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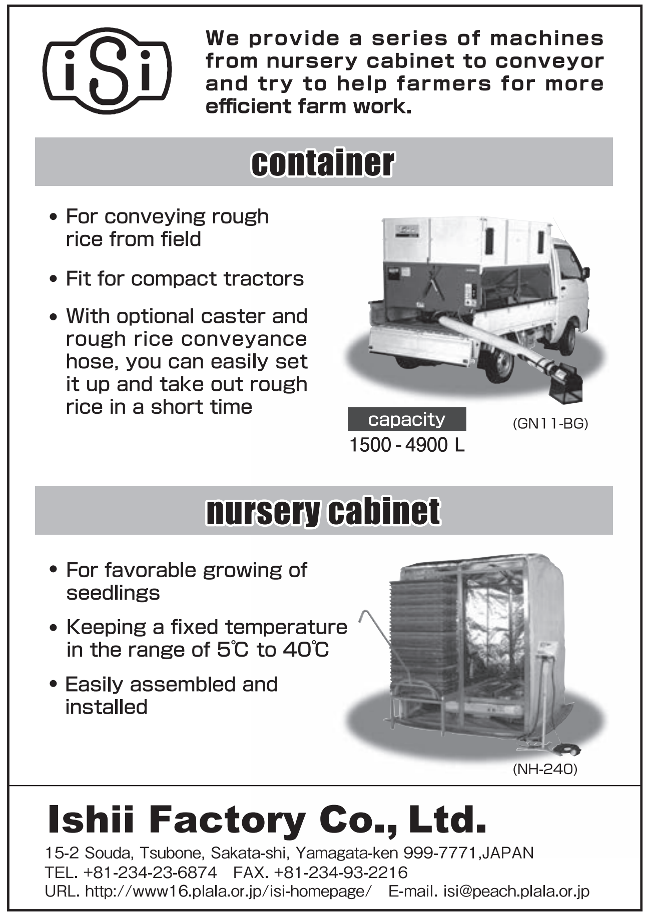
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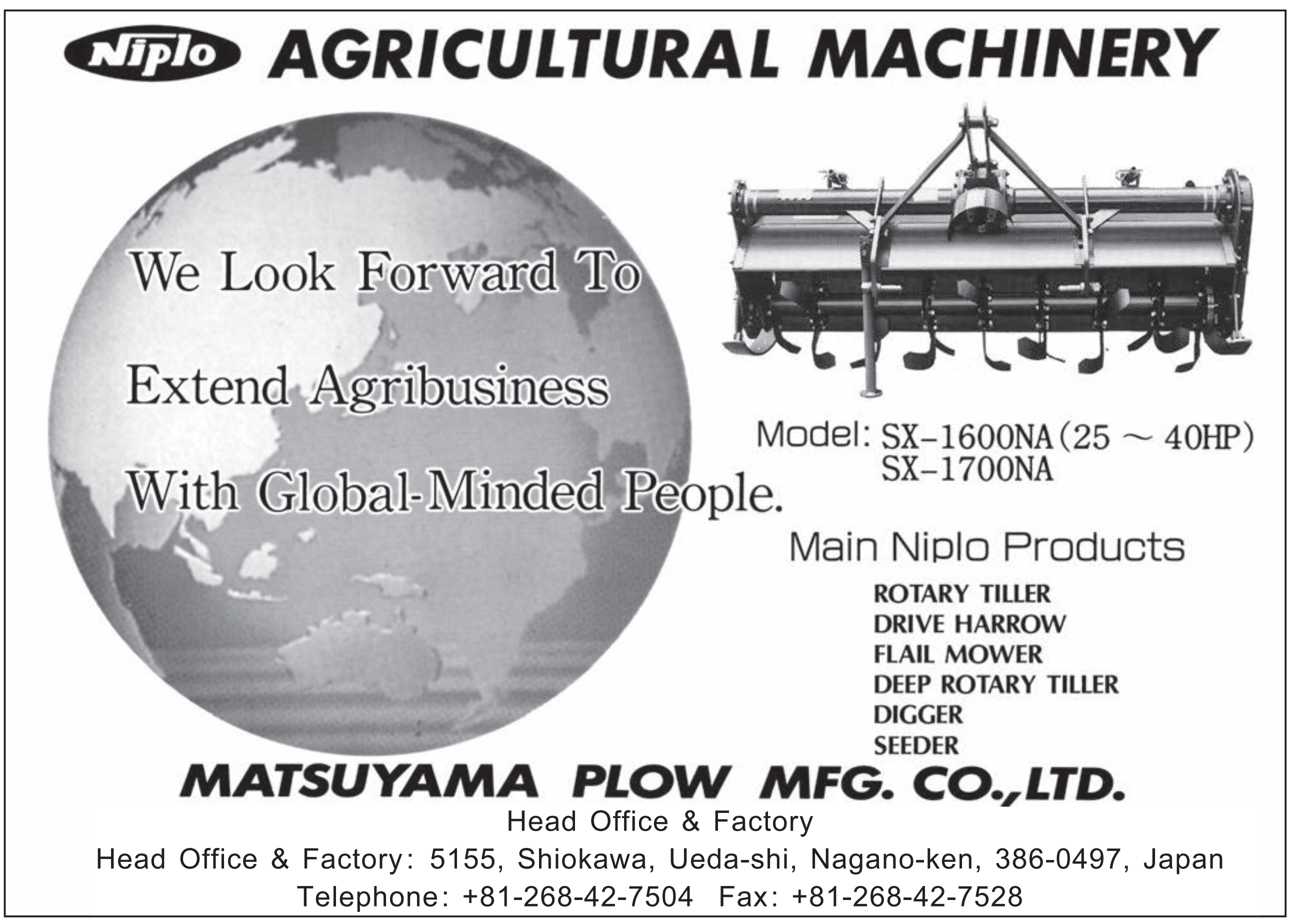
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EDITORIAL

On September 16th 2016, the celebration party for my decoration of Kyokujitsu Shoujushou (THE ORDER OF THE RISING SUN, GOLD RAYS WITH ROSETTE), awarded by the Emperor of Japan this spring, was held at the Palace Hotel Tokyo. A great number of people came to celebrate the occasion. This decoration is a result of many readers and people related to agricultural machinery engineering who had supported me over the years and I would like to show my sincere appreciation and gratitude to all. My 60 years friend Dr. Bill Stout (former president of CIGR) from the U. S, Dr. Oleg Marchenko (Head in All-Russia Research Institute for Mechanization in Agriculture) from Russia, Dr. Enkhbayar Gonchigdorj (Director of School of Engineering & Technology, Mongolian University of Life Sciences) from Mongolia, Dr. Gao Yuanen (Honorary president of China Association of Agricultural Machinery Manufacturers and former president of Chinese Academy of Agricultural Mechanization Sciences) from China and many other friends came from abroad.

Shin-Norinsha, a parent company of Farm Machinery Industrial Research Corp. which publishes AMA, was founded to publish specialized newspaper and magazine regarding agricultural machinery in 1933 by former president Yoshikuni Kishida. Since then, Shin-Norinsha has been engaged in the promotion of agricultural mechanization for 83 years. Spreading and promoting of agricultural mechanization have been the most essential issues when one sees the trends in agriculture and population of the globe. When publication of the AMA was started in 1971, 80% of world population was farmers in the developing countries. Economic disparity between the urban and the rural farming communities was huge therefore an improvement of farmers' income through new agricultural mechanization was a real requirement. With this objective in mind, the publication of the AMA was started for making an international network to communicate with worldwide experts.

At present, urban population is increasing in the globe. In China, the neighbor country of Japan, the urban population has occupied 70% of the total. Agricultural labor shortage has been seen in various countries even though we have to increase agricultural production. In order to keep agricultural productivity growth to meet the needs of the growing population, it is vital to enhance not only the land productivity but also the labor productivity. Thus, agricultural mechanization is really important.

For advancing agricultural mechanization in developing countries, a concept of "Appropriate technology" is very important. Until 1970, it was said that important things were to be simple, easy-to-produce and easy-to-repair. But we have to rethink what the "Appropriate technology" is for now. For example, smart phone have become popular and their use is spread in developing countries. Smart phone is a mass of high-tech and we can say it as the appropriate technology. Like this phenomenon, there is a possibility that agricultural robots that everybody can operate could become the appropriate technology. There need to be a dialogue to discuss and explore again about what the appropriate technology must be in promoting agricultural mechanization of the world.

In promoting practical achievement of agricultural robot, the most important factor is the use of new ability of artificial intelligence (AI). The ability of AI is progressing at an accelerated pace and people involved in agricultural machinery development and research have to give due consideration for using this new technology. Now precision agriculture and its mechanization are proceeding in advanced countries. For those projects, production of systems that everybody in the world can apply by using AI is needed. Now it is the time when the engineering community involved in production agriculture around the world need to decide on linking precision agriculture with AI for a new improved and efficient agricultural mechanization and agricultural production in near future.

Yoshisuke Kishida
Chief Editor

October, 2016

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Investigation on Possibilities for Sustainable Provision of Corn Stover as an Energy Source: Case Study for Vojvodina

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Abstract

Corn stover, among other crop residues, is becoming important an energy source, as non food/feed feedstock, especially for biofuels. A problem is to ensure a secure supply, which is influenced by drought. The further requirement is to eliminate or minimize biomass removal impact on soil fertility and erosion. The objective of the investigation was to assess possibilities for sustainable provision of corn stover as an energy source, considering these issues. The investigation is conducted in the province Vojvodina, an agricultural part of Serbia, for seasons 2011 and 2012. Weather in 2011 was dry and in 2012 extremely dry. Stover samples were divided in the following fractions: the lowest 0.2 m, stalk + leaves, cobs and husks. Yields and relative yields of these fractions were calculated and thereafter used to determine the total and usable mass of stover, considering three stover harvest procedures. The on-field remaining mass of stover was used to determine if the prerequisites for conservation soil tillage, i.e. erosion protection, can be achieved. Relative harvestable yields (related to grain yield) for three harvest procedures, and both seasons, were 53, 43, 19% (2011) and 16% (2012). The harvestable mass, i.e. stover yield, in 2012 was, compared with 2011, reduced due to unfavorable weather by 31% for two harvest procedures and even 42% if only cobs are harvested. The on-field remaining mass of stover was sufficient to achieve conservation tillage and protection from soil erosion. Determination of nutrient removal costs can represent significant problem, and results from this investigation may contribute. The potential of corn stover harvestable yield depends on harvest procedure. When developing novel harvest solutions, it is recommendable that they should minimize the reduction of grain harvest productivity and stover contact with soil. This needs further R&D activities.

Introduction

Ligno-cellulosic crop residues are becoming important as a feedstock, especially for production of second generation biofuels (non food and non feed raw materials). The problem is to identify realistic potentials, i.e. available amounts. This is related to identification of harvestable mass and harvest losses, which depend on procedure and weather conditions. The other issue is that the removal of crop residues has short or long term negative influences on soil fertility and soil erosion. The removed biomass contains plant nutrients and soil organic matter (SOM), i.e. soil organic carbon (SOC). This should be quantified and expressed as additional value of removed biomass.

With the average annual production of over 800 × 106 Mg Worldwide, corn (*Zea mays L.*) is one of the most important field crops. Corn grains are already intensively used for the production of biofuels. Only in the USA, for the production of bioethanol, about 130 × 106 Mg is used (Shinners *et al.*, 2006). This contributes positively to the reduction of GHG emissions, but simultaneously it influences food security supply issues.

Crop residues present a significant potential as renewable energy source in Serbia, especially in the Vojvodina province, which is, due to its good agro-ecological conditions, the main agricultural region of the country. Corn acreage accounts for about 35% of the total arable land in the country, i.e. about 1.25 × 106 ha with an annual production of about 6.5 × 106 Mg.

Corn Stover as Energy Source

Corn stover, or its parts, in the past was considered mostly as a solid fuel, for combustion. Schneider and Hartmann (2006) defined some characteristics of corn plant important for the combustion. The Net Heating Value was found to be from 16.5 MJ/kg for leaves, up to 17.8 MJ/kg for stalks. The contents of ash and chlorine are lower than for most other agricultural biomass, 2.2 and 0.9% respectively. Avila-Segura *et al.* (2011) reported a Net Heating Value for different stover fractions to be in the range 17.8 to 18.6 MJ/kg. Johnson *et al.* (2010) measured chlorine content in the range 0.20 to 0.26%. Relatively low ash content was reported in many publications, whereby it depends on harvesting technology (ash content increases due to the dirt-soil contamination). It is significantly lower if the stover was not in contact with the soil.

In many publications, corn stover was considered as a feedstock for ethanol production (Allmaras *et al.*, 2004; Atchison *et al.*, 2004; Klingenfeld, 2008; Sheehan *et al.*, 2003; Shinners *et al.*, 2007b; Sokhansanj *et al.*, 2010; Sokhansanj *et al.*, 2002). Some authors defined potential ethanol yield for the corn plant fractions. It is between 405 for leaves, up to 477 L/Mg of DM (dry matter) for cobs (Shinners *et al.*, 2007a). The most usable stover parts, as an energy source, are located in its upper parts, particularly in cobs and husks. Recently, corn stover is being considered as a substrate for biogas production with possibility of biomethane generation. Li *et al.* (2011) measured the highest biogas production from corn stover 403.7 L/kg of volatile solids (VS).

Corn Residue

Knowing the Harvest Index (HI) enables a rapid but rough estimation of gross above-ground biomass, based on the measured grain yield. Harvest Index is defined as the mass of grain divided by the total mass of above ground biomass. HI of corn was reported in many publications. It is on average slightly over 0.5, which is similar to many other field crops, especially cereals. Numerous investigations also resulted in definitions of stover fractions' share. Stover is mostly divided into stalks + leaves, cobs and husks (Shinners *et al.*, 2007a; Shinners *et al.*, 2007b; Sokhansanj *et al.*, 2002). Typical ranges of fractions' percentages are: stalks+leaves 69-77%, cobs 12-20% and husks 8-14%. The influence of seasonal weather conditions on HI and stover yield potential has not been studied. The yield reduction can have significant influence on available mass and impact supply security.

The moisture content of stover is higher than that of grain. A typical ratio reported by Shinners and Binversie (2007) is 2.15: 1. The highest moisture content is measured in the lowest part of stalk. The moisture content depends on weather conditions, hybrid and plant maturity, i.e. time of harvest. It has a big influence on storage procedures and losses, as well as on possibilities for energy generation utilization. For combustion, the moisture content should be as low as possible, the best under 30%.

Corn Stover Harvesting

The majority of reports related to the harvesting technology of corn stover, originate from the USA. In most cases, corn stover harvesting is adequate for big plots that are more frequent in developed countries. Generally, stover harvesting can be divided into single-, two- and multi-pass procedures. Depending on the applied procedure, it is possible to harvest different fractions or almost the complete stover. For the single-pass, the stover or its fractions are harvested simultaneously with the grain. There are different systems for harvesting only combine outcome -- MOG (material other than grain), or additionally stalks + leaves. Typical is split-stream harvest, reported in some publications (Darr *et al.*, 2009; Hoskinson *et al.*, 2007; Shinners *et al.*, 2009; Shinners *et al.*, 2007a; Shinners *et al.*, 2006). A specific type of single-pass is the harvest of combine output -- MOG, whereby cobs and husks provide the largest part of biomass (Reese, 2009). For all single-pass harvest procedures, a significant reduction of productivity (ha/h), compared with solely grain harvest, was recorded, in some cases up to 60%. Two-pass procedure is mostly related to the harvesters with built-in shredders which form windrows and corn rower (Straeter, 2011). The positive effect is that biomass, which comes out from combine harvesting, falls down on formed windrow. This results in considerably lower losses of cobs and husks, as well as reduction of dirt, i.e. ash content. Subsequently, biomass is collected by balers or forage harvesters. The multi-pass procedures include diverse shredding and stover displacing (raking) operations. This is accompanied by higher labor demand and increase of stover dirt.

In the countries where small plots dominate, including Serbia, harvest of corn ears is widely used. Approximately 40% of corn in Serbia is harvested using a picker-husker, machine with a snapper-head and husker. Harvested ears, without husks, are dried naturally and the grain threshed afterwards. That means that corn cobs are available on site, in farms. Remaining stalks and leaves can be harvested in few passes, mostly finalized by baling. Similar harvesters are also used for corn seed production, whereby cobs are used as a fuel for the drying of ears. Another possibility is to use ear picker (snapper-head), whereby the husks are removed on farm, using stationary dehuskers (Singh *et al*., 2011). The self-propelled type of these machines, six and eight rows, is reported by Atchison and Hetternhaus (2004).

In some publications (Cook, 2011; Petrolia, 2008; Sokhansanj *et al*., 2010), the economy of stover harvest for different utilizations, considering all influences, was elaborated. The economic evaluation should be based on realistic, harvestable, corn stover amount, which depends on weather conditions and harvest procedure. The costs should include the value of nutrients removed with stover, and possibly the value of organic carbon since this issue is not sufficiently investigated and commonly agreed.

Generally, there is no stover harvest procedure that could be indicated as superior, since grain harvest efficiency and operating costs could not be satisfied at once. It rather could be concluded that stover harvest is not yet solved to a satisfactory extent.

Stover Removal Effects

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

Nutrient removal is 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 (Cook and Shinners, 2011; Hoskinson *et al*., 2007; Karlen *et al*., 2011; Schneider and Hartman, 2006; Sheehan *et al*., 2003). Some researchers also quantified nitrogen removal, 5 to 9.1 kg/Mg, and some concluded that due to stover removal, the following crop needs less nitrogen due to high C : N ratio of corn stover (Avila-Segura *et al*., 2011; Cook and Shinners, 2011; Coulter *et al*., 2008; Petrolia, 2008). Still, this is valid only for the first and occasionally for the second following year. The lowest nutrients content was measured in cobs (Avila-Segura *et al*., 2011), and therefore lowest losses due its removal. A thorough measurement of nutrients removal was performed by Johnson *et al*. (2010) for eight sites in the USA. N, P, K and C were measured in three groups of stover, below ears, above ears and cobs. The total nutrients content was largest in stover below ears, and smallest in cobs. On the other hand, the content of carbon was the opposite. It is known that more than half of the SOC source of the corn plant is located in the root and rhizosphere, and in Allmaras *et al*. (2012) this is specified to be over 80%.

In many publications, the measure of erosion protection of the soil by conservation tillage was as defined in Anonymous (2005). In this publication, any tillage or seeding system that maintains a minimum of 30% residue cover on the soil surface after planting to reduce soil erosion by water; or where soil erosion by wind is the primary concern, maintains at least 1,100 kg/ha of flat small grain residue equivalent on the soil surface during the critical erosion period is considered as conservation tillage.

Values of removed nutrients have been assessed as well. The range is 4.64 to 30 US$/Mg of stover DM (Avila-Segura *et al*., 2011; Cook and Shinners, 2011; Zych, 2008). Possibly the most realistic costs are given by Johnson *et al*. (2010), 18.1, 17.6 and 11.7 US$/Mg for below-ear stover, above-ear stover and cobs, respectively. In one article (Cook and Shinners, 2011), SOM removal has been estimated at 130 kg/Mg and price 0.9 US$/Mg of stover DM. The impact of stover removal on erosion value expressed as 15 US$/Mg. This value should be further studied, considering the amount of nitrogen that can be used by the following crops. The reduction of usable nitrogen can influence the nutrients value considerably.

Objectives

After a review of existing literature, it has been concluded that the background for the assessment of corn stover potentials, i.e. harvestable biomass that can be used as an energy source, are missing, as well as seasonal drought influence upon it. Background for the assessment of stover removal on nutrients and SOC value and soil protection of erosion are missing as well. The main objective of the investigation was to define these backgrounds for the Province of Vojvodina, an agricultural region of Serbia, in order to assess possibilities for sustainable provision of this biomass as energy source. The specific objectives were:

1. To define the potential, i.e. harvestable amount, of corn stover depending on seasonal weather, applied for two years, with dry (recently common for the region) and extremely dry conditions.
2. To quantify above-soil residues remaining on the field, after stover removal, for three harvest procedures, and evaluate amounts for erosion protection.
3. To create background for the cal-

culation of indirect costs of corn stover removal, such as the value of plant nutrients and SOC.

Materials and Methods

Weather conditions in 2011 were identified by the Hydro-meteorological Service of Serbia as very dry with precipitation around 400 mm, although such an amount is common for the last decade. In 2012 the precipitation was higher, 450 mm, but extremely reduced during the reproductive period. That is why that year was declared as extremely dry, considering the agro climatic conditions. This was followed by a significant yield reduction for all crops.

During the harvest period (full grain maturity) of 2011 and 2012, eight and seven samples of hybrids typical for the region were collected at three locations in the province of Vojvodina (**Table 1**). Harvest, typically, starts in the second half of September, for hybrids of the FAO group 400, and finishes at the end of November, for the hybrids of the FAO group 700. The samples were taken on farms that apply high levels of agro-technology. The row distance on all plots was 0.7 m, and crop density 60,000 to 70,000 plants per ha, as common in the region.

For each hybrid and location, five samples, from area of 1.4 m^2 each, were taken from different plots randomly selected. Corn plants were cut to the ground, packed and transported to the Laboratory of Biosystems Engineering, Faculty of Technical Sciences, Novi Sad.

Every single plant was processed as follows: the 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. 1**.

The mass of each part was measured using a balance, with an accuracy of 0.1 g. For the determination of moisture content, grains were dried using the procedure defined by Anonymous (2008) and stover fractions calculated according to the procedure defined by Anonymous (2012).

Based on obtained data, yields and moisture contents were calculated for: grain, cobs, husks (shanks included), the lowest 0.2 m, stalks + leaves (over 0.2 m in height) + tassels (further referred as stalks + leaves). Relative yields of residual parts are calculated by dividing measured values by grain yield, all of dry matter. The mean values for each hybrid and location were calculated, as well as the mean for all hybrids. All above-ground plant residual parts make the total mass. The first 20 cm of stalks is treated as not usable for energy generation and other uses and is difficult to harvest. Total mass minus the first 20 cm of stalks, is defined as usable mass. The residual mass that is expected to be harvested, depending on harvest procedure, is assigned as harvestable mass. On-field remaining mass of crop residues is calculated by subtracting harvestable from total mass.

Table 1 The list of tested hybrids

Code	FAO group	Hybrid	Code	FAO group	Hybrid
2011/1	400	PR 36 R 10	2012/1	400	NS 444
2011/2	490	PAKO	2012/2	480	DKC 5276
2011/3	550	LUCE	2012/3	500	ZP 505
2011/4	620	SYCORA	2012/4	550	LUCE
2011/5	620	DKC 6120	2012/5	600	KORIMBOS
2011/6	700	NS 7070	2012/6	700	GRECALE
2011/7	700	GRECALE	2012/7	700	VITORINO
2011/8	700	VITORINO			

The calculation of harvestable mass is performed based on harvest procedures, formerly described in Golub *et al.* (2012). This includes harvested fractions and harvest losses. The selection of procedures was done based on tested solutions in practice, and a major criterion was that the stover harvest may not cause significant influence on the main operation productivity –grain harvest. Single-pass procedure, described by some authors, is followed by a productivity reduction up to 40% (Keene *et al*., 2013; Shinners *et al*., 2012; Shinners *et al*., 2009). The stover harvest procedures and assumed losses are:

1. Two-pass harvest. Grain harvest by combine with snapper-head and integrated shredder-cornrower described in Straeter (2011) and Shinners *et al.* (2012). The stover is picked up from windrow by a round or big rectangular baler. Cutting height is 0.2 m. Percentages of harvested fractions are 70, 90 and 90%, for stalks+leaves, cobs and husks respectively, with additional baling losses of 20%.
2. Multi-pass harvest. This is the conventional stover harvest procedure. As previous, but the combine harvester is equipped with an integrated stover shredder. It is followed by raking, forming windrow and baling. The cutting height is 0.2 m. Percentages of harvested fractions are 70% for

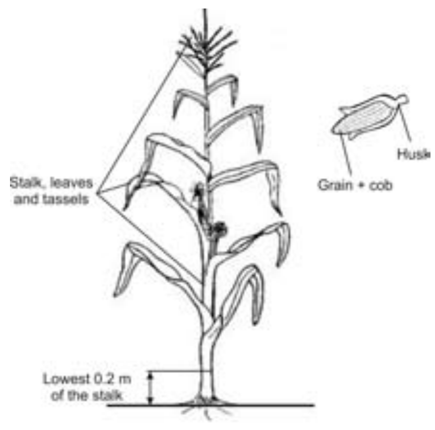


Fig. 1 Classification of corn plant parts.

stalks+leaves and 40% for cobs and husks combined, with additional baling losses of 20%.

3. Ears harvest. For the harvest, a picker-husker is used. All cobs are available after natural drying and threshing in the yard, without losses. (Additional collection of other stover parts can be performed by using a flail residues shredder, raking and baling, but this has not been considered here.)

The losses are determined based on literature data (Shinners *et al.*, 2012; Shinners *et al.*, 2009), for two-pass harvest, and local farmers' experiences (interviews with six farmers conducted by the crop residues collectors), for multi-pass harvest. The harvestable mass has been calculated using relative yields of stover fractions.

Based on estimated yield, drought influence on harvestable corn stover yield was indicated, as a background for supply security considerations.

As the measure of soil erosion protection, the criterion defined in Anonymous (2005) was applied as previously described. Due to the dominant impact of wind erosion, the criterion of surface coverage with more than 1,100 kg/ha DM of flat small grain residue equivalent was used as the measure of soil protection. The mass of stover equivalent to this has been defined using guidelines given in Hickman and Schoenberger (1989).

Results and Discussion

The main data of measured crop characteristics are presented in **Table 2**.

In 2011, the average grain yield of samples was 10.8 Mg/ha of dry matter (DM). Harvest Index (HI) was 0.51 which is similar to other cereals and is considered as common. The average grain yield was in 2012 considerably lower at 5.3 Mg/ha DM, less than half of 2011, as the consequence of extremely dry weather conditions and very high temperatures during the reproductive period. The average HI of 0.41 was also a result of this, although the average total mass of stover was 7.2 Mg/ha DM, which is 31% less than that in 2011.

Yields and relative yields of stover parts are presented in **Table 3** and in **Fig. 2**.

Average yields of stover fractions for 2012 are 29, 42 and 40% lower than those in 2011, for stalks + leaves, cobs and husks, respectively. Due to grain yield in 2012 the relative yields of stover fractions are higher, with a much wider span between min and max values.

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

Code	Grain		Residual biomass			
			Total		Usable	
	Y, Mg/ha DM	HI	Y, Mg/ha DM	RY, %	Y, Mg/ha DM	RY, %
2011/1	11.2	0.52	10.4	92.8	9.3	83.4
2011/2	8.0	0.53	7.1	88.7	6.5	81.2
2011/3	12.0	0.51	11.3	94.5	10.0	83.2
2011/4	10.3	0.48	11.0	106.7	9.0	87.4
2011/5	10.5	0.53	9.4	90.0	8.6	81.6
2011/6	11.5	0.50	11.7	101.3	10.7	92.3
2011/7	13.6	0.51	13.0	95.9	11.6	85.0
2011/8	9.0	0.50	8.9	99.2	8.0	89.2
Mean	10.8	0.51	10.4	96.1	9.2	85.4
SD	1.6	0.02	1.7	5.6	1.5	3.7
2012/1	5.8	0.45	7.7	122.9	6.7	110.8
2012/2	3.9	0.35	5.6	188.7	4.8	163.5
2012/3	6.7	0.46	7.2	115.9	6.5	104.7
2012/4	6.6	0.47	7.4	111.3	6.6	99.3
2012/5	2.3	0.30	7.8	237.2	7.0	201.9
2012/6	6.1	0.44	7.4	124.7	6.4	108.6
2012/7[1]	15.04	0.62	9.1	60.26	7.9	52.7
Mean	5.3	0.41	7.2	136.1	6.3	120.
SD	1.6	0.07	0.7	46.8	0.7	38.1

Y: yield, RY: relative yield to the grain, HI: harvest index, SD: standard deviation, DM: dry matter

[1] the data for hybrid 7 for 2012 (code 2012/7) were not included in the calculation of mean values and SD, while the values are extremely different than for others. The much higher grain yield 15 Mg/ha, is the consequence of applying the irrigation. This indicates potential yield increase in the case of irrigation.

Harvestable and Remaining Mass

Based on defined harvest procedures, the harvested biomass and that remaining on-field have been calculated and presented in **Table 4**.

Harvest procedure 1, compared with harvest procedure 2, results in approximately 22% higher harvestable mass, due to lower losses. However, according to Shinners *et al.* (2012), this is followed by 9 to 11% lower productivity of grain harvest, and up to 0.2%, additional grain losses. This should be taken into account in the selection of harvest procedure, and calculation of costs. The inconvenient weather conditions cause significant reduction of harvestable mass, for all harvest procedures, 31% for 1 and 2 and 42% for 3. The greater reduction in harvestable mass reduction for harvest procedure 3 is due to the effect of drought and high temperatures on grain/ears development in the reproductive period.

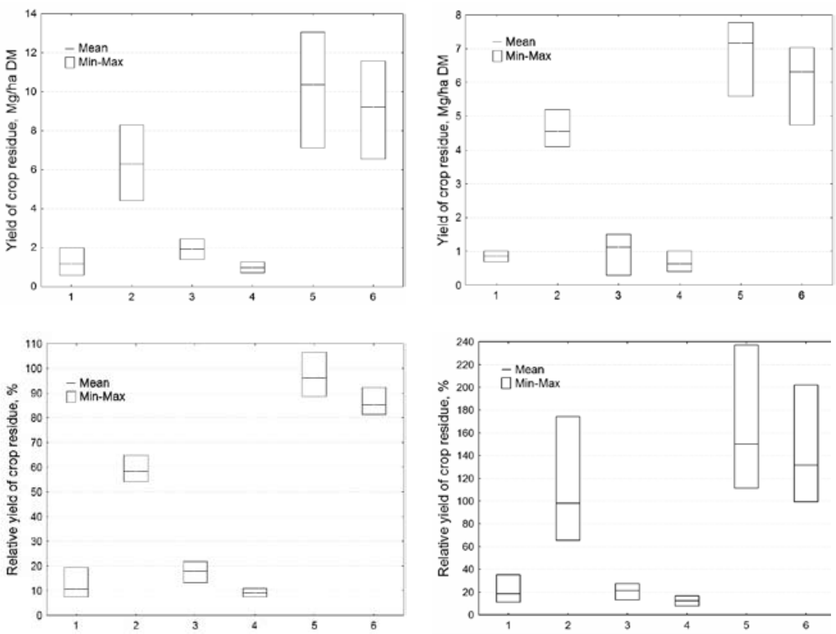
Obviously, for the exact calculation of corn stover potentials as energy source the reductions of yield caused by drought, but also other yield reductions (extreme diseases and insect infestation, flood, etc.), have to be analyzed and included in the planning. This should be performed at the level of administrative units, communities, counties, countries etc., but also for single users (small, medium and large). Harvest procedure 3, usually used at small family farms for household heating and other purposes, results in a significant reduction of available corn cobs (42%). Because of this, it is difficult to rely on residues amounts available in average years. This should be solved by having some reserves, or using other energy sources. Generally, every user of corn stover should perform an assessment of the risk related to the feedstock supply and management.

