pumps

A propeller pump is specifically adopted to high discharge low head pumping. It is most suitable to lift water from canals, rivers and streams and in dewatering schemes. It has high efficiency under low heads, especially within 4 meters. It

Fig. 4 A typical Petti and Para

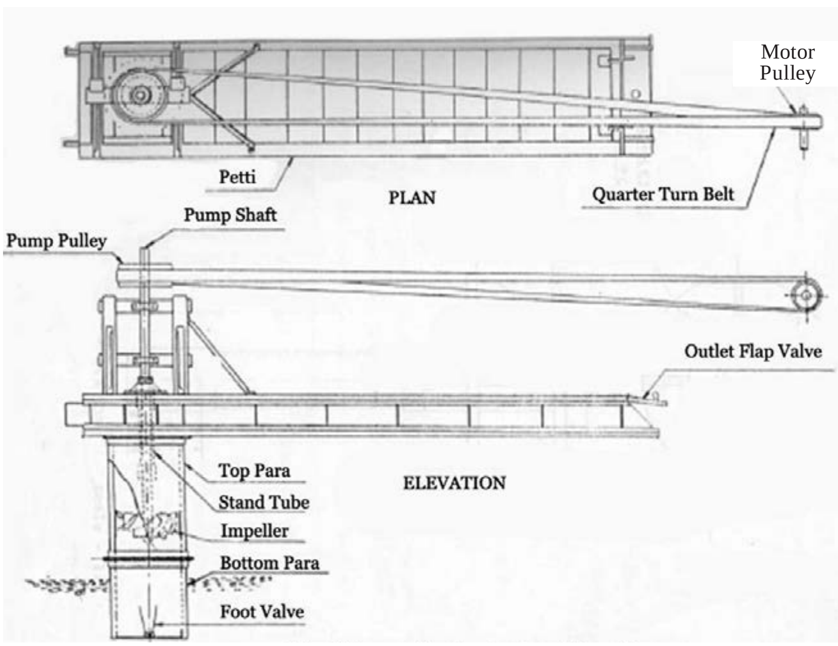


Fig. 5 Portable axial flow pump (IRRI)

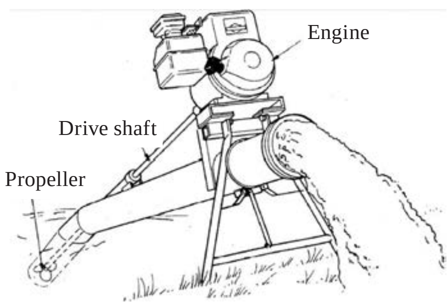


Fig. 6 A giant-sized impeller mounted on drive shaft

can be used as portable units operated by light weight engines or in permanent installations using electric motor or engines. Propeller pumps are axial flow pumps in which the pressure head is developed mostly by the propelling or lifting action of the propeller blades on water. It can be used as portable units operated by light weight engines or in permanent installations using electric motor or engines.

Review of the Study

Small scale propeller pumps are quite successfully improvised but not usually manufactured; ordinary boat propellers mounted on a long shaft have been used for flooding rice paddies in parts of South East Asia. The International Rice Research Institute (IRRI), Los Banos Philippines (1979), developed this concept into a properly engineered, portable high volume pumping system, as shown in **Fig. 5** that is designed to deliver up to 180 m3/h at heads in the range l - 4 m. The pump requires a 5 HP (3 kW) engine or electric motor capable of driving its shaft at 3,000 rpm; its length is 3.7 m, the discharge tube is 150 mm in diameter and the overall mass without the prime mover fitted is 45 kg. A maximum efficiency of 69.1 percent at a discharge of 45 lps against a head of 2.5 m at 2,890 rpm was observed.

A propeller pump designed by TNAU with the flexible transmission system was operated by power tiller. The rigid transmission system was developed by Thakur (1998) and tested under laboratory conditions and by Rai and Dilmani (1999) under field conditions in the College of Agricultural Engineering, Pusa, Bihar, India. Due to high power input, the efficiency of the pump was very low (4 percent).

A transmission system with a portable diesel engine was designed, fabricated and tested under field conditions to operate the propeller pump with good discharge and efficiency. The pump was operated with a 5 HP diesel engine at 1000 rpm under field situation and was tested at different heads at the fixed speed. The variation of discharge was in a narrow range at lower heads. The optimum operating head of the pump was 1.2 m at which the discharge rate was 33 lps and efficiency of the pump was 14.8 percent (Sharma and Singh, 2003).

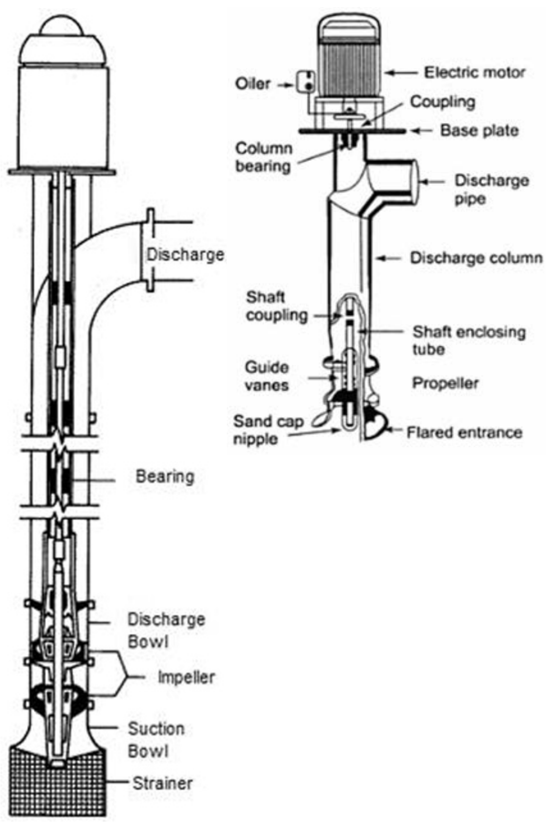
Rini Rani (1998) conducted experiments on the performance characteristics of 15 cm axial and mixed flow pumps at an especially designed and constructed test bench. The pumps were tested at different speeds. Mixed flow pump maximum efficiency of 42.16 percent was obtained at a speed of 1,000 rpm against a total head of 217.33 cm and a discharge rate of 49.47 lps. The input power was 3.4 HP. For axial flow pumps, the maximum efficiency was 18.05 percent at a speed of 2,500 rpm at a total head of 160.55 cm with a discharge of 24.88 lps. The corresponding input power was 2.95 HP.

Construction of the Pump

The parts of a propeller pump may be divided into four assemblies: propeller and diffuser assembly (bowl assembly), pump column, discharge head and pump drive as shown in **Fig. 7**. The basic elements of a propeller pump are the propeller and diffuser, often forming a distinct bowl assembly which is submerged under the liquid to be pumped. A flared entrance below the propeller is used to reduce entrance losses. The impeller operates in a cylindrical casing that is an extension of the discharge column assembly. The impeller usually has 3-6 blades (as shown in **Fig. 6**, depending on the design specific speed. The blades are set on the shaft at angles determined by the total head and operating speed of the pump. The propeller is mounted on a suitable shaft. The propeller blades are carefully filed and scraped to reduce skin friction. They are keyed to the drive shaft and are accurately positioned by a locking collar and nut. A cone-shaped cover is usually installed over the locking nut to eliminate eddies and prevent the entry of sand or grit into the lower pump bearings. The diffusion vanes smooth out the disturbances caused by the propeller. The propeller is mounted on a suitable shaft.

The column assembly of a propeller pump comprises the line shaft, which joins the impeller with the driving head shaft. The line shaft is provided with suitable bearings,

Fig. 7a Propeller pump elements, **b** View of propeller pump with the propeller and lower shaft assembly exposed



usually grease lubricated. The discharge column is a combination of a column pipe and delivery bend, and is designed so as to reduce hydraulic losses to the minimum. It is especially machined for accurate alignment. A cover plate is bolted on top of the discharge head that provides a seat to the skirt of the driving head, which comprises a vertical motor and arrangement for oil/water lubrication. An impeller adjusting nut is provided at the top of the motor. The thrust is borne by a thrust bearing located in the top cover of the motor. The propeller pump elements are shown in **Figs. 7a** and **b**.

Operation of the Pump

Propeller pumps are axial flow pumps in which the pressure head is developed by the propelling or lifting action of the propeller blades on water. Propeller pumps may be oil lubricated or water lubricated. There are only a few firms in India dealing in factory made propeller pumps. These pumps are manufactured for specified head and discharge ranges. The prices of these pumps are disproportionately high and beyond the capacity of an average farmer. In such a situation, the farmers have no other choice but to use the centrifugal pump which is inefficient at low heads and result in high cost of irrigation or drainage and huge loss of energy.

Ultra low head technologies consist of locally made axial flow pumps driven by similar or identical single and multi cylinder engines (Perry, 1997). While centrifugal pumps are able to operate against lifts of 30 m, propeller pumps work efficiently up to 5 m lift, but provide a much larger flow. These pumps propel water by the reaction to lift forces produced by rotating its blades. This action pushes the water past the impeller while imparting a spin to the water that passes through fixed guide vanes to straighten the flow and convert the spin component of velocity into extra pressure. The flow path of axial pumps is shown in **Fig. 8**.

Installation

Propeller pumps may be used as portable units or may be installed permanently. When installed permanently, a propeller pump should be set on a firm foundation of adequate load bearing capacity. The entire weight of the pump is supported at the base of the floor plate. The foundation should be able to support the weight evenly on all sides of the base plate, and allow the pump to hang freely. In permanent installations, propeller pumps are mounted vertically. For portable pumping platforms, they are mounted on trailers or they are mounted on pontoons for use as floating intakes. Portable propeller pumps are commonly mounted in almost horizontal positions (low angles) to allow them to pump into pipelines easily as well as to be backed into a water source. Portable propeller pumps are commonly powered by the power-take-off (PTO) on tractors. On many farms, propeller pumps are used to pump out waste storage lagoons.

For large drainage installations, two or more pumps with different capacities may be necessary, one or more of them for handling the surface run-off during rainy seasons and the others for seepage or flow from tile drains. The size and number of pumps are determined mainly by the quantity of water to be pumped. When pumping from large areas and where high value crops are involved, a large number of pumps will provide more efficient pumping over a wide range of pumping rates and also provide continued pumping even when there is a breakdown in one of the pumps.