For both seasons the percentage of harvestable mass related to the total was the same for the harvest procedures 1 and 2, 53 and 43% respectively, and for procedure 3 19% for 2011 and 16% for 2012. There are different statements about the percentage of the stover that can be removed without impacting soil fertility. According to the literature sources listed in Radhakrishna *et al.* (2012), this percentage is between 33 and 58%. If the percentage is too high, the stover harvest can be omitted every second or third year, or biomass demand can be compensated by other crops included in the crop rotation. In any case, these issues should be studied and residues management plans developed.

Table 3 Yields, of DM, and relative yields of stover fractions.

Code	Stalk, lowest 0.2 m		Stalk+leaves		Cobs		Husks	
	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %
2011/1	1.1	9.5	6.1	54.1	2.4	21.8	0.8	7.4
2011/2	0.6	7.5	4.4	55.0	1.4	17.3	0.7	8.9
2011/3	1.3	11.3	6.5	54.0	2.3	19.4	1.2	9.8
2011/4	2.0	19.3	6.1	59.5	1.9	18.9	0.9	8.9
2011/5	0.9	8.4	6.3	60.5	1.4	13.1	0.8	7.9
2011/6	1.0	9.0	7.5	65.0	1.9	16.4	1.3	10.9
2011/7	1.5	10.9	8.3	60.9	2.1	15.7	1.1	8.5
2011/8	0.9	10.0	5.1	57.1	1.9	21.2	1.0	11.0
Mean	1.2	10.7	6.3	58.3	1.9	18.0	1.0	9.2
SD	0.4	3.5	1.1	3.6	0.4	2.7	0.2	1.2
2012/1	1.0	16.2	4.3	69.8	1.4	22.2	1.0	16.6
2012/2	0.8	35.3	4.1	174.2	0.3	13.0	0.4	14.7
2012/3	0.7	12.1	4.5	77.2	1.2	21.4	0.7	12.3
2012/4	0.8	12.0	4.3	65.3	1.5	23.2	0.7	10.8
2012/5	0.8	11.2	5.2	77.0	1.3	19.9	0.5	7.8
2012/6	1.0	25.1	4.9	124.3	1.1	27.3	0.5	12.0
2012/71	1.1	7.6	4.1	27.0	2.3	15.5	1.5	10.2
Mean	0.8	16.1	4.5	86.3	1.1	21.7	0.6	12.0
SD	0.1	8.8	0.4	39.2	0.4	4.3	0.2	2.8

Y: yield, RY: relative yield to the grain, SD: standard deviation
1 as for previous table, the data of hybrid 7 for 2012 (code 2012/7) were not included in the calculation of mean values and SD



Season 2011 Season 2012

1: lowest 0.2 m of stalks, 2: stalk+leaves, 3: cobs, 4: husks,
5: sum of 1 to 4 (total mass), 6: sum of 2, 3 and 4 (usable mass).

Fig. 2 Range of relative yields of stover fractions, result of statistical elaboration.

Erosion Protection

Remaining biomass in season 2011 was between 4.8 and 8.4 Mg/ha DM and in season 2012 those values were 3.4 and 6.0 Mg/ha DM. The residues mass needed to ensure 1,100 kg/ha of flat small grain equivalent, depends on residue configuration. For the case of flat corn residue: 60% stalk, 40% fines in diagram given by Hickman and Schoenberger (1989), 2,200 kg/ha DM of residues is equal to 1,100 kg/ha of small grain equivalent. In the same literature reference, influences of weathering and different tillage and planting influences on residual mass reduction are given. For example, in 2012 remaining mass for the harvest procedure 1 was the lowest 3.4 Mg/ha DM. The autumn tillage using chisel plow with straight

Table 4 Harvestable and remaining corn residues for defined harvest procedures.

Season	Harvest procedure	Harvestable mass			Remaining mass
		RY, %	M, Mg/ha DM	PTM, %	M, Mg/ha DM
2011	1	51	5.5	53	4.8
	2	41	4.5	43	5.9
	3	18	1.9	19	8.4
2012	1	72	3.8	53	3.4
	2	59	3.1	43	4.0
	3	22	1.1	16	6.0

RY: relative yield (to grain), M: mass calculated based on average grain yield
PTM: percentage of total mass

Table 5 Price and specific costs for replacement of key soil macronutrients.

	Price, $/kg	Specific cost[1] for first and second procedure, $/Mg DM	Specific cost[1] for third procedure, $/Mg DM
N	1.26	8.13	3.82
P_2O_5	1.96	1.65	0.65
K_2O	1.16	13.06	7.41
Total economic value		22.84	11.88

1 cost of nutrient removed per mass of stover Dry Mass removed

shovel points and winter weathering reduce the amount of residues by 25 and an additional 10% respectively. It means that on the field, before spring operations, there remains 2.3 Mg/ha DM, which is over the defined minimum for conservation tillage, i.e. protection of erosion. This is even more in all other cases.

Indirect Costs of Corn Stover Removal

Values presented in **Table 5** are estimated based on data shown in Cook and Shinners (2011). It can be seen that even though cobs presents only 19% to 16% of total mass, specific cost by nutrient removal more than half compared to whole stover. These data can be used to evaluate nutrient removal costs from field, whereby moisture content should be taken into account since it may vary in range from 30 to 70%.

Conclusions

The measurement of stover fractions' yield and relative yield to grain, results in data usable for the determination of expected harvestable and remaining stover mass, depending on the harvest procedure. These data can also be used for defining offtake nutrients and soil organic carbon as well as for quantifying the impact on the soil of stover removal. For a season with common weather conditions (here 2011), the average Harvest Index was 0.51 and the relative yield of stover fractions were 10.7, 58.3, 18.0, and 9.2% for the lowest 20 cm of stalk, stalk + leaves, cobs and husks respectively. The average relative yield, related to grain, of the total mass of stover, for this common season was 96.1% and usable part 85.4%. These data can be used, after getting the components of harvested stover, for the calculation of nutrients and soil organic carbon offtake, mass and value, while the fractions in this regard have different contents.

The unfavorable weather conditions, with drought and high temperatures during the reproductive period in the season 2012, impact the yield of grain and stover considerably. The average Harvest Index is reduced to 0.41 and usable mass of stover to about 31.5%. This is also reflected in the harvestable mass, i.e. the realistic potential of corn stover. Every user of corn stover should account for this in the planning stage, perform supply risk analyses and develop adequate supply management. There are also other potential reasons of the reduction of harvestable yield of corn stover.

The percentage of harvested mass was 53, 43 and 16 to 19% of total, for harvest procedures 1, 2 and 3, respectively. If the on field remaining mass should be provided, 33% of total mass (the minimal value mentioned in literature), in order to reduce offtake of nutrients and soil organic carbon, the appropriate harvesting procedure can be applied or offtake compensated by other crops included in crop rotation.

Note that the obtained results within this investigation can be used by biomass suppliers/users or decision makers, in order to estimate available biomass quantities and to ensure supply security, when considering energy generation and biofuels production from biomass. Thereby, prevention of erosion and sustainable nutrients provision should be ensured.

Novel stover harvest procedures are still under development. The idea is to harvest as much as possible of stover usable mass, to omit or reduce contact of stover and soil and to perform stover harvest with no, or negligible, reduction of corn harvest productivity. Here two conventional harvest procedures and one new, which is in demonstration phase, were considered with integrated stover shredder windrower. The later results in higher percentages of harvest stover, reduction of stover-soil contact, but, according to conducted measurements, this is followed by a 9 to 10% corn harvest productivity reduction. As previously stated by Golub *et al.* (2012) and partially tested by Shinners *et al.* (2012), efficient grain and corn stover harvesting, with minimum operating costs, can be obtained if the upper part of stalks-leaves, cut below ears, plus cobs and husks can be harvested. In this case the nutrients offtake will be reduced (their concentration in lower parts of stalks and leaves is higher), this part has lower moisture content and fiber quality is better.

Further measurements of the corn fractions yield are planned (the stalk + leaves will be split in two parts: lower, i.e. about 15 cm below ears and upper).

Aknowlegements

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Design and Evaluation of Biomass Combustor and Solar Dryer for Turmeric Processing

by

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Abstract

Boiling and drying of raw turmeric rhizomes is essentially very important for development of an attractive yellow colour and the aroma. The quality of the final product turmeric depends largely on curing process (Purthi, 1992). The post harvest unit operations for turmeric processing are boiling and drying carried out by conventional method which are slow, tedious and labour intensive. Use of petroleum fuel or electricity for drying of turmeric is an expensive process at village scale in developing countries. Therefore, an appropriate technology for boiling and drying of turmeric was developed and was evaluated for the boiling and drying of turmeric rhizomes. The results indicate that boiling and drying practice as intensified the colour and curcumin content. It was observed that time required to reduced moisture content in turmeric from 82% to 8% in solar drying was 42 h while 56 h in open suns drying. Hence, it is recommended that the improved biomass combustor and solar dryer be used for turmeric processing.

Introduction

Turmeric (*Curcuma Longa L.*) is one of the essential elements of the Indian recipes. Turmeric is used for medicinal value silence ancient times. Turmeric has an important place in spices. World's 90% turmeric is produced in India. Turmeric is exported as turmeric dry, turmeric fresh, turmeric powder, turmeric oleoresin and turmeric oil. The turmeric mostly exported from India to Iran, Japan, South Africa, Singapore, Sri Lanka, USA, UAE, Malaysia, Germany and Bangladesh. Presently in India 6, 54, 000 Metric tonnes of turmeric produced under 160, 000 hectare (Vikash, 2003). Turmeric mainly grown in the states of Tamil Nadu, Kerala, Maharashtra, Orissa, West Bengal and Northeastern states. In Rajasthan turmeric is cultivated in Jhadole, Dungarpur, Bichiwara, Gogunda (Udaipur Division), Chittorgarh, Kota and Bhilwara blocks.

The post harvest processing of turmeric involves many units operations such as washing, cleaning, curing, drying, polishing, size reduction and packaging. Curing is the process of boiling the raw rhizome in water for the development of attractive colour and aroma. Boiling also destroys the viability of the fresh rhizomes, reduces the raw odour and the time of drying. It also ensured an even distribution of colour in the rhizomes and found a better quality product by gelatinisation of the starch in turmeric (Purseglove *et al.*, 1981). Mother and finger rhizomes were boiled separately for about 40-60 minutes under slightly alkaline condition (100 g of sodium bicarbonate or sodium carbonate in 100 L of water). Traditional unit operation methods required more time and energy compare to improved processing technology. These improved technology could be maintain the quality and hygiene of product, hence enhances the profit of farmer. Therefore, an appropriate technology for boiling and drying of turmeric was developed and evaluated for the drying of turmeric rhizomes.

Materials and Methods

Designed and developed biomass combustor was used for boiling of turmeric. The capacity of biomass combustor was decided on the basis of quantity of heat required for curing a batch of about 50 kg raw turmeric. The initial design consideration and assumptions made for the design of biomass combustor (inverted natural down draft gasifier) system for boiling of turmeric was as follows (Panwar and Rathore, 2008):

1. Combustor efficiency (ή) : 35%
2. Calorific value of feed stock (CV) : 16.79 MJ/kg
3. Specific gasification rate : 80 kg/h^{-1}/m^2
4. Biomass density : 285 kg/m^3

Total Energy Required

In turmeric curing process, the turmeric was boiled up to 50-60 minute in the proportion 0.75 : 1 of raw turmeric: water (Sharma *et al.*, 2008), with considering one hour curing to a batch. Total heat requirement, Q was estimated from equation (-i) (anonymous 2009)

$Q = (W_tC_t + W_wC_p) \times (T_d - T_a) + (MC_V + UA)(T_d - T_a) + U_sA_s \times Tm$ ....(i)

= (50 × 0.837 + 38 × 4.185) × (100 - 30) + (4 × 0.22 + 14 × 0.785) ×70 + 5 0 × 0.196 × 65

= 29.90 MJ/h

Where,

Q = total heat required for curing, MJ/h

W_t = Weight of turmeric, 50 kg

W_w = weight of water =38 kg

C_p = Specific heat of water, 4.185 kJ /kg °C

T_d = boiling temperature, 100 °C

T_a = Ambient temperature, 30 °C

C_t = specific heat of turmeric = 3.87 kJ/kg °C

C_V = specific heat of aluminium vessel = 0.22 kJ/kg

M = mass of container using for boiling = 10 kg

U = over all heat transfer coefficient from sidewall=60 W/m^2 - °C

U_s = over all heat transfer coefficient for liquid surface=140 W/m^2 - °C

Fuel Consumption Rate

The total amount of fuel required for curing of 50-kg/batch capacity of turmeric was estimated. The amount of actual fuel required for generation of heat was determined using equation (ii) (Belonio *et al.* 2005).

$FCR = Q / (CV\acute{\eta})$ = 29.90 / (16.79 × 0.35) = 5.09 kg/h ....(ii)

Where,

FCR = fuel consumption rate, kg/h

Q = heat energy needed, 29.9 MJ/h

CV = calorific value of fuel, 16.79 MJ/kg

$\acute{\eta}$ = Combustor efficiency, 35%

Reactor Diameter, D

The diameter of cylindrical shape reactor of combustor was calculated as below

$$D = \sqrt{\frac{1.27\,FCR}{SGR}}$$

= 0.351m ≈ 36cm

Where,

D = diameter of reactor, m

FCR = fuel consumption rate, 5.09 kg/h

SGR =specific gasification rate of biomass, 80 kg/h/m^2

Height of the Reactor, H

The height of cylindrical shape reactor of combustor was determined as below

H = SGR × T / ρ = 80 × 1 / 285 = 0.28 m

Where,

H = length of the reactor, m

T = time required to consume biomass, 1 h

ρ = biomass density, 285 kg/m^3

The biomass combustor consists of gasifier reactor, grate, ash chamber, burner assembly, primary air control supply system etc the line diagram showed in **Fig. 1**.

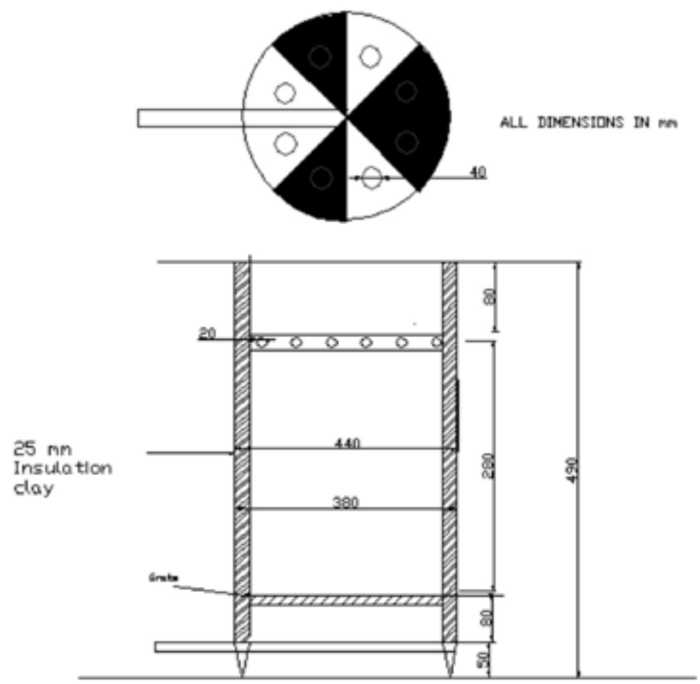

Fig. 1 Line diagram of biomass combustor

The drying was carried out under sun and in the developed indirect natural convection solar cabinet dryer showed in **Fig. 2**. The drying was done from 9 AM to 5 PM in the month of January 2012. Temperature and relative humidity of the ambient air and hot air inside the solar dryer and exit air were recorded in one hour interval. The sample was dried until the moisture level in the sample reduced to a safe storage level of 8% (w.b.). The dried sample was grounded in powder and the colour b value that is yellowness and Curcumin content were determined.

Result and Discussion

Performance of Biomass Combustor

The water boiling test was carried out as per protocol of the Ministry of New and Renewable Energy, Government of India, to evaluate the thermal performance of the system. The thermal efficiency of biomass combustor was obtained as 35%. The biomass combustor was used to boiling of 50 kg batch turmeric rhizomes as shown in **Fig. 3**. The fire hole of combustor was filled with dried wood, grasses, paper waste up to with in the 5 cm of top hole. It was observed that the blue flame was found with in 10 minute of ignition. It was observed that biomass combustor produced heat continuously up to 2.5 h. During the testing the temperature of the outer surface of stove was recorded as about 80 ºC, which indicated that there was a still chance to minimize conduction and radiation heat losses from the outside of combustor. The flame temperature was recorded by K-type thermocouple and it was 68 during the peak hour of combustion.

Fig. 2 Solar Cabinet Dryer

Fig. 3 Turmeric Curing with Biomass combustor

Safety During Operation

The outside temperature of the combustor during testing was recorded as 80, which can burns the user, so for safety purpose the combustor was provided with wooden handle. During the operation of bio-combustor initially the carbon monoxide was obtained, which is toxic in nature. Therefore, it is recommended the first flame must be escaped in open area than bring it inside the close room or house for curing purpose. Subsequently after completion of the burning some charcoal was obtained as unburned fuel. If the combustor was closed before complete burning of charcoal, there was a chance of fire hazard. Disposal of the charcoal in safe places where it does not produce a fire or waiting until it cools to a safe temperature (Panwar and Rathore, 2009), is also an important requirement in operating a biomass combustor.

Performance a Solar Cabinet Dryer

The maximum temperature obtained inside the drying chamber was 59.4 at 01.00 hour in the month of January corresponding to ambient temperature of 34.8 and solar intensity of 792 W/m^2. The average air temperature raised inside drying chamber over ambient temperature was 15-25 during the full load condition. It was also observed that the outlet temperature of drying chamber was lower than inlet temperature of drying chamber. The hourly temperature and solar intensity variation inside drying chamber observed is graphically presented in **Fig. 4**.

Outlet relative humidity of drying chamber was more than inlet. This was due to addition of water vapours into heated air. It is observed from

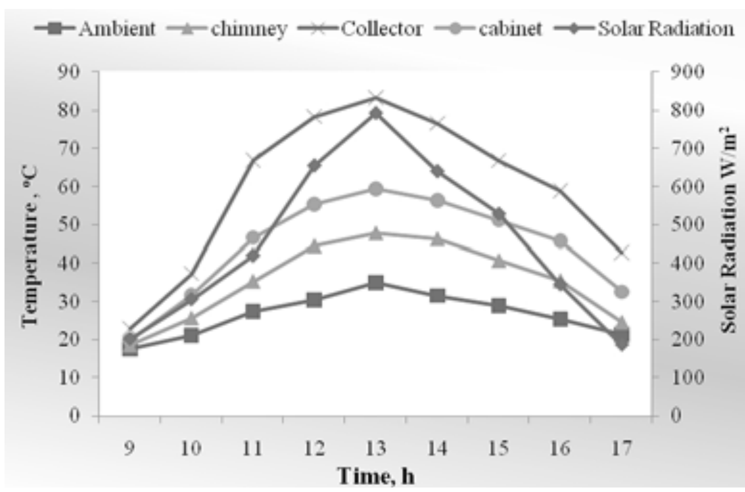

Fig. 4 Variation in temperature during full load test in solar cabinet dryer

Fig. 5 that, the relative humidity inside the solar cabinet dryer varies from 52 to 24% and corresponding ambient humidity varies from 64 to 35%. The average relative humidity inside the solar dryer was found to be 33.44% as compared to 49% of ambient air and exit air average relative humidity found as 37.55%. The result of moisture content with time is shown in **Fig. 6**. The initial moisture content of turmeric was 82% (w.b.). It was also observed that at the end of sixth day moisture content was reduced up to 8% (w.b.) in the developed cabinet dryer. It was found that solar cabinet dryer took 42 h as compared to open sun drying as it required 56 h. It was observed that solar cabinet dryer saved two days compared to open sun drying.

Quality Evaluation

The colour value (b value) of dried turmeric inside solar cabinet dryer varied from 45.18 to 49.45 instead of commercial sample that varied from 26.5-39.7 and open dried turmeric varied from 32.30 to 37.98. The curcumin content of solar cabinet dried turmeric ranged between 5.14 to 5.50% while open sun dried sample showed 4.35 to 4.58% and commercial sample showed 3.75 to 4.33%. It was observed that higher curcumin and colur in solar cabinet dried sample was for better quality product.

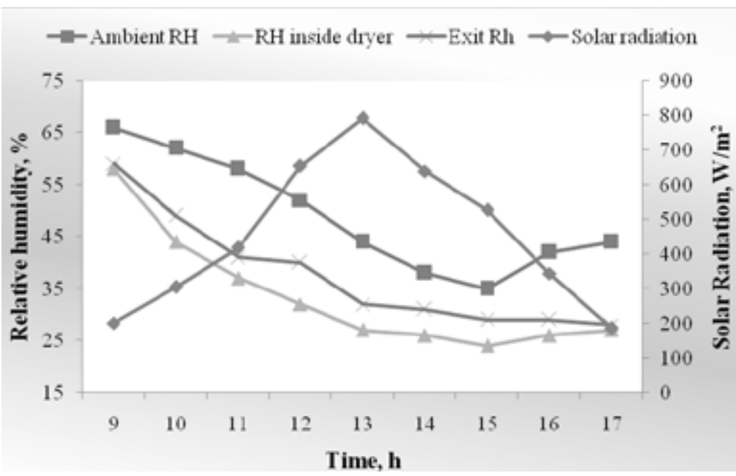

Fig. 5 Variation of relative humidity during full load test in solar cabinet dryer

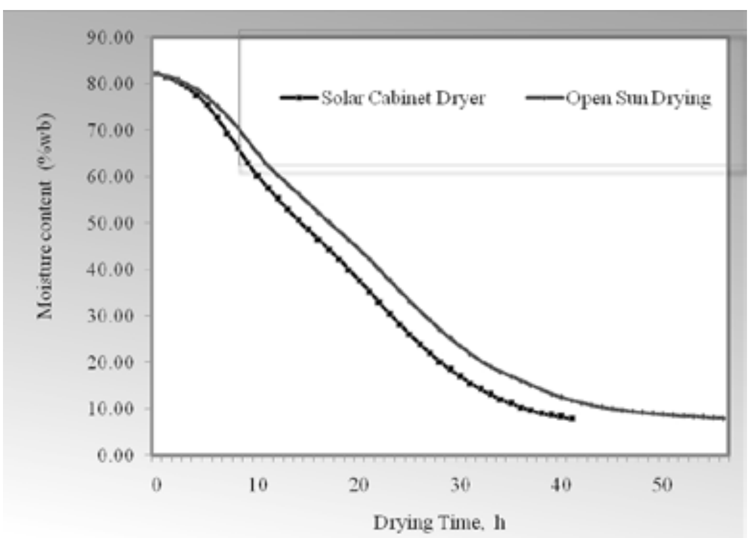

Fig. 6 Variation of moisture content for turmeric drying

Conclusions

The post harvest unit operations of turmeric like curing and drying carried out by conventional method were tedious and labour intensive. Attempt was made to develop an efficient biomass combustors which reduced drudgery, labour cost and maintained the quality of final product. The thermal efficiency of biomass combustor was better than efficiencies of open fires and traditional stoves. The solar cabinet dried turmeric sample had higher colour value and higher curcumin content for better quality product.

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Effect of Conservation Agricultural Practice on Energy Consumption in Crop Production System in India

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Abstract

Energy input in agriculture is important in terms of crop production and agro-processing for value addition. Human, animal and mechanical energy are extensively used for crop production in Indian agriculture. A study was conducted to assess the potential of energy savings in rice-wheat and soybean-wheat production systems under conservation agriculture (CA) practice as compared to conventional practice (CP). The survey was conducted in four selected northern states of India viz. Punjab, Haryana, Madhya Pradesh and Uttar Pradesh to assess the energy requirements during various farm operations in crop production systems by farmers practicing conservation agriculture and conventional agricultural practices. Direct and indirect energy input and output energy for rice-wheat and soybean cropping systems were analysed to quantify total energy consumption during CA and CP practices. The energy requirement during conventional agriculture (CP) practice was higher as compared to those during CA practice and was the highest in Punjab (21,432 MJ/ha) and followed by Haryana (19,744 MJ/ha), Uttar Pradesh (13,508 MJ/ha) and Madhya Pradesh (5,266 MJ/ha). It was observed that energy output per unit energy input was significantly higher in CA practice as compared to CP. The energy output per unit energy input ratio was 8.0, 7.7, 7.0 and 6.8 for the states of Madhya Pradesh, Punjab, Haryana and Uttar Pradesh, respectively under conservation agriculture (CA) practice. The energy productivity under CA in Punjab (0.244 kg/MJ), Haryana (0.222 kg/MJ), Uttar Pradesh (0.217 kg/MJ) and Madhya Pradesh (0.254 kg/MJ) was higher as compared to CP in Punjab (0.203 kg/MJ), Haryana (0.188 kg/MJ), Uttar Pradesh (0.173 kg/MJ) and Madhya Pradesh (0.197 kg/MJ) states. Therefore, it may be concluded that the energy use efficiency and productivity could be improved by adopting conservation agriculture practices supported with suitable agricultural machinery.

Key words: Conservation agricultural, energy analysis, direct energy, indirect energy, conventional agricultural.

Introduction

Energy input is one of the most important indicators of crop productivity. The net energy and monetary return of a cropping system can be quantified by sound planning of sustainable systems (Chaudhary *et al*., 2006). Yield and economical parameters increased linearly as the level of fertility increased, while reverse trend was observed with energy-use efficiency, energy productivity and energy intensity (Bilore *et al*., 2005). The share of agriculture in national energy consumption has been rising consistently over the last three decades. Presently, it accounts for nearly a quarter of the country's electric consumption. The yields of different crops can be increased up to 30% by using optimal level of energy input (Sidhu *et al*., 2004; Chaudhary *et al*., 2006). In North-West Himalayas, there are small and fragmented land holdings, insufficient draught power and lack of farmer resources, due to which the yield levels are very low.

In recent years, conservation agriculture (CA) has gained importance owing to the need of farmers to reduce variable cost of cultivation, as major portion of energy (25-30%) is utilized for field preparation and crop establishment. This can be minimized by reducing the intensity of tillage operations. The zero tillage method of sowing is cost effective, energy efficient and beneficial to environment as compared to conventional practices of sowing (Tripathi *et al*., 1999; Filipovic *et al*., 2006). Conservation tillage reduces soil degradation, energy consumption and production costs (Allen, 1981; Crosson *et al*., 1986).

Energy in agriculture is important in terms of crop production, processing and value addition. Human, animal and mechanical sources of energy are extensively used for crop production. Energy requirements in agriculture are divided into two groups i.e. direct and indirect. Direct energy is required to perform various farm operations related to crop production such as land preparation, irrigation, interculture, threshing, harvesting and transportation of agricultural inputs and farm produce. It is seen that direct energy is directly used at farms and on fields. Indirect energy, on the other hand, consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (Bockari *et al*., 2005; Chaudhary *et al*., 2006). Major items included in indirect energy are fertilizers, seeds, machinery production, pesticides etc. These inputs and methods represent various energies that need to be evaluated to ascertain their effectiveness and to know how to conserve them.

Energy analysis, therefore, is necessary for efficient management of scarce energy resources for improved agricultural production. It will identify production practices that are economical and effective. Other benefits of energy analysis are to determine the energy invested in every step of the production process, to provide a basis for conservation and to aid in making sound management and policy decisions (Baruah & Bora, 2008). The energy analysis shows the methods to minimize the energy inputs and therefore to increase the energy productivity (Fluck & Baird, 1982).

Therefore, it highlights the need to look into the methods of farm operations, which reduces the energy consumption with an increase in energy output for sustainable development of Indian agriculture. Taking into account the facts, the study was done to compare energy consumption during conservation agriculture practice and traditional agricultural practice for rice-wheat and soybean-wheat cropping systems.

Materials and Methods

Selection of Farmers for the Study

A survey was conducted in selected four northern states of India namely Punjab, Haryana, Uttar Pradesh and Madhya Pradesh under ICAR funded project National Initiative on Climate Resilient Agriculture (NICRA) at ICAR - Central Institute of Agricultural Engineering, Bhopal during 2011-12 and 2012-13. Rice-wheat was the major cropping system of Punjab, Haryana and Uttar Pradesh states and soybean-wheat of Madhya Pradesh state. These cropping systems were selected to conduct the study. Total 48 farmers (24 conservation agriculture and 24 conventional agriculture practicing) were statistically selected from each state and were surveyed using a questionnaire to study the use of conservation agriculture machinery

Table 1 Farm operations performed under conventional and conservation agricultural practices in the surveyed states

Farm Operations	Crops	Punjab		Haryana		Uttar Pradesh		Madhya Pradesh	
		CV	CA	CV	CA	CV	CA	CV	CA
Land preparation	Rice	1MB + 2H + 2C + 2PH	---	1H + 1C + 1R +2 PH	--	3C + 1R	--	3H + 2C (Soybean)	1H + 1C (Soybean)
	Wheat	2H + 2C	---	3H + 1C or 3R	-	3C or 3R	--	2H+1C	--
Sowing operation	Rice	TR = 225 man-h/ ha	DSR = Zero till drill	TR = 225 man-h /ha	DSR = Zero till drill	TR= 225 man-h / ha	DSR = Zero till drill	Seed drill (Soybean)	Seed-cum-ferti drill (Soybean)
	Wheat	seed-cum-ferti drill	Happy seeder	seed-cum-ferti drill	Happy seeder	seed-cum-ferti drill	Zero till drill	Seed drill	Seed-cum-ferti drill
Intercultural operation	Rice	2CW	Herbicide	2CW	Herbicide	Manual	Herbicide	Manual (Soybean)	Herbicide (Soybean)
	Wheat	--	Herbicide	--	Herbicide	-	Herbicide	-	Herbicide

CV: Conventional agricultural practices; CA: Conservation agricultural practice
H: Harrow; C: Cultivator; MB = Mould board plough, R = Rotavator, DSR = Direct seeded rice, CW = Cono weeder, ZT = Zero-till drill, PH = Paddy harrow, TR = Transplanting

by the farmers.

Energy Analysis for Different Farm Operations Under Conventional and Conservation Agriculture Practices

In the survey, the energy input and output data were recorded for cultivation of major cropping system of each state. The information related to energy inputs for carrying out various farm operations by farmers practising conventional agriculture (CV) and conservation agriculture (CA) under rice-wheat and soybean-wheat cropping systems were recorded by enquiry in the states. The farm operations performed under rice-wheat and soybean-wheat cropping systems in different states under different practices are given in **Table 1**. For example, **Table 1** indicated that seed cum fertiliser drill was used by farmers for sowing of wheat in Punjab, Haryana and Uttar Pradesh states under conventional practice (CV) as compared to use of happy seeder in Punjab and Haryana states and zero till drill in Uttar Pradesh state by farmers practicing conservation agriculture (CA).

Energy requirement in mechanised agriculture is of two types. The energy analysis of direct (fuel, human labour and electricity) and indirect (machinery, seed, fertilizer, pesticides, etc) energy sources involved in the crop production process was performed for different farm operations like land preparation, sowing/transplanting, interculture, fertilizer application, pesticides application, spraying, irrigation and harvesting. Under normal circumstances, water pumping was also required for one irrigation of kharif soybean crop and recommended irrigation for rice crop.

The field capacity of farm tools and equipment, fuel consumption, labour requirement and irrigation water requirement were recorded for each farm operation to ascertain the direct energy use per hectare under rice-wheat cropping system in Punjab, Haryana and Uttar Pradesh states and soybean-wheat in Madhya Pradesh state. The data on other production inputs such as total weight of machine, useful life of machines, seeds, fertilizer, pesticides, etc in these cropping systems were determined for each farm operation to ascertain the indirect energy use per hectare. These inputs were converted into equivalent energy (MJ/ha) using standard conversion factors given in **Table 2**.

Energy output arises mainly from the product itself and from the by-products. Energy output from main product was calculated by multiplying production and their corresponding energy equivalent. The data on yields under different practices were recorded to calculate output energy under rice-wheat and soybean-wheat cropping systems in the surveyed states.

The procedure for calculation of direct and indirect energy requirement for various farm operations is given below.

Direct energy

Direct energy required to perform various farm operations included fuel consumed, human or/and animal power used and electrical power consumption during irrigation. The direct energy use (MJ/ha) for each field operation was computed by the following equations (Bockari *et al*., 2005; Chaudhary *et al*., 2006)

(a) Fuel energy use

$$ED_{Fuel} = h \times FC \times FE_qF \times RU \quad \text{...(1)}$$

Where,

ED_{Fuel} = Direct fuel energy used for the field operation, MJ /ha

h = Working hours per run, h/ha

FC = Average fuel consumption, L/h

FE_qF = Fuel energy equivalent per litre of fuel, MJ/l

RU = Number of runs for each field operation.

(b) The labour energy use (MJ/ha) at every stage in the rice-wheat and soybean-wheat cropping systems

$$ED_{Labour} = (Labour \times Time) / Area \times LE_qF \quad \text{...(2)}$$

Where,

ED_{Labour} = Direct energy use (labour), MJ/ha

$Labour$ = Number of working labours

$Time$ = Operating time, h

$Area$ = Operating area, ha

LE_qF = Labour energy equivalent factor, MJ/h

(c) Electric energy consumption during irrigation (MJ/ha)

$$ED_{Electric} = P \times EE_qF \quad \text{.......................(3)}$$

Where,

$ED_{Electric}$ = Direct energy use (Electrical), MJ/ha

P = Power consumption, kWh,

EE_qF = Electric energy equivalent factor, MJ/kWh

Table 2 Energy equivalent for direct and indirect sources of energy (Singh and Mittal, 1992; Singh *et al*., 1997; Singh *et al*., 2008)

Particulars	Unit	Energy equivalent, MJ
(A) Direct sources		
1. Human labour		
a. Adult men	Man-hour	1.96
b. Women	Women-hour	1.57
2. Diesel	litre	56.31
3. Electricity	kWh	11.93
(B) Indirect sources		
4. Farm Machinery	kg	62.7
5. Fertilizer		
a. N	kg	60.6
b. P2O5	kg	11.1
c. K2O	kg	6.7
6. Chemicals		
a. Superior chemicals	kg	120
b. Inferior chemicals	kg	10
7. Seeds		
a. Wheat	kg	15.2
b. Paddy	kg	15.2
c. Soybean	kg	15.2
8. Straw		
a. Wheat	kg	12.5
b. Paddy	kg	12.5
c. Soybean	kg	12.5

Table 3 Energy consumption (MJ/ha) pattern during different farm operations under conventional and conservation agricultural practices in the surveyed states

Treatment	Energy Input								Total energy output	Ratio
	Land Preparation	Sowing	Fertilizer	Pesticides	Inter-culture	Irrigation	Harvesting	Total		
T1	8,057[h]	1,134[a]	22,145[d]	710[e]	470[b]	21,432[h]	1,604[a]	55,553[h]	354,586[d]	6.4[d]
T2	3,621[d]	1,975[d]	22,145[d]	808[f]	235[a]	15,849[g]	1604[a]	46,237[f]	35,4229[d]	7.7[g]
T3	6,829[g]	1,144[a]	19,760[c]	690[e]	470[b]	19,744[f]	1,608[a]	50,245[g]	296,838[c]	5.9[b]
T4	3,208[c]	1,772[c]	19,760[c]	785[f]	235[a]	15,113[e]	1,608[a]	42,480[e]	296,721[c]	7.0[f]
T5	6,186[f]	1,132[a]	1,4657[b]	498[b]	474[b]	13,508[d]	1,602[a]	38,057[d]	206,566[b]	5.4[a]
T6	2,018[b]	1,762[c]	14,657[b]	594[d]	235[a]	9,382[c]	1,608[a]	30,256[c]	206,563[b]	6.8[e]
T7	5,255[e]	1,388[b]	6,542[a]	458[a]	490[c]	5,266[b]	1,580[a]	20,838[b]	129,004[a]	6.2[c]
T8	1,651[a]	1,936[d]	6,542[a]	555[c]	490[c]	3,538[a]	1,595[a]	16,151[a]	128,981[a]	8.0[h]

Note: Means within the same column, followed by the same letter are not significantly different at the 5% level of significance

Indirect energy

Indirect energy is used during manufacturing, packaging and transportation of herbicides, insecticide, fungicides and farm equipment. The indirect energy use per hectare for each field operation was computed by the following equations (Bockari *et al*., 2005; Chaudhary *et al*., 2006).

(a) Energy contribution of machinery/tractor for each field operation

$EI_{Machinery}=(Wx\ ME_q\ F) / UL \times h \times RU$ .... (4)

Where,

$EI_{Machinery}$ = Specific indirect energy for machinery use for a field operation, MJ/ha

W = Total weight of the machine, kg

MEqF = Machine energy equivalent factor, MJ/ kg

UL = Useful life of machinery, h

h = Working hours per run, h/ha

RU = Number of runs for each field operation.

(b) Energy inputs for fertilizer, pesticides and seed (MJ/ha)

$EI_{Input} = RATE_{Input} \times IEqF$ .... (5)

Where,

EI_{Input} = Indirect energy use (inputs), MJ/ha

$RATE_{Input}$ = Application rate of applied inputs, kg/ha

IEqF = Energy equivalent factor for applied input, MJ/kg

Statistical Analysis

The collected data were statistically analysed in a completely randomised block design with 8 treatments and three replications. The 8 treatments were four states viz. Punjab (P), Haryana (H), Uttar Pradesh (UP) and Madhya Pradesh (MP) and two agricultural practices i.e. conventional practice (CP) and conservation agriculture (CA). The treatments were designated as T1 (PCP=Punjab with conventional agricultural practice), T2 (PCA= Punjab with conservation agriculture practice), T3 (HCP), T4 (HCA), T5 (UPCP), T6 (UPCA), T7 (MPCP) and T8 (MPCA). Each replication has one village with mean input and output data of 8 farmers. The energy inputs and output for various farm operations under conventional and conservation agriculture practices were analysed using SPSS (V-10) and arranged values according to DMRT are given in **Table 3.**

Results and Discussion

The operational energy input data of conventional and conservation agriculture practices for various farm operations for rice-wheat and soybean-wheat cropping systems were collected. Direct energy inputs for wheat and rice crops contained human energy, electricity for pumping irrigation water and fuel energy. The indirect energy sources were machine use for field preparation, seed, fertilizer and plant protection agro-chemical for different operations.

Energy Requirement for Different Farm Operations

Seedbed preparation and sowing

Energy consumption (direct and indirect) in conventional field preparation under rice-wheat cropping system was significantly higher as compared to conservation agriculture practices in all four surveyed states at 5% level of significance (**Table 3**).

In land preparation for rice-wheat cropping system, energy consumption under conventional agriculture practice was the highest in Punjab (8,057 MJ/ha), and followed by Haryana (6,829 MJ/ha), Uttar Pradesh (6,186 MJ/ha) and Madhya Pradesh (5,255 MJ/ha). Similar trend was observed in conservation agriculture practice. The difference in energy consumption in land preparation may be due to difference in soil texture and land preparation practices of the surveyed states. Energy consumption during sowing (seed, machine and operational energy) under CA practices was found significantly higher as compared to CP in all four states. However, highest energy requirement during sowing under CA sowing was observed in Punjab state (1,975 MJ/ha) and followed by Madhya Pradesh (1,936 MJ/ha), Haryana (1,772 MJ/ha) and Uttar Pradesh (1,762 MJ/ha). Maximum energy consumption under CA practice in Punjab may be due to zero tillage sowing under heavy residue condition after harvesting of rice. Sowing energy in Madhya Pradesh under CA practice was also found higher and on par with Punjab because zero tillage sowing practices in vertisol is difficult and more energy consuming as compared to the light textured soil of other surveyed states.

Fertilizer application

The direct and indirect energy consumption during fertilizer application under rice wheat cropping system was recorded and analysed data are given in **Table 3**. No difference in fertilizer application energy was observed between CA and CP practices in four surveyed states. However, the energy consumption in fertilizer application among four states was significantly different at 5% level of significance. Maximum fertilizer energy consumption was observed in Punjab (22,145 MJ/ha) and followed by Haryana (19,760 MJ/ha), Uttar Pradesh (14,657 MJ/ha) and Madhya Pradesh (6,542 MJ/ha). It was also observed that fertilizer application consumed maximum input energy as compared to other input energies under rice-wheat cropping system.

Pesticide application

The application of glyphosate @ 1,000-1,500 ml/ha was done under CA practice for controlling pre-emergence weeds. For control of second flush of weeds, post emergence application of quizalofop (Targa Super 10 EC) @ 50 g a.i./ha was done after 30-45 days of sowing. The direct and indirect input energies in pesticide application under rice-wheat cropping system were recorded/calculated and analysed data were shown in **Table 3**. The analysed data revealed that the energy consumption in pesticide applications was significantly different at 5% level of significance. Energy consumption during pesticide application was significantly higher in CA practice as compared to CP. In CA, soil was not disturbed and residue was left in the field for proper surface cover. In this situation, the incidence of insects and pests under CA practice were higher as compared to CP. Due to availability of suitable sowing machinery under heavy residue cover (Turbo Happy Seeder), farmers of Punjab and Haryana did not burn paddy crop residue before sowing of wheat. In this practice, the field worthy and beneficial microbes remained safe in their field. However, some harmful insects and pests also remained in the field. For controlling these insects and pests, farmers of Punjab and Haryana used significantly higher pesticide energy as compared to farmers of Madhya Pradesh and Uttar Pradesh.

Interculture operation

In general, herbicides were used under CA practice in Punjab, Haryana and Madhya Pradesh states. However, in conventional practice, mechanical/manual means were used. The energy consumption during weeding under CA practice was significantly higher ($P \leq 0.05$) as compared to conventional practice in Punjab, Haryana and Uttar Pradesh. However, in Madhya Pradesh farmers followed manual weeding under both CA and CP practices consuming same input energy (490 MJ/ha) and significantly higher as compared to other states.

Irrigation

The direct and indirect energy consumption in irrigation under rice wheat cropping system of four surveyed states were recorded/calculated and arranged according to DMRT in **Table 3**. Variation of irrigation energy requirements was significantly different ($P \leq 0.05$) for different states. Irrigation energy requirement under CA practice was significantly lower ($P \leq 0.05$) as compared to CP practice in all four surveyed states. The energy requirement during CP was higher as compared to those during CA practice and was the highest in Punjab (21,432 MJ/ha) and followed by Haryana (19,744 MJ/ha), Uttar Pradesh (13,508 MJ/ha) and Madhya Pradesh (5,266 MJ/ha). However, the energy requirement during CA practice was the highest in Punjab (15,849 MJ/ha) and followed by Haryana (15,113 MJ/ha), Uttar Pradesh (7,382 MJ/ha) and Madhya Pradesh (3,538 MJ/ha).

Total Energy Input, Output and Output-Input Ratio

Net energy output of rice-wheat cropping system included energy output both from grain and straw. The output data of rice-wheat cropping system from all four states were recorded and analysed using SPSS (V-10) and values arranged according to DMRT are given in **Table 3**. In four surveyed states, no significant difference in output energy was observed between CA and CP practices under rice-wheat cropping system at 5% level of significance. The highest energy output of 354,586, 296,838, 206,566 and 129,004 MJ/ha was observed during conventional practice in the states of Punjab, Haryana, Uttar Pradesh and Madhya Pradesh, respectively. However, the highest energy output of 354,229, 296,721, 206,563 and 128,981 MJ/ha was observed during CA practice in the states of Punjab, Haryana, Uttar Pradesh and Madhya Pradesh, respectively. Energy inputs under CA practice for rice-wheat cropping system were observed significantly lower as compared to CP practice in all four surveyed states. It was due to significant energy saving in seedbed preparation under CA practice. Similar trend was observed by Singh *et al.* (2008) for soybean-wheat cropping system. The energy output per unit energy input was found significantly higher under CA practice as compared to CP practice in the surveyed states. The energy output per unit energy input ratio was 8.0, 7.7, 7.0 and 6.8 for the states of Madhya Pradesh, Punjab, Haryana and Uttar Pradesh, respectively under conservation agriculture practice. Similarly, energy output per unit energy input

Table 4 Energy productivity of surveyed states under rice-wheat cropping system

Treatments	Total input energy, MJ/ha	Grain output, t/ha	Energy productivity, kg/MJ
T1	55,553	11.275	0.203
T2	46,237	11.263	0.244
T3	50,245	9.438	0.188
T4	42,480	9.435	0.222
T5	38,057	6.568	0.173
T6	30,256	6.568	0.217
T7	20,838	4.102	0.197
T8	16,151	4.101	0.254

ratio was 6.4, 6.2, 5.9 and 5.4 for the states of Punjab, Madhya Pradesh, Haryana and Uttar Pradesh, respectively under conventional agriculture practice.

Energy Productivity

The energy productivity for different treatments was calculated and given in **Table 4**. Energy productivity under CA treatments T2 (0.244 kg/MJ), T4 (0.222 kg/MJ), T6 (0.217 kg/MJ) and T8 (0.254 kg/MJ) were found higher as compared to CP treatments T1 (0.203 kg/MJ), T3 (0.188 kg/MJ), T5 (0.173 kg/MJ) and T7 (0.197 kg/MJ). It was evident from the results that the energy productivity could be improved by adopting conservation agriculture practice supported with suitable machinery.

Conclusions

The energy output per unit energy input was higher under CA practice as compared to traditional practice in all four surveyed states. This ratio was higher in Punjab and Haryana states as compared to states of Uttar Pradesh and Madhya Pradesh due to use of appropriate CA machinery, athough their input energies were higher. The use of conservation agriculture practice equipped with suitable CA machinery like zero till seed-cum-ferti drill, happy seeder, raised bed planter, laser guided land leveller were proved a better option to save energy during various farm operations. The higher energy productivity in highly mechanised states of India viz Punjab and Haryana was due to use of suitable machinery for various farm operations. It was concluded that the energy productivity not only depends on agricultural practices but also on use of suitable machinery either during conventional practice or during conservation agriculture practice.

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Moisture Dependent Dimensional and Physical Properties of Re-Fabricated Rice

by

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Abstract

The present study was carried out to evaluate the effect of moisture content on some dimensional and physical properties of re-fabricated rice grains obtained through six dies of different dimensions. Three levels of moisture content 10, 12 and 14% were used. The relationship between moisture content and selected properties was expressed by regression equations. All the physical and dimensional properties except l/b ratio, aspect ratio (Ra) and porosity (ε) were found to have significant ($R^2 > 0.92$) positive correlation with moisture content. Both l/b ratio and porosity had significant ($R^2 > 0.82$) negative relationship with moisture content except in re-fabricated grains obtained through die-III, where a non-significant positive correlation was seen. The effect of moisture content on aspect ratio was found non-significant in all the six types of re-fabricated rice grains.

Keywords: Moisture content, Physical properties, Extrusion, Die

Introduction

Extrusion processing utilizes the high temperature and high shear force to produce a product with unique physical and chemical characteristics (Pansawat *et al.*, 2008). Nowadays, extrusion processing is widely used in food industry due to its versatility, high productivity, low cost and energy efficiency. A new area of extrusion technology utilizes the higher moisture levels combined with twin screw extruder for making un-conventional products. Extrusion at high moisture level also known as wet extrusion was almost impossible by single screw extruder. However, twin screw extrusion with sophisticated barrel design, screws and dies are enabling wet extrusion. Twin screw extruders have superior conveying capabilities compared to single screw extruders, hence they offer extended range of applications (Harper, 1981).

Rice (Oryza Sativa) is the most popular cereal worldwide, serving as a staple food for 39 countries and nearly half of the world's population. About 95% of the world's rice is produced in developing countries, 92% of it in Asia (Juliano, 1993). India is the 2nd largest producer and consumer of rice in the world. However, in developing world most of the millers rely on obsolete equipments to mill the paddy, which leads to high broken rice percentage during milling. Therefore, considering the broken rice percentage which is considerably high and is readily available at low cost in developing countries, the development of re-fabricated rice is essential and has potential. Thus, a detailed research programme on development of technology for the production of re-constituted rice fortified with micronutrients by extrusion process was undertaken. Previously we have conducted studies on effect of extrusion conditions on pasting behaviour and microstructure of re-fabricated rice (Syed and Baljit, 2013); Viscous and thermal behaviour of vitamin A and iron fortified re-constituted rice (Syed *et al.*, 2014); Functional properties of re-fabricated rice as affected by die during extrusion process (Syed and Baljit, 2014) and Cooking behaviour of re-fabricated rice as affected by extrusion (Syed *et al.*, 2015). These studies clearly demonstrate the sensory attributes and cooking characteristics of re-fabricated rice. The present study on moisture dependent dimensional and physical properties of re-fabricated rice was deemed useful and form the basis of our research programme on development of micronutrient fortified re-constituted rice using extrusion technology.

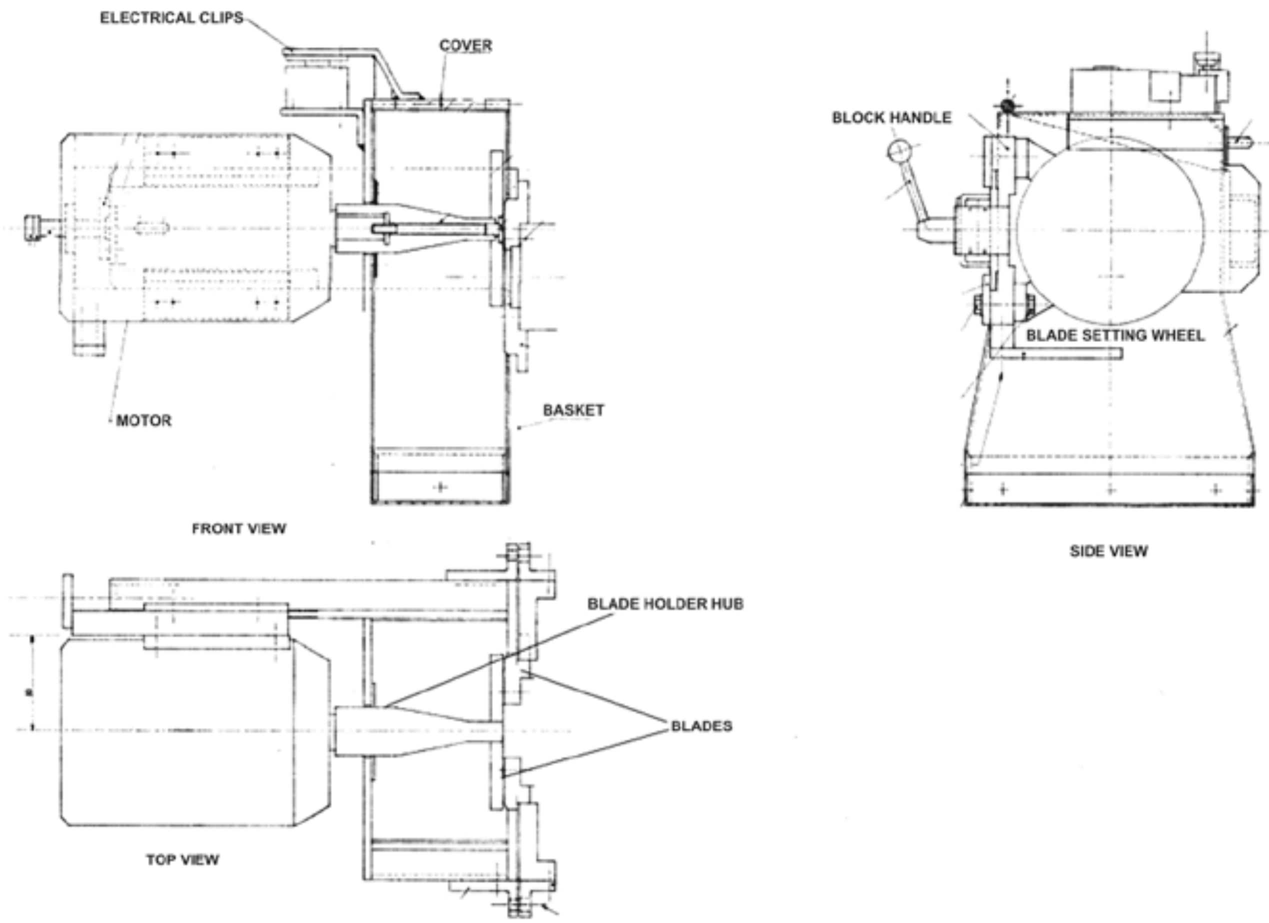


Fig. 1 Line diagram of cutter

Materials and Methods

The small rice brokens (≤1/8th of actual kernel size) of PR-116 variety were ground in a lab mill model 3303 (Perten, Sweden) to fineness that passes through 200 µm sieve. Sodium alginate and calcium salts ($CaCl^2$ and $CaSO^4$) were used as structural and cross-linking agents in forming re-fabricated grains with desired grain structure and integrity and were obtained from Sigma-Aldrich (Canada). The moisture contents of the flours were determined by oven drying method (AACC 2000) before mixing. The flours were mixed for 30 min using a Hobart mixer (Hobart Corp., Troy, Ohio, U.S.A), and target feed moisture content of 35% was achieved by injection of water into the extruder with a pump. All the extrusion experiments were conducted in a co-rotating intermeshing twin screw extruder model BCH (Clextral, Firminy, France). The extruder barrel is divided into four zones. Temperature of first, second and third zone was maintained at 20°C, 30°C and 40°C respectively, throughout the experiments. The pre-optimised extrusion conditions - screw speed, feed moisture and temperature at fourth zone were maintained at 130 rpm, 36% and 89°C respectively (Syed and Baljit, 2013). A special cutter (Length 415mm, width 315mm, height 360mm and weight 20 kg) and six dies made of stainless steel (dimensions 9 × 2 mm, 9 × 1.5 mm, 8 × 2 mm, 8 × 1.5 mm, 7 × 2 mm and 7 × 1.5 mm) as shown in **Figs 1** to **3**, were used for shaping of the re-fabricated rice grains (Syed and Baljit, 2014). Extruded rice grains were collected on stainless steel, mesh trays. Trays were loaded into a Tray dryer (NSW-154, S-Narang, Scientific works, New Delhi, India) with a small fan and 220 volt Thermoly © heating unit circulating air from bottom of the cabinet to the top. The extruded rice grains were pre-dried for 2-2.5 hours at 70°C. The partially dried grains were then stacked in trays and placed in conditioning chamber at 25°C and 40% relative humidity for 8 hours for final drying at 60-70°C to reach a moisture content of 10-14% (w.b.). After making three levels of moisture contents 10, 12 and 14% (w.b.), the samples were sealed in polyethylene bags and equilibrated for 48 h at 5°C. Before starting each test, the required quantities of samples were taken out of the refrigerator and allowed to warm up to the room

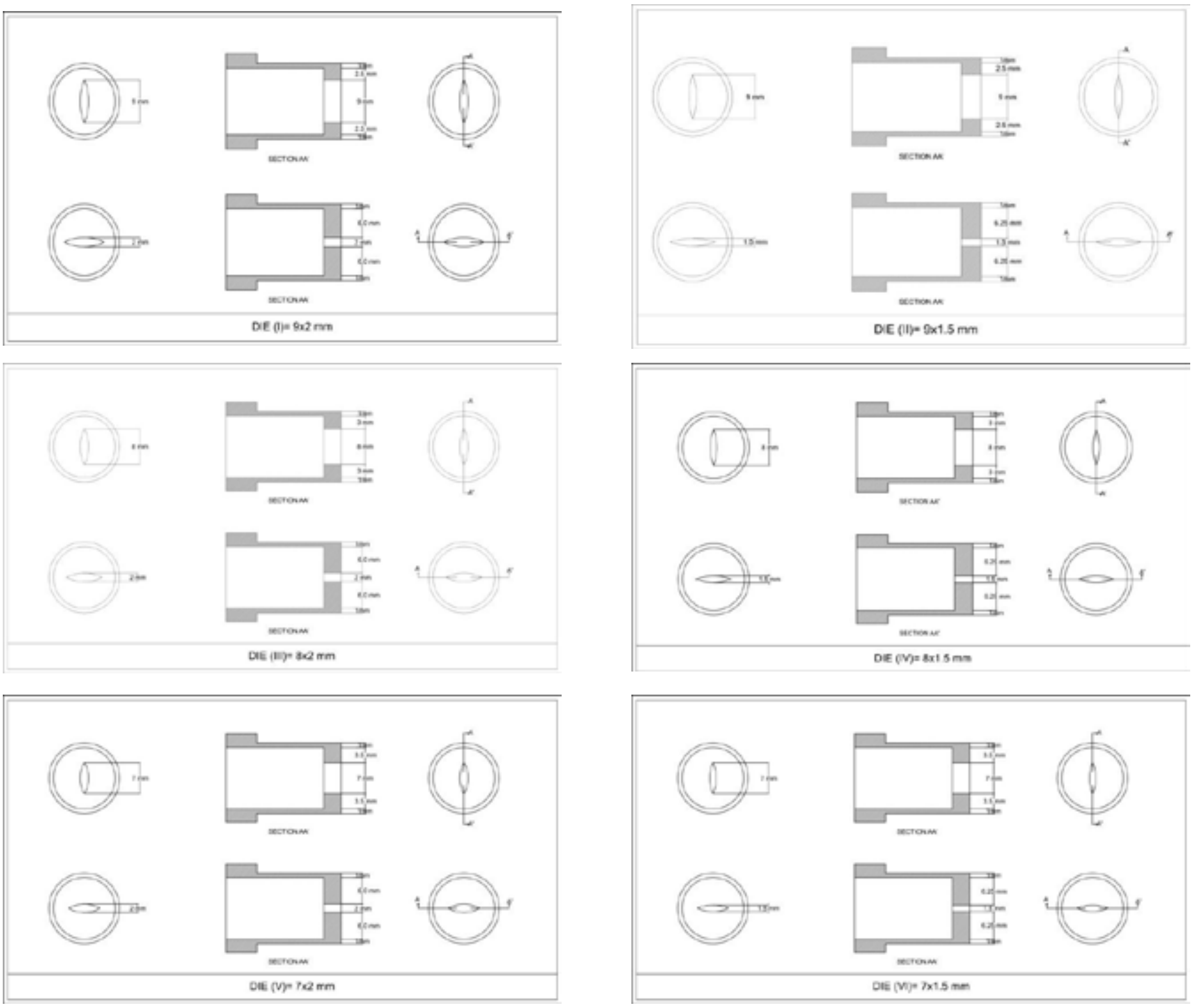


Fig. 2 Line diagram of dies

temperature for about 2 h.

Dimensional and Physical Properties

Standard methods/formulas have been used to study the different dimensional and physical properties (length, width, thickness, equivalent diameter, geometric diameter, arithmetic diameter, sphericity, surface area, area of transverse surface, aspect ratio, volume, moisture content, thousand grain mass, bulk density, true density and porosity) of re-fabricated rice obtained through different dies. 2.3 Statistical analysis

The data collected was subjected to statistical analysis for regression analysis using standard statistical software (SPSS).

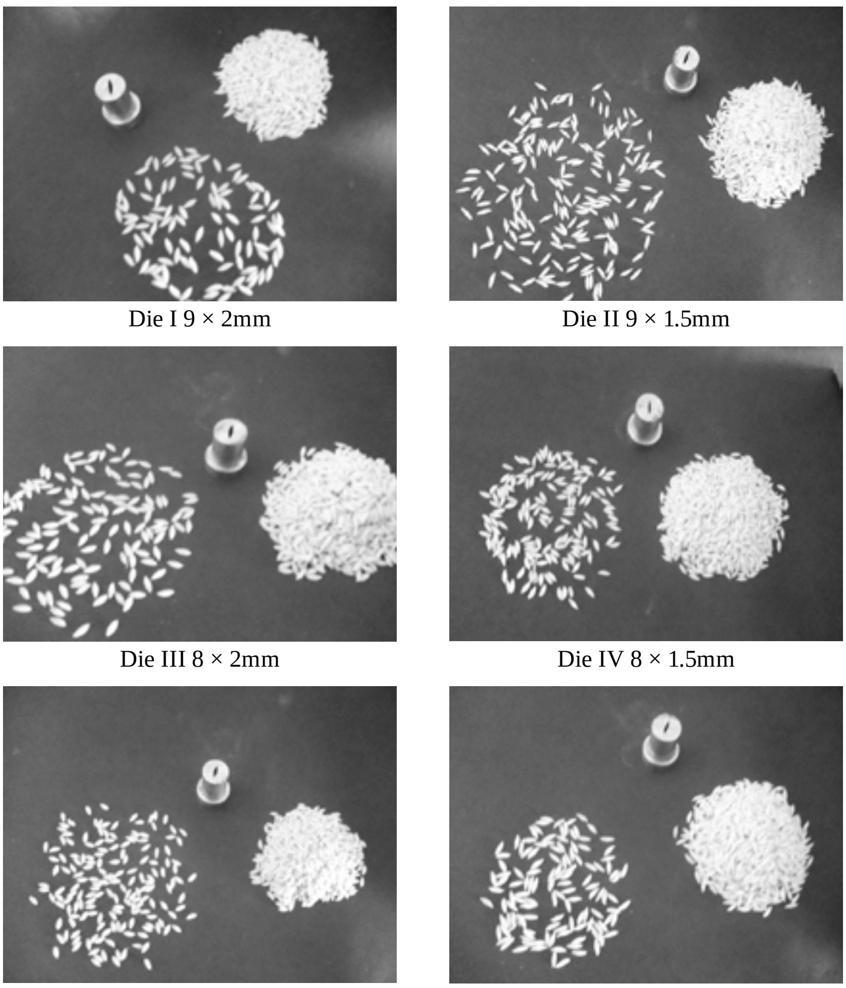
Results and Discussion

The dimensional and physical properties of re-fabricated rice grains obtained through different dies were investigated as function of moisture content (**Table 1** and **2**). The regression equations for all the parameters except l/b ratio, aspect ratio and porosity were highly significant with high coefficient of determination ($R^2 > 0.92$). All the dimensional properties except l/b ratio and aspect ratio were found to have significant positive relationship with moisture content, which indicate that these properties increase with the increase in moisture content. The negative coefficients of moisture content indicate that l/b ratio decreases with the increase in moisture content. However, the regression equations for aspect ratio were found to be non-significant for all the six types of rice samples. Overall strong correlation was observed between the dimensional properties and moisture content indicating that upon moisture absorption, the extruded rice grains expand in length, width and thickness within the moisture range of 10 to 14%. Similar trends have been reported by Reddy and Chakraverty (2004) in raw and parboiled rough rice; Zareiforoush *et al.* 2011 for natural rice.