Criteria for Selection of Propeller Pumps

Propeller pumps are usually selected up to maximum head of 4 m. The data needed to select propeller pumps include the following:

- Capacity of pump, liters/second
- Discharge conditions:
  Discharge above water level
  Submerged discharge
  Siphon
- Static lift, meters
- Length of discharge pipe, meters
- Power available:
  Electricity: voltage and phase
  Stationary engine/ tractor
- Type of driver:

Fig. 8 Flow path in axial pumps

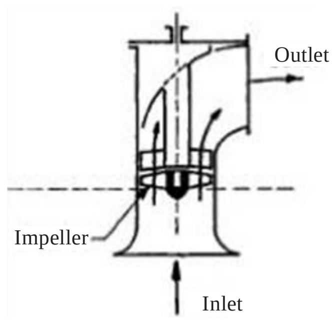
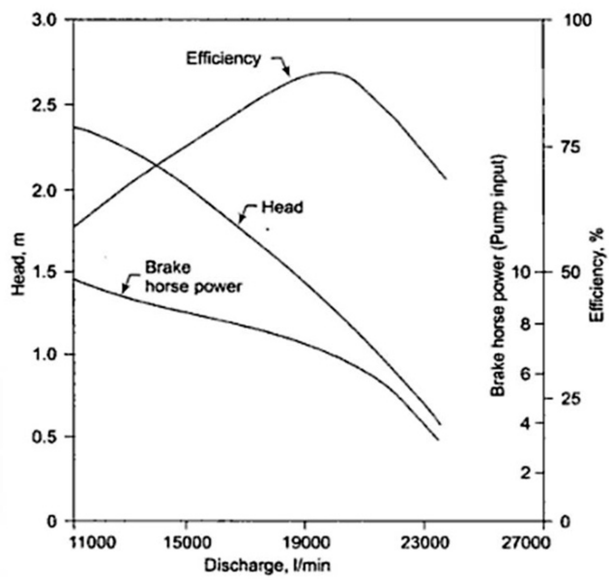


Fig. 9 Performance curves of a typical propeller pump



Direct-connected, vertical hollow shaft motor, flat belt, V-belt

Performance Characteristics of a Propeller Pump

The head capacity curve of a propeller pump is steeper than that of the centrifugal pump. The propeller pump should be operated at rated head as slight increase in the pumping head causes a large decrease in the quantity of water delivered. The brake horsepower curve slopes downward to the right, in contrast to that of the centrifugal pump which slopes upward to the right, with a slight downward hook at very high capacities. The performance curve of a propeller pump is shown in **Fig. 9**. Thus, the power requirement of a propeller pump is increased as the head is increased and the capacity is reduced, whereas, in a ccentrifugal pump, the power required is decreased as the head is increased and the capacity drops down (Michael et al., 2008).

Overload is likely to occur in a propeller pump, when the discharge valve, if provided, is nearly closed. Because of the steep horse power curve at shut off, propeller pumps are started against an open discharge. There is tendency for a propeller pump to overload as the head is increased. Motor or engine of adequate power is selected to operate the pump through the entire range of conditions caused by the variations in water level.

Propeller pumps are not suitable under conditions where it is necessary to throttle the discharge to secure reduced delivery (Thomas, 1993). The head against which water is pumped using a propeller or mixed flow pump is an important factor influencing efficiency. Since the movement of the water is in the axial direction and there is a large free passage, there is very little frictional resistance to flow.

A disadvantage of the propeller pump is the high power required to operate it against a low discharge. This difficulty is eliminated in some makes of propeller pumps by providing adjustable blades. The blades are adjusted manually or automatically to suit the rate of discharge and operating head. This arrangement is advantageous where the head varies over a considerable range or where it is necessary to adjust the discharge of the pump.

Conclusion

Utilization of improved modern farm machinery would enhance optimum utilization of agricultural inputs, increase efficiency in farm operations and reduce cost of cultivation and mitigate the problems due to shortage of farm laborers. The use of the traditional Petti and Para system in the low lying lands of Kerala is inefficient in terms of power requirement and operation.

The use of propeller pumps results in substantial saving in energy and expenditure in drainage pumping which is the most expensive component of farming in Kuttanad and Kole lands of Kerala. The low cost of the technology relative to currently available equipment will facilitate acquisition and reduced operating costs will make use more sustainable.

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Effects of Threshing Unit Feature on Threshing Unit Losses for Thai Axial Flow Rice Combine Harvesters

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Abstract

The objective of this research was to investigate the effects of threshing unit features on threshing unit losses for Thai axial flow rice combine harvesters. Chainat 1 variety is the most susceptible to the losses by the threshing units. The results indicated that the concave rod clearance (RC) was the most effect on threshing unit loss, at 27.54 %, followed by the side concave clearance (SC), concave clearance (CC), and upper concave clearance (UC), at 25.86, 20.29, and 15.27 %, respectively. The number of spike teeth (NT), rotor diameter (RD), and height of spike teeth (HT) showed relatively low losses by the threshing units, at 9.14, 1.90, and 0.22 %, respectively. The increase of RC, SC, UC, RD, NT, and HT reduced threshing unit losses, whereas the increase of CC increased the loss.

Acknowledgments

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Introduction

At present rice combine harvesters play an important role in rice harvesting in Thailand. About 10,000 Thai rice combine harvesters are spread all over the country (Chinsuwan, 2010), as shown in **Fig. 1**. These combine harvesters are capable of harvesting all rice varieties in Thailand and all of them are axial flow type, as shown in **Fig. 2**.

Threshing loss is an imperative problem for Thai combine harvesters. Chuan-udom and Chinsuwan (2010) found that the threshing unit caused approximately 90 percent of the total losses and was particularly true with the hybrid varieties. The threshing unit losses were not only caused by the difference in threshing feature, but also by threshing unit adjustments and operation conditions.

The study of operations and adjustments of the Thai axial flow combine harvester by Chuan-udom and Chinsuwan (2009a) showed that the rotor speed, guide vane inclination, grain moisture content, feed rate, and grain to material other than grain, had significant effects on the threshing unit losses. Besides operation and adjustments, the feature or design of the threshing unit

Fig. 1 Thai axial flow rice combine harvesters

Fig. 2 Axial flow threshing unit

was also an important factor leading to losses from the threshing unit. Despite the fact that the combine harvester manufacturers in Thailand produce similar axial flow combine harvesters, the sizes and the various clearances in the threshing units are different from one to another. The study by Chinsuwan *et al.* (2003) on the effects of the threshing bar inclination and concave rod clearance on threshing losses of an axial flow rice thresher, used with Thai Hommali rice, revealed that the threshing bar inclination did not affect to threshing unit loss. Concave rod clearance of 17 to 20 millimeters was recommended. Chinsuwan *et al*. (2004) also studied the clearance between the threshing bars for a sticky rice thresher and recommended the 17 to 22 millimeter clearance. A study by Chuan-udom and Chinsuwan (2009b) on the concave rod clearance and the number of concave bars was made for Chainat 1. They found that concave rod clearance between 15 to 20 millimeters was recommended and that the number of concave bars had no effect on the losses. Past studies emphasized the operations of threshing units. The important factors in the feature of axial flow combine harvesters only included the concave rod clearance, the threshing bar inclination, and the number of concave bars. Some research has been done on other major factors on the features of threshing units, especially in the Thai axial flow rice combine harvester. Additionally, the past research was performed on one particular factor at a time, which may not have greatly affected the overall operation of threshers. Hence, the objective of this research was to study the effects of the overall threshing unit feature on threshing unit losses for Thai axial flow rice combine harvesters. The results would be useful for designing the feature of threshing units for reducing the losses on a combine harvester.

Methodology

Experimental Factors

The important factors that affected the threshing unit losses (TL) of Thai axial flow rice combine harvester were comprised of the rotor diameter (RD), concave rod clearance (RC), concave clearance (CC), side concave clearance (SC), upper concave clearance (UC), number of spike teeth (NT), and height of spike teeth (HT), as shown in **Fig. 3**. The operational factors affecting the losses from the threshing unit and, thus taken into account, included the tangential rotor speed (RS), guide vane inclination (GI), grain moisture content (MC), feed rate (FR), and grain to material other than grain (GM) (Chuan-udom and Chinsuwan, 2009a). The finding indicator, Chainat 1, which is the most susceptible variety to threshing unit losses in the Thai axial flow rice combine harvesters, were used in the test.

Experimental Design

Since there were many factors taken into account in the study, a normal experimental plan would be costly and required a very large size of experimental field. Furthermore, the samples had to be collected within the experimental day so that their conditions would not alter too much. Thai axial flow rice combine harvesters, even though they have been developed and improved until they become suitable for domestic harvesting, the design of clearances and sizes of the various components were different. These limitations, together with the condition of the axial flow rice combine harvester being used in the country necessitated the use of sampling experimentation by random. Different feature factors of threshing units from seventeen combine harvesters at work through the harvesting season were sampled for measurement before the data on the operations and loss were collected.

Data Collection

The experiment was conducted in 3 replicates, each time with the combine harvesters operating for not less than a 15-meter distance

Fig. 3 Clearances of threshing unit feature

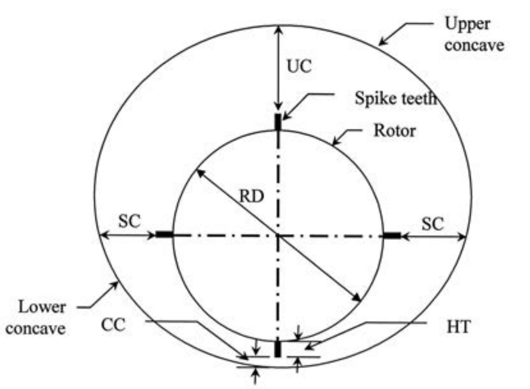


Fig. 4 Collection of samples of threshing unit losses of axial flow rice combine harvesters

so that the machine would have attained its constant operation condition and the data on losses were collected after 10 meters.

The experimental steps included collection of materials discharged from the threshing unit using a net bag (**Fig. 4**) and then straw was separated in order to obtain the grains that were still on the ears (the threshing losses), and the threshed grains. Both of these losses were designated as the TL.

Analysis

The feature factors and the operation results affecting the TL were determined from the collected data through the multiple linear regression equation, shown in **Eqn. 1**:

$$Y = A_0 + A_1X_1 + A_2X_2 + A_3X_3 + \ldots + A_nX_n \quad (1)$$

where Y = threshing unit loss
$X_1, X_2, \ldots, X_n$ = factors
$A_0, A_1, \ldots, A_n$ = constants

From the multiple linear regression, an analysis was conducted to determine the influence of the feature factors based on the results of factors affecting R^2 and tendency of the factors to affect the TL.