The regression equations depicted in **Table 2** indicates significant linear positive effect ($R^2 > 0.93$) of moisture content on 1000 grain weight, bulk density and true density. This was possibly due to the reason that an increase in mass owing to the moisture gain during extrusion was higher than the accompanying volumetric expansion of the re-fabricated rice. These results were similar to those reported by Kingsly *et al.* (2006); Garnayak *et al.,* (2008). Porosity was found to be negatively correlated with moisture content ($R^2 > 0.82$) in all types of re-fabricated rice samples, except in grains obtained through die-III, where a positive non-significant relationship was observed between moisture content and porosity. The decreasing trend in porosity with the increase in moisture content was in concordance with the findings of Kingsly *et al.* (2006) reported in case of hemp seed and dried pomegranate seeds.

Conclusions

This study concludes with the information on moisture dependent dimensional and physical properties of re-fabricated rice, which may be useful for food designers in developing micronutrient enriched re-fabricated rice through extrusion technology.



Die I 9 × 2mm | Die II 9 × 1.5mm | Die III 8 × 2mm | Die IV 8 × 1.5mm | Die V 7 × 2mm | Die VI 7 × 1.5mm

Fig. 3 Re-fabricated rice obtained through different dies

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Table 1 Equations representing the relationship between moisture content and dimensional properties

Parameters	Extruded rice obtained through different dies					
	Die-I	Die-II	Die III	Die IV	Die V	Die VI
L	7.93 + 0.0275M (R^2 = 0.975)	7.8300 + 0.0325M (R^2 = 0.982)	6.8500 + 0.0325M (R^2 = 0.982)	7.3733 + 0.0250M (R^2 = 0.986)	6.4867 + 0.0250M (R^2 = 0.949)	6.4000 + 0.0275M (R^2 = 0.975)
B	2.3167 + 0.02 M (R^2 = 0.923)	1.9367 + 0.0150M (R^2 = 0.964)	2.2600 + 0.0225M (R^2 = 0.964)	1.8767 + 0.0125M (R^2 = 0.986)	2.2667 + 0.0300M (R^2 = 0.990)	2.0133 + 0.0250 M (R^2 = 0.949)
L/B	3.4133 - 0.015 M (R^2 = 0.871)	4.0033 - 0.0100M (R^2 = 0.923)	3.0100 - 0.0125M (R^2 = 0.892)	3.9067 - 0.0100M (R^2 = 0.923)	2.8233 - 0.0200M (R^2 = 0.979)	3.1500 - 0.0200M (R^2 = 0.842)
T	1.4300 + 0.0275 M (R^2 = 0.987)	1.6233 + 0.0125M (R^2 = 0.986)	1.4967 + 0.0175M (R^2 = 0.993)	1.4267 + 0.0150M (R^2 = 0.964)	1.9167 + 0.0275M (R^2 = 0.997)	1.5867 + 0.0250M (R^2 = 0.986)
Dp	3.0833 + 0.0250M (R^2 = 0.986)	2.8733 + 0.0225M (R^2 = 0.995)	2.8867 + 0.0250M (R^2 = 0.986)	2.7267 + 0.0175M (R^2 = 0.993)	3.0667 + 0.0300M (R^2 = 0.990)	2.7367 + 0.0300M (R^2 = 0.990)
Dg	3.0433 + 0.0250M (R^2 = 0.986)	2.8967 + 0.0200M (R^2 = 0.979)	2.8533 + 0.0250M (R^2 = 0.986)	2.7167 + 0.0175M (R^2 = 0.993)	3.0367 + 0.0325M (R^2 = 0.998)	2.7267 + 0.0300M (R^2 = 0.990)
Da	3.9267 + 0.0225 M (R^2 = 0.995)	3.7967 + 0.0200M (R^2 = 0.979)	3.5267 + 0.0250M (R^2 = 0.986)	3.5567 + 0.0175M (R^2 = 0.993)	3.5567 + 0.0275M (R^2 = 0.997)	3.3133 + 0.0275M (R^2 = 0.997)
At	2.7433 + 0.0675M (R^2 = 0.988)	2.4033 + 0.0450 M (R^2 = 0.983)	2.6167 + 0.0650M (R^2 = 0.998)	2.0833 + 0.0400M (R^2 = 0.994)	3.2667 + 0.1150M (R^2 = 0.999)	2.4400 + 0.0825M (R^2 = 0.975)
S	26.4467 + 0.4375M (R^2 = 0.985)	24.1733 + 0.3475 M (R^2 = 0.989)	22.6867 + 0.4100M (R^2 = 0.995)	21.2600 + 0.2850M (R^2 = 0.999)	24.8067 + 0.5675M (R^2 = 0.998)	20.6400 + 0.4600M (R^2 = 0.987)
V	14.9467 + 0.4425M (R^2 = 0.980)	12.4567 + 0.3175M (R^2 = 0.989)	12.2533 + 0.3975M (R^2 = 0.991)	10.3500 + 0.2450M (R^2 = 0.998)	14.0100 + 0.5975M (R^2 = 0.999)	10.3333 + 0.4350M (R^2 = 0.982)
Ra	0.3100 + 0.00M (R^2 = 0)	0.2633 + 0.00M (R^2 = 0)	0.3500 + 0.00M (R^2 = 0)	0.2333 + 0.0025M (R^2 = 0.75)	0.3567 + 0.0025M (R^2 = 0.75)	0.3133 + 0.0025M (R^2 = 0.75)
Φ	38.4667 + 0.1675M (R^2 = 0.987)	36.9600 + 0.0975M (R^2 = 0.998)	41.7400 + 0.1475M (R^2 = 0.999)	36.7867 + 0.1125M (R^2 = 0.992)	46.9433 + 0.2925M (R^2 = 0.991)	42.9333 + 0.2425M (R^2 = 0.903)

L = length, B = breadth, T = thickness, Dp = equivalent diameter, Dg = geometric diameter, Da = arithmetic diameter, At = area of transverse surface, S = surface area, V = volume, Ra = aspect ratio, Φ = Sphericity

Table 2 Equations represented the relationship between moisture content and physical properties

Physical Properties	Extruded rice obtained through different dies					
	Die I	Die II	Die III	Die IV	Die V	Die VI
1000 Grain weight	14.4133 + 0.2575M (R^2 = 0.999)	14.6400 + 0.2850M (R^2 = 0.991)	15.5333 + 0.2200M (R^2 = 0.989)	16.1933 + 0.1600M (R^2 = 0.962)	14.9800 + 0.1925M (R^2 = 0.990)	15.3400 + 0.1950M (R^2 = 0.969)
Bulk Density (ρb)	811.4 + 4.1075M (R^2 = 0.997)	778.0933 + 3.417M (R^2 = 0.973)	843.8667 + 3.8500 M (R^2 = 0.994)	802.1267 + 3.5975M (R^2 = 0.985)	859.40 + 3.1250M (R^2 = 0.990)	829.5600 + 4.1975M (R^2 = 0.998)
True Density (ρt)	691.180 + 5.222M (R^2 = 0.999)	1547.94 + 4.277M (R^2 = 1.0)	1730.3967 + 8.445M (R^2 = 0.916)	1595.3167 + 4.115M (R^2 = 0.985)	1808.0667 + 3.125M (R^2 = 0.939)	17598.090 + 4.440M (R^2 = 0.992)
Porosity (ε)	51.9767 - 0.0875M (R^2 = 0.9681)	49.7133 - 0.0775M (R^2 = 0.8218	51.226 + 0.015M (R^2 = 0.0311)	49.6833 - 0.0900M (R^2 = 0.983)	52.45 - 0.0875M (R^2 = 0.939)	52.80 - 0.1125M (R^2 = 0.998)

Design of Rotary Weeder Blade

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ABSTRACT

The tillage, seeding/planting and harvesting technologies available in the country are at its edge of success, for major crops like wheat, paddy, sugarcane, and cotton etc. However, there is large gap in the available technologies world over and in the country for inter-cultural or weeding operations. Amongst the weeders, most common and efficient are rotary weeders, which may be manual, power tiller operated or tractor operated. However, all of them require an integral unit to cut the weed, i.e. blade. The available blades in the weeders either do not take sufficient depth, damage the plants or consumes extra power from the prime mower. Therefore, a rotary weeder blade was redesigned with the help of existing studies and computer aided designing (CAD) software, 'CATIA', for tackling the problem effectively. After a thorough study, a J-shaped blade having an edge curve was found most suitable for weeding. The static and dynamic forces acting on the blade were calculated to be 196.3 N and 55.5 N respectively. The maximum rotary power required per rotary assembly was calculated to be 8.44 kW. The solid model of the blade was analyzed using Finite Element Analysis (FEA) tool in CATIA. The analysis results were studied for Von-Misses-Stress values and deflection, and based on these results, the design was optimized. The blade was found safe in analysis under working stresses. Thereafter, the blades were fabricated from the local market according to the design specifications.

Key words: weed, rotary weeder, blade, CAD, CATIA, FEA.

Introduction

Weed is a plant growing where it is not desired. Weeds are unwanted for number of reasons. The weeds use nutrients from soil, restrict light, they might be unsightly or crowd out; hence they increase the competition for main crop plants. Thus, weeds are serious menace to crops and cause a great loss to field crops (Tekade and Dhaliwal, 2007). Majority of the weeds grow and develop in top 2-5 cm layer of soil due to the availability of nutrients at this depth and dominate the surrounding main crop plant in the initial period of their growth (Reddy and Reddy, 1992). In India losses due to weeds alone have been assessed to be 33.8% in the production of major wide-row crops (Rangasamy *et al.*, 1993). The purpose of weeding and inter-culture operation is to provide best suitable conditions for crops to grow.

Amongst the weeders, most common and efficient are rotary weeders, which may be manual, power tiller operated or tractor operated. However, all of them require an integral unit to cut the weed, i.e. blade. Hence design of a rotary weeder blade is very important. The purpose of weeding is to remove the weeds i.e. complete or partial burial of weeds which lead to their mortality, to loosen the soil, to break the capillaries which will ultimately avoid lower water evaporation, to earth up the plants and lastly to improve water infiltration in the soil. To perform all these functions

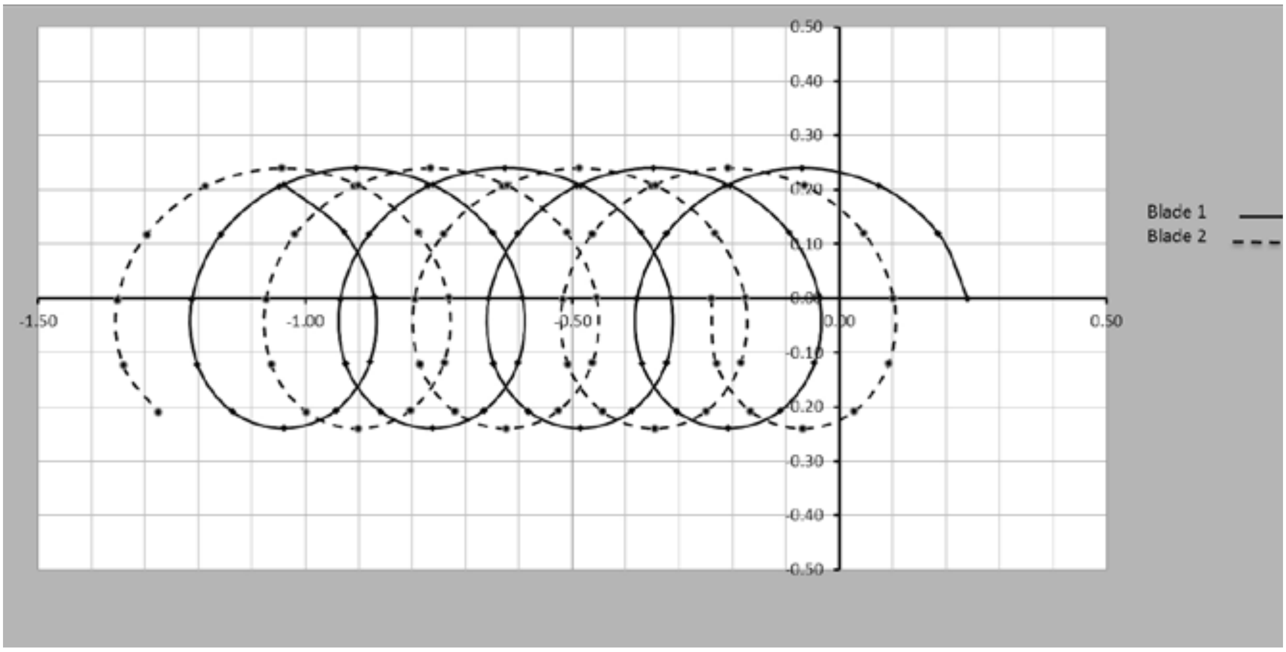

Fig. 1 Trochoidal curve traced by blade tip

effectively, blade plays a vital role. Hendrick and Gill, (1971 and 1974) reported the method of determination of effect of depth of operation, direction of rotation, ratio of peripheral, forward velocities and blade clearance angle on efficiency and performance of blade. Bernacki (1972) reported the theoretical design consideration of various parameters which affect the rotary blade. Sakai (1978) studied the designing process and theories of rotary blades for better rotary tillage operation. Tafesse (2007) optimized the design parameters in terms of total specific energy requirements for the rotary blade power tiller under unsaturated sandy clay loam soil condition. The information available for design of rotary weeder blade was in piecemeal. Therefore, there was a need to integrate the information regarding the various design parameters which influence the efficiency and performance of blade and analyse of stresses developed at various points by various forces using modern technology available in computer aided designing and analysing software like 'CATIA'.

Theoretical Considerations for Design of Blade

Design of blade

The blades were designed such that blade was able to cut majority of weeds, circumvent excessive weed growth before cutting and the energy requirement for weeding should be minimum. This could be achieved by optimizing blade parameters. The information is presented under the following subheads.

Determination of cutting forces acting on blade

Minimum cutting force, is observed at optimum bite length i.e. between 50-75 mm (Tekade and Dhaliwal, 2007; Cherkiattipol *et al*., 2008) and the optimum bite length results in optimum volume of cut soil and hence the cutting force would be optimum. Therefore, the cutting force was calculated under following subheadings:

(Determination of static forces, Determination of dynamic forces)

The Bite Length (L_b) (**Fig. 1**) of rotary unit could be found out, by following formula (Hendrick and Gill, 1971a):

$L_b = (v / n) \times (60 / z)\ (m)$ .... (1)

Where

v = Forward velocity of the machine (m/s)

n = Rotational velocity of rotor(rpm)

z = Number of blades on each flange in the working width.

Bite length depends upon, forward velocity and rotational speed of the blade rotor. Hence, fixing the forward speed (v) at 5 km/h and optimizing the bite length for different values of rotational speeds (n) and number of blades on each flange in the working width (z), by using following approach:

$X = vt + R \cos \alpha$ ....(2)

$Y = R \sin \alpha$ .... (3)

Where

X = Horizontal position of blade tip (m)

Y = Vertical position of blade tip (m)

t = Time (s)

R = Radius of rotation (m)

v = Machine forward velocity (m/s)

α = Angular acceleration(rad /s^2) = $\omega t = 2\pi nt / 60$

The maximum cutting force would occur at 10-12 degree after initial soil entry (Hendrick and Gill, 1971a).

Blade enters the soil at angle, α_p

$\alpha_p = \sin^{-1} [R - Hm / R]$ .... (4)

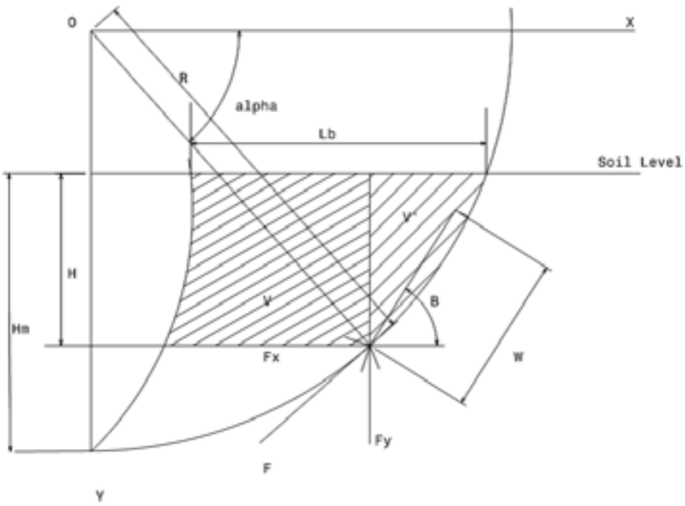

Fig. 2 Tilled soil above and in front of rotary blade at the depth 'H'

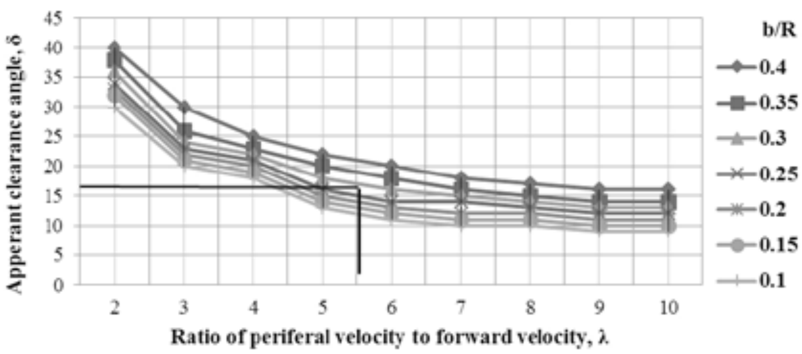

Fig. 3 Apparent clearance angle v/s ratio of peripheral to forward velocity at Tillage Depth = 0.2R

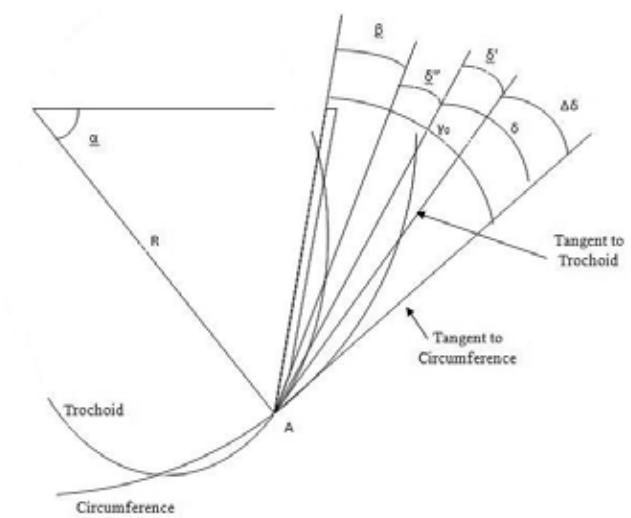

Fig. 4 Angles of blade

Where,

R = Rotor radius (m)

Hm = Maximum depth of cut (m),

Suppose maximum cutting force will occur at a depth H, then it could be calculated at an angle α i.e. ($\alpha = \alpha_p + 12$) as, H = Hm - R + R Sin α

or

$\alpha = sin^{-1} (R - Hm + H) / R$

Hence, total volume of soil tilled in one slice of blade could be calculated as:

$V = L_b \times H \times S$ .... (5)

Where,

S = Span or blade, m

H = Depth of cut, m

For determining acceleration force, the total volume V could be used, because all the soil in front of rotating blade is accelerated, while for calculating the force due to vertical pressure and friction, only the soil mass which is directly above the blade could be considered. It was assumed that the cross sectional area of soil mass above blade has a shape of trapezoid (V' in **Fig.** 2), then the volume V' could be calculated as:

$V^1 = 1 / 2\ [H + (H - WSin\beta_a)]SWCos\beta_a$ .... (6)

Where,

W= *Width of the blade, m* = $Hh / Sin\beta_a$ = $(Hm / 2) / Sin\beta_a$ .... (7)

β_a = Angle of inclination of the blade from horizontal or angle of attack (degree),

Hm = Maximum tillage depth(m),

$\beta_a = 90 + \gamma 0 - \alpha$ ....(8)

Hendrick and Gill (1971a) reported that the maximum cutting force occurred at 10 to 12 degrees after the entry of blade into the soil, so angles at which blade enter into soil could be calculated by:

$\alpha_p = Sin^{-1}[(R - Hm) / R]$

and

γ_0 is cutting angle of the blade,

$\gamma_0 = \beta + \delta'' + \delta$ .... (9)

δ = Apparent clearance angle δ can be found from λ (i.e. ratio of peripheral velocity to forward velocity of tillage tool, Hendrick and Gill, 1974).

i.e. $\lambda = u / v = 2\pi Rn / (60 \times v)$.... (10)

δ value for tillage depth of 0.2R and could be found out from corresponding value of λ in the **Fig. 3**.

Hence, the Geometrical parameters could be enlisted in terms of all angles and could be given as shown in **Fig. 4**: βa = Angle of inclination or attack = 90 + γ_0 - α; α = Angle of rotation of blade with horizontal; γ_0 = Apparent cutting angle defined as angle between the blade plane and tangent to circumference = β + δ'' + δ; β = Sharpening angle of blade edge; δ" = Actual clearance angle between edge of blade and tangent to the trochoid (Should not be more than 3° - Hendrick and Gill, 1974); δ = Apparent clearance angle defined as angle between edge of blade and tangent to circumference = Δδ + δ'; Δδ = Increment of cutting angle i.e. angle between tangent to trochoidal curve and the tangent to the circumference of blade rotor; δ' = Effective clearance angle i.e. angle between edge of blade and tangent to trochoidal curve (Should not be lower than 50 - Bernaki *et al.* 1972)

Determination of static forces

Hendrick and Gill (1971 a) reported that the cutting force of a rotary blade consisted of two major components i.e. static and dynamic force. Static force (Fs) was dependent on the specific resistance of the soil and was determined by the equation:

$F_s = p. A$ .... (11)

Where,

p = Specific soil resistance (N/m^2); According to Tafesse (2007) for rotary cultivator (p) = 5000 kg/m^2; A = Cross sectional area of soil slice (m^2); S. Hm, S = Span or blade(m) and Hm = Maximum working depth(m)

Determination of dynamic forces

The other component of the forces i.e. dynamic force of rotary blade could be dependent on many factors, but major factor of this force could be the energy required for throwing soil slice and overcome frictional forces. Basically, the dynamic force includes three forces; Determination of acceleration Force, Determination of the force due to pressure of soil above the blade, Determination of Friction force

According to Hendrick and Gill, 1971a the dynamic forces could be given as:

$$F_d = \sqrt{Fx^2 + Fy^2} \quad \text{..........................(12)}$$

Where,

Fd = Dynamic force, N

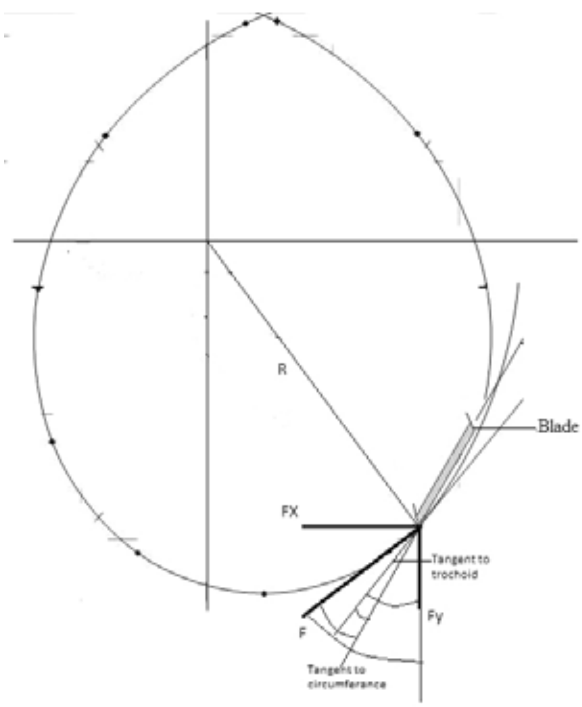

Fig. 5 Force components acting on rotary blade

$Fx = F \sin(\alpha + \gamma - \Delta\delta)$ (**Fig. 5**) .... (13a)

$Fy = F \cos(\alpha + \gamma - \Delta\delta)$ (**Fig. 5**) .... (13b)

Bernaki *et al.* (1972) derived the dynamic forces in other form and expressed them as:

$Fx = Fax + Fwx + Ffx$ .... (14)

and

$Fy = Fay + Fwy + Ffy$ .... (15)

Where, Fax and Fay = Horizontal and vertical components or acceleration forces, Fwx and Fwy = Horizontal force due to vertical pressure of the soil and vertical down -ward force due to vertical pressure of soil / mass, Ffx and Ffy = Horizontal and vertical force due to friction of soil - metal.

Determination of acceleration Force

Acceleration force could be determined as

$F = ma$ .... (16)

Where;

F = Accelerate force (N)

m = Mass of total soil tilled (kg)

a = Acceleration of rotary blade (m/s^2)

$m = V \times K = (L_b. H. S) \times K$ .... (17)

K = 1400 kg/ m^3 .... (Tafesse, 2007) for hard soil

Hendrick and Gill (1978), described the equations to describe acceleration 'a' could be determined by using the Kinematics of rotary blade

$a_x = |R\omega^2 \cos\alpha|$ = *Component of acceleration in X direction, m/s*^{2} (18)

$a_y = |R\omega^2 \cos\alpha|$ = *Component of acceleration in Y direction, m/s*^{2} (19)

R = rotor radius, m and ω = Angular velocity, rad/s

Therefore, Fax = m. a_x and Fay = m. a_y .... (20)

Determination of the force due to pressure of soil above the blade

The vertical pressure force Fwy was due to weight of soil mass above the blade

$Fwy = V'k$ .... (21)

Substituting value of V' (**Fig. 1**), Fwy = 1/2 K [H + (H - W Sin β)] S. W. Cos β

To determine horizontal, component of force due to soil mass above blade, first component of vertical force (Fwy) on blade surface F'wy was found out. This force was also called as tangential force on the blade surface and could be calculated as:

$F'wy = Fwy\ Cos\ (\pi/2 - \beta)$ .... (22)

$F'wy = Fwy\ Sin\beta$ and $Fwx = F'wy\ Cos\ \beta$ .... (23)

or

$Fwx = Fwy\ Sin\ \beta.\ Cos\ \beta$ .... (24)

Determination of Friction force

The friction force on blade surface was equal to normal force multiplied by coefficient of friction and could be calculated as:

$\tau = \mu_k N$ .... (25)

and Normal force (N) as,

$N = Fwy\ Cos\ \beta$ .... (26)

$$\mu_k = \frac{1.09}{\sqrt{0.105 \times R \times n}}$$

(Gupta and Vishvanathan, 1993) .... (27)

Now, calculating horizontal and vertical components of friction τ as

$F_{fx} = \tau\ x\ Cos\ \beta$ .... (28)

and

$F_{fy} = \tau\ x\ Sin\ \beta$ .... (29)

Hence, Total dynamic force,

$$F_d = \sqrt{Fx^2 + Fy^2}$$ .... (30)

Where,

Fx = Fax + Fwx + Ffx - Horizontal dynamic force component

Fy = Fay + Fwy + Ffy - vertical dynamic force component

Shape of rotary blade

Basically many rotary blade shapes such as C-shaped, L-shaped, J-shaped, RC-shaped, pick or hook shaped etc. could be used in rotary cultivator and each and every blade could be used for its specific purpose. Just scratching of the soil was needed along with weeds. However, tillage depth up to 75 mm was considered as this will increase the pulverization of upper soil and which would act as a capillary breaking and mulching activity which would suppress the next growth of weeds. Although C-shaped blades could reduce the energy consumption, but to have greater shearing action perpendicular to soil surface and hence L-shaped blade served the purpose but the energy consumption and surface area of the L-shaped blade is quite large. Hence the optimum shape would be J-shape as it had minimum surface area exposed to soil and its performance was also good. Hence, J-shaped blades were chosen and its geometrical parameters were finalized.

Determination of edge curve of rotary blade

According to Sakai (1978), the coiling trouble of grass and straw to the rotary blades occur more easily on the soft soils than hard soil and generally weeding is done in tilled or soft soils. The grass removing ability of a blade would be better with the bigger edge curve angle 'αc'. According to experiments done in Japan and Philippines, the edge curve angle, α_t at the tip potion of such a straight blade recommended to be 57.5° and the angle at the rotary axle, α_n should be 67.5°(30). Thus in actual design, these angles, α_t, α_n, α' (as shown in **Fig. 6**) are rationally decided in accordance with grass and straw conditions on the given field and edge curve will be obtained by spiral equation of polar coordinates as:

$$r = r_o\ .\ Sin^{\frac{1}{k}}\ \alpha_o \left[Sin^{-\frac{1}{k}} (\alpha_0 + K\theta) \right]$$

edge curve equation of straight portion .... (31)

Where,

r_0 = Maximum radius the tip point of edge curve (m),

r = Calculated radius of spiral that depends upon the variable θ in the function (m),

α_0 = Edge curve angle at r_0 (degree),

K = A constant to give charging angles from α_t to α_n. (According to increment), Hence, α' can be calculated as:

$$\alpha' = \alpha_t + \left[\left\{ \tan^{-1} \frac{n\pi\sqrt{H(2R-H)}}{30v - n\pi(R-H)} \right\} \right] + 90°$$

.... (32)

Where;

α' = Edge curve angle at curved portion of blade (degree);

n = Speed of rotary axle(rpm);

H = Maximum depth of cut(cm);

v = Machine traveling speed (cm/s);

R = Rotation radius of the blade(cm);

The edge curve equation of side long portion could be obtained by substituting the angle α' into the following equation;

$r = r_0.\ e^{-(cot\ \alpha')\theta}$ .... (33)

Material of blade

According to Sakai (1978), 65 Mn Steel or 60 Si_2Mn spring steel

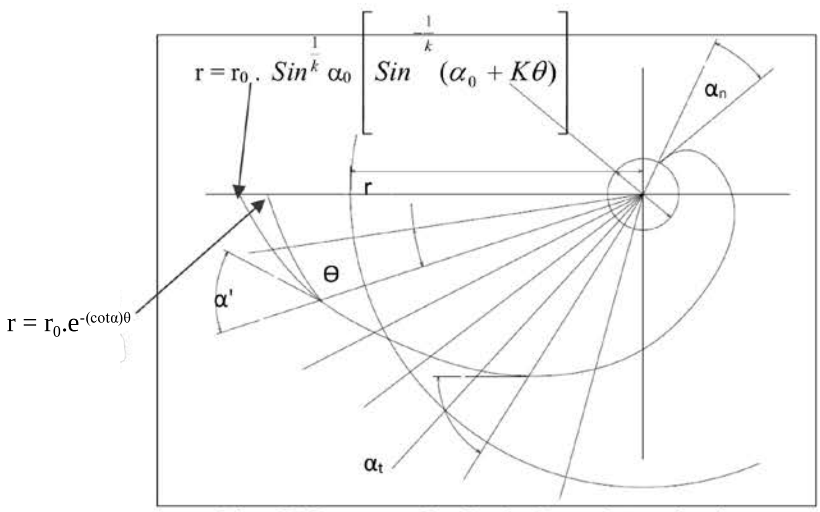

Fig. 6 Edge curve for blade shape determination

Table 1 Material specification recommended for rotary blades Material: 65 Mn Steel/ $60Si_2Mn$, Chemical component (%)

Material	C	Si	Mn	S	P	Cr	Ni	Cu
$60Si_2Mn$	0.56-0.64	1.50-2.00	0.60-0.90	≤0.035	≤0.035	≤0.25	≤0.25	≤0.25
65 Mn	0.62-0.70	0.17-0.37	0.90-1.20	≤0.035	≤0.035	≤0.035	≤0.035	≤0.25

(forged) with Hardness of 38-42 HRC was recommended. However, in market 60 Si2Mn, 65 Mn, EN-45 or EN-48 (**Table 1**) are available spring steel materials with hardness of 42-48 HRC and which would suffice the purpose.

The minimum sectional Width × Thickness should be (20 to 35) × (8 to 12) mm. Bolts of 10 mm diameter are recommended for tractor drawn rotary tillers.

Materials and Methods

Operational and Design Parameters of the Study

The research could not cover all the aspects of the study and hence some of the results should be reviewed from the past studies. Hence, some of the operational requirements, theoretical considerations and design parameters could be enlisted as under.

Working depth, mm

50-75 [Reddy and Reddy (1992), Tekade and Dhaliwal (2007), Yahia *et al.* (1999), Padole (2007)]. Most of the weeds germinate from top 2 to 5 cm layer of soil (Reddy and Reddy, 1992). However, a little more depth was essential, as pulverization of soil was also needed to break up the capillaries and to avoid lower water evaporation. Secondly the pulverized soil will dry faster and thus re-emergence of weeds would be reduced.

Bite length, mm

60-75 [Tekade and Dhaliwal (2007), Cherkiattipol *et al.* (2008)]. Most of the rotary cultivators had rotor speed of 300-350 rpm and bite length of 60-75 mm. Also this optimum bite length would chop and mix all the weeds coming in the path and would handle the volume of soil easily with minimum energy consumption.

Cutting force of blades

It includes the total static and dynamic forces acting on the blade surface. Static force is dependent on the specific resistance of the soil and the other part dynamic force of rotary blades is dependent on many factors, but major parts of this force are due to energy required for throwing soil layer and to overcome frictional forces. Basically, the dynamic force includes acceleration force, soil-metal friction force and force due to pressure of soil above the blade.

Shape of blade

Just scratching of the soil is needed along with weeds. However, maximum tillage depth up to 75 mm was considered as this will increase the pulverization of upper soil and will act as a capillary breaking and mulching activity which will suppress the next growth of weeds. Hence, according to the recommendations from the review J-shaped blade was chosen. According to Sakai (1978), the coiling trouble of grass and straw to the rotary tillers occurred more easily on the soft soils than hard soil and generally weeding is done in tilled or soft soils. The grass removing ability or blade would be better with the edge curve angle and thus the shape formed by the edge curve is called as trochoid.

Diameter of rotor

As per review of literature, the rotor diameters vary between 400-500 mm. Also the blades used for cultivator should have sufficient length to accommodate the edge curve shape.

Some parameters which were kept constant for the study were given in **Table 2**.

Table 2 Parameters kept constant for the study

Quantity	Unit	Values
Rotary speed	rpm	300
Depth of working	mm	50 to 75
Forward speed of tractor	Km/h (m/s)	5 (1.39)
Rotor diameter (radius)	mm	480 (240)
Span of blade	mm	40

Parameters for Performance Evaluation in the Field

Weeding efficiency

It determines the magnitude of weed reduction due to weed control method. Weeding efficiency was measured by collecting the sample of weight of weeds (g) in one m-square area before and after weeding operation.

Mixing index

Mixing index is the percentage of weeds mix with soil the after the weeding operation. Weeding efficiency was measured by collecting the sample in one m-square area before and after weeding operation.

Theoretical design results of blade

Design of blade

All the forces coming on the machine initiates from blade. The blades were designed so that the energy required for weeding should be minimum. It could be achieved by optimizing the blade parameters, which affect the cutting force of the rotary blade. Hence the parameters which influence the cutting force of rotary blade, i.e.: static force, dynamic force Trochoidal curve of blades and Material of blade was determined.

Material of blade

Spring Steel ($60Si_2Mn$/ASTM 9260, Forged) Hardness 42-48 HRC was used as material. Two number, 10 mm diameter bolts were used for bolting the blade with flange.

Solid modeling of blades

The solid modeling of the blade was done in CATIA tool. It was

Table 3 Trochoidal curve values

Divisions	t	vt	R sin ωt	vt + R cos ωt	x	y
0	0	0	0.24	0.24	0.24	0
1	0.0167	-0.0231	0.2078	0.1847	0.1847	0.1200
2	0.0333	-0.0463	0.1199	0.0736	0.0736	0.2079
3	0.0500	-0.0694	-0.0002	-0.0696	-0.0696	0.2400
4	0.0667	-0.0926	-0.1202	-0.2128	-0.2128	0.2077
5	0.0833	-0.1157	-0.2080	-0.3237	-0.3237	0.1198
6	0.1000	-0.1389	-0.2400	-0.3789	-0.3789	-0.0003
7	0.1167	-0.1620	-0.2077	-0.3697	-0.3697	-0.1203
8	0.1333	-0.1852	-0.1196	-0.3048	-0.3048	-0.2080
9	0.1500	-0.2083	0.0005	-0.2079	-0.2079	-0.2400
10	0.1667	-0.2315	0.1204	-0.1110	-0.1110	-0.2076
11	0.1833	-0.2546	0.2081	-0.0465	-0.0465	-0.1195
12	0.2000	-0.2778	0.2400	-0.0378	-0.0378	0.0006
13	0.2167	-0.3009	0.2075	-0.0934	-0.0934	0.1206
14	0.2333	-0.3241	0.1194	-0.2047	-0.2047	0.2082
15	0.2500	-0.3472	-0.0008	-0.3480	-0.3480	0.2400
16	0.2667	-0.3704	-0.1207	-0.4911	-0.4911	0.2074
17	0.2833	-0.3935	-0.2083	-0.6018	-0.6018	0.1193
18	0.3000	-0.4167	-0.2400	-0.6567	-0.6567	-0.0009
19	0.3167	-0.4398	-0.2074	-0.6472	-0.6472	-0.1208
20	0.3333	-0.4630	-0.1191	-0.5821	-0.5821	-0.2084
21	0.3500	-0.4861	0.0011	-0.4850	-0.4850	-0.2400
22	0.3667	-0.5093	0.1210	-0.3883	-0.3883	-0.2073
23	0.3833	-0.5324	0.2084	-0.3240	-0.3240	-0.1190
24	0.4000	-0.5556	0.2400	-0.3156	-0.3156	0.0012

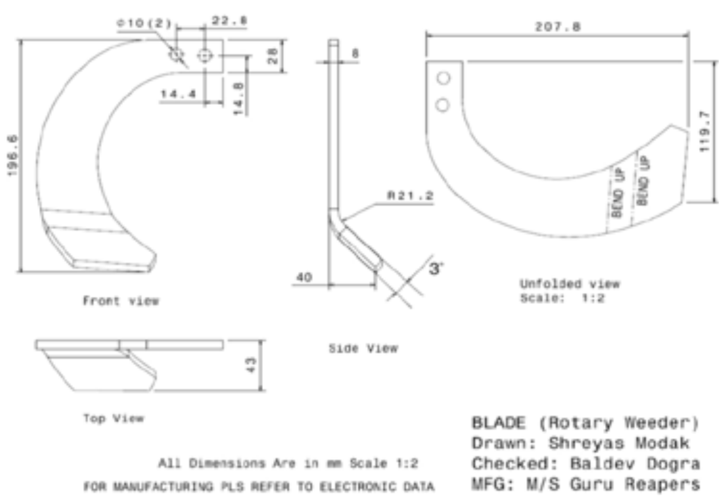

Fig. 7 Drawing of blade

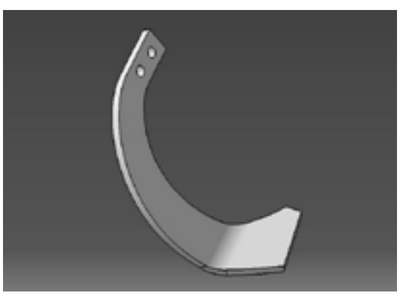

Fig. 8 Solid model of blade

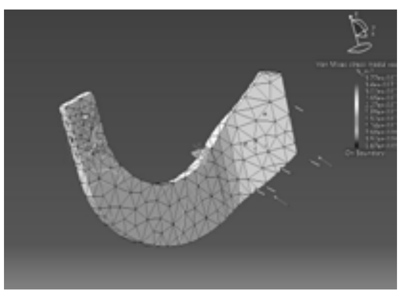

Fig. 9 A view of analyzed blade with stress values

designed using part, sheet metal and surface modules of the CATIA. Many tools viz. combined solid, blend, multi-section solid, recognize, extract, offset, etc. were utilized for the modeling. (Solid model of blade are shown in **Fig. 8**)

The blade was dressed-up with Dress-up Features by giving Edge Fillet of 5 mm on the edge side (the edge come in contact with soil) of the blade. The material (60Si2Mn/ ASTM 9260 Spring Steel) was given from Apply Material toolbar.

Results and Discussion

Determination of Cutting Forces Acting on Blade

The forces acting on the blade includes:

Determination of static forces, Determination of dynamic forces

As per the discussion in the previous section and after optimizing the rotational speed from the iterations (governed by equation 2 and 3), the Bite Length (L_b) of rotary unit came out to be 69.4 mm (from equation 1). Also as per the reviewed literature, this bite length was optimum to weed out and pulverize the soil. Hence, the corresponding volume of soil tilled, V came out to be 1.668×10^{-4} m^3 (from equation 5) by taking into the fixed depth of cut and the span of the blade. The total Volume, V was considered for determining acceleration force, because all the soil in front of rotating blade was accelerated and for calculating the force due to vertical pressure and friction, only the soil mass which was directly above the blade was considered. If we assume that the cross sectional area of soil mass above blade has a shape of trapezoid (V' in **Fig. 2**), then the volume (V') was found out to be 9.744×10^{-6} m^3 (from equation 3) with width of the blade as 60 mm.

The angle of attack $ß_a$ was found out to be 51.5 degrees from equation-5, by calculating value of α as

56.5 degree from value of α_p (equation 4) and that of γ_0 as summation of δ and δ''.

Where,

δ = 15° = Apparent clearance angle and could be found from λ (Refer **Fig. 3**)

i.e. $\lambda = u / v = 2\pi Rn / (60 \times v) \sim 5.5$, Also δ'' should be at most 3° (Hendrick and Gill, 1974).

Hence, γ_0 came out to be 15 + 3 = 18 degree.

The J shaped blade was selected as per the justification given in the previous chapter. Hence, various angles of the blade calculated as given in **Fig. 4**:

α_p = Angle of entry of blade into the soil, degree = 44.5;

α = angle of rotation of the blade with horizontal, degree = 56.5;

βa = Angle of inclination or attack, degree = 51.5;

δ = Apparent clearance angle, degree = 15;

$\gamma 0$ = Apparent cutting angle defined as angle between the blade plane and tangent to circumference, degree = 18;

δ'' = Angle between Edge of blade tip and tangent at intersection point, degree = 3

Determination of static forces

From equation-11 the static forces came out to be 196.2 N by taking into account the specific soil resistance, p = 5000 kg/ m^2 (Tafesse, 2007) and cross sectional area of soil slice, A = S. Hm = 0.004 m^2

Determination of dynamic forces

The other part of the forces, the dynamic force on rotary blade was found out by applying the equations from 12 to 29. Hence components of the dynamic force in X and Y directions were:

The acceleration force (Fa), Fax = 30.53 N and Fay = 46.12 N

The force due to vertical pressure of the soil (Fw), Fwx = 0.065 N and Fwy = 0.134 N

The frictional force on the blade due to the soil-metal interaction (Ff);

Ffx = 0.021 N and Ffy = 0.026 N

Hence, Fx = Fax + Fwx + Ffx = 30.616 N and Fy = Fay + Fwy + Ffy = 46.28 N

Therefore, the dynamic force would be,

$$F_d = \sqrt{Fx^2 + Fy^2} = 55.5 \text{ N}$$

Trochoidal curve of blades

The bite length (as shown in **Fig. 1**) was optimized by doing following iterations of rotor speed, radius of rotor, forward speed and number of blades. From the equations 2 and 3 the trochoidal curve was obtained as shown in graph with following readings given as in the **Table 3** and **Table 4**.

Also, Critical depth of cut = 6 cm, So, Each interval of 30° Corresponds to: 0.016667sec

Determination of edge curve of rotary blade

According to Sakai (1978a&b), taking into account the generally used curve angle α_t at the tip potion of such a straight blade to be 57.5° and α_n at the rotary axle to be 67.5°; the angle α' (using equation 32) was estimated to be equal to 83.67 degree (**Fig. 7**). However putting the corresponding values into the equation 31 and 33 the two relations were estimated as:

$r = 0.993\ r_0$ and $r = 0.9144\ r_0$

Where, r is a function of θ value and could be calculated for all θ values.

Thus taking the average of them, the equation for the value of α_0 was estimated. The α_0 came out to be equal to 62.66 degree. Hence the blade shape was decided by using these values.

Analysis of blade: The blade was analyzed using Generative Structural Analysis tool in CATIA. The blade was first meshed properly into nodes. Then the constraints were put on the model. The blade behaves like a cantilever hanging around a flange and having dynamic forces with cyclic loading. Various functions like Connection Properties, Analysis Supports, Restrains, Loads, etc. were used. The calculated static and dynamic forces were applied on the blade surface and the Von-Mises stresses (as shown in **Fig. 9**), displacement maps were plotted. Hence, the Finite Element Analysis (FEA) yielded the following results. The **Fig. 9** shows that the maximum stress lie just below the first hole on the blade surface with value of 3.77×10^7 N/m^2. However the yield stress of the spring steel is 2.2-3.8 x 10^{11} N/m^2.

As it is sufficiently more than the stresses on the part, the blade was safe. The **Table 5** shows the properties of the material applied and the minimum and maximum values of the results obtained like Von-Mises Stresses, displacement of the nodes, principal stresses, and estimated local error in the model. The results showed that the part was safe with high factor of safety. (Developed blade is shown in **Fig. 10**)

Table 4 Iterative values for trochoidal curve

R =	0.24	m
V =	1.39	m/s
let, n =	300	rpm
So, ω =	5.33	Hz

Table 5 Analysis results of blade in CATIA V5R19

Name	Value	
Material	60Si2Mn/ASTM 9260 Spring Steel (Forged) HRC: 42-48	
Density, kg/m^3	7860	
Young's modulus, N/m^2	2×10^{11}	
Poisson's ratio	0.290	
Yield strength, N/m^2	8.5×10^{11}	
Results	Minimum Value	Maximum Value
Von-Mises Stress, N/m^2	1.67 x 10^5	3.77 x 10^7
Displacement, mm	0	0.783
Principal stress tensor, N/m^2	-3.21×10^7	3.84×10^7
Estimated local error %	8.06 x 10^{-13}	0.000387

Performance Evaluation

A prototype of inter row rotary weeder for three rows was fabricated with the help of a local manufacturer. In this prototype, developed blades were used. The field testing of inter row rotary weeder was carried out at research farm of the department by operating it over an area of more than 1 ha. The machine was operated at 70 cm row to row spacing at depth of 12-14 cm for three rows at speed of 2-5 km/h. Cutting width of each assembly was 52 cm. Its effective field capacity ranged from 0.30-0.79 ha/h. Approximately 50 cm soil strip was tilled by each weeding assembly of the machine. Weeding efficiency and mixing index of the machine were 70-74% and 94-96% respectively. There were no blade breakdowns during field operation.

Conclusions

During the process of study the following conclusions were drawn:

1. Bite length of the machine was calculated to be 69.4 mm with rotor speed as 300 rpm, depth of working as 60 mm and keeping four blades per unit of working width.
2. J-shaped blade having a proper curve edge was selected for the weeder after reviewing its suitability and working efficiency.
3. The static forces acting on the blade was calculated to be 196.3 N, whereas the dynamic forces calculated to be 55.5 N. Spring Steel ($60Si_2Mn$/65Mn, Forged) with hardness of 42-48 HRC was used as a material for the blade.
4. Maximum stress lies just below the first hole on the blade surface with value of 3.77 × 107 N/m^2. However the yield stress of the spring steel was 2.2-3.8 × 1011 N/m^2 and it was sufficiently more than the stresses on the part, the blade was safe.
5. Weeding efficiency and mixing index of the prototype fitted with developed blades were 70-74%, and 94-96% respectively.

Fig. 10 Developed blade for rotary weeder

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Selected Anthropometric Study and Energy Required for Grading Tomatoes by Farmers using Hoes in Zaria

by
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Abstract

This study investigates the anthropometric parameters of the farmers using hand hoes in the Zaria metropolis as well as the work rate of these tomatoes farmers in grading tomatoes. In this study, the whole of the subjects were male farmers. The results show that the width of any tool to be handled with the two hands of a male/farmer should not exceed 560 mm. While the radius of reach of devices and implements to be actuated by farmer in any workplace should be within 480mm for devices that should be frequently used, devices which requires less monitoring but should be within the work position can be placed within 780 mm from the operator's position. The average time for grading about 36 kg of tomatoes manually by the subjects was found to be 18.26 minutes, while the average energy expended by the subjects was 5.15 kJ/min. The results indicate that the energy required for grading tomatoes exceeds the 4.5 kJ/min limit recommended for continuous heavy workloads. High significant differences exist between manual and mechanical methods of grading tomatoes in terms of time consumed, total energy used and the energy consumed per kilogramme of tomatoes graded

Keywords: Upper limb length, shoulder breadth, hand hoe, tomatoes grading, anthropometry, posture, oxygen consumptive rate, heart beat.

Introduction

In spite of major strides in the development of machinery for mechanized farming, the bulk of the small-holder farmers in Nigeria are still using the hand hoes and cutlasses for their cultivation. From time immemorial, the hand hoe has been a major tool for farming activities (Ahaneku, 1997). The hand hoe (**Fig. 1**) is a traditional implement used by farmers in the cultivation of a wide range of crops; these include vegetables, cereals, pulses and orchards. Although, the Nigerian smallholder farmers are estimated to account for the cultivation of 90% of the total landmass cultivated in Nigeria (CTA, 1997), these farm-

Fig.1 A hand hoe in tomatoes farm

Fig. 2 A farmer using the hand hoe

ers are believed to have little or no capital to operate their farms (Oni, 2011). Hence, the continuous usage of hand hoes and cutlasses as major tools for crop farming in Nigeria (Bassi, 1997). These smallholder farmers are involved in both the rain-fed agriculture and the irrigated farming. But because of the sizes of their farms, the availability of human labour, and the lack of capital, these farmers have to-date stuck with manual farming using the hand hoe. Besides, the farmers use human labour to carry out virtually all their agricultural tasks with little or no recourse to mechanization in any of the stages of their production. The human and animal powers are the most used energy sources on smallholder farms in Nigeria. However, these smallholder farmers produce the bulk of the fresh vegetables, cereals, grains, pulses and other food items available in local markets in Nigeria. While some of these farmers practice subsistence farming, others produce a little amount of crops above their consumptive needs and sell the excess output at local markets to earn income.

The posture often adopted when using the hand hoe (**Fig. 2**) is to bend at the waist with the legs slightly astride and the two hands holding the tool (hoe) in front of the operator so as to till the soil with the hoe (Nwuba and Kaul, 1986). Similar body posture is often adopted in the course of carrying out some other agricultural activities such as the grading of tomatoes on farm floors after the harvest, especially by male farmers. Singh and Arora (2010) reported that most women would prefer to squat while grading tomatoes on farms. The hoe, which is forged by local blacksmith, is made from metal blade fixed in wooden handle. There are different shapes and sizes of local hoes which vary from place to place across Nigeria. The variation in types and sizes of hand hoes becomes vivid as one traverses the geographical terrains, the soil types and the ethnic groups in Nigerian (Bassi, 1997).

The hand hoe is used for ridging, weeding, making of basin etc and Nwuba (1981) has listed these tasks among the heavy workloads. Nwuba (1981) listed other types of agricultural tasks as light workload and medium workload. Abdulkarim and Kaul (1986) stated that the amount of energy expended per minute for continuous work should not exceed 4.5 kJ. But the amount of energy expended when using the hand hoe is above the stated energy level. The excessive muscular exertion and the high energy expended when using the hand hoe may lead to fatigue and musculoskeletal disorder. There are numerous types of musculoskeletal disorders that are reported among agricultural workers. Singh and Arora (2010) have listed back pain, neck pain, tendon, shoulder and low back disorders as some of these musculoskeletal disorders common among farmers. Others are cumulative trauma, repetitive motion disorder and carpal tunnel syndrome. All of these musculoskeletal disorders are traceable to the posture adopted to perform the task, the repetitive nature of the task, the types of tools being used for the task and the amount of energy required in carrying out the task.

Due to the nature of the posture adopted in the course of using the hand hoe, there is the need for the anthropometric study of the body parts which are important for maintaining the posture and for an investigation into the physiological and energy costs of maintaining the posture to carry out the intended tasks. Anthropometry is the measurement of physical characteristics and abilities of people which provides information that is essential for the appropriate design of occupational and non-occupational environments as well as for the design of consumer products, clothing, tools and equipment (Piquet and Feather, 2004). Anthropometric studies would help in the design of the hand tools as well as in fitting the work tools to the man; and thereby reduce drudgery and musculoskeletal disorders which are common amount the workers in the given industry (Singh and Arora, 2010). The physiological costs of using the hoe and of grading tomatoes are influenced by the health status of person doing the task, his/her nutrition, his/her basal metabolic rate and the amount of energy expended while carrying out the task (Singh, 2013). The physiological cost of carrying out a task may be indirectly measured by the oxygen consumption rate and/or hearth beat rate of the person performing the task. Pheasant (1991) concluded that the heart beat rate is the best index for the evaluation of the overall physiological demand of an activity and it has the advantage of being easy to measure on the field. Hence, the heart beat rate is used in the evaluation of the energy demands of the tasks being investigated in this study.

The purpose of this study is to look into the anthropometric parameters of farmers using the hand hoe in Zaria metropolis as well as to investigate the work rate and the metabolic energy dissipation of these tomatoes farmers when carrying out their occupation. The study would be helpful in the redesigns of hand hoes and similar hand implements and tools which would be used by farmers in the metropolis. The study would also be useful in the design of and scheduling of manual works on farms and would make recommendations on tomatoes grading and on the development of tomatoes grader for use of the farmers.

Materials and Methods

The anthropometric study was carried on selected local and smallholder farmers in the Zaria metropolis. Zaria, which is in Kaduna State in the central-north region of Nigeria, is located on latitude of

11°03'N and longitude 07°37'E and an elevation of 686 m above the sea level and has a landmass of 329,000 hectares (Kowal and Andrew, 1973). The climatic seasons of Zaria are divided into three weather conditions. The seasons are dry-cold harmattan season (October-middle February), dry-hot season (middle February-May) and wet-humid season (June-September) (Anjekele, 2003 and Afolabi, 2008). Farmers in Zaria plant all the year round. They plant in the rainy season using rainwater for their crops and in the dry season using water from small reservoirs and streams and lakes around the town for irrigation. The two major rivers in Zaria are Galma and Kubanni. The farmers cultivate tomatoes and other vegetables between October and January and maize and other cereals in the rainy season. In all these seasons, the hand hoe is the major implement use by the farmers for the cultivation of their crops. In Zaria, the month of June marks the advent of annual rainfall which lasts till the end of September. Zaria experiences its peak rainfall in the month of August and has an average annual rainfall of about 1000 mm. The rainy season temperature ranges from 23.5 to 26°C (Igbadun *et al.*, 1999). The dry-hot season is often very sunny and with a high dry bulb temperature varying from 25 to 30°C. For the anthropometric data used in this study, fifty farmers were randomly selected around the cultivated farm areas in the town. These farmers have their farms scatter around the town near the rivers and dams which serve as their sources of water to complement rainfall during rainy season or to serve as the sole water source in the dry season.

A measuring tape was used for all the measurements on the subjects and the measured parameters taken to the nearest millimeter. The whole of the subjects were male farmers which used the hand hoe as major implement in their day-to-day farming. The measured anthropometric parameters are the height from the feet to the waist (Waist height), the height from the waist to the shoulder, length from shoulder to finger tip (upper limb length), length from elbow to finger tip and the width from shoulder to shoulder (shoulder breadth bi-deltoid). These parameters were selected because they are considered to be the relevant anthropometric features necessary for the posture assumed in using the hand hoe (**Fig. 2**) and in the grading of tomatoes. The general human physiological structure was also considered in the selection of the parameters. For each of the anthropometric measured parameters, the range (minimum to maximum), mean, standard deviation, coefficient of variation and fifth, fiftieth and ninety-fifth percentiles were computed.

For the energy required to grade tomatoes, ten farmers were randomly selected to grade a basket of tomatoes each. Each of them graded the same quantity of about 36 kg of tomatoes manually and with the aid of a simple mechanical tomatoes grader. The mechanical grader was a set of three trays with the sieve holes decreasing in descending order to allow tomatoes smaller than each sieve diameter to pass through while shaking the devise. The energies expended by the farmers on both manual and mechanical grading of the tomatoes were evaluated by measuring the increase in their heartbeat rates after performing each exercise. The stethoscope was used to evaluate the heart beat rates of the subjects before and after performing each exercise. The oxygen consumption rate of subjects at their measured heart beat rates was estimated based on an equation given by Singh *et al.*, (2008)

$Y = 0.0114X - 0.68$ …….........…… (1)

where,

Y = oxygen consumption rate, L min^{-1}

X = heart rate, beats min^{-1}

The oxygen consumption rate (L min^{-1}) was converted into energy according to Singh (2013) by taking calorific value of oxygen as 20.93 kJ L^{-1}. The amount of energy expended in grading a unit kilogramme of tomatoes during both the manual and the mechanical grading were gotten by dividing the total energy expended by the mass of the tomatoes graded (equation 2)

$E = (\dot{E} \times T) \div M$ ……..……...…….. (2)

where,

E = energy expended in grading a unit kilogramme (kJ kg^{-1})

$\dot{E}$ = energy expended by subject per minute (kJ min^{-1})

T = total time taken to grade a given basket of tomatoes

M = mass of the basket of tomatoes graded

The time rates of grading the tomatoes both mechanically and manually, by the farmers, were measured by means of a quartz stopwatch. The student-t test was used to compare the manual to the mechanical grading of the tomatoes in terms of time taken, the total energy expended by the graders and the energy expended in grading a unit mass of tomatoes.

Results and Discussion

The range (minimum to maximum), mean, standard deviation, coefficient of variation and fifth, fiftieth and ninety-fifth percentiles were computed for the measured anthropometric parameters (**Table 1**). The measured anthropometric parameters are the height from the feet to the waist, the height from the waist to the shoulder, length from shoulder to finger tip, length from elbow to finger tip and the width from shoulder to shoulder (shoulder breadth bi-deltoid). From **Table 1**, it can be seen that the width of any implement to be handle with the two hands of a male/farmer should not exceed 560 mm. This is the 95th percentile of the length of shoulder

Table 1 showing results of the selected anthropometric study

Description	Range (mm)	5^{th} Percentile (mm)	50^{th} percentile (mm)	95^{th} percentile (mm)	Standard Deviation (mm)	Coefficient of variation (%)
Waist height	990.6-1,041.4	932.71	988.84	1,044.96	33.47	3.4
Waist - Shoulder height	457.2-660.4	444.95	532.89	620.84	52.46	9.8
Upper limb length	736.6-889.9	719.9	783.34	846.77	37.83	4.8
Elbow-fingertip length	381.0- 558.9	419.26	483.61	547.98	38.39	9.2
Shoulder breadth	431.8 -584.2	454.12	507.99	560.87	31.84	6.3

to shoulder for the studied farmers and should serve as the maximum width of implements to be handled by the farmers. Also, the range of the height of machines to be fed by the farmer while performing any agricultural task should be from 1000 mm to 1500 mm. The lower limit is the average height of the farmers from foot to shoulder arm. This range is the convenient height that an average farmer may reach while loading or offloading a machine. Similarly, the radius of reach of devices and implements to be actuated by farmer in any workplace should be placed within 480 mm for devices that should be frequently used while devices which requires less monitor but should be within the work position can be within 780 mm from the operator position. This is suggested from the statistical analysis of the studied anthropometric data-the 50^{th} percentile for length of fingertip from the elbow and shoulder were got as 483 and 783 mm respectively. The small values of the coefficients of variation of studied anthropometric parameter are pointers that the variations of the measured parameters are small, since each of the coefficients of variation is small, with the highest just about 10%.

Table 2 shows the result of the manual grading of a basket of tomatoes each by ten subjects. The subjects were all tomatoes farmers which use the hand hoe for their cultivation. The range, in kilogramme, of the baskets of tomatoes graded was 34.7 kg to 37.9 kg. The average time for grading the tomatoes by the subjects was 18.26 minutes, while the average energy expended by the subjects was 5.15 kJ/min. The result indicates that the energy required for grading tomatoes exceeds the 4.5 kJ/min recommended for continuous work by Abdulkarim and Kaul (1986). Thus the grading of tomatoes should not be a continuous task but farmers are advised to take a regular break of at least 20 minutes after about 1½ to 2 hours of manual grading of tomatoes. **Table 2** also shows that the average energy utilized for grading tomatoes is 2.61 KJ per kilogramme of tomatoes.

Table 3 shows the result of the mechanical grading of tomatoes in which the hands were used to shake a mechanical grader by the farmers. The same basket of tomatoes that was manually graded by each subject was mechanically graded by the same subject. It must be noted that the average time for the mechanical grading of the tomatoes is less than that of the manual grading. The average times for the mechanical and manual grading were found to be 2.19 and 18.26 minutes respectively. However, the physical energy for vibrating the mechanical grader is higher than the energy required to grade manually. This is seen from the average energy required to vibrate the mechanical grader which is 7.04 kJ/min as compared with the energy required for the manual grading which is 5.15 kJ/min. But the energy required to grade a unit kilogramme of tomatoes is lower when using the mechanical grader than when using the mere hand to grade. The energy expended for the grading of a unit mass of tomatoes manually and mechanically are 2.61 KJ kg^{-1} and 0.43 kJ kg^{-1} respectively.