Results and Discussion

The experiment was conducted in May and June, 2010. Seventeen axial flow rice combine harvesters were investigated. The rice conditions, threshing unit feature, operations, and the TL are shown in **Tables 1** and **2**.

From the data in **Table 2**, the multiple linear regression equation was constructed based on the pattern of **Eqn. 1**. **Eqn. 2** was obtained of the threshing unit feature factors and the operations affecting the TL with the coefficient of determination (R^2) equal to 0.729.

$$TL = 63.417 - 0.009(RD) - 1.822(RC) + 0.213(CC) - 0.119(SC) - 0.041(UC) - 0.02(NT) - 0.009(HT) - 0.211(GI) - 0.059(RS) + 0.151(MC) + 0.071(FR) - 0.371(GM) \quad (2)$$

Influences of Feature Factors on Threshing Unit Losses

Eqn. 2 was used to analyze the factors in the feature and operations of the threshing unit of the axial flow rice combine harvesters that affected the TL as shown in **Table 3**. The first 5 factors with an influence on the TL were in the threshing unit feature. RC had the greatest effect on the TL (22.80 %), followed by SC, CC, UC, and NT, with the effects on the TL at 21.41, 16.80, 12.64, and 7.57 %, respectively. The total effect of these 5 factors on the TL was roughly 80 %. The other threshing unit feature factors, RD and HT had an effect on losses of 1.57 and 0.18 %, respectively. The operation factors of the threshing units, GI, MC, FR, RS, and GM affected TL at 7.11, 5.72, 3.41, 0.42,

Table 1 Condition of rice tested with the combine harvester

Height of Crop plant, cm	Inclined angle of crop plant, degree	Plant population per square meter	Straw Moisture contend, %wb	Total yield, kg/ha at 14 % wb
73.2	11.2	388	64.39	5,291
70.4	12.1	608	63.74	5,201
65.9	11.7	543	61.32	5,581
66.5	11.5	687	66.19	5,664
68.8	9.9	441	69.85	4,713
70.7	11.9	521	63.66	4,324
69.9	14.0	505	65.52	5,463
64.6	12.3	392	65.75	5,125
66.1	12.5	514	65.54	6,126
71.2	11.8	403	66.62	5,943
71.0	11.0	477	64.44	6,550
77.3	10.8	687	61.09	5,523
75.0	11.2	546	61.98	4,828
78.5	11.5	431	58.13	4,493
65.0	11.7	243	63.08	3,230
79.0	11.4	443	61.12	5,262
75.2	10.5	515	61.35	4,199

Table 2 Threshing unit feature, operating conditions of combine harvesters, and losses from threshing units

RD	RC	CC	SC	UC	NT	HT	GI	RS	MC	FR	GM	TL
521	18.0	25.4	37.5	157.5	200	82.6	69.0	16.8	24.37	16.9	0.97	3.63
572	18.0	25.4	28.8	169.8	165	76.2	69.0	16.8	22.58	13.6	0.75	3.82
572	18.0	21.3	28.8	169.8	185	76.2	69.0	16.5	29.36	10.2	1.38	4.98
508	15.9	13.0	31.1	201.1	156	88.9	68.0	17.6	28.21	16.9	0.46	8.73
559	15.9	21.2	51.1	196.1	140	88.9	68.0	17.6	29.72	9.3	0.77	5.22
445	15.9	14.0	41.1	131.1	132	88.9	66.5	15.8	25.19	9.6	1.02	8.31
457	15.9	25.4	38.4	162.4	132	101.6	60.0	13.8	26.14	18.6	0.87	14.37
457	15.9	25.4	50.8	177.8	148	76.2	65.0	17.8	24.25	11.7	0.89	7.73
508	15.9	23.0	35.1	206.1	156	88.9	67.0	14.8	23.63	22.8	0.64	5.96
508	15.9	10.0	36.1	154.1	148	88.9	70.0	21.5	26.96	9.2	1.06	4.35
559	15.9	22.7	53.8	193.8	185	76.2	68.0	18.7	21.91	23.4	0.90	5.46
508	18.0	16.0	16.1	151.1	132	88.9	67.0	18.4	22.90	10.9	0.80	8.58
559	15.9	25.4	53.8	193.8	185	76.2	75.0	17.5	21.31	12.8	0.96	5.64
483	15.9	17.0	51.1	151.1	210	88.9	66.0	18.3	23.75	13.0	1.04	5.78
533	15.9	20.0	21.4	193.4	165	101.6	67.0	16.1	22.23	9.5	0.62	7.54
546	15.9	22.0	46.1	216.1	156	88.9	70.0	15.5	22.03	18.5	0.74	4.07
546	15.9	20.0	46.1	216.1	160	88.9	67.0	15.1	25.65	13.5	1.16	4.81

and 0.37 %, respectively.

The threshing unit feature factors were compared to the threshing unit operation factors. The threshing unit feature greatly affected the TL. The influence on the loss was about 83 %. The threshing unit operation factors affected the TL at about 17 %. The threshing unit feature was very important for the harvesting loss, especially the TL. The effect of **Eqn. 2**, when considering only the threshing unit feature factors on the TL, are shown in **Table 4**.

Table 4 shows that the seven threshing unit feature factors taken into consideration were divided into two groups. The first group consisted of factors affecting the TL at a relatively high level. RC had the greatest effect on the TL at 27.54 %, followed by SC, CC, and UC where the effects were 25.86, 20.29, and 15.27 %, respectively. The second group including NT, RD and HT showed relatively low effects on the TL; i.e., at 9.14, 1.90, and 0.22 %, respectively. This showed that these factors operate effectively in the Thai axial flow rice combine harvesters.

Table 3 Influences of threshing unit feature and operation factors of axial flow rice combine harvesters on the loss of threshing unit

Factor	Percent of the factors influencing the loss of threshing unit
RD	1.57
RC	22.80
CC	16.80
SC	21.41
UC	12.64
NT	7.57
HT	0.18
GI	7.11
RS	0.42
MC	5.72
FR	3.41
GM	0.37

Table 4 Influences of threshing unit feature and operation factors of axial flow rice combine harvesters on the loss of threshing unit

Factor	Percent of the factors influencing the loss of threshing unit
RD	1.90
RC	27.54
CC	20.29
SC	25.86
UC	15.27
NT	9.14
HT	0.22

The Tendency of Threshing Unit Features on Threshing Unit Losses

Eqn. 2 was used to determine the relationships between each factor of the threshing unit feature and the TL. In the analysis, the operations of the combine harvester were set. The RS was 18 m/s and the GI was 68 degrees, harvesting rice at 23 % w.b. MC. The FR was 14 tons/h, harvesting rice with 0.6 GM, which was the appropriate rice condition for the operation (Chuan-udom, 2007). The results are presented below.

Fig. 5 shows the effect of RD on the TL when the threshing units had 18 mm RC, 15 mm CC, 40 mm SC, 170 mm UC, 175 NTs, and 88.9 mm HT. The results show that when the RD size was increased, the TL tended to decrease since the increasing diameter of the rotor necessitated a larger concave that resulted in a greater area for threshing and removal of straws from grains. More grains were able to fall down to the cleaning unit, thus, decreasing loss.

The following effects of RC were found on the TL, on the condition of 508 mm RD, 15 mm CC, 40 mm SC, 170 mm UC, 175 NTs, and 88.9 mm HT, as shown in **Fig. 6**. The increase of RC decreased the TL since the increase of the RC meant the enlargement of the space for more threshed grains to pass the mesh before being blown away with the straw by the straw rotor blades. Therefore, the TL, especially losses from separation of grains from

Fig. 5 Effect of rotor diameter on threshing unit loss

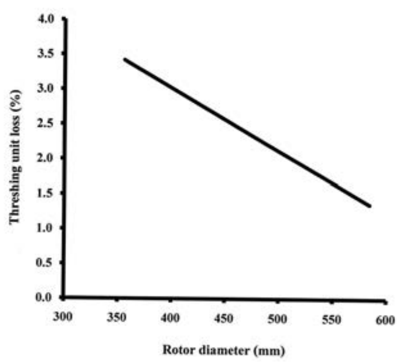


Fig. 6 Effect of concave rod clearance on threshing unit loss

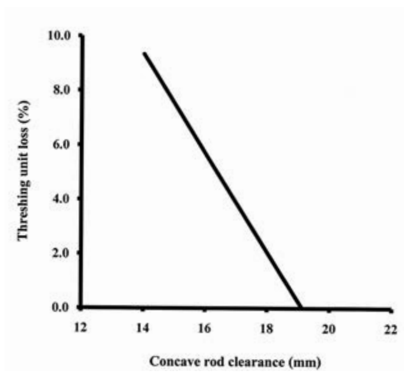


Fig. 7 Effect of concave clearance on threshing unit loss

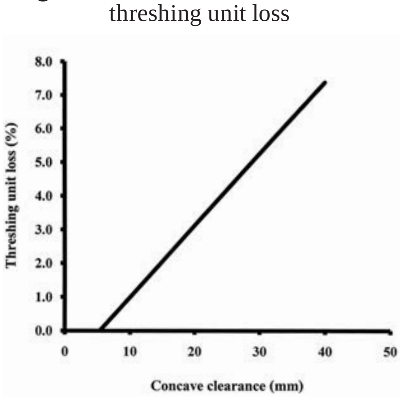
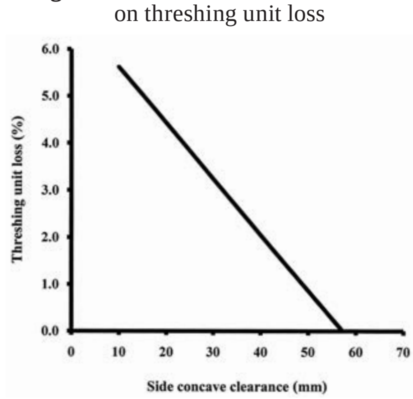


Fig. 8 Effect of side concave clearance on threshing unit loss



straw, decreased. This result agreed with the results of the previous study of Chuan-udom and Chinsuwan (2009b).

Fig. 7 shows the results of CC on the TL when RD was 508 mm, RC was 18 mm, SC was 40 mm, UC was 170 mm, with NT of 175, and HT was 88.9 mm. The TL increased with the increase of CC. This result correlated with the study of Joshi and Singh (1980). The increasing of this clearance lowered the threshing action, leading to less capacity of the thresher in removing the grains from the ears that are, in turn, blown away by the rotor blades resulting in increasing the TL.

The effects of SC on the TL were found when RD was 508 mm, RC was 18 mm, CC was 15 mm, UC was 170 mm, there were 175 NTs, and HT was 88.9 mm, as shown in Fig. 8. When the SC increased the TL showed a tendency to decrease since the increase of this clearance reduced disentangling the straws, which meant the straws no longer held the threshed grains when they were blown out of the straw chute. The action was simultaneous with the beating of straws to loosen the grains from the ears by the rotor and the lower concave. This was done alternately with the action of the combing of straws by the rotor with the concave horizontal. Nevertheless, the clearance should be limited at a certain level because, if it is too wide, the strength on the structure of the threshing unit and the combine harvester will be reduced. This can result in manufacturing complexity and cost.

Fig. 9 shows the effects of UC on the TL with 508 mm RD, 18 mm RC, 15 mm CC, 40 mm SC, 175 NTs, and 88.9 mm HT. When the SC increased, the TL was likely to decrease. The timing of rotational beating of straws towards the upper part of the threshing unit (at the UC) with the large clearance could lead to blowing or the disentangling of straws and dropping of the grains, leading to less loss. However, the clearance should not be too high because it, also, could affect the thresher structure or the upper combine harvester.

The effects of NT on the TL occurred when RD was 508 mm, RC was18 mm, CC was 15 mm, SC was 40 mm, UC was 170 mm, and HT was 88.9 mm as can be seen in **Fig. 10**. The increase of NTs led to the decrease of the TL. A higher number of threshing spike teeth increased the impact of beating, making more grains drop from the ears and, hence, lowered the TL, especially threshing losses. Also, the straws could be cut into shorter strings because the beating or impact action resulted in ease of grains separating from straw and reduced loss. However, increasing the number of threshing spike teeth meant more energy required in threshing.

Fig. 11 shows the effects of the HT on TL, with 508 mm RD, 18 mm RC, 15 mm CC, 40 mm SC, 170 mm UC, and 175 teeth of NTs. When the HT was greater, the TL decreased since the increase of the height of the spike teeth increased the impact of beating the grains from the ears. The disentangling action of the straws and the removal of the grains from the straws, which was done alternately with the beating, were also more efficient. However, the increase of the spike teeth height meant more energy required in threshing.

The results from the relationships between the threshing unit feature and the TL indicated that, to keep the TL value at less than 2.5 percent, the RD should not be smaller than 457 mm or 18 in. The RC should not be less than 17.5 mm and the clearance should not be over 20 mm, which could make more straw falling into the cleaning unit. The CC should not be over 17 mm, whereas the SC should be lower than 35 mm, and the UC not less than 170 mm. For threshers 1.80 m (6 ft) long, NT should not be less than 150 teeth and the HT should be over 50 mm or 2 in.

Conclusions

The study found that RC affected the TL most, followed by the SC, CC and UC. The NT, RD and HT were a insignificant influence of the

Fig. 9 Effect of upper concave clearance on threshing unit loss

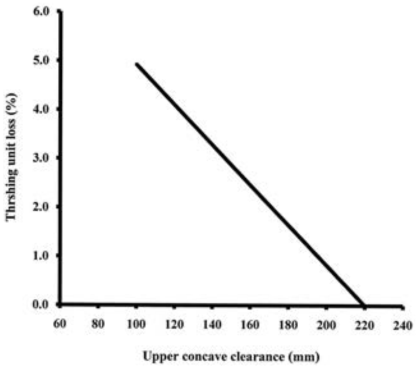


Fig. 10 Effect of number of spike teeth on threshing unit loss

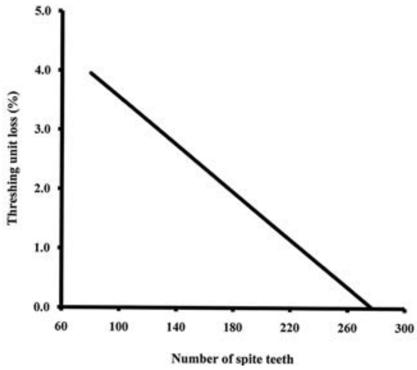
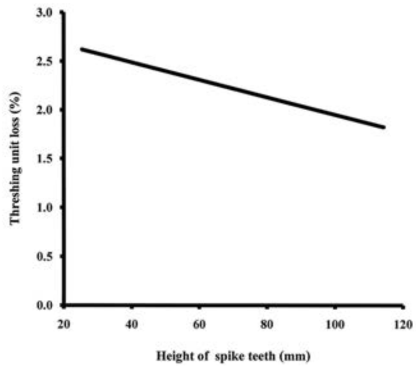


Fig. 11 Effect of height of spike teeth on threshing unit loss



TL.

For the Thai axial flow rice threshing unit, if the TL is less than 2.5 percent, then RD should not be less than 457 mm. RC should not be less than 17.5 mm, but not be over 20 mm. CC should not be more than 17 mm. SC should not be less than 35 mm. UC should not be less than 170 mm, and a 1.80 m axial flow combine harvester should have at least 150 spiked teeth with a height not less than 50 mm.

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NEWS

◇ Sad Demise Of Two Co-Editors of AMA

Dr. Giuseppe Pellizzi, known as the Past President of CIGR, President of ISAE, and the founder of Club of Bologna deceased on 21st of August, 2012. He was born in 1928 in Italy. During his lifetime, he made numbers of researches for agricultural machinery and engineering. ASABE Kishida International Award, which was established by Kishida family, has been given to him in 1997. He had been the co-editor of AMA since 1973 to 2012.

Dr. Wang Wanjun, the Ex-Co-editor of AMA in China, has passed away in September 2012. He was born in 1917. He was the past Vice President of Chinese Academy of Agricultural Mechanization Sciences (CAAMS), and eagerly promoted agricultural mechanization of China in life. Also, as a co-editor of AMA, he has contributed for more than 30 years, since 1980 and retired this year. President Kishida and his father both had a close friendship with him.

We give sincerest condolence to both of the co-editors,
and deeply appreciate their contribution for AMA in life.

Corn Stover Harvesting for Renewable Energy and Residual Soil Effects


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Abstract

Corn is one of the most significant field crops worldwide and in Serbia. Corn stover has the highest potential of agricultural residual biomass for energetic utilization, especially for second generation of biofuels. The objective of this investigation was to define backgrounds for assessment of corn stover potentials as a renewable energy source, considering soil fertility preservation and procedure of stover harvesting.

During the grain harvest season of 2011, samples of the eight locally most represented hybrids from different FAO maturity groups, were taken from three locations. The stover fractions were categorized as follows: lowest 0.2 m of stalks above ground, stalks plus leaves, cobs and husks. Seven stover harvesting procedures were considered, four that are commonly applied for big and three for small plots. Based on literature and farmer experience, percentages of harvestable stover mass were determined.

Average harvest index of all hybrids, was 0.51. Mass percentages of stover fractions were 11, 60, 19 and 10 % for lowest 0.2 m of stalks above ground, stalks plus leaves, cobs and husks, respectively. The percentage of harvestable stover was between 18 and 80 % of total, depending on harvesting procedure. Consequently, determined remaining biomass on the field was between 2.1 and 8.5 Mg/ha. This should enable, depending on tillage procedure, biomass field coverage, after planting, of over 30 %, which was defined as a minimum for erosion protection. Removal of nutrients should be compensated, and values for it added to the stover price. It seemed, concerning all aspects, that the optimal scenario was to harvest cobs, husks and upper half of stalks plus leaves.

The existing stover harvesting technologies are not mature yet, primarily due to significant productivity reduction of grain harvest. This should be developed separately for big plots, dominating in developed countries, and small plots, prevailing in developing countries.

Acknowledgment

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Introduction

Corn (*Zea mays L.*) is one of the most significant field crops worldwide, with annual production over 800 × 106 Mg. Corn is already intensively used for the production of biofuels. Just in the USA more than 130 × 106 Mg is used for the production of bioethanol. This contributes positively to the reduction of GHG emissions, but simultaneously it influences food security issues. In Serbia, and especially in the province Vojvodina that is situated in the

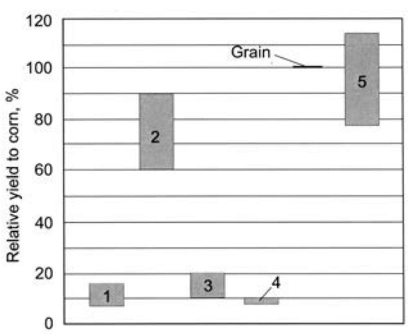
Pannonia plane, due to good agro-ecological conditions, corn yields are high. Corn acreage is about 35 % of the entire arable land in the country, about 1.25 Mha, or an annual production of about 6.5 × 106 Mg. Share of small plots is about 80 %, where harvesting with picker-husker prevail, followed by natural drying of ears.

Residual biomass presents significant potential as a renewable energy source in many countries, as well in Serbia, and corn stover is one of the most important. This is new, especially for the production of second generation biofuels. From the other point of view, removal and energetic utilization of corn residues should be performed in a sustainable manner, without negative impact on soil fertility and environment.

Corn residue

Harvest index (HI) of corn has been reported in many publications. It averages slightly over 0.5, which is similar to many other crops, especially cereals. HI enables rapid estimation of gross above ground biomass. Numerous investigations resulted with definition of share of stover fractions. Stover is mostly divided into stalks plus leaves, cobs and husks (Shinners *et al.*, 2007c; Sokhansanj *et al.*, 2002; Shinners and Binversiem, 2004 and 2007b). Typical ranges of percentages are: stalks plus leaves 69-77 %, cobs 12-20 % and husks 8-14 %. Previous assessment from a two year investigation of relative yield of corn residue in Serbia is presented in **Fig. 1**. The lowest fraction of 0.2 m of stalk above ground is separately measured and treated as difficult to be harvested. This has the highest moisture content and is less suitable for combustion.