The student t-test was used to compare the result of the manual and mechanical grading of tomatoes by the ten subjects. The parameters compared were the energy expended per minute by the subjects, time

Table 2 Result of manual grading of tomatoes by 10 subjects

Subject	HB_1	HB_2	O_2(L min^{-1})	$\dot{E}$ (kJ min^{-1})	T (min)	M (kg)	E /kg
A	73	99	0.3	6.2	15.53	34.7	2.78
B	77	94	0.19	4.06	16.3	38.3	1.73
C	78	99	0.24	5.01	20.08	35.4	2.84
D	74	93	0.22	4.53	16.73	36.5	2.08
E	72	100	0.32	6.68	22.13	35.6	4.15
F	75	96	0.24	5.01	15.87	35.7	2.23
G	75	95	0.23	4.77	19.35	37.9	2.44
H	73	97	0.27	5.73	17.07	36.4	2.69
I	74	97	0.26	5.49	18.48	35.6	2.85
J	75	92	0.19	4.06	21.05	34.7	2.46
Average	74.6	96.2	0.25	5.15	18.26	36.08	2.61

Key HB_1 = Initial Heartbeat rate (min^{-1}), HB_2 = Final Heartbeat rate (min^{-1}), O_2 = Oxygen consumption (L min^{-1}), $\dot{E}$ =Energy expended (kJ min^{-1}), T= time to grade give mass by subjects (min), M = mass graded by each subject (kg) and E/kg = Energy expended per kg graded (kJ/kg) taken to grade the tomatoes and the energy utilized to grade a unit kilogramme of tomatoes during the manual and mechanical gradings of the vegetable. **Table 4** shows the result of the t-test and the F-calculation for the compared parameters. The Table shows that the F-calculated for the total energy expended is not significant. This implies that the variances are equal and confirms that the sources of the energies for the two types of grading are the same. However, for the same energy expended per minute of grading, the t calculated is greater than the t tabulated. This means that there is highly significant difference in the energy consumed during each of the two types of grading. Since the energy expended per minute for the mechanical grading is higher than that of the manual grading for each subject as seen from the comparison of columns for energy (column 5) in the **Tables 2** and **3**. It suggests that there is a heavier energy demanded when grading using the manually vibrated machine than to merely grade by hand sorting. Thus, in order to shun the excessive human energy consumed by handshaking the mechanical grader, it is recommended that a mechanical vibrator should be used.

The column for time in **Table 4** shows the result of the comparison of time required to grade tomatoes manually and by the use of the simple mechanical devise. It can be seen that the variance are not equal from the comparison of the F calculated and tabulated (α = 5%) for the time. This is an indication that the two methods used for grading the tomatoes are not the same in terms of the time taken to carry out the tasks. Also, there is a high significant difference in the time spent on grading using the two methods of grading as seen from the calculated and the tabulated t values. This implies that the time for the two methods of grading tomatoes are not the same and that it takes more time to grade by mere hand sorting than by the use of the mechanical devise. Thus, a lot of time may be saved by mechanical grading than by mere hand sorting/grading.

The F and t values for energy used per kilogramme of tomatoes graded is also given in **Table 4**, the energy used per kilogramme of tomatoes graded also follows a similar trend as the time taken to grade. Comparing the F calculated and its tabulated value, it is clear that their variances are not the same. Going on to compare the t values, it shows that a highly significant difference exist between the two methods of grading in terms of the energy consumed per kilogramme of produce graded. In the light of this, and taking a view on the columns for energy consumed per kilogramme from **Tables 2** and **3**, it reflects that lesser energy is required in grading a unit mass of tomatoes with the mechanical grader than with the mere hand sorting. Similar results were also obtained by Singh (2013) who evaluated hand operated maize dehusker-sheller using farm women.

Table 4 showing the result of comparison of mechanical and manual grading of tomatoes by subjects

Pair test	Energy /min ($\dot{E}$)	Time (T)	Energy per kg graded(E)
F cal	1.43	532	191
F table(α = 0.05)	3.18	3.18	3.18
T cal	5.26	21.97	10.68
T table(α = 0.1)	2.10	1.83	1.83

Table 3 Result of mechanical grading of tomatoes by 10 subjects

Subject	HB_1	HB_2	O_2 (l min^{-1})	$\dot{E}$(kJ min^{-1})	T (min)	M (kg)	E/kg
A	73	106	0.38	7.87	2.07	34.7	0.47
B	77	104	0.31	6.44	2.17	38.3	0.37
C	78	112	0.39	8.11	2.15	35.4	0.49
D	74	101	0.31	6.44	2.25	36.5	0.40
E	72	99	0.31	6.44	2.38	35.6	0.43
F	75	106	0.35	7.40	2.03	35.7	0.42
G	75	100	0.29	5.97	2.18	37.9	0.34
H	73	104	0.35	7.40	2.11	36.4	0.43
I	74	102	0.32	6.68	2.23	35.6	0.42
J	75	107	0.36	7.64	2.32	34.7	0.51
Average	74.60	104.10	0.34	7.04	2.19	36.08	0.43

Key HB_1 = Initial Heartbeat rate (min^{-1}), HB_2 = Final Heartbeat rate (min^{-1}), O_2 = Oxygen consumption (L min^{-1}), $\dot{E}$ = Energy expended (kJ min^{-1}), T = time to grade give mass by subjects (min), M = mass graded by each subject (kg) and E/kg = Energy expended per kg graded (kJ/kg)

Conclusions

Selected anthropometric indices were measured and analyzed for 50 tomatoes farmers. Out of which the manual and mechanical energy requires for tomatoes grading was investigated using 10 of the farmers as subjects. It is recommended that a fully mechanized tomatoes grader should be designed and fabricated for use by the farmers.

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Low Cost Fermenter for Ethanol Production from Rice Straw in Egypt

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Abstract

In Egypt, significant emissions arise caused by rice straw burning on the field. The total amount produced yearly about three million Mg, essential nutrients and organic matter are lost. The combined energy and material utilizations of rice straw can realize an important contribution to climate protection and resource conservation.

To produce bio-ethanol from rice straw, there are four steps that should be taken: 1-Chop rice straw; 2-Mill rice straw; 3-Rice straw sterilization; and 4-Fermentation the milled rice straw in the fermenter using yeast micro-organism.

The present investigation included; manufacture fermenter locally, using computer design software Version 4.0, and techno-economic study using three proposed fermenters scales (300, 600 and 900 litres capacity) at Central Laboratory for Agricultural Climate (CLAC), Dokki, Agricultural Research Center (ARC), Giza, Egypt. A cost-benefit analysis approach was calculated and total return for the three scenarios was estimated for different percentages of ethanol extraction (15, 17 and 20%).

The obtained results indicated that, using fermenter 900 litres capacity (third scenario) for 20% of ethanol extraction was the economical and effective one to produce bio-ethanol appropriate for small growers; where profit value was USD 566. The net present value at discount rate (D.R) of 30% was estimated to be a positive value of USD 1.096. The benefit cost ratio (B/ C) at the same D.R. was estimated to be 1.22; and the internal rate of return (IRR) reached about 30%.

Keywords: Benefit cost ratio, Ethanol, Fermenter, Internal rate of return, Net present value, Net return, Rice straw.

Introduction

Rice straw is approximately 50% of the total weight of rice plants (Putun *et al*., 2004) by weight the rice straw consist mainly of cellulose and hemicelluloses (74%), lignin (18%), fat (1%) and protein (3%) (Phuong *et.al.* 2010). The total area of rice crop in Egypt was 0.567 million hectares, with an output of 5.5 million tons rice and about 3 million tons of rice straw in 2014. Only a small amount of rice straw is used to produce bio-fertilizers, cattle feed, and grow mushrooms. The rice straw leftover in the field is burned on the field causing environment pollution and increasing CO^2 in the air. Therefore, the use of straw resources to produce ethanol will have enormous impact in many aspects, environmentally and economically (MALR, 2014).

Ethanol from biomass has become an increasingly popular alternative to gasoline as one option, to reduce dependence on oil use and mitigate global warming. Bio-ethanol is commercially produced on a moderate scale (approximately 80 million tons worldwide in 2010). The ethanol mainly produced from sugar cane, corn, and other starchy biomass sources (Balat M. and H. Balat, 2009).

The production of liquid fuels from ligno-cellulosic materials, with emphasis on ethanol, is being extensively investigated in both developed and developing countries. Most of the studies and early stage applications are directed towards the production of ethanol in large scale facilities of capacities around 15-100 Mm^3/y, taking into consideration the high transport costs especially in rural communities, where ligno-cellulosic biomass was generated. It seems appropriate to investigate the techno-economics of ethanol production on a relatively small-scale (about 2.8-4.0 Mg/y). Using small- scale ethanol production units from rice straw, as a typical lingo- cellulosic material that is currently an environmental nuisance, is technically and economically viable (Tewfik S. R. *et al*., 2010).

Produced bioethanol biologically by fermentation from a variety of biomass sources is widely recognized as a unique transportation fuel and original material of various chemical with powerful economic, environmental and strategic attributes (Zhang *et al*., 2011).

Lignocelluloses are mainly composed of three groups of polymers, namely cellulose, hemicellulose and lignin. Cellulose and hemicellulose are sugar rich fractions of interest for use in fermentation processes, since microorganisms may use the sugars for growth and production of value added compounds such as ethanol (Mussatto and Teixeira, 2010).

Materials and Methods

In this paper, optimize fermenter design by computer software version 4.0, and techno-economic studies for the ethanol production from rice straw for proposed fermenter scale have been conducted at CLAC laboratory. Technology and process aspects were carried out by 20 kg/ day rice straw comprising the processing stages. A benefit-cost analysis approach was the core of getting at the financial reliability of the production of ethanol from rice straw. In that context, measures of net present value (N.P.V), and internal rate of return (IRR) were applied as discounted measures.

The chemical composition of rice straw was presented in **Table 1**.

Table 1 Rice straw: chemical composition

Component	Rice straw (%)
Moisture	8.4
Ash	19.3
Protein	5.3
Nitrogen	0.8
Cellulose	35
Lignin	12.2
Water Binding capacity	19.0

Source: Central Laboratory for Agricultural Climate (CLAC), CEMUWA project 3145, ARC, Egypt, 2013.

Machines Selection

Two machines were selected for rice straw chopping. The first machine was designed to chop rice straw size between (10-15cm), the machine capacity is one Mg/h. The machine specifications are feeding chute, two feeding drums 20 cm width. Machine drum has six cutting knives; the machine was driven by electric motor 10 kW to overcome rice straw cutting resistance. The second machine equipped with hammer mill drum and fixed knife, machine capacity is 0.250 Mg/ h and equipped by 2 kW electric motor, rice straw sizes were grind from 10-15 cm, to less than 2 mm, the machine was modified by replacing 2 kW, electric motor, and powered by 3.5 kW electric motor, the second modification was milling drum component by using adjustable knifes instead of fixed knife to overcome rice straw cutting, milling and grinding resistance.

Table 2 lists chopper and milling machine costs per hour, and **Table 3** lists material energy consumption with cost.

Table 2 Chopper and milling machine costs per hour

Equipment	Fixed cost (USD/ h)	Power consumption cost (USD/h)	Total cost (USD)	Operation cost/ton (USD/ Mg)
Chopper (1Mg/h)	1.22	0.5	1.72	1.72
Mill (0.250Mg/h)	0.56	0.11	0.67	2.67

Source: Central Laboratory for Agricultural Climate (CLAC), CEMUWA project 3145, ARC, Egypt, 2013.

Table 3 Material energy consumption and costs

Product	Energy (kW/ kg)	Cost (USD/ Mg)
Chopped rice straw	0.013	1.72
Milled rice straw	0.025	4.39

Source: Central Laboratory for Agricultural Climate (CLAC), CEMUWA project 3145, ARC, Egypt, 2013.

Fermenter Manufacturing

A fermenter or bioreactors is a container designated to provide an optimum environment in which micro-organisms or enzymes can interact with a substrate and perform the desired products. Batch fermenter design was carried out using fermenter design software version 4.0, and solid state fermentation bioreactor fundamentals of design; also hand- book operation, fermentation monitoring, design, operation and biochemical engineering III course notes. Two fermenters were built as follow: First fermenter 20 litres capacity, with the following features: capacity 20 litres double cool and heat jacket, control panel, electric voltage and temperature indicator. The fermenter has 5 props to measure solution PH, temperature, dissolved oxygen, pressure outlet and material inlet hole, also, fermenter equipped with three sample valves and drain valve from bottom side. Second fermenter specifications are: capacity 300 litres, double cool and heat jacket to control optimum temperature required by two electric sensors, electric control panel, electric voltage, overload control, fermenter has 5 props to measure fermenter temperature, materials PH, stirrer and gas out-let, as shown in (**Fig. 1**).

Ethanol Production Process from Rice Straw

Method of ethanol extraction from ligno-cellulosic materials, input materials essentially comprises the following:

- Shredded and milled rice straw;
- Micro-organism strain; and
- Distilled water

The output material comprises the following:

- Ethanol product (raw liquid); and
- Solid material (safe compost).

Table 4 Total investment costs for small scale fermenter

Items	Capacity		
	300 Litres	600 Litres	900 Litres
Cost of fermenter USD	1.000.00	1.333.33	1.666.67
Administrative fees USD (1%)	10	13.33	16.67
Indirect costs USD (4%)	40	53.33	66.67
Total USD	1.050.00	1.400.00	1.750.00

Proposed Appropriate Small-Scale Capacity Fermenter

Based on this composition and realistic conversion factors, ethanol yield, the annual quantity of ethanol produced and economic factors, the following are three assumptions of fermenter capacity scenarios.

Scenario I: fermenter 300 litres capacity.

Scenario II: fermenter 600 litres capacity.

Scenario III: fermenter 900 litres capacity.

Results and Discussion

Costs Estimate

The Investment costs have been estimated for available equipment and local prices for the equipment manufactured in 2013.Concerning the assumption of 3 scenarios the investment costs have been estimated respectively, USD 1.050, USD 1.400 and USD 1.750 as shown in **Table 4**.

Ethanol Production Costs for Each Scenario:

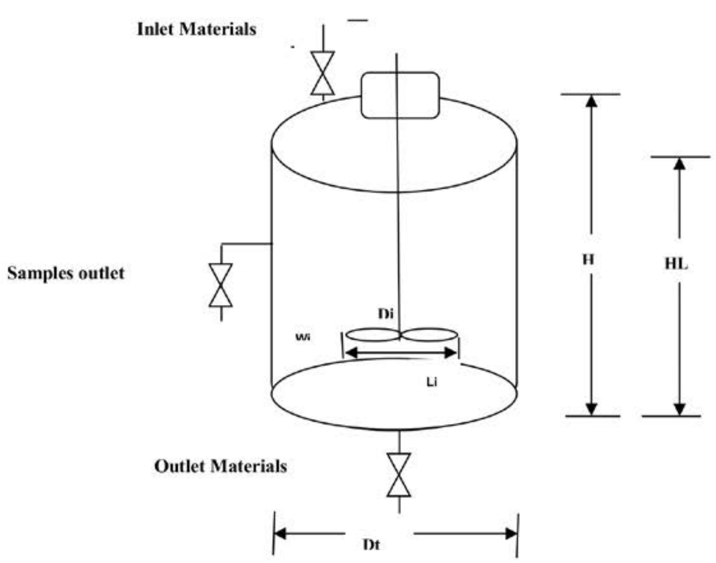
Operating costs have been estimated according to prevailing prices of rice straw raw materials, micro-organism strain, utilities (water and electricity) and labor. Maintenance cost has been assumed to be 1% of the capital investment of the various cases.

Net ethanol production costs were estimated according to the following parameters: investment costs (depreciation or fixed cost), rice straw costs, fixed operating costs (labor and maintenance costs), and variable operating costs (other materials and energy costs).

Ethanol production cost- first scenario (fermenter 300 litres)

Table 5 reveals that the total cost

Fermenter dimension



Where:
Dt = Tank diameter
HL = Liquid height
Di = Impeller diameter
Li = Impeller blade length
Wi = Impeller blade height

Fig. 1 Fermenter image (300 Liter).

Table 5 Cost analysis of ethanol production from rice straw first scenario

Description	Total needs	Unit price USD	Total price USD	Rank %
Depreciation investment cost			52.44	6.5
Operational costs/ year				
Rice straw (Kg)	5,200	0.02	115.56	15.32
Electricity (watt)	36	0.04	1.4	0.19
Water (litre)	280	0.06	15.56	2.06
Maintenance (1% of capital cost)			10.6	1.41
Workers (man/ day)	27	11.11	300	39.78
Yeast (micro- organism)			311.11	41.25
Total cost (USD)			806.67	100

Table 6 Total return for first scenario (300 litres capacity)

Items	Ethanol extraction %		
	15	17	20
Total production (litre ethanol)	780	884	1.040
Raw ethanol selling Price (USD/litre)	0.44	0.44	0.44
Selling value (USD)	346.67	392.89	462.22
By-product selling value (compost) (USD)	104.44	104.44	104.44
Total cost (USD)	806.67	806.67	806.67
Total return (USD)	451.11	497.33	566.67
Negative income (USD)	-355.56	-309.33	-240.00

Table 7 Cost analysis of ethanol production from rice straw

Description	Total needs	Unit Price USD	Total Price USD	%
Investment cost depreciation			70.00	7.3
Operational costs/day				
Rice Straw (Kg)	10.400	0.02	231.11	26.00
Electricity (watt)	36	0.04	1.40	0.16
Water (Litre)	560	0.06	31.11	3.50
Maintenance (1% of capital cost)		0.00	14.11	1.59
Workers (man/ day)	27	11.11	300.00	33.75
Yeast (micro- organism)			311.11	35.00
Total cost (USD)			958.89	100

Table 8 Total return for second scenario (600 litres capacity)

Items	Ethanol extraction%		
	15	17	20
Total production (litre ethanol)	1560	1.768	2.080
Raw ethanol selling price (USD/litre)	0.44	0.44	0.44
Selling value (USD)	693.33	785.78	924.44
By- product selling value (compost) (USD)	208.00	208.00	208.00
Total cost (USD)	958.89	958.89	958.89
Total return (USD)	901.33	993.78	1,132.44
Profit (USD)	(-) 57.56	34.89	173.56

of ethanol production from rice straw for first scenario is about USD 806.67. The yeast (micro-organism) came in first rank with USD 311.11, which represents about 41.25% of the operational costs, while worker wages came in the second rank being on average 39.78% of the operational costs. Whereas, value of rice straw came in the third rank representing 15.3% of the operational costs. The revenues have been estimated based on the price of raw ethanol in the range of about USD 0.44 for one litre ethanol raw.

Table 6 shows that the total production was 780, 884 and 1.040 litres ethanol, for 15%, 17%, and 20% of ethanol extraction respectively; the total value estimates of USD 346.67, 392.89 and 462.22 for 15%, 17%, and 20% of ethanol extracted respectively and 3.12 tons compost, with total value USD 104.44, meanwhile, the total return has reached USD 451.11, USD 497.33 and USD 566.67 for 15%, 17%, and 20% of ethanol extracted respectively, the cost estimate indicated to be USD 355.56, USD 309.33 and USD 240.00, for 15%, 17%, and 20% of ethanol extraction, respectively.

Ethanol production cost- second scenario (fermenter 600 litres)

Table 7 reveals that the total cost of ethanol production from rice straw in second scenario is about USD 958.89. The yeast (micro-organism) came in first rank with USD 311.11, which represents about 35% of the operational costs, while the worker wages came in the second rank being on average 33.75% of the operational costs. Whereas, value of rice straw came in the third rank representing 26% of the operational costs.

Table 8 shows that the total ethanol production was 1.560, 1.768 and 2.080 litres ethanol, at 15%, 17%, and 20% of extracted ethanol respectively, the total price estimates was USD 693.33, USD 785.78 and USD 924.44, at 15%, 17%, and 20%

Table 9 Cost analysis of ethanol production from rice straw

Description	Total needs	Unit price USD	Total price USD	%
Operational costs/day				
Rice straw (Kg)	15,700	0.02	348.89	34.01
Electricity (watt)	36	0.04	1.40	0.14
Water (Litre)	840	0.06	46.67	4.55
Maintenance (1% of capital cost)		0.00	17.67	1.72
Workers (man/ day)	27	11.11	300.00	29.25
Yeast (micro- organism)			311.11	30.33
Total cost (USD)			1,143.56	100

Table 10 Total return for third scenario (900 litres capacity)

Items	% of Ethanol extraction		
	15	17	20
Total production (litre ethanol)	2,355	2,669	3,140
Raw ethanol selling price (USD/litre)	0.44	0.44	0.44
Selling value (USD)	1,046.67	1,186.22	1,395.56
By- product selling value (compost) (USD)	314.00	314.00	314.00
Total return (USD)	1,360.67	1,500.22	1,709.56
Total cost (USD)	1,143.56	1,143.56	1,143.56
Profit (USD)	217.11	356.67	566.00

Table 11 Investment and replacement costs (USD)

Item	No. of units	Price/unit	Cost	Project lifespan (Years)	Replacement (Years)
Fermenter	1	1,666.67	1,666.67	20	-
Land Rent	1	33.33	33.33		-
Administrative fees	-		16.67		-
Indirect costs	-		66.67		-
Total			1,750.00		-

Table 12 Operational costs (USD)

Year	Rice straw cost	Electricity cost	Water cost	Maintenance cost	Labor cost	Yeast cost	Total
1	348.89	1.40	46.67	17.67	300.00	311.11	1,025.78
2	348.89	1.40	46.67	17.67	300.00	311.11	1,025.78
3	348.89	1.40	46.67	17.67	300.00	311.11	1,025.78
4-20	348.89	1.40	46.67	17.67	300.00	311.11	1,025.78

of extracted ethanol respectively, also, obtained by product was 6.24 tons of compost, with total price USD 208.00, the total return has reached USD 901.33, USD 993.78 and USD 1.132.44 for 15%, 17%, and 20% of extracted ethanol respectively, while, the profit was estimated to be USD -57.56, USD 34.89 and USD 173.56, at 15%, 17%, and 20% of extracted ethanol respectively.

Ethanol production cost- third scenario (fermenter 900 litres)

Table 9 reveals that the total cost of ethanol production from rice straw in third scenario is about USD 1,143.56. The value of rice straw came in the first rank, with USD 348.89, which represent about 34% of the operational costs; while, the value of yeast (micro-organism) came in the second rank being represented by 30.3% of the operational costs. Whereas, worker wages came in the third rank represent 29.25% of the operational costs.

Table 10 shows that the total production was 2.355, 2.669 and 3.140 litres of ethanol, at 15%, 17%, and 20% of ethanol extraction respectively; with total price estimates of USD 1.046.67, USD 1.186.22 and USD 1,395.56 at 15%, 17%, and 20% of extracted ethanol respectively, also, obtained 9.42 tons of compost, with total price USD 314.00. The total return has reached USD 1,360.67, USD 1,500.22 and USD 1,709.56 at 15%, 17%, and 20% of extracted ethanol respectively; therefore, the profit was USD 217.11, USD 356.67 and USD 566.00, at 15%, 17% and 20% of extracted ethanol respectively.

Financial Analysis for Third Sce-

Table 13 Total project cost (USD)

Year	Investment cost	Operating cost	Total cost
1	1,750.00	1,025.78	2,775.67
2	0.00	1,025.78	1,025.78
3	0.00	1,025.78	1,025.78
4-20	0.00	1,025.78	1,025.78

Table 14 Total project return (USD)

Year	Ethanol	By product	Total return
1	1,395.56	314.00	1,709.56
2	1,395.56	314.00	1,709.56
3	1,395.56	314.00	1,709.56
4-20	1,395.56	314.00	1,709.56

nario (20% ethanol)

Financial analysis was carried out to measure the project profitability in **Tables** (**11-14**), respectively.

Results of financial analysis

- The net present value at discount rate (D.R) of 30% was estimated to be a positive value of USD 1,096;
- The benefit cost ratio (B/ C) at the same D.R. was estimated to be 1.22; and
- The internal rate of return (IRR) reached about 30%.

Conclusions

To produce bioethanol from rice straw, the following steps should be conducted, rice straw should be chopped and milled using two different machines, then rice straw were grinded should be sieved into 4 sizes (10-15, 5-10, 2-5 and less than 2 cm).

There are three scenarios for different fermenter volumes (300, 600 and 900 litres capacity) and different percentages of ethanol extraction (15, 17 and 20%). The economic scenario is fermenter 900 litres capacity (third scenario).

The expansion and development of the bioethanol from rice straw will have positive developmental impacts on the economy, the people and the environment in Egypt. All these results indicate there are promising investment opportunities, and the projects could be a great success, if well managed for scenario II (600 litres capacity) and scenario III (900 litres capacity).

There is a need to increase the percentage of bioethanol production from rice straw, for the betterment of national economy, efficient use of local funds, increase of employees and decrease of noxious emissions of CO^2 and N^2O.

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Development and Evaluation of a Pneumatic Dibble Punch Planter for Precision Planting

by

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Abstract

One of the best solutions of controlling soil erosion in conservation tillage is using punch planters which can plant through residue covers and gravelly soils with slope. In the present research, a precision dibble punch planter with pneumatic seed metering device was developed and evaluated. The laboratory and field tests were conducted to find the effects of forward speed and soil surface conditions on multiple index, quality of feed index, miss index, precision in spacing, and percentage of seeded holes. The results showed an increase in forward speed increased the multiple index, miss index and precision but decreased the quality of feed index and percentage of seeded holes. The field test showed that the soil condition had significant effect on multiple index and precision in spacing, but no significant difference was found in other parameters determined. The forward speed of 5.5 km/h had acceptable performance in three soil surface conditions.

Keywords: Precision planting, Pneumatic punch planter, Forward speed, Soil condition

Introduction

Planting machines play a major role in increasing the farm performance and decreasing production cost. Traditional tillage practice is required if the conventional planters are employed for planting (Kepner *et al.*, 1978). Conservation tillage is a better choice compared to traditional tillage, since it reduces the production cost and soil erosion and improves the soil texture and conditions compared to traditional tillage (Kromer, 1986). The problems associated with the traditional tillage can be overcome if conservation tillage is used for planting. On the other hand, the same interval, appropriate space and suitable planting depth improve the field performance. These parameters are affected by soil texture, seeds variety and tillage method. Unfortunately, the developed conventional planters did not have the acceptable performance so far to fulfill these goals.

In this condition, punch planter is one of the best selections for suitable seed planting (Debeki and Shaw, 1996). It employs some form of ground-engaging part to punch a hole in the soil and then drops a seed in the hole as (or after) the soil-engaging part leaves the hole it has just made (Adekoya and Buchele, 1987).

The benefits of punch planter over the conventional planters are listed below:

- Eliminating the unequal space between planted seed that is caused by seed skipping in the furrow
- Being capable of planting through residual covers and gravelly soil with slope
- Being able to plant in no-tilled condition and thus decreasing soil erosion
- Planting at the same depth regardless of the surface level
- Reducing the thinning cost
- Punctual replanting in the emergency conditions
- Reducing the required seed per hectare

Generally, the punch planters can be divided into three groups: (a) bucket-punch planters, (b) spade-punch planters, and (c) dibble-punch planters (Debicki and Shaw, 1996).

Many researchers have attempted to develop bucket-punch planters (Shaw *et al.*, 1978; Shaw and Kromer, 1987; Adekoya and Buchele 1987; Hezroni *et al.*, 1986).

When this type of planter was used in wet soil or with a high accumulation of plant residue, some difficulties arise. Moisture accumulated on the inner surface of the buckets caused flat squash seeds to stick inside the punches and some holes were not planted. Therefore, the planter's operation had to be limited to dry soil conditions (Debicki and Shaw, 1996).

Several researchers developed spade-punch planters (Srivastava and Anibal, 1981; Shaw and Kromer, 1987; Molin, 2002; Yeon and Shaw, 2004). Generally, these systems were complicated and costly.

The dibble punch planters are classified into two groups according to their seeding method: (1) pushing seeds into the ground, and (2) making holes in the ground for seeds to be deposited later into the holes (Debicki and Shaw, 1996).

The first group of planters inserts seeds into the ground directly. Wilkins *et al.*, (1979) and Gary and Heinemann (1977) designed dibble-punch planters, in which individual seeds were placed mechanically on the tips of the dibbles and kept magnetically. Flake and Brinkmann (1983) designed a completely mechanical dibble-punch planter. The second group of planters requires a proper synchronization between the seed meter and punching the holes in the ground in order to deposit single seeds in the previously formed holes (Debicki and Shaw, 1996). Jafari and Fornstrom (1972) designed a dibble punch planter for sugar beets which was equipped with a special centrifugal seed metering device. The structure of this planter was complicated and expensive.

Heinemann *et al.* (1973) designed two different dibble planters with the same type of seed meter, but different dibble engaging mechanisms. The seed meter had a vertical rotating wheel with slots for individual seeds. In the first planter, the holes were made in the soil by a pneumatic cylinder. In the second planter, there were spring-mounted, cylindrical punches on the front wheel of a tandem-wheel unit. However, these planters are not flawless; the first type planters are sensitive to variations in forward speed; while in the second type planters, the belt tends to creep with respect to the soil surface and the seeds often miss the dibbled holes.

Lawrence *et al.* (2007) developed a pneumatic dibbling machine for plastic mulch of small horticultural seeds (onions and potatoes). They reported acceptable performance for the developed planter in tilled soil condition.

The primary objective of this project was to develop a prototype of a dibble punch planter with a pneumatic seed metering device for conservation tillage to overcome the problems associated with the previous designs.

Materials and Methods

Development

A new pneumatic dibble punch planter was developed in the workshop, Department of Agricultural Machinery, College of Agriculture, University of Shiraz, Iran. The schematic view of the developed pneumatic dibble punch planter is displayed in **Fig. 1**. The developed planter was tested in laboratory and field condition (tilled, wheat residue covered and no-till).

It consists of frame, punch wheel, pneumatic seed metering device, vacuum fan, covering disks, power train system and press wheel. Seed metering device: An eight-celled vacuum disk was used. The diameter of each cell and the thickness of the disk were 5.5 mm and 2.5 mm, respectively. The required vacuum was provided using a fan powered by tractor P.T.O. shaft.

Punching unit (Punch wheel): An appropriate device is required to penetrate in the soil sufficiently and create holes at the same depth and interval. Therefore, a punch wheel with 6 cm-high cones was utilized. Jafari and Fornstrom (1972) proved that the cone angle should be 90°. Due to the fact that cones with angles less than 90° shake the soil and fill the developed holes, whereas the cones with angles more than 90° dig wider holes with undesirable shape (**Fig. 2**).

Covering disks: two side-sharpened covering disks of 5 mm thick with a diameter of 340 mm were fabricated. These disks were installed on a height adjustable L-shaped unit at an angle of 25° (**Fig. 3**).