Fig. 1 Relative yield of corn plant residual parts (yield of grain represents 100 %); 1: first 20 cm of stalk above the ground, 2: stalk without first 20 cm above ground plus leaves, 3: cobs, 4: husks, 5: sum of usable residuals 2 + 3 + 4 (Martinov and Topalov, 1984)



Characteristics of corn residue

Schneider and Hartmann (2006) defined some characteristics of the corn plant important for the combustion. Net heating value was estimated to be from 16.5 MJ/kg for leaves, and 17.8 MJ/kg for stalks. The contents of ash and chlorine were lower than for most other agricultural biomass, 2.2 % and 0.9 %, respectively. Avila-Segura *et al.* (2011) reported net heating value for different stover fractions to be in the range 17.8 to 18.6 MJ/kg. Johnson *et al.* (2011) measured chlorine content in the range 0.20 to 0.26 %. Relatively low ash content was reported in many publications

This depended on harvesting technology (ash content increases due to dirt content). It is significantly lower if the stover was not in the contact with soil. In many publications corn stover was considered as a feedstock for bioethanol production (Shinners *et al.*, 2007c; Sokhansanj *et al.*, 2002 and 2010; Allmaras *et al.*, 2004; Atchison and Hettenhaus, 2004; Klingenfeld, 2008; Sheehan *et al.*, 2003). Some authors define potential ethanol yield for the fractions. It was between 405 for leaves and 477 L/Mg of DM (dry matter) for cobs (Shinners *et al.*, 2007b). The most energetic usable stover parts were located in its upper parts, particularly in cobs and husks. Moisture content of stover was higher than of grain. Typical moisture ratio reported in Shinners and Binversie (2007a) was 2.15:1. The highest moisture content was in the lowest part of stalk. Moisture content depended on weather conditions, hybrid and maturity; i.e., time of harvest. It has a big influence on storage procedure and losses, as well as on possibility for energetic utilization. For combustion, the moisture content should be as low as possible, the best under 30 %.

Harvesting of stover

The majority of reports related to the harvesting technology originated from the USA. This was in most of cases technology adequate for big plots that were more represented in developed countries. Generally, stover harvesting could be divided into single-, two- and multi-pass procedures. Depending on the procedure, it was possible to harvest different fractions or almost complete stover.

For the single-pass, the stover or its fractions were harvested simultaneously with the grain. There were different systems for harvesting only combine outcome –MOG (material other than grain), or also stalks plus leaves. Split-stream harvest was typical and reported in some publications (Darr *et al.*; Hoskinson *et al.*, 2007; Shinners *et al.*, 2006; 2007b; 2009a and 2009b; Wold *et al.*, 2010). A specific type of single-pass was the harvest of combine output –MOG, whereby cobs and husks make the highest part of biomass (Reese, 2009). For all single-pass harvest procedures significant reduction of productivity (ha/h) compared with solely grain harvest, was recorded, in some cases up to 60 %.

Two-pass procedure was mostly related to the harvesters with built-in shredders, which form windrows (cornrower) (Straeter, 2011). The positive effect was that the biomass coming out of combine falls down on a formed windrow. This gave lower losses of cobs and husks and less dirt; i.e., ash content. Subsequently, biomass was collected by balers or forage harvesters. The multi-pass procedures included diverse shredding and stover displacing (raking) operations. This was followed with higher labour demand and increased stover dirt.

In developing countries, including Serbia, different grain harvest technology is widely used, and therefore of crop residue as well. Approximately 60 % of corn in Serbia is harvested using a picker-husker with a snapper-head and husker. Harvested ears, without husks, are dried naturally and grain threshed afterwards. That means that corn cobs are available on site in farms. Similar harvesters are used also for corn seed production. Another possibility is to use an ear picker (snapper-head with the husks removed on the farm, using stationary dehuskers (Singh *et al*., 2011). The self-propelled machines of this type, six and eight rows, are reported by Atchison and Hetternhaus (2004). In some publications, the economy of the stover harvest for different utilizations has been discussed with all influences (Cook and Shinners, 2011; Sokhansanj *et al*., 2010; Petrolia, 2008). An economic evaluation must include costs of nutrients removed with stover.

Generally, there is not a stover harvest procedure that could be identified as superior. It rather could be concluded that stover harvesting is not yet satisfactorily solved to the extent.

Impact on Soil Characteristics

The effects of residual corn biomass offtake have been treated by many researchers. Most significant effects include removal of nutrients available in stover, impact on SOC (soil organic carbon), reduction or elimination of erosion and soil compaction protection cover, impact on soil structure and others. This should be considered in order to preserve soil. Wilhelm *et al.* (2004) related to these issues. Some of investigations resulted with the conclusion that offtake of residual biomass is followed by the reduction of grain yield in following years. Some long-term investigations did not confirm this statement. A general conclusion was that sustainable management of stover offtake and its compensation should be provided.

Nutrient removal was quantified in the range 0.5 to 3.2 kg for phosphorus and 5 to 16.5 kg for potassium for every Mg of corn stover DM (Karlen *et al*., 2011; Cook and Shinners, 2011; Hoskinson *et al*., 2007; Schneider and Hartman, 2006; Sheehan *et al*., 2003). Some researchers quantified nitrogen removal (5 to 9.1 kg/Mg), and some concluded that, due to stover removal, the next crop needed less nitrogen due to high C:N ratio of corn stover (Cook and Shinners, 2011; Avila-Segura *et al*., 2011; Petrolia, 2008; Coulter *et al*., 2008). Still, this was valid only for the first and eventually the second following year. The lowest nutrient content was measured in cobs (Avila-Segura *et al*., 2011), and, therefore, lowest losses of its removal. Thorough measurement of nutrient removal for eight locations in the USA was performed by Johnson *et al.* (2011). They measured N, P, K and C into three groups of stover, below ears, above ears and cobs. Content of all nutrients was largest in stover below ears, and smallest in cobs and content of carbon was opposite. Generally it was concluded that more than the half of SOC source of the corn plant was located in the root and rhizosphere, and Allmaras *et al*. (2004) specified this to be over 80 %.

Values of removed nutrients have been assessed as well. The range was 4.64 to 30 US$/Mg of stover DM (Cook and Shinners, 2011; Zych, 2008; Avila-Segura *et al*., 2011). Maybe the most realistic costs were given by Johnson **et al**. (2011) as 18.1, 17.6 and 11.7 US$/Mg for below-ear stover, above-ear stover and cobs, respectively. Cook and Shinners (2011) estimated that SOC was 130 kg/Mg of stover DM with the impact of stover removal on erosion being 15 US$/Mg. In almost all publications it was agreed that minimal crop residues for erosion prevention was 30 %, after planting, as defined in ASAE EP291.3 (Anonymous, 2005). However, if the biomass was shredded and homogenously distributed, this could be achieved with min 1.100 kg/ha of flat small grain residue equivalent (at least about 2.2 Mg/ha of fine shredded and uniformly distributed biomass) on the soil surface. A common response was that the residue management has to be adapted for on-site conditions, including soil characteristics, climate conditions and crop rotation.

Objectives

The main objective of this investigation was to define corn residue for typical hybrids grown in Serbia, as well as harvestable yield. This would enable calculation of the potential of corn residual biomass and the impact on soil fertility. Specific objectives were:

1. To assess yield of above ground corn residual mass for the stover fractions related to grain.
2. To quantify the percentage of harvested crop residues for selected harvesting procedures for large and small plots; i.e., the amount of biomass that remains on field after harvesting and contributes to soil quality.
3. To define uncertainness and propose of future investigations.

Materials and Methods

During the harvest period in 2011, eight samples of hybrids belonging to five FAO groups typical for the region were collected at three locations in the Vojvodina province of Serbia, **Table 1**. The region is semi arid and precipitation of 450 to 600 mm per year, but well distributed with maximal rains in June and July.

Harvest typically starts in the second half of September for hybrids of FAO group 400, and finishes at the end of November.

The samples were taken on farms that apply high level of growing technology. The row distance of all crops was 0.7 m, and crop density 60,000 to 70,000 plants per ha, as was common in the region. Samples were taken during the harvest period.

Estimation of Relative Yields of Stover Fractions

For each hybrid and location five samples were taken, from different plot parts, uniformly distributed. The average number of plants was ten. This meant that they were taken, on an average, from 1.4 m^2. Corn plants were cut to the ground, packed in plastic bags and transported to the laboratory. Each plant was processed as follows: lowest 0.2 m of the stalk was cut off, ears separated, husks were removed and grain threshed manually. Parts of the plant are presented in **Fig. 2**.

The mass of each part was measured with a balance (accuracy 0.1 g). For the determination of moisture content, grains were dried using procedure defined by ASAE S352.2 (Anonymous, 2008b) and stover fractions according to the procedure defined by ASAE S358.2 (Anonymous, 2008a).

Yields and moisture contents were calculated for grain, cobs, husks (shanks included), lowest 0.2 m, stalks plus leaves plus tassels (later given only as stalks plus leaves). Relative yields of residual parts were calculated by dividing measured values with grain yield, all of dry matter. The mean values for each hybrid and location was calculated, as well as mean values for all hybrids.

Table 1 The list of tested hybrids

Sample	FAO group	Hybrid
1	400	PR 36 R 10
2	490	PAKO
3	550	LUCE
4	620	SYCORA
5	620	DKC 6120
6	700	NS 7070
7	700	GRECALE
8	700	VITORINO

Harvestable Mass –Remaining Mass

The amount of above ground biomass (stover) that could be harvested depended on harvesting procedure and accompanied losses. Total biomass minus harvested was the mass that remained in the field. Generally there were two different groups of corn harvesting technologies:

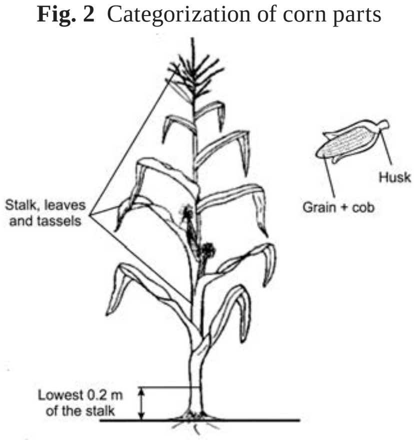
A. Applicable for developed countries; i.e. big plots.

B. Applicable for developing countries; i.e. small plots.

In order to define harvested fractions and losses, the following stover harvesting procedures were considered, based on literature review and survey of the farmer experiences:

A1 Single–pass, dual stream harvest. Harvester was equipped with a special head modified to collect stalks and leaves, and collector for combine outcome –MOG. It could harvest the entire stover, above cutting height of 0.2 m. The fractions were collected in two separate wagons, one pulled behind combine, and one running parallel to the combine (described in Shinners *et al.* (2006, 2007, 2009, Cook and Shinners, 2011). Losses of harvested fractions were estimated to be about 10 %.

Fig. 2 Categorization of corn parts



A2 Single-pass, collecting combine outcome –MOG. The harvester was equipped with snapper/head and gathering device for MOG (Reese, 2009). Complete cobs and husks were harvested, plus about 10 % of upper part of stalks plus leaves. Losses of harvested combine outcome were estimated to be about 10 %.