Press wheel: A height adjustable rubber press wheel with a diameter of 380 mm was employed in order to press the soil on the planted seeds, to carry a portion of the weight of the planter and to avoid vertical vi-

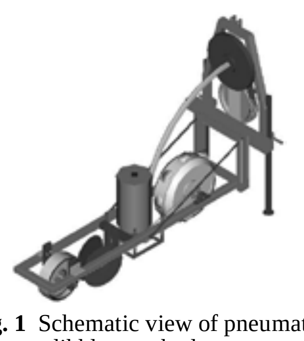

Fig. 1 Schematic view of pneumatic dibble punch planter

Fig. 2 Schematic view of punch wheel

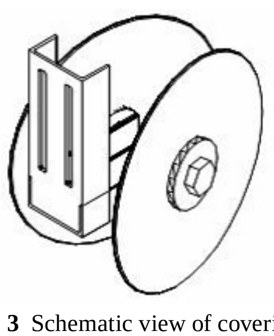

Fig. 3 Schematic view of covering disks

Fig. 4 Schematic view of press wheel

Fig. 5 The developed prototype of pneumatic dibble punch planter

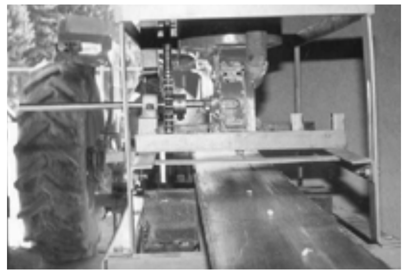

Fig. 6 The laboratory tests

bration of the frame (**Fig. 4**).

Power train system: The seed metering device should be synchronized with the punch wheel in such a way that seeds fall into their proper holes (one seed for each hole) independent of the travel speed of the planter. For this purpose a chain and sprocket with the gear ratio of 1:1 was used.

Punch planter operation: The punch wheel was developed to dig holes to a depth of 6 cm and at intervals of 25 cm. The seed metering device picked single seeds and dropped it into the dug holes. The seed metering device was installed on a special frame with three degrees of freedom. The covering disks fill in the hole with soil after locating a single seed in them. Finally, the press wheel passed on the planted row and proportionally pressed the soil. The developed planter was mounted on a three-point-hitch (**Fig. 5**).

Test Procedures

Laboratory tests

In this study, a greased belt was used to evaluate the developed planter. Its surface area was greased in order to avoid seed skipping and record precise locations of seeds. It was driven using 2kW electrical motor. In order to simulate field conditions, the seed metering device was forced by greased belt pulley. In this study, six levels of forward speed of greased belt (2.8, 3.7, 4.6, 5.5, 6.4 and 7.3 km/h) were used. In these tests, seed metering device and seed hopper were only installed on the greased belt. In order to provide the required vacuum of seed metering device, the planter was mounted on the three-point-hitch. The created vacuum was carried to seed metering device by tube. An area equal to dibble cross section was drawn on greased belt to simulate the created holes in the field condition. After putting the seeds by seed metering device on the greased belt, their intervals were recorded. MF-285 tractor and corn seeds (704- cultivar) were used in all tests (**Fig. 6**). To evaluate the planter performance, a completely randomized design with three replications was used.

Field tests

The field tests were conducted at five forward speeds of 1.7, 2.8, 4, 5.5 and 7 km/h engaged with five different gear positions. The PTO shaft operated at the engine-drive position (540 rpm). Field tests were conducted on three farms located in "Shiraz Agriculture Faculty Farm Station" (**Fig. 7**). The soil texture of farms was sandy (40% sand, 36% silt and 24% clay). The farms conditions are listed below:

(1) Tilled soil; it was deeply plowed by a moldboard plow and was also loosened twice using disk harrow
(2) No-tilled soil; it has not been plowed for 3 years
(3) Wheat residue; it was a wheat-planted farm and stubbles (1.45 ton/ha) and weed were released on the soil surface after combine harvesting

In order to record seeds interval it was necessary to prevent seed covering, so covering disk and press wheel were detached from the planter. To evaluate the farm tests, 3 × 5 factorial test in completely randomized block design (3 soil surface conditions and 5 level of forward speed with the three replications for each treatment) were used. Means of the tests were compared using Duncan multiple range tests.

Evaluation Factors

The International Organization for Standardization has defined a number of measures based on the theoretical spacing for the planter. These measures include the multiple index, miss index, quality of feed index and precision. In addition to these measures, in this study a new special index named seeded holes

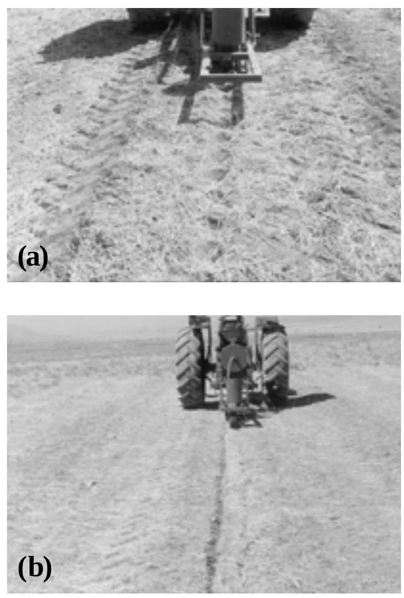

Fig. 7 The field tests **(a)**: Planter without covering disk and press wheel and **(b)** Planter with covering disk and press wheel

was measured. The theoretical spacing is X_{ref} in cm which is used to divide the observed spacings into several regions: [0, 0.5X_{ref}], [0.5X_{ref}, 1.5X_{ref}], [1.5X_{ref} , 2.5X_{ref}], [2.5X_{ref} , 3.5X_{ref}], and [3.5X_{ref} , ∞). In this research, the theoretical spacing was 25 cm.

The five regions correspond to the following classification of regions: (1) as a multiple, closer to the previous plant than the theoretical spacing; (2) as a single, closer to the theoretical spacing than either the previous plant or a single skip; (3) as a single skip, closer to a single skip than either the theoretical spacing or a double skip, and so on. These measures are defined in the following sections (Raoufat and Mahmoodieh, 2005; Katchman and Smith, 1995).

Multiple index

The multiple index (D) is the percentage of spaces that are less than or equal to half of the theoretical spacing.

$D = \{n_1 / N\} \times 100$ .... (1)

Where n1 is the number of spacings in the first region; and N is the total number of distances measured. Smaller values of D indicate better performance. With the theoretical spacing of 25 cm, the multiple index is the percentage of spacings that are less than or equal to 12.5 cm.

Miss index

The miss index (M) is the percentage of the spaces greater than 1.5 times the theoretical spacing.

$M = \{(n_3 + n_4 + n_5) / N\} \times 100$ .... (2)

Where nj is the number of spaces in the region j.

Smaller values of M indicate better performance than larger values. With the theoretical spacing of 25 cm in this study, the miss index is the percent of spacing that are greater than 37.5 cm.

Quality of feed index

The quality of feed index (A) is the percentage of spaces that are more than half but no more than 1.5 times the theoretical spacing.

$A = (n_2 / N) \times 100$ .... (3)

Larger values of A indicate better performance than smaller values. With the theoretical spacing of 25 cm in this study, the quality of feed index is the percent of spacing that are greater than 12.5 cm and smaller than 37.5 cm.

Precision

Precision (C) is the measure of the variability in spacing between plants after accounting for variability due to both multiple and skips. The precision is the coefficient of variation of the spacings that are classified as the singles.

$C = S_2 / X_{ref}$ .... (4)

Where S_2 is the sample standard deviation of the n_2 observation in region 2. (Kachman and Smith, 1995; Singh *et al*., 2005; Raoufat and mahmoodieh, 2005; Yazgi and Degirmencioglu, 2007).

Seeded holes index: This index is only used for the evaluation of punch planting systems.

Seededholes = (m / M) × 100 ..... (5)

Where m is the number of seeded holes and M is the total number of dug holes.

Results and Discussion

Laboratory Evaluation

Table 1 shows the effect of forward speed on the indexes using greased belt. The statistical analysis showed that there was no significant difference (P > 0.05) in multiple index, quality of feed index and miss index by increasing forward speed from 2.8 to 7.3 km/h. Adekoya and Buchele (1987), Hezroni *et al*., (1986) and Molin *et al.* (1998b) reported similar finding for the effect of forward speed on multiple index and miss index. Molin *et al.* (1998b) reported similar results for the effect of forward speed on the quality of feed index.

Precision in spacing was affected (P > 0.05) by increasing forward speed from 2.8 to 3.7 km/h and 6.4 to 7.3 km/h, but no significant difference was observed in this parameter by increasing in forward speed from 3.7 to 6.4 km/h. It is mentioned that the lower percent of precision in spacing is a desirable factor. Also, the results showed that there was a significant difference (P < 0.05) in seeded holes by increasing forward speed from 6.4 to 7.3 km/h, but there was not a significant difference in it (P > 0.05) by increasing in forward speed from 2.8 to 6.4 km/h.

Increasing the forward speed from 6.4 to 7.3 km/h decreased the seeded hole index. Generally, in vacuum seed metering device, the seeds lose contact with the seed separator as the forward speed decreases and the seeds are discharged from disk by eliminating the vacuum. But at high forward speeds, the seeds have full contact with the seed separator. On other hand, the different positions of seeds on the disk cells cause more intensive skip of the discharged seeds at high forward speeds than the low forward speed. Molin and D'Agostini (1996) and Molin *et al*., (1998a) reported similar justification for the effect of forward speed on seeded holes index. Chenghua *et al*., (1999) also found similar finding.

Field Evaluation

Table 1 Statistical analysis for laboratory tests

	speed levels (km/h)					
Parameters	2.8	3.7	4.6	5.5	6.4	7.3
Multiple index (%)	0.55 [a]*	1.03 [a]	1.03 [a]	1.03 [a]	1.13 [a]	2.17 [a]
Quality of feed index (%)	97.50 [a]	96.88 [a]	94.60 [a]	93.03 [a]	92.50 [a]	91.60 [a]
Precision in spacing (%)	7.79 [a]	13.30 [b]	14.60 [bc]	15.00 [bc]	16.60 [bc]	19.00 [c]
Miss index (%)	3.50 [a]	3.57 [a]	4.35 [a]	5.92 [a]	6.27 [a]	6.87 [a]
Seeded holes (%)	97.10 [a]	93.10 [ab]	91.10 [ab]	91.10 [ab]	89.20 [ab]	85.1 [b]

* For each parameter, means within each row followed by the same small letters are not significantly different at probability P < 0.05.

Multiple index

Analysis of the variance of data on multiple index indicated that soil condition, forward speed and their interaction have significant effects on multiple index (P < 0.05). Comparison of mean data on multiple index as affected by soil condition and forward speed (**Table 2**) revealed that average multiple index was significantly higher for wheat residue soil condition and forward speed of 7 km/h, respectively (P < 0.05). Furthermore, the average multiple index had not been affected between (no-till and wheat residue) and (tilled and no-till) conditions. The maximum multiple index was obtained for wheat residue soil condition at forward speed of 7 km/h. This is explained by the fact that wheat residue soil surface condition had an uneven surface and vibrated the planter more intensively than other soil conditions. The obtained multiple index in laboratory tests was much lower than the farm tests which could be related to low vibration in laboratory tests. Similar trends were reported by Molin *et al.* (1998b) and Hezroni *et al.* (1986).

Table 2 Statistical analysis for field tests

Factor	Surface condition▶ Travel speed (km/h) ▼	Tilled	Wheat residue	No-till	Mean
Multiples index	1.7	0.00 d*	0.00 d	0.00 d	0.00 C**
	2.8	0.00 d	0.00 d	0.00 d	0.00 C
	4	0.00 d	1.72 c	1.64 cd	1.12 B
	5.5	1.66 c	3.18 c	2.68 c	2.50 B
	7	8.30 b	12.44 a	9.98 b	10.24 A
	Mean	1.99 B***	3.46 A	2.86 AB	
Quality of feed index	1.7	97.90 a	97.44 ab	97.84 a	97.72 A
	2.8	97.26 ab	96.24 abc	96.66 abc	96.72 A
	4	94.60 abc	92.86 abc	94.22 abc	93.89 AB
	5.5	92.85 abc	90.54 bc	90.66 c	91.35 B
	7	67.81 d	63.58 d	69.38 d	66.92 C
	Mean	90.08 A	88.13 A	89.75 A	
Precision in spacing	1.7	3.82 d	5.80 cd	5.77 cd	5.13 C
	2.8	5.83 cd	6.64 cd	7.31 cd	6.59 BC
	4	7.67 cd	8.25 cd	7. 78 cd	7.90 BC
	5.5	7.75 cd	9.42 bc	9.26 bc	8.81 B
	7	12.77 ab	15.82 a	15.53 a	14.70 A
	Mean	7.56 B	9.19 A	9.13 A	
Miss index	1.7	2.10 b	2.56 b	2.16 b	2.27 B
	2.8	2.74 b	3.76 b	3.34 b	3.28 B
	4	5.40 b	5.50 b	4.14 b	5.01 B
	5.5	5.49 b	6.78 b	6.66 b	6.31 B
	7	23.89 a	23.96 a	20.64 a	22.83 A
	Mean	7.93 A	8.51 A	7.38 A	
Seeded holes	1.7	98.50 a	95.50 abc	96.04 abc	96.68 A
	2.8	97.50 ab	95.47 abc	92.60 abc	95.19 A
	4	91.99 bc	95.46 abc	92.57 abc	93.34 AB
	5.5	91.68 bc	90.51 c	92.46 abc	91.55 B
	7	81.33 de	77.12 e	84.20 d	80.88 C
	Mean	92.20 A	90.81 A	91.57 A	

* For each parameter, means followed by the same small letters are not significantly different at probability P < 0.05.

**For each parameter, means within each column followed by the same capital letters are not significantly different at probability P < 0.05.

***For each parameter, means within each row followed by the same capital letters are not significantly different at probability P < 0.05.

Quality of feed index

The analysis of variance of data indicated that the forward speed and interaction of the forward speed and soil surface condition had significant effects on this index (P < 0.05). The analysis also revealed that quality of feed index had not been affected by the soil surface condition. This is an extra evident to the non-sensitivity of the developed planter to the soil surface condition for this factor. Comparison of mean data on quality of feed index as affected by forward speed (**Table 2**) showed that the average quality of feed index was significantly lower for the highest forward speed. The highest mean of quality of feed index was obtained for the tilled soil surface condition at lowest forward speed. The minimum quality of feed index was obtained in wheat residue soil surface condition at forward speed of 7 km/h. Molin *et al.*, (1998a) and Molin and D'Agostini (1996) reported that the forward speed had non-significant effect on the quality feed index. This could be due to the low-value difference in the forward speeds (maximum of 2.5 km/h) considered by them.

Precision in spacing

Analysis of data on precision in spacing showed that soil condition, forward speed and their interaction had significant effects on this index (P < 0.05). Comparison of mean data on precision in spacing as affected by soil condition (**Table 2**) revealed that average precision in spacing was significantly lower for tilled soil surface condition. Also, comparison of mean data on precision in spacing as affected by forward speed showed that average of this index was significantly higher at forward speed of 7 km/h. The minimum value of quality of feed index was 3.82% for tilled soil surface condition at forward speed of 1.7 km/h. The maximum value of quality of feed index was 15.82% for wheat residue soil surface condition at forward speed of 7 km/h. It is mentioned that the higher values of precision in spacing index are regarded as an undesirable factor. Molin *et al*., (1998a) and Molin and D'Agostini (1996) reported similar results.

Miss index

The forward speed and interaction of the forward speed and soil surface condition had significant effects on this index ($P < 0.05$). The analysis also indicated that miss index had not been affected by the soil surface condition. Comparison of mean data on miss index as affected by forward speed (**Table 2**) indicted that average miss index was significantly higher at the highest forward speed. The minimum and maximum miss index were obtained for tilled soil surface condition at forward speed of 1.7 km/h and wheat residue soil surface condition at forward speed of 7 km/h, respectively. Increasing the forward speed from 1.7 to 5.5 km/h had no significant effect on the miss index, but increasing the forward speed from 5.5 to 7 km/h had significant effect on this index. This could be due to of the dramatic increase in irregularities of the seed metering device operation and vibrations of the frame as the forward speed increases from 5.5 to 7 km/h. The obtained miss index in laboratory tests was considerably lower than the farm tests. This could be due to the skipping of seeds in farm condition. This result is similar to those published by Molin *et al*. (1998b) and Adekoya and Buchele (1987).

Seeded holes

The analysis indicated that the forward speed and interaction of the forward speed and soil surface condition had significant effects on this index ($P < 0.05$). The seeded holes had not been affected by the soil surface condition. Comparison of mean data on seeded holes as affected by forward speed (**Table 2**) indicated that the average of seeded holes was significantly lower for the highest forward speed. The minimum value of seeded holes was 77.12% for wheat residue soil surface condition at forward speed of 7 km/h. The maximum value of quality of feed index was 98.50% for tilled soil surface condition at forward speed of 1.7 km/h. Generally, increasing the forward speed decreased seeded holes for the same reason explained in laboratory results. Other researchers have found similar results (Molin *et al*., 1998a; Molin and D'Agostini, 1996). Therefore, according to above and the acceptable indexes for forward speed of 5.5 km/h, it is suggested as the best option based on the field tests.

Conclusions

The new pneumatic dibble punch planter for precision planting was developed and evaluated in laboratory and field condition. The developed planter was successfully employed for corn planting in different soil surface conditions. Evaluation of data obtained in laboratory and field test indicated that planter had a successful precision and rapid operation in planting corn in three soil surface conditions (tilled, no-till and wheat residue). The developed planter could be used for planting a suitable number of seeds per hectare to reach the optimal performance of farm. From the study carried out in this paper, it was found that the pneumatic dibble punch planter can be used in conservation tillage which is considered as an important operation in sustainable agriculture. This planter can offer considerable benefits in precision and faster planting as compared to the conventional planter. This planter can be used for planting different seeds with very little reconfiguration of machine components.

Some suggestions are listed below to improve the planter performance:

1. Equipping the planter with adjustable dibble height and interval to plant different types of seed at variable distance and depth
2. Supplementing the punch wheel with an adjustable weight to penetrate in the soil with different cone index
3. Developing a punch wheel with different levels of diameter to improve the shape and quality of created holes
4. Adding pesticide and fertilizer broadcasting systems the planter
5. Supplementing the planter with depth adjustment wheel to avoid further penetration in wet and loose soil

It is interesting to note that planter development was quite difficult and its acceptable performance is quite challenging due to the large number of parameters involved. Therefore, the developed planter is suitable for planting in different soil conditions with a higher precision and faster planting.

The advantages of present design are versatility, accuracy, simplicity, cheapness, low required maintenance, low imposed seed damage and high speed planting.

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Development and Evaluation of Improved TNAU Mini Dhal Mill

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Introduction

Pulse milling is an important agro-based industry in India next to rice and wheat milling industries. India is the largest producer and consumer of pulses in the world, accounting for about 25% of production and 27% consumption. Consumption of pulses along with cereals provides a vital role in human nutrition (Tiwari *et al.*, 2007; Kethireddipalli *et al.*, 2002; Ravi and Harte, 2009). Pulses are the main source of proteins for vegetarians in India, where about 15-30% of daily protein needs are supplied only from edible pulses.

The World Health Organization (WHO) has recommended 80 g of pulses per person per day considering the Indian food habits. But the per capita availability of milled pulses has been reduced considerably over the past 20 years due to increase in population and stagnation of pulse production. The annual production is around 14 million tonnes which has remained stagnant since last three decades. At the current level of production, the per capita availability of pulses is around 30 g as against the requirement of 70 g per day for an optimal diet (Mangaraj and Kapur, 2005).

Pulses contain 17 to 25% of protein, 1.01% of crude fibre, 59.21% of carbohydrate and remaining moisture content. On an average, the percentage of husk and endosperm in pulses is 15% and 85%, respectively. Pulses are mostly consumed in the form of dhal i.e. dehusked splits. Usually cotyledons are the protein storing part of the seed, which is tightly adhered by husk, the outer seed coat, due to the presence of gummy layer (Kurien, 1981). The process of husk removal and cotyledons is termed as milling. Due to the gummy layer, a pretreatment for loosening of husk prior to milling is desirable as it increases the dhal recovery (Sahay *et al.*, 1985; Mangaraj *et al.*, 2004). Recovery of dhal varies from 60-75% depending upon the type of pulses and the milling techniques (Agrawal *et al.*, 2003; Chacko *et al.*, 2001; Erskine *et al.*, 1991; Mangaraj and Kapur, 2005). By adopting improved techniques, the dhal recovery can be increased (Singh *et al.*, 2004).

Based on the overall study, there is a requirement of small scale processing of pulses at rural level and hence, an improved mini dhal mill has been developed and evaluated.

Methods and Materials

Development of an Improved Tnau Dhal Mill

The existing TNAU dhal mill has the provision for milling of pulses only. The other operations *viz.*, cleaning and grading have to be done manually. To improve its performance, the TNAU dhal mill was attached with pitting, cleaning and grading units. Hence, the improved TNAU dhal mill has the provision for feeding, milling, pitting, cleaning and grading operations.

The pitting unit has a feed hopper of size 15 × 15 cm, a tapered conical abrasive roller of 15 cm diameter at one end and 12.5 cm diameter at the other end with a length of 20 cm, which is fully covered with a perforated concave of 20 × 2 mm oblong sieve. A progressive increase in gap between the roller and concave was maintained and provision was also made to adjust the gap for improving the pitting/scratching action. Based on the pitting experimental trial, the pitting abrasive roller was operated at the optimum speed of 550 rpm. After pitting, the pulses viz., red gram, green gram and black gram were soaked in water and then dried to the final moisture content level of 8-10%. The dried pulses were used for the milling study.

The milling unit has a feed hopper of size 25 × 25 cm, fitted with a sliding gate for uniform feeding of pretreated pulses in to the milling section. The milling unit is of a vertical attrition type, which has a stationery rubber disc and rotating corrugated steel disk of 15 cm diameter for the abrasive action on the materials (**Fig. 1**). The gap between the rubber disk and steel disk can be adjusted through a hand wheel depending upon the size of pulses. The milling capacity of the unit was found to be 25 kg/h.

The dehusked / milled pulses were exposed to the blower operated by a 1/4 hp motor with the adjustable air flow rate of 3-4 m^3/s, which separated the husk from the dhal. Then, the milled dhal was allowed to fall on the sieves for separation. The sieving mechanism consisted of two sieves with three outlets for collecting whole/undehusked, dehusked split dhal and broken dhal separately. The top sieve was made with the dimension of 55 cm length and 40 cm width, fitted with the oblong sieve of size 20 × 4 mm, which separated the whole/undehusked dhal as the over flow material and allowed the dehusked split and broken dhal through the sieve as the under flow materials. The bottom sieve was made with the dimension of 55 cm length and 40 cm width fitted with the oblong sieve of size 20 × 1.5 mm. The bottom sieve separated the dehusked split dhal as its over flow material and allowed the broken dhal to collect at the bottom outlet as the under flow material. The inclination and the stroke length of the sieves were fixed as 15^o and 5 cm, respectively.

For operating the milling unit, pitting unit and sieving mechanism, power was taken from one hp single phase motor attached with 3 groves pulley. All these separations were done simultaneously.

Grain Preparation

Three thousand gram of pulses *viz.*, red gram, black gram and green gram from each variety were selected for conducting experimental studies. The soaking trials were conducted with pitting and without pitting treatments. The water absorption of pulses with pitting and without pitting was recorded at hourly interval. They were dried to the moisture content level of 8-10% before milling. The properties of the selected pulses were determined and the performance of dhal milling was evaluated using the improved TNAU dhal mill based on the percentage of dhal recovery and broken dhal. All the experiments were replicated thrice and the average values were reported.

Experimental Details

Independent variables

i. Pulses - Two varieties

1. Red gram (CO7 and BSR1)
2. Black gram (CO5 and VBN4)
3. Green gram (VBN2 and CO7)

ii. Pre treatments

1. Soaking (with pitting and with-

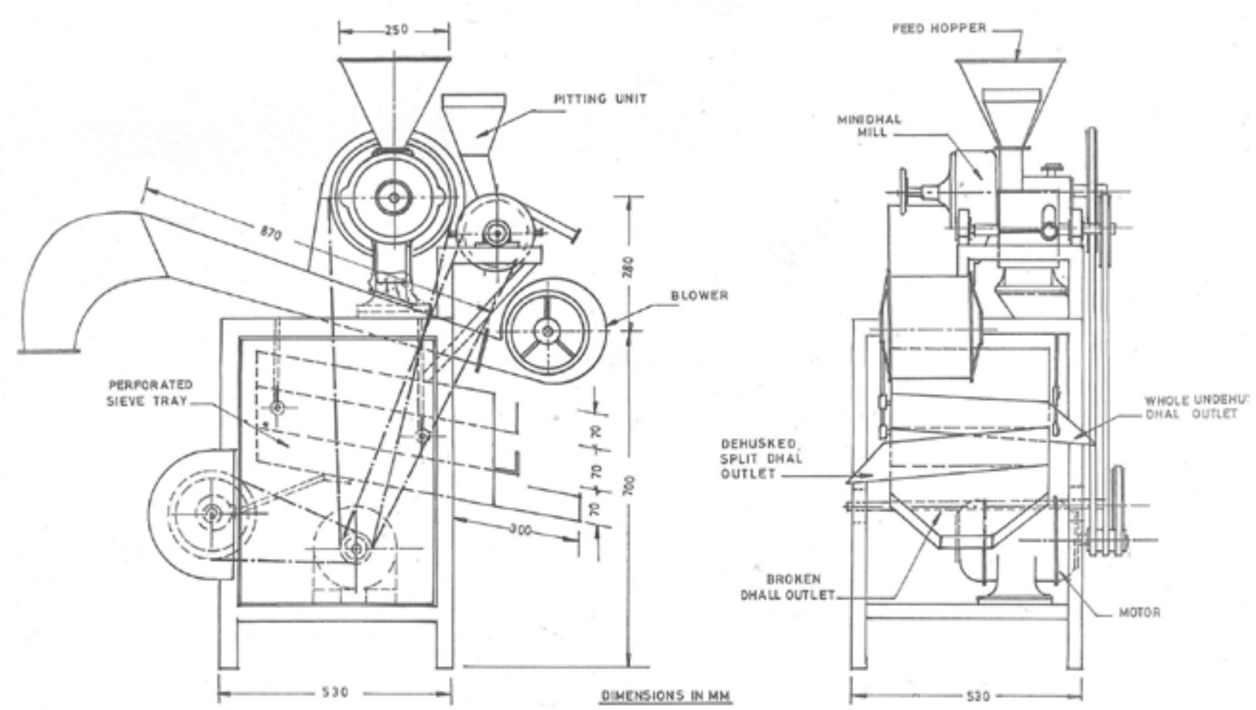

Fig. 1 TNAU improved dhal mill

out pitting)

2. Milling (with pitting and without pitting)

iii. Milling at 200, 300 and 400 rpm

Dependent variables

From the milled dhal, the percentage recovery of dehusked split dhal, whole undehusked and broken dhal were separated and calculated as follows:

1. Percentage of dhal recovery/dehusked splits

This was calculated from the following equation

$D_r = D_s / D_f \times 100$ .... (1)

where,

D_r = Percentage of dehusked split dhal

D_s = Mass of dehusked split obtained from the main dhal outlet

D_f = Mass of the sample taken for dehusking

2. Percentage of broken dhal

$D_b = D_m / D_f \times 100$ .... (2)

where,

D_b = Percentage of broken dhal

E = Mass of broken dhal collected in the broken dhal outlet

F = Mass of the sample taken for dehusking

3. Percentage of undehusked whole

This was calculated from the following equation

$D_h = D_w / D_f \times 100$ .... (3)

where,

D_h = Percentage of undehusked

D_w = Mass of undehusked obtained

D_f = Mass of the sample taken for dehusking

Table 1 Dimensions of pulses

Dimensions	Red gram		Black gram		Green gram	
	CO 7	BSR 1	CO 5	VBN 4	VBN 2	CO 7
Length, mm	5.5	5.7	5.1	4.8	4.1	4.8
Breadth, mm	3.8	4.8	4.1	3.3	3	3.3
Thickness, mm	4.8	4.1	3.5	3.4	3	3.4

Results and Discussion

The geometrical mean dimensions of the selected pulses are shown in **Table 1**. From the **Table 1**, it is observed that the length of the red gram BSR1 (5.7) was slightly longer than the length of CO7 (5.5mm) variety. The length of the CO5 black gram (5.1mm) was slightly longer than the VBN 4 (4.8) variety and also the length of the green gram CO7 (4.8mm) was longer than the VBN 2 variety. From the **Table 1**, it is also observed that there were variations in the breadth and thickness of the red gram, black gram and green gram varieties used for this evaluation. Ehiwe and Reichert, (1986) reported that seed size is also one of the important parameters influencing the dehulling of red gram, black gram and green gram.

Water Absorption Characteristics

Without Pitting

The water absorption characteristics of the selected pulses namely red gram (CO7 and BSR1), black gram (CO5 and VBN4) and green gram (VBN2 and CO7) varieties are shown in the **Fig. 2**. From the figure, it is observed that the time taken for absorption of water was found to be 10 hours for all the selected pulses.

There was a steady increase in water absorption up to 7th hour for red gram varieties after that the absorption remains constant till it reaches the 10th hour, where as the black gram and green gram varieties, the water absorption was steadily increasing up to the 8th hour after that they remained constant till the 10th hour. Overall, the water absorption of red gram varieties was higher than the water absorption of black gram and green gram varieties. This may be due to higher size of red gram varieties compared to black gram and green gram varieties.

Water absorption characteristics with pitting

After pitting, all the selected puls-

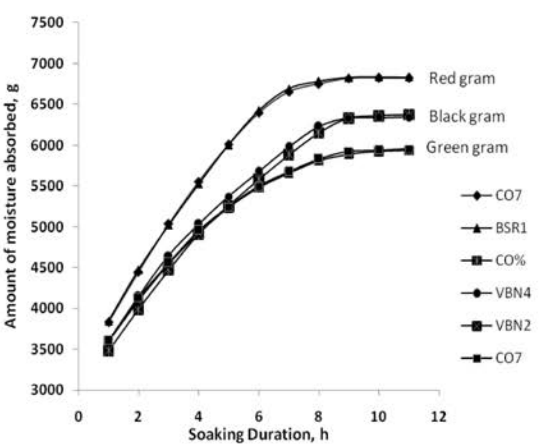

Fig. 2 Water absorption characteristics of pulses without pitting

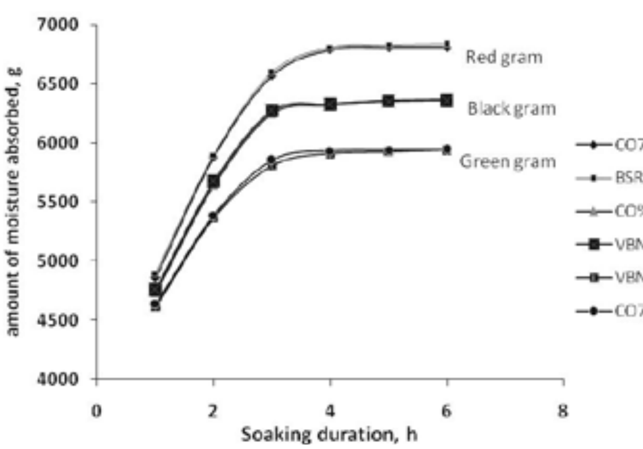

Fig. 3 Water absorption characteristics of pulses with pitting

es were soaked in water. The water absorption characteristics are shown in the **Fig. 3**.

The results indicated that the time required to achieve complete water absorption was significantly reduced to five hours as against 10 hours required for the pulses without pitting. This might be due to the scratches produced during the pitting operation, which facilitated the rapid water absorption inside the pulses. There was a rapid water absorption for the first three hours for all the pulses, after that the water absorption remained constant till they reach 6^{th} hour.