A3 Two-pass harvest. The combine used a snapper–head with integrated shredder-cornrower (Straeter, 2011). The stover was collected from windrow by round or big rectangular baler. Cutting height was 0.2 m. Estimated loses of cobs and husks were 10 % and additional baling losses about 20 %.

A4 Multi-pass harvest. The combine harvester was equipped with snapper-head with integrated stover shredder. It was followed by raking and baling. The cutting height was 0.2 m. Losses of stalks plus leaves were about 20 % for raking operation. Losses of cobs and husks were about 40 %. Additional baling losses were about 10 %.

B1 Harvest of ears with husks. A picker, snapper-head was used. Husking was provided on yard, and threshing of ears after drying. Complete cobs and husks were available.

B2 Harvest of ears. A picker-husker with snapper head and husker was used. This dominates corn harvesting procedure in Serbia. All cobs were available on a yard after drying,

B3 Multi-pass ears harvest. Same as B2 but with integrated stover shredder. It was followed by raking and baling. Cutting height was 0.2 m. It harvested complete cobs, and about 40 % of husks. Raking losses of stalks plus leaves were about 20 %. Overall baling losses, excluding husks, were about 10 %. The losses were determined based on literature data and farmer experience (it was provided inquiry). The harvestable mass was calculated using relative yield of stover fractions.

Results and Discussion

The climatic conditions during 2011 were not typical for the region of Vojvodina. From the middle of July until harvest there was no significant precipitation, and raining started the first of October. This caused rapid ripening of plants. Also, harvest of middle late maturity hybrids started two weeks earlier; at the beginning of September. The consequence of this was untypical low moisture content of harvested grain, and differences of moisture content of stover fractions were smaller than common.

Relative Yields of Stover Fractions

Although the climatic conditions were unfavorable during maturation period, the mean yield was rather high with an average of 10.8 Mg/ha of dry matter –DM. This was 12.6 Mg/ha, for 14 % of equilibrium moisture content. This was a result of applying good growing technology. Significance was also low moisture content of grains (mean 15.4 %) with a maximum of 21.5 %, **Table 2**. It was expected for common weather conditions in the region, between 18 % for early maturity hybrids, to 28 % for late.

The HI, average of 0.51, was higher than for some other field crops and relative yield of total above ground residues was consequently lower. The same was valid for harvestable residues; average 85.4. Thus, this was approximately 10 % lower than presented in **Fig. 1**. Breeding efforts in the last three decades resulted with positive effects, more grain – less residue. Moisture content of residual parts is presented in **Table 3** and relative yield in **Fig. 3**.

The average moisture contents were lower than usual, especially for cobs, as after-effect of dry weather conditions in the period of grain harvest. As expected, it was highest for the lowest 0.2 m of stalks. The average percentages of stover fractions was 11, 60, 19 and 10 % for the lowest 0.2 m of stalks, stalks plus leaves, cobs and husks, respec-

Table 2 General data of grain and relative yields of residual biomass

Hybrid	Grain			Relative (to grain) yield of residual biomass, %	
	Moisture content, %	Yield, Mg/ha DM	HI	Total	Harvestable
1	11.4	11.2	0.52	92.8	83.4
2	13.9	8.0	0.53	88.7	81.2
3	21.5	12.0	0.51	94.5	83.2
4	15.2	10.3	0.48	106.7	87.4
5	13.0	10.5	0.53	90.0	81.6
6	15.9	11.5	0.50	101.3	92.3
7	18.1	13,6	0.51	95.9	85.0
8	14.0	9.0	0.50	99.2	89.2
Mean	15.4	10.8	0.51	96.1	85.4
SD	2.9	1.6	0.02	5.6	3.7

SD– standard deviation

Fig. 3 Range of relative yields of stover fractions, result of statistical elaboration 1: lowest 0.2 m of stalks, 2: stalks plus leaves, 3: cobs, 4: husks, 5: sum of 2, 3 and 4, 6: sum of 1 and 5 (total aboveground residues)

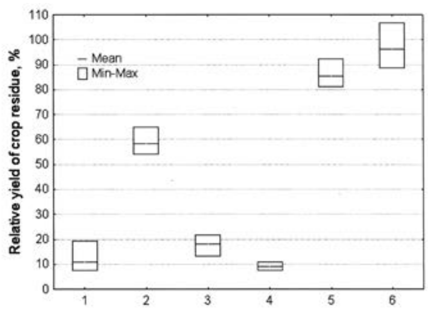


Table 3 Moisture content and relative yields of stover fractions

Hybrid	Stalk, lowest 0.2 m		Stalks plus leaves		Cobs		Husks	
	W, %	RY, %	W, %	RY, %	W, %	RY, %	W, %	RY, %
1	9.2	9.5	9.5	54.1	9.4	21.8	9.7	7.4
2	9.8	7.5	8.7	55.0	10.0	17.32	8.7	8.9
3	45.0	11.3	40.3	54.0	40.0	19.4	26.4	9.8
4	49.3	19.3	11.8	59.5	13.4	18.9	11.4	8.9
5	28.6	8.4	9.5	60.5	11.1	13.1	9.7	7.9
6	36.9	9.0	12.8	65.0	18.3	16.4	9.5	10.9
7	34.3	10.9	13.3	60.9	23.0	15.7	8.9	8.5
8	13.3	10.0	20.0	57.1	10.8	21.2	10.1	11.0
Mean	28.3	10.7	15.7	58.3	17.0	18.0	11.8	9.2
SD	14.8	3.5	9.9	3.6	9.8	2.7	5.6	1.2

W: moisture content, RY: relative yield to the grain, SD: standard deviation tively. If the lowest 0.2 m of stalks were treated as inferior for energetic utilization, the percentages of remained stover fractions were 68, 21 and 11 % for stalks plus leaves, cobs and husks, respectively. The relative yields are comparable with these presented in the figure 1 and slightly lower for stalks plus leaves.

Harvested and remaining biomass

Based on defined harvest procedures, the harvested corn residues and that remained on field were determined and presented in **Table 4**.

The percentage of harvested corn residue was between 18 and 80 % related to total available (based on mean yield and HI). The total stover mass was 10.4 Mg/ha DM. This meant, on an average, 1.9 to 8.3 Mg of dry matter per hectare. Good harvested yield of wheat straw was about 3.5 Mg/ha (15 % moisture content). If the procedure A3 is applied, the harvested biomass was more than double and illustrated the high yield of corn residual biomass.

The remaining biomass was between 2.1 and 8.5 Mg/ha. Depending on shredding and distribution of this residue, almost in all cases, it could be achieved by the covering of a minimum 30 % of the field surface (more than 1,100 kg/ha of small grain residue equivalent on field surface) before tillage and other operations This was what was defined as minimum for conservation tillage, according to ASAE EP291.3 (Anonymous. 2005). If the stover fraction characteristics would be respected, the following scenario may be recommended as optimal: to harvest all cobs and husks, and half of stalks plus leaves. This meant, the upper stalk height, approximately above 0.2 m under ears. In this case about 59 % of mass of stover would be harvested. For average grain yield, that meant about 6.1 Mg/ha DM (Johnson *et al.*, 2010, calculated 4 Mg/ha). Remaining biomass would be about 4.3 Mg/ha DM after harvesting. Nearby other harvest costs, the value of removed nutrients and SOC should be added in order to pay for their compensation. It depended on current nutrient costs.

Table 4 Harvested and remaining corn residues for defined harvest procedures

Harvest procedure	Harvested biomass			Remaining biomass
	RY, %	M, Mg/ha DM	PHS, %	M, Mg/ha DM
A1	77	8.3	80	2.1
A2	30	3.2	31	7.2
A3	66	7.1	68	3.3
A4	57	6.2	60	4.2
B1	27	2.9	28	7.5
B2	18	1.9	18	8.5
B3	63	6.8	65	3.6

RY: relative yield (to grain); M: mass calculated based on average grain yield; PHS: percentage of harvested stover

Conclusions

Corn is one of most significant field crops worldwide and in Serbia. Corn stover presents one of the feedstocks that have highest potential for bio energy production coming from agriculture, especially for production of second generation biofuels. Removal of corn residue from the field influences soil fertility and other characteristics. This investigation was aimed to quantify available residual biomass, harvestable and that which remaining on a field.

The HI of investigated hybrids, meant 0.51, was similar to those in other regions as well as percentage of stover fractions. The measurements should be repeated in coming years to broaden the data pool for different weather conditions. Obtained data may serve for further analyses of corn stover potentials and issue of soil fertility conservation. Removed nutrients and SOC should be compensated, and costs for them added to other costs for the calculation of total biomass price. Farmers should consult competent experts, in order to define production technology and amount of removed corn residues. All potential impacts should be considered and appropriate measures respected.

The percentage of harvested biomass related to total above ground was 18 to 80 %, depending on harvesting procedure. In all cases, remaining biomass was over 2 Mg/ha. This, combined with proper shredding and distribution, could result with field coverage over 30 % before tillage. A reasonable upper limit of stover offtake was about 60 % of total. In that case, all cobs and husks as well as the upper 50 % of stalks plus leaves should be harvested. For the average stover yield, it meant about 6.1 Mg/ha DM was harvested and 4.3 Mg/ha DM of biomass remained on field. Stalks should be cut approximately 0.2 m under ears, and lower part of stalks and leaves shredded and distributed uniformly. A general conclusion was that the existing stover harvesting technologies were not yet properly adopted, especially for big plots, which dominate in developed countries. For all seven considered procedures, the productivity was considerably lower than for simple grain harvesting. On the other hand, when combining a few passes, it might considerably increase overall costs. The adequate harvesting procedure should be adapted for planned biomass storage and utilization.

There is also room for improvement of harvesting procedure for small plots, which prevail in developing countries. Dominant natural drying of ears is environmentally sound but the whole process should be further improved, to ensure higher overall productivity and lower production costs. Harvesting and energetic utilization of corn stover will not only support efforts related to renewable energies, but can contribute to higher revenue to farmers and rural development.

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A Low Head, Minimum Pressure-Loss Equipment for Fertilizer Application Through Drip Irrigation

by
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Abstract

The methods of fertilizer application through drip irrigation are by-pass tank, venturi and pump system. The venturi is most commonly used for fertilizer application through drip irrigation. The main limitations of the venturi are large pressure drop and high head. So. equipment called an orifice meter was developed for the fertigation purpose in the drip irrigation system which operates at inlet pressure below 1 kg/cm^2.

Six different sizes of orifice meters were developed and evaluated at the Research Farm, Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. Four orifices had a diameter 3.18 mm and thickness 25.4 mm, 19.05 mm, 12.7 mm and 9.53 mm. Two orifices that had diameters of 2.38 mm and 1.59 mm with a thickness of 12.7 mm were evaluated in the range of 0.42 to 0.944 kg/cm^2. The maximum injection rate was 45 lph with an orifice meter having a diameter 3.18 mm and thickness of 12.7 mm operating at an inlet pressure 0.702 kg/cm^2. This was found to be best. The developed equipment was also suitable for farmers having small land holdings or in a greenhouse.

Introduction

There has been a tremendous growth in fertilizer use throughout the world in the 20th century. By the end of 20th century developing countries had increased their utilization to 60 percent of the world's fertilizer use and produced 55 percent of total nitrogenous fertilizer (Rajput and Patel, 2002).

Drip irrigation offered several advantages like higher irrigation efficiency, labour and energy savings, improvement in quality and yield of produce and opportunity to manipulate inputs, as per the crop demands, over the conventional irrigation techniques. Black (1976), Miller *et al*. (1976), Kaneworthy (1979) and Smith *et al.* (1979) indicated that up to 50 percent if the fertilizer could be saved when applied through a drip irrigation system.

Fertigation is the technique of supplying water soluble fertilizers to crops through an irrigation system. It has become a common practice in modem agriculture. Ferigation through drip irrigation can yield a fertilizer savings in the range of 25 to 50 percent (Haynes, 1985). Fertilizers can be injected into irrigation systems by three principal methods: (1) by-pass tank (2) venturi and (3) pumps. The venturi is considered as the best mechanism for fertigation. The main limitations of venturi are large pressure drop and high head requirement for its operation. Lewitt (1952) gave the mathematical equation for measurement of flow by pipe orifice. Ree (1977) conducted an experiment on the accuracy of shop made orifice plates. The results indicated that shop-built orifices, when used without correcting to true diameter, may yield errors in a discharge estimate as large as 15 percent for the 2.54 cm diameter orifice and 6 percent for the three larger (4.44, 6.35, 8.89 cm) orifices. Eisenhauer and Bockstadter (1990) studied injection pump flow considerations for center pivots with corner watering systems and concluded that injecting chemicals at constant rates into center pivots equipped with either guns or swing-booms resulted in systematic chemical application rate errors due to the variable wetted radius of the irrigation system. Replogle and Wahlin (1994) constructed a special venturi meter from a plastic pipe fitting and attempted to address these economic limitations, fouling problems and water management requirements. Thirty venturi meters were constructed. It was established that individual calibrations were not required for effective application in irrigation practice. Camp *et al.* (2000) conducted an experiment to develop a variable rate, digitally controlled metering device to permit variable flow of a fluid. The device consisted of a reservoir that was alternatively filled and emptied at a rate dependent upon a digital pulse from an external source. The above review showed that there are a number of methods such as by-pass tank, venture and pumps for fertilizer application through drip irrigation system. The most commonly used device for fertilizer application is the venturi. But it needs high pressure head: i.e. 1 kg/cm^2 to 4 kg/cm^2 for operation. Thus, it was thought of to develop another system which could operate at low head for fertilizer application through a drip irrigation system. It will also be useful for farmers having small land holdings or in green houses.

Material and Methods

The orifice meter was developed on the principal of Bernoulli's theorem, which is defined as an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy (Chanson,2009).

$$\frac{p_1}{w} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + Z_2 \quad ......(1)$$

Substitution of Z_1 =Z2 for horizontal orifice, and $V_1 = (a_2V_1) / a_1$, in **Eqn. 1** and its simplification yields:

$$h = \frac{V_2^2}{2g}\left[1-\left(\frac{d}{D}\right)^4\right] \quad ....(2)$$

$$\text{or } V_2 = \sqrt{\frac{2gh}{1-\left(\frac{d}{D}\right)^4}} \quad ....(3)$$

The theoretical discharge is

$Q_{th} = a_2V_2$

$$= a_2 \sqrt{\frac{2gh}{1-\left(\frac{d}{D}\right)^4}} \quad ....(4)$$

Table 1 Various sizes of the developed orifice meters

Orifices	Thickness, mm	Diameter of orifice, mm	Diameter of fertilizer injection hole, mm
O_1	25.40	3.18	1.59
O_2	19.05	3.18	1.59
O_3	12.70	3.18	1.59
O_4	9.53	3.18	1.59
O_5	12.70	2.38	1.59
O_6	12.70	1.59	1.59

Where a1 is the cross-sectional area of inlet pipe (mm^2); a_2 is the cross-sectional area of orifice meter (mm^2); D is the diameter of inlet pipe (mm); d is the diameter of orifice meter (mm); V_1 is the velocity of water approaching orifice meter (m/s); V_2 is the velocity of water through orifice meter (m/s); p_1 is the pressure of fluid before orifice meter (kg/cm^2); p_2 is the pressure of fluid after orifice meter (kg/cm^2); h is the measured difference of pressure (cm), w is the unit weight of water (kg/cm^3) and Q_{th} is the theoretical discharge rate without the equipment (l ph)

The losses due to passage of the fluid through the orifices, the actual rate of discharge is obtained by:

$$Q_{act} = C_d\, a_2 \sqrt{\frac{2gh}{1-\left(\frac{d}{D}\right)^4}} \quad ....(5)$$

Where, Q_{act} is the actual discharge rate with equipment (l ph) and C_d is the coefficient of discharge.

Due to drop in pressure in the orifice meter, water soluble fertilizer was injected into the orifice meter. Then it was mixed with the water flowing through the orifice meter. The discharge rate at the outlet i.e. from the emitters was given by:

$$Q_{act} = Qe \times N \quad ....(6)$$

or

$$C_d = Q_{act} / Q_{th} \quad ....(7)$$

Where, N is the total no. of emitters in the given area of fertigation and Q_e is the emitter discharge rate (l ph).

Design of Equipment for Fertilizer Application:

Orifice meters with various thicknesses and diameters that were fabricated are given in **Table 1**. The figures of different thicknesses of the developed orifice meter are given in **Fig. 1**.

As the diameter decreased, the injection rate increased. By keeping the orifice meter diameter of constant (3.18 mm), the thickness of the orifice meter was varied to get the optimal value. For fertilizer injection a hole of diameter 1.59 mm was drilled just at the edge of the orifice meter. A plastic tube was connected from the orifice meter to the fertilizer tank which was placed at a height of one meter above the ground. The amount of pressure drop and the amount of fertilizer injection rates were recorded. The difference between the inlet pressure and outlet pressure was measured by the difference in height of mercury of two limbs of the V-tube manometer. This pressure gradient was related by the following **Eqn**.

$h = R\,\{(S_m / S) - 1\}$

h = Water head in cm

R = Reading of the U-tube manometer, cm

S_m = Specific gravity of mercury

S = Specific gravity of water

Fig. 1 Different thicknesses of fabricated orifice meters

The equipment studies were conducted to determine the injection rate through the different sizes of the orifice meters. After preparing the fertilizer solution, the water flowing through orifice meter was applied to the area under fertigation. All developed equipment were tested under various inlet discharges and rates of fertilizer injection. All orifice meters were tested for areas 450 m^2, 300 m^2 and 150 m^2

Results and Discussions

The developed orifice meters were evaluated in the range of 0.42 kg/cm^2 to 0.944 kg/cm^2 of inlet pressure and the areas under fertigation were 150 m^2, 300 m^2, 450 m^2. The orifice meter having maximum injection rate and the corresponding operating pressure for different orifice meters are given in the **Table 2**.

The maximum injection rate depended upon the outlet pressure for a particular inlet pressure. The best fit equation of average injection rate and outlet pressure for orifice meters (0_1-0_6) are given below:

For orifice meter 0_1

$S = 2292.1 P^2 - 924.74 P + 99.326$

$R^2 = 0.9448$

For orifice meter 0_2

$S = 45937 P^2 - 12322 P + 833.65$

$R^2 = 1$

For orifice meter 0_3

$S = 1498.1 P^2 - 573.94 P + 64.788$

$R^2 = 0.9778$

For orifice meter 0_4

$S = 1541.7 P^2 - 519.09 P + 58.239$

$R^2 = 0.9956$

For orifice meter 0_5

$S = 1061.9 P^2 - 409.21 P + 47.007$

$R^2 = 0.9517$

For orifice meter 0_6

$S = 4610.1 P^2 - 1105.1 P + 84.857$

$R^2 = 0.9952$

Where S = Average injection rate, l ph

P = Outlet pressure, kg/cm^2

Cost Estimation of the Best Developed Orifice Meter

The materials used were two pieces of flanges with thickness-12.7 mm (Rs.150.00), 900 mm length of GI pipe with diameter-12.7 mm (Rs. 30.00), and two 12.7 mm diameter elbows (Rs.100.00). The total cost of the system including the best developed orifice meter was Rs.300.00.

Conclusions

The performance of all the developed orifice meters were tested at a pressure less than 1 kg/cm^2, while the venturi operates at 1 kg/cm^2 to 4 kg/cm^2. The orifice meter with 12.7 mm thickness and 3.18 mm diameter was best with maximum fertilizer application rate of 45 lph at inlet pressure 0.72 kgicm^2. The orifice meter was cheaper than the most commonly used device; the venturi. The cost of the orifice meter was around Rs. 300/-, where as, the cost of the venturi was Rs. 1048/- for same purpose of fertigation.