Milling characteristics of red gram

The percentage recovery of dehusked split dhal, undehusked whole and broken dhal with and without out pitting treatments milled at different rotor speeds are shown in the **Table 2**. The percentage recovery of dehusked split dhal was higher in pitting treatment compared to without pitting treatment. This might be due to the pitting treatment, which created the difference between the seed coat and the endosperm through rapid water absorption and subsequent drying operations. This treatment helped in enhancing the separation of husk and splitting of

Table 2 Percentage recovery of dehusked split dhal, undehusked whole and broken dhal in red gram with and without pitting treatments at different milling speeds.

Milling rotor speed, rpm	Red gram - Varieties	Dehusked split dhal (%)		Whole / undehusked (%)		Broken dhal (%)	
		With pitting	Without pitting	With pitting	Without pitting	With pitting	Without pitting
200	CO7	67.8	62.3	12.7	14.6	5.5	7.1
	BSR1	69.2	64.2	10.6	13.6	5.2	7.2
300	CO7	72.1	67.1	8	9.8	4.9	8.1
	BSR1	72.9	68.2	7.5	8.3	4.6	8.5
400	CO7	68.2	64.9	7.5	9.6	9.3	10.5
	BSR1	69.3	66.8	7.2	8.7	8.5	9.5
$p \leq 0.05$		2.16	2.21	0.53	0.58	0.22	0.31

dhal during milling process. The complete dhal milling unit with actual dhal milling of red gram is shown in the **Fig. 4**.

Among the milling rotor speeds, milling at 300 rpm resulted in significantly higher dhal recovery of 72.9% in BSR1 and 72.1% in CO7 varieties of red gram compared to milling at 200 and 400 rpm.

The dhal recovery was lower in milling at 200 rpm as the speed was not sufficient to mill the dhal in turn, which produced higher amount of unmilled dhal. Milling at the higher speed of 400 rpm, the breakage was significantly higher resulting lower dhal recovery. Similarly, Mangaraj *et al*., (2011) reported that by increasing the peripheral speed, the milling efficiency was increased up to 10.47 m/s after that the milling efficiency decreased when the peripheral speed was 12.03 m/s. There was no significant difference in dhal recovery between the varieties milling at different speed. From the **Table 2**, it is also observed that the percentage recovery of dhal obtained without pitting treatment produced lower amount of dhal at all the rotor speeds. This might be due to the strong adhering of husk with endosperm.

Milling characteristics of black gram

The percentage of dehusked split dhal, undehusked whole and broken dhal without pitting treatments at different milling speeds of black gram are shown in the **Table 3**. In black gram varieties also, the percentage recovery of dehusked split dhal was higher in pitting treatment compared to without pitting treatment. Among the milling speeds, milling at 300 rpm resulted in significantly higher ($p \leq 0.05$) dhal recovery of 69.1% in CO5 and 67.8% in VBN 4 varieties of black gram compared to milling at 200 rpm resulted with the dhal recovery of 64.9% in CO5 and 62.9% in VBN 4 and 400 rpm resulted with the dhal recovery of 65.1% in CO5 and 64.2% in VBN 4 varieties.

The dhal recovery was lower in milling at 200 rpm as the speed

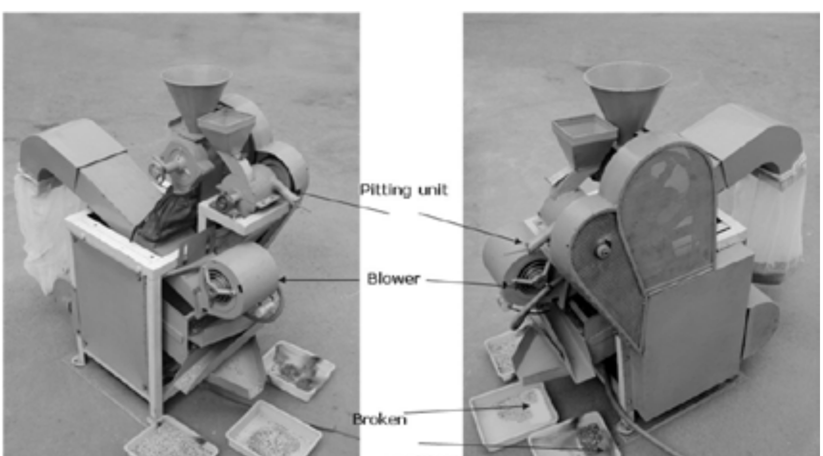

Fig. 4 Improved TNAU mini dhal mill

was not sufficient to mill the dhal and at higher speed of 400 rpm, the breakage was higher resulting in lower dhal recovery. Between the varieties, the dhal recovery was significantly higher in CO5 than VBN 4, milled at 300 rpm. But the other rotor speeds of 200 and 400 rpm, there was no significant difference in dhal recovery between the varieties. Overall the dhal recovery was lower in without pitting treatments due to the hard husk removal process. The percentage recovery was significantly higher ($p \leq 0.05$) than the treatment without pitting.

Milling characteristics of green gram

The percentage of dehusked split dhal, undehusked whole and broken dhal without pitting treatments at different milling speed of green gram are shown in the **Table 4**. Based on the milling speeds, milling at 300 rpm resulted in significantly higher dhal recovery of 69.2% in CO7 and 68.9% in VBN 2 green gram varieties than milling at 200 rpm recorded the dhal recovery of 66.3% in CO7 and 65.4% in VBN 2. The present results are similar to the results reported by Mangaraj *et al.*, (2001) for green gram in which the milling efficiency was decreased when the peripheral speed was increased from 10.47 m/s to 12.03 m/s. But beyond the speed of 300 rpm, there was no significant difference in dhal recovery. From the **Table 4**, it is also observed that the breakage was higher by milling at 400 rpm compared to 300 rpm whereas the percent recovery of broken dhal at 200 and 400 rpm was on par with each other. From the **Table 4**, it is also clear that the percentage recovery of dehusked split dhal was higher in pitting treatments compared to without pitting treatments.

Conclusions

An improved TNAU mini dhal was used to increase the dhal recovery. The dhal recovery was found to be higher in the pulses with pitting treatment. Among the milling speeds, milling at 300 rpm produced higher recovery of dhal in all the selected pulses viz., red gram, black gram and green gram varieties. Among the selected pulses, the red gram varieties recorded higher recovery of dhal compared to black gram and green gram varieties.

Table 3 Percentage of dehusked split dhal, undehusked and broken dhal in black gram with and without pitting treatments milled at different speeds

Milling rotor speed, rpm	Black gram - Varieties	Dehusked split dhal (%)		Whole / undehusked (%)		Broken dhal (%)	
		With pitting	Without pitting	With pitting	Without pitting	With pitting	Without pitting
200	CO5	64.9	61.2	13.6	15.3	7.5	9.5
	VBN4	62.9	60.5	15.5	16.2	7.6	9.3
300	CO5	69.1	64.5	12.1	13.4	4.8	8.1
	VBN4	67.8	63.9	13.3	13.6	4.9	8.5
400	CO5	65.1	63.8	12.3	11.4	8.6	10.8
	VBN4	64.2	62.9	12.6	13.2	9.2	9.9
$p \leq 0.05$		2.1	2.17	0.42	0.51	0.25	0.42

Table 4 Percentage of dehusked split dhal, undehusked and broken dhal in green gram without pitting milling rotor speed, rpm

Milling rotor speed, rpm	Green gram - Varieties	Dehusked split dhal (%)		Whole / undehusked (%)		Broken dhal (%)	
		With pitting	Without pitting	With pitting	Without pitting	With pitting	Without pitting
200	VBN2	65.4	61.6	14.8	17.5	5.8	6.9
	CO7	66.3	62.7	14.6	16.8	5.1	6.5
300	VBN2	68.9	65.3	13	14.9	4.1	5.8
	CO7	69.2	66.2	12.9	14.4	3.9	5.4
400	VBN2	67.1	64.3	12.3	14.4	6.6	7.3
	CO7	68.2	64.9	11.3	13.9	6.5	7.2
$p \leq 0.05$		2.04	2.21	0.7	0.58	0.67	0.65

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Development of Three-Dimensional Force Measurement Instrument for Plough in Mountain Region

by

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Abstract

At present underdeveloped countries like Bhutan are obliged to use the animal tillage system as use of better technologies are either not appropriate due to rugged terrain or affordability. Therefore, improving the animal tillage system to reduce drudgery is needed. Thus, this study was carried out to establish an appropriate data acquisition system of animal plough in real time operations under an incline field condition. Calibration of the senor was done using the cross coupling coefficients methods. Preliminary field tests were conducted and the result revealed that the developed system can be incorporated for the animal plough operations.

Introduction

A good implements design for soil preparation needs a thorough study on the forces acting on it. Research data like, draft requirement, vertical force, and side force for tillage implements are important factors in selecting suitable tillage implement for a particular farming situation. If the effective vertical force on the implement is reduced and if the implement is pull at steeper angle, the implement draft can be reduced. Also, the sever side force on the implements affects steering ability (Chen, 2007).

Studies have been done on the draft forces acting on the tractor implements by the use of the strain gauge-based octagonal ring transducer. They are either designed as a single EOR (O'Dogherty, 1996 and Khan *et al.*, 2007) or with double EOR placed "back to back" as a single unit (Watyotha *et al.*, 2001) or two units oriented vertically to the drawbar of the tractor (Chen, 2007). However, there is very limited studied in animal tillage where multi EOR are being used. Earlier studies done, either used single EOR for measuring two forces and moment (Gebresenbet *et al.*, 1997) or mostly used load cells (Mouazen, 2007) which measured only the draft of the plough. Those former forces measurement system were not matched for animal tillage in the mountain region like Bhutan. In this region, most of fields are steeply inclined where significant lateral force should be considered as it causes large torsion on the drawbar beam and instability during ploughing.

Thus, the objective of this study was to develop a real time data acquisition system to be able to measure the draft, vertical, lateral forces and respective moments and tilt of drawbar beam of animal plough in real time.

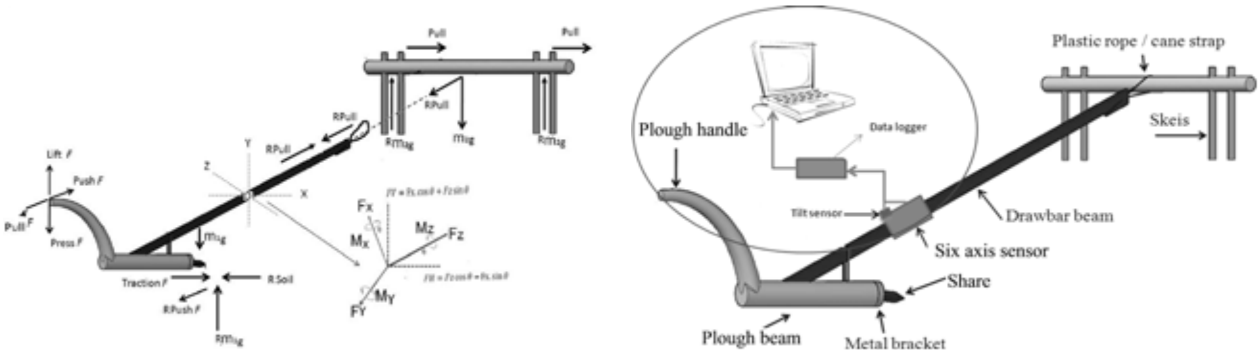


Fig. 1 (a) Free body diagram of the forces acting on animal plough, **(b)** Real time data acquisition

Materials and Methods

Design Criteria

When the animals pull the plough to till the soil, various forces act on the plough. Horizontal force (draft), FH, used to predict the energy input of animal and to match with implement size; the vertical force, F_X, occurred due to the weight of the plough and forces exerted by operator which affects the performance and dynamic stability of the implements; and the side force, F_Y which affect the steering ability of the implements, are the three main forces that need to be measured. Also, the bending moments caused due to these forces that will enable to locate the point of application of the resultant force that can be used to develop the better plough implement. Further, the plough base is being pulled at certain angle and this angle must be measured to convert the pull force to draft and vertical force. The extended octagonal ring (EOR) was chosen due to its greater stability to tangential force and zero rotation on the top of its ring section (O'Dogherty, 1996). In the earlier study carried out by Mouazen *et al.*, 2007, a pair of oxen using Ethiopian plough had maximum draft of 1.37 kN during dry season with the tillage depth of 150 mm. Further, Goe (1987) found that at the travelling speed between 0.35-0.58m/s, a pair of oxen draft ranged between 0.83-1.04 kN for ploughing in inclined field by using Ethiopian animal plough. With safety factor of 1.5, the EOR was designed for 2.1kN (F) in pull direction, 1.05 kN (P) on the side forces and the moment caused by the forces of 1.05 kN-m (M).

Two EOR is capable of measuring pull force, F_Z, side force, F_X and F_Y, and moment, M_Y and M_X, while the torsion bar was used to measure the rotational moment, M_Z, of the plough. Further, a tilt sensor (cross bow CXTA02 dual-axis analog) was fixed with the EOR to measure tilt of the plough beam (**Fig. 1 (a)**). The system was connected to NR600 Keyence data logger with a personal computer to acquire the data (**Fig. 1 (b)**). The designs of EOR and torsion bar, arrangement of strain gauges, calibrations of the sensor, and calibration of the tilt sensor are presented below.

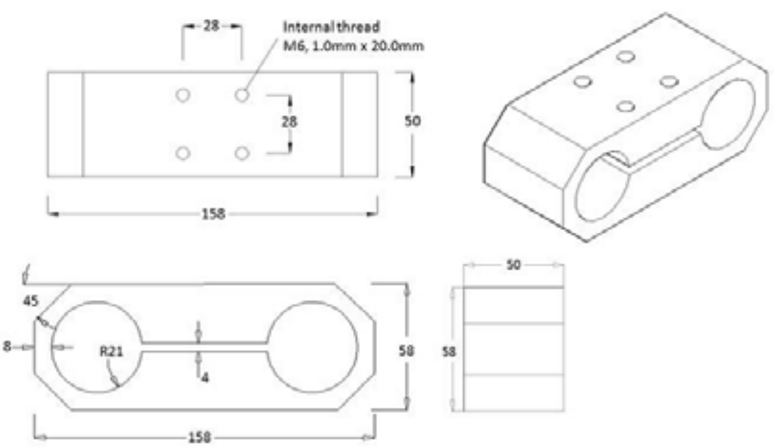


Fig. 2 Detail drawing of EOR

Design of Extended Octagonal Ring (EOR)

The Castiglione's theorem, the thin ring theory and the principle of stress-strain were used to design the octagonal ring transducers (Korkut, 2003 and Yaldiz, 2007). The main parameters to be considered in designing the EOR for sensitivity and stiffness are the mean radius of the ring (r), the thickness of the ring (t) and the length between the rings (2L). Since the sensor unit is to be mounted on the drawbar beam, its weight, size, and natural frequency were the key factor in design of the EOR. Based on the yield strength of 395 MPa of EOR and the shear stress of 71.99 MPa torsion bar, aluminum alloy 5056 was found appropriate. Thus, the design dimension of the EOR was obtained and shown in the **Fig. 2**.

In this study, strain gauges connected in full wheat stone bridge were used. Based on the force-displacement relation (O'Dogherty, 1996), the maximum deflection (δp) of the EOR is 0.034 mm when the force (P) of 1.05 kN acts on the EOR. This deformation must be confirmed with the strain gauge maximum elongation (Korkut, 2003). So, to meet this criterion, a most commonly used strain gauge of 120.0 Ω, 5 mm gauge length with 5% elongation and 2.11 GF was selected, as the maximum elongation is considerably higher than the material elongation. Twenty-four numbers of this type of gauge (KFG-5-120- C1-23L1M3R, Kyowa make) for three force and two moments were used and connected in a wheat stone bridge.

Design of Torsion Bar

Torsion caused on the drawbar beam was rarely reported in the earlier studies especially for the tractor pulled implements. However, in animal drawn implements, it is mare impossible to maintain a steady speed of operation and uniform depth of ploughing as required. Therefore, it is important that while optimizing the animal drawn implement stability in the inclined field, torsion occurred at the drawbar beam is studied.

The maximum shear stress is developed at the outer surface of the hollow circular shaft materials at an angle of 45 deg to the longitudinal axis when torsion, T, is applied. Based on this elementary mechanics theory (James, 2000) the thickness of the circular tube was found to be 2.5 mm. Therefore, a thickness of 3 mm was chosen. The outer radius, ro of 30 mm and the inner radius, ri of 27 mm was found satisfactory. The shear strain was found to be 2.66 × 10 - 3. With no axial deflection and ease of fabrication a length of 30mm was chosen. Based on the shear strain calculated above, two cross strain gauges of 120.0 Ω; 5 mm gauge length with 5% elongation and gauge factor of 2.11 (KFG-5-120-D16-23L1M3S, Kyowa make) were used. The strain gauges were connected in wheat stone bridge and then connected to the same data logger.

Sensor Configuration

In order to have greater stability, rigidity and no rotation on the top of the EOR and for ease mounting to the drawbar beam, the arrangement of the EORs and the torsion bar was done as shown in the **Fig. 3 (a)** below. The EORs were placed separately with the torsion bar in the centre. One EOR was placed horizontally while the other was placed vertically. This arrangement enables to measure draft; vertical and side force concurrently with three moments (**Fig. 3 (b)**) with much stability and less interference and also can be easily incorporated to the plough beam with simple brackets.

Calibration Setup and Procedures

The cross coupling coefficients method was used for calibration. This method is effective for removing the cross talk produced when any extraneous loads are applied to the multi axis sensors. To do this, a calibration frame operated by the pneumatic system was designed and fabricated as shown in **Fig. 4 (a)** below. The sensor was fixed to the base plate frame so that it could be tilted to 20 degree angle. From the earlier studies, the average angle of pull of the ploughs with reference to the plough base was 22 degree. With this setup, the sensor can be loaded with the required direction of force and moment (**Fig. 4 (b)**)

The sensor was designed to measure forces and moment along defined axes, typically labeled X, Y, and Z. The sensor has six measurement channels: three force channels (F_X, F_Y, and F_Z) and three moment channels (M_X, M_Y and M_Z).

By applying the incremental loads at each axis and recording all the channel outputs, a series of equation is created at each axis point in the form: Channel output $OF_X = K_1$ (sensitivity) × F_X (applied load). The other channel output ("cross talk") also takes the same form but with different sensitivity as shown in the

$$\begin{Bmatrix} O_{FX} \\ O_{FY} \\ O_{Fz} \\ O_{Mx} \\ O_{My} \\ O_{Mz} \end{Bmatrix} = \begin{Bmatrix} Fz \\ FY \\ Mx \\ Fx \\ MY \\ Mz \end{Bmatrix} X \begin{Bmatrix} K_1 & K_2 & K_3 & K_4 & K_5 & K_6 \\ K_7 & K_8 & K_9 & K_{10} & K_{11} & K_{12} \\ K_{13} & K_{14} & K_{15} & K_{16} & K_{17} & K_{18} \\ K_{19} & K_{20} & K_{21} & K_{22} & K_{23} & K_{24} \\ K_{25} & K_{26} & K_{27} & K_{28} & K_{29} & K_{30} \\ K_{31} & K_{32} & K_{33} & K_{34} & K_{35} & K_{36} \end{Bmatrix}$$

.... **Equation (1)**

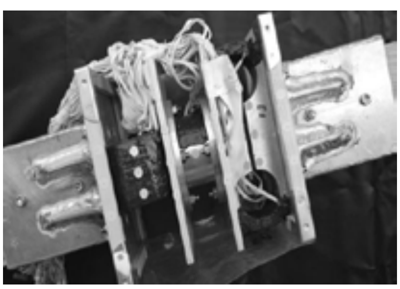


Fig. 3 (a) Photograph of sensor assembly

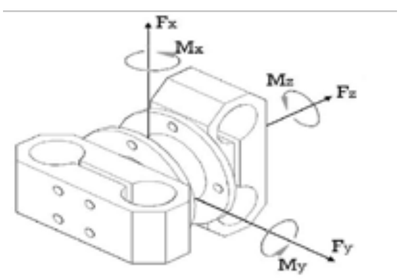


Fig. 3 (b) Six axis forces and moments direction

Equation (1).

Arranging the values of K in a 6 × 6 matrix, these equations can be solved. However, the input loads are unknown and to predict the inputs loads we use the simple inverse matrix methods, so the general equation matrix takes the following shape.

F_X (applied load) = K^{-1} × OF_X (chan-

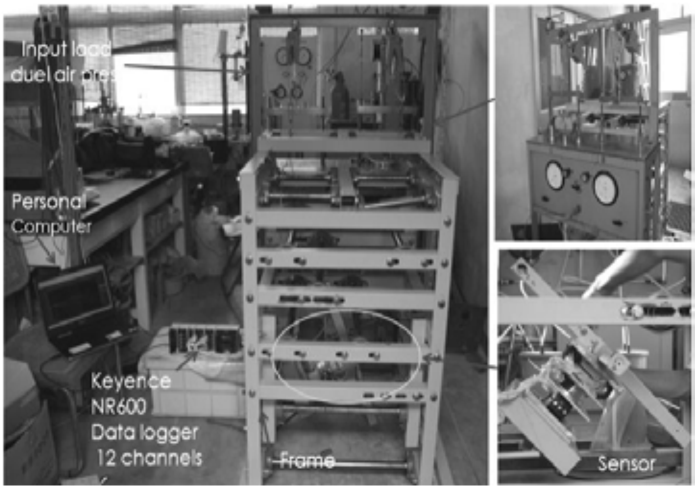


Fig. 4 (a) Photograph of applied force during sensor calibration

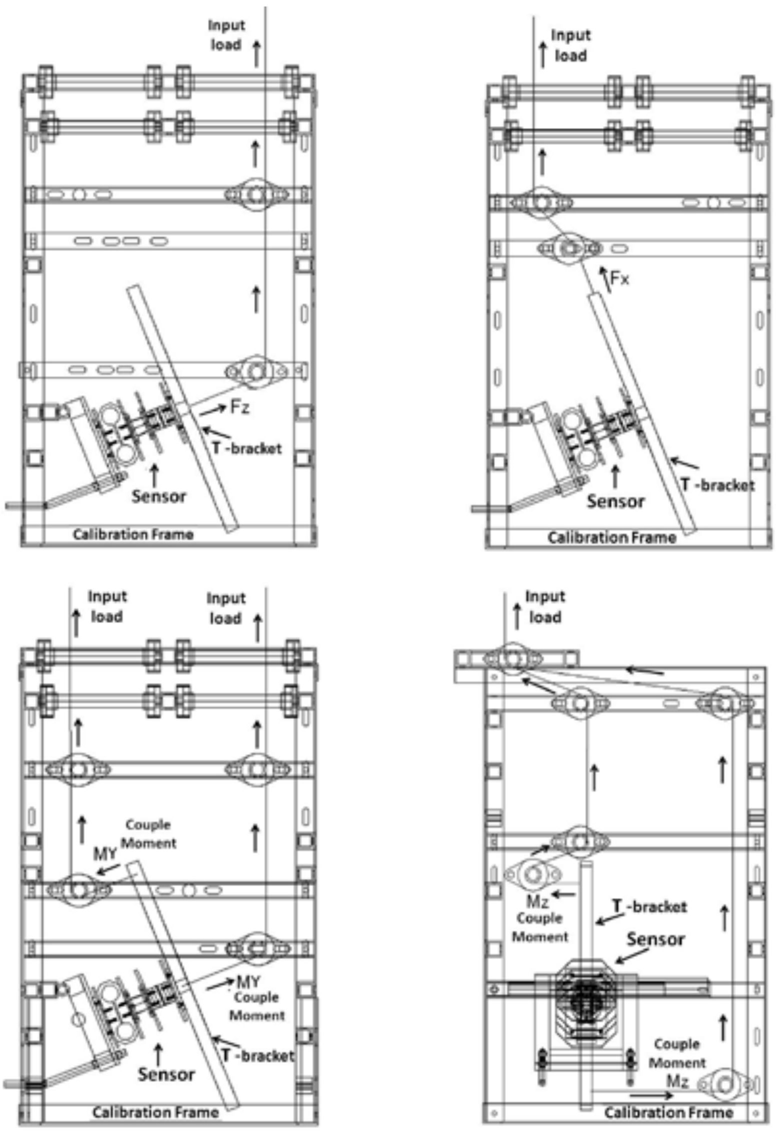


Fig. 4 (b) Force application during calibration (F_z and F_x) and Couple moment application during calibration (MY and MZ)

nel output) .... (2)

Now the K^{-1} matrix is the calibration matrix that can be used as calibration constant to predict any input load to the sensor. Also, some initial offset values were expected due to slight differences in the resistance of the strain gauges following manual installation, which results in the unbalance bridge at zero loads. The data logger used has specialized signal conditioners as auto balancing mechanism to remove the initial offset values. Prior to each loading, auto balance was done to avoid this. The results of the calibration are presented later.

Tilt Sensor

While the animal pulls the plough, the angle of pull with reference to the sensor center of axis also changes. Further, the operator often vibrates the plough sideways (perpendicular to the pull direction) to reduce the draft. In order to measure these angles; a Crossbow tilt sensor, CXTA02 dual-axis analog tilt sensor capable of measuring the angle in two directions was installed on the developed forces sensor.

Preliminary Field Test of the System

In order to see the sensor's responses to the actual field operation, preliminary field tests were conducted. Tests were conducted by pulling the plough by tractor. A field 25 m length, ploughed by the tractor and which was left for a week was used as the experimental field. No soil data were taken as the test was conducted to see the sensor response to pull. The fabricated plough was of similar shape and size as traditional Bhutanese plough. The sensor was fixed at 1 m distance from one end of the plough beam. Using the above mention real time data acquisition system and sampling rate of 30 s per data, the experiment was carried out. The results of the experiments are discussed below

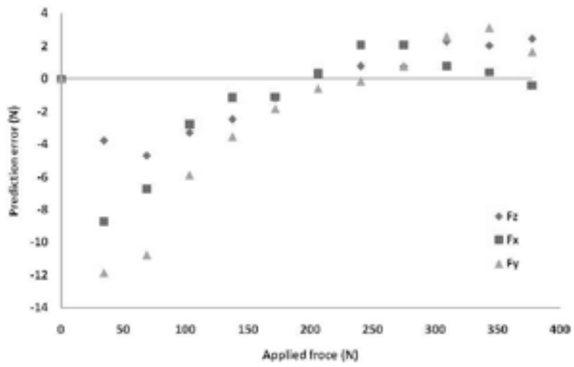
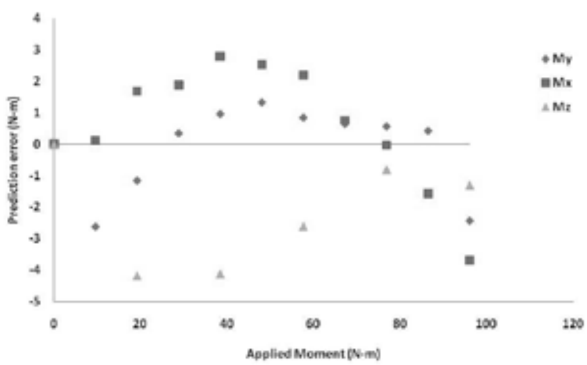


Fig. 6 (a) Prediction error for applied forces



(b) Prediction error for applied moments

Results and Discussion

The sensor was calibrated statically and tested in the laboratory using the simple calibration frame design. During calibration, load was applied to the EOR centre axis for the three (X, Y, Z) axes, while couple moment was applied to the top of the sensor.

Calibration of the Sensor

Uniform static load was applied with an increment of 34.32 N and a maximum of 377.5 N at X-axis and Y-axis and 926 N at Z-axis. For the moment at X-axis and Y axis, a maximum of 96 N-m was applied with an increment of 9.61 N-m, while at Z-axis a maximum of 192 N-m with an increment of 19.22 N-m was applied. Three replications were done for each force and moment. The micro strain output of the applied forces was plotted and linear coefficient and the correlations coefficient were calculated (**Fig. 5** ※see the next page). The linear coefficient and the correlations coefficient were also calculated and shown with each figure.

The above result revealed that the moment channels are more susceptible to sensitivity than the force channels as the linear coefficients are very high when moments are applied to the sensor. With high linearity and high correlation coefficients of the calibration curve, it can be concluded that the sensor responded very well. Further, when a load is applied to any one of axes of the EOR output on any of the other measurement channels are very low.

To remove interference, the coefficient (K-value) of each curves plotted above was arranged in the equation matrix form as shown in **Equation 3**.

$$\begin{Bmatrix} O_{FX} \\ O_{FY} \\ O_{Fz} \\ O_{Mx} \\ O_{My} \\ O_{Mz} \end{Bmatrix} = \begin{Bmatrix} Fz \\ FY \\ Mx \\ Fx \\ MY \\ Mz \end{Bmatrix} X \begin{Bmatrix} -0.845 & -0.031 & -0.920 & 0.010 & -0.228 & -0.109 \\ -0.026 & 0.758 & -0.176 & -0.017 & -0.293 & -0.091 \\ -0.047 & -0.059 & 7.024 & -0.050 & -0.516 & -0.127 \\ 0.001 & -0.048 & 0.437 & 0.813 & 0.003 & -0.036 \\ -0.020 & 0.025 & 0.043 & -0.086 & 7.860 & 0.015 \\ -0.022 & -0.016 & 1.727 & 0.042 & 0.727 & -4.834 \end{Bmatrix}$$

.... **Equation 3**

$$K^{-1} = \begin{Bmatrix} -1.173 & -0.058 & -0.162 & -0.004 & -0.050 & 0.032 \\ -0.044 & 1.319 & 0.031 & 0.036 & 0.052 & -0.025 \\ -0.008 & 0.011 & 0.142 & 0.010 & 0.010 & -0.004 \\ 0.003 & 0.071 & -0.072 & 1.227 & -0.002 & -0.009 \\ -0.003 & -0.004 & -0.002 & 0.013 & 0.127 & 0.000 \\ 0.002 & 0.000 & 0.050 & 0.016 & 0.023 & -0.208 \end{Bmatrix}$$

.... **Equation 4**

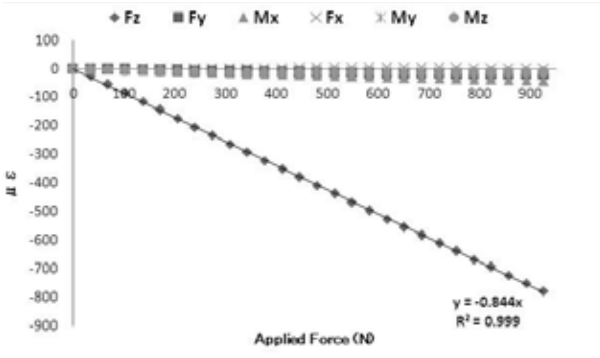
The input forces and moments were calculated by using the sensor output signals and getting the inverse matrix of the K-matrix above. This matrix is now called as the calibration constant (**Equation 4**) which is incorporated in order to remove or reduce the interference error.

Prediction Error of the Sensor

Using the calibration constant, the sensor output of the applied loads was cross checked and the prediction error for input forces