Table 2 Maximum injection rates and the corresponding operating pressures for different orifice meters (0_1-0_6)

Orifice meter	Size, mm		Maximum injection rate, l ph	Operating pressure, kg/cm^4	
	Thickness, mm	Diameter, mm		Inlet pressure	Outlet pressure
0_1	25.4	3.18	24.82	0.772	0.117
0_2	19.05	3.18	12.00	0.784	0.124
0_3	12.7	3.18	45.00	0.702	0.037
0_4	9.53	3.18	27.70	0.795	0.102
0_5	12.7	2.38	15.00	0.830	0.108
0_6	12.7	1.59	27.67	0.944	0.078

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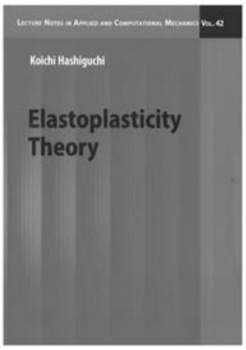
BOOK



Lecture Notes in Applied and Computational Mechanics
"Elastoplasticity Theory"

Publisher: Springer
Author: **Koichi Hashiguchi**
3-10-10-201, Ohtemon, Fukuoka, 810-0074, Japan

This book was written to serve as the standard textbook for instruction of elastoplasticity theory. It opens with an explanation of the mathematics and continuum mechanics which are necessary as a foundation of elastroplasticity theory. Subsequently, conventional and unconventional elastroplasticity theories are explained comprehensively for description of general loading behavior covering monotonic, nonproportinal, and cyclic loading processes. Fundamental notions such as continuity and smoothness conditions, decomposition of deformation into elastic and plastic parts, the associated flow rule, the loading criterion and the anisotropy are defined, and then presented with their mechanical interpretations. Explicit constitutive equations of metals and soils, which are useful in engineering practice for the mechanical design of machinery and structures, are also introduced. Moreover, constitutive equations of friction with transition from static to kinetic friction and vice versa,and rotational and orthotropic anisotropy are provided. They are indispensable for analyses of boundary-value problems.

A distinguishing feature of this book is that it is written to be understandable without difficulty even by beginners in the field of elastroplasticity, explaining physical backgrounds with illustrations and descriptions of detailed derivation processes of all equations without a jump. Furthermore, the history and the latest results related to elastroplasticity are explained thoroughly to the extent that the fundamentals of elastroplasticity theory can be understood and be applicable readily to analyses of engineering problems. Therein, the subloading surface model is delineated, which possesses the high ability for the description of elastroplastic deformation behavior. In addition it is furnished with the noticeable advantage for the numerical calculation with the automatic controlling function to attract the stress to the yield surface in the plastic deformation process and thus it does not require to incorporate the convergence computer algorithm such as the return mapping in the yield state.

TRACTORES AGRÍCOLAS: TECNOLOGÍA Y UTILIZACIÓN (AGRICULTURAL TRACTORS: TECHNOLOGY AND UTILIZATION)

Author: **Luis Márquez** Ph. Doctor in Agricultural Engineer

Consultation book in which the technology of the modern agricultural tractors is summarized, managed to technicians and specialists of the sector.

Index:

Concept of the agricultural tractor: Types; Normalization / Elements for the propulsion: Tires, track and rubber bands / Motors; Transmissions; PTO; Hook and hydraulic system; Direction, primary suspension, brakes / Traction power: Ballasted of the tractor; Reduction of the consumption of fuel; Classification of tractors / OECD Test; Field Tests; Approval “type CE” / Ergonomics and security: ROPS and FOPS; Electronic and helps to the conduction / Other agricultural vehicles / Forecast of utilization costs

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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.

1072

Development and Performance Evaluation of Tractor front mounted Crop Stalk Slasher: **B. Sanjeeva Reddy,** Senior Scientist (FMP), Central Research institute for Dryland Agriculture Hyderabad -500 059, Andhra Pradesh, INDIA. srbaddigam@gmail.com; **G.R.Korwar,** Pincipal Scientist & Head, Division of Resource Management, same; **Ravikanth V. Adake,** Scientist (FMP), same

The soils of semi arid tropics of Andhra Pradesh, India are predominantly Inceptisols, Entisols and Alfisols, which are shallow in depth and coarse in texture. The quality of these soils is deteriorating over the years due to non addition of organic matter, neglected use of FYM, mono cropping practice and increased use of chemical fertilizers by the farmers. On the other hand, large quantities of crop stalks from crops like maize, castor, sunflower and residue from pulse crops is being burnt or left on the fields due to increase in farm labour cost constraining its conversion into useful manure. Hence, to manage such stalks in situ, a tractor front mounted crop stalk slasher was designed and developed. The machine could able to slash and spread the slashed pieces uniformly on the soil surface. The rotary shafts speed was kept at 300 rpm in the designed machine. The field capacity of the machine was 0.4 ha per hour. The machine slashed cut pieces surface coverage efficiency was 91% with dry stalk amount of 3340 kg per hectare in maize field, and 24 % in castor with a dry bio-mass yield of 1,260 kg per hectare.

1086

Influence of Biokinetic Parameters for the Production of Ammonia from Fertilizer Company Effluent for Agricultural Application and Improvement on Soil/Water Environment: **Ukpaka C. P.**, Dept. of Chemical/Petrochemical Eng. Rivers State Uni. of Science and Technology, Nkpolu, P.M.B. 5080, Port Harcourt, NIGERIA. chukwuemeka24@yahoo.com

Production of ammonia from fertilizer company effluent (Urea) for agricultural application and improvement on soil/water environment was studied by growing pseudomonas aeruginosa in a batch reactor. The progress on reaction process was monitored by measuring the production rate of ammonia, Urea consumption and microbial growth. Also studied was the effect on the biokinetic parameters of specific rate, maximum specific rate and equilibrium rate constant on ammonia production from the fertilizer company effluent. Results obtained revealed that at 50 ºC and a concentration of 10-2 mol/l the rate of production of ammonia is at maximum at the progressive phase. From the results, it was observed that the maximum specific rate of ammonia produced and Urea consumed at the progressive phase increases with increase in microbial growth rate, ammonia produced and Urea consumed. The fertilizer plant effluent discharged into the soil/water environment influence the total nitrogen concentration and other useful parameters that are helpful for improvement of soil/water nutrient for effective yield as recommended by Federal Environmental Protection Agencies (FEPA) on the minimum and maximum acceptable limit of 5 and 100 mg/l respectively. This paper is therefore concerned on monitoring and predicting the possible requirement that is needed in meeting these limits by reacting urease with the discharged effluent thereby producing ammonia from the effluent and reducing the concentration of the discharged effluent to the acceptable limit for its usefulness in agricultural application and improvement of soil/water nutrient.

1247

Power-Efficient Method of Tillage and Its Technology Model: **A. Tukhtakuziev,** Republic of UZBEKISTAN; **A. N. Khudoyorov,** same.

At present time soil tillage for sowing and crops preparation are mainly put into practice by means of traditional technologies and engineering tools, that is plowing firstly, harrowing and leveling secondly, after which ridges are cut. Such multi-step tillage provokes big labor inputs, expenditure of energy and fuel, delays sowing time that results in yield drop of agriculture.

On the assumption of the above-stated we have developed a new tillage technology model for cotton-plant sowing and a component unit for its implementation.

The engineered unit is composed of chassis 1 with mounted element 2, rippers 3, fertilizer plows 4, ridge-forming tools 5, chemical fertilizers feeder 6 and support wheels 7.

The unit in a run mellows the bottom of the last years' irrigation furrows at a depths of 30-40 cm , moulds the old ridges in furrows, moulds new ridges dressing them with two-layer strip of chemical fertilizers. In that way, the new ridges are cut due to demolition of the old ridges and soil slip to the area of old ridges. At the same time a layer of loose soil of 55-65 cm depth is formed as compared to 30-40 cm in the case of plowing. In spring the ridges are touched up and chemical fertilizers are dressed for cotton-plant sowing. Thus there is no need to carry out such traditional operations as harrowing, chisel plowing and leveling. Consequently, fuel consumption and labor inputs are reduced.

■■

EVENT CALENDAR

◆ Asian Forum of 2012

—CSAM International Academic Annual Meeting "Innovation, Win-win, Development"—

October 27-30, 2012, Hangzhou, CHINA

http://www.aaae.org.cn/DEB7A59D-08D7-47F1-BFF6-DA45754C5760.html

Chinese Society for Agricultural Machinery (CSAM) is going to hold an international academic annual meeting with the theme "Innovation, Win-win, Development." The organizer of this event will be Zhejiang University and Chinese Academy of Agricultural Mechanization Sciences (CAAMS). Technical tour in Zhejiang University is included in the program.

◆ KIEMSTA 2012

October 30th- November 3rd, 2012, Cheonan City, Chung-Nam, KOREA

http://kiemsta.co.kr/

◆ EIMA International 2012

November 7-11, 2012, Bologna, ITALY

http://www.eima.it/it/index.php

◆ IEA Bio Energy Conference

13-15 November, 2012, Vienna, AUSTRIA

The IEA Bioenergy Conference 2012 will provide to stakeholders in R & D, industry and policy an insight into the recent research and market developments in bioenergy.

http://www.ieabioenergy2012.org/welcome.html

◆ EuroTier

13-16 November, 2012, Hannover, GERMANY

The world's leading exhibition for animal husbandry and management

http://www.eurotier.com/home-en.html

◆ 7th International CIGR Technical Symposium

—Innovating the Food Value Chain—

November 25-28, 2012, SOUTH AFRICA

Http://www0.sun.ac.za/postharvest/cigr2012/

The Convenor of this symposium is Prof. Linus Opara, South African Research Chair in Postharvest Technology Faculty of AgriSciences, University of Stellenbosch. He is also known as the co-editor of AMA, and has been contributing many essential papers from the past.

Dr. B. A. Stout of CIGR and Dr. Shujun Li of AAAE are invited as keynote speakers.

◆ 2012-International Conference

—Challenges of Water & Environmental Management in Monsoon Asia—

November 27-29, 2012, THAILAND

http://pawees.net/

◆ Spring Farm Machinery Show Millstreet

January 16th-17th, 2013, Cork, IRELAND

Largest indoor agricultural machinery exhibition in Ireland.

http://www.biztradeshows.com/trade-events/spring-farm-machinery-show-millstreet.html

◆ 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 13th-16th, 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.

◆ 2013 AMC Conference

May 6-8, 2013, Waterloo, Iowa, USA

http://www.amc-online.org/About.html

◆ Agritech Astana 2013

March 13th-15th, 2013, World Trade Centre (WTC) Complex, ASTANA

http://www.tntexpo.kz/agritek_as.php?lang=en

◆ 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—

EVENT CALENDAR

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

◆ 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

◆ 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


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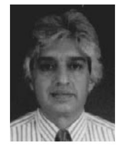
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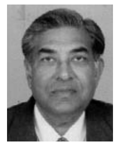
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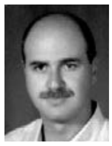
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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Vol.43, No.3, Summer 2012

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Priority in the selection of article for publication is given to those that –

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b. are relevant: to the promotion of agricultural mechanization, particularly for the developing countries;
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e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
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   (vi) bibliography
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e. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
f. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
g. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
h. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
i. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
j. Convert national currencies in US dollars and use the later consistently.
k. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
l. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers..., or Five tractors..."instead of 45 workers..., or, 5 tractors.

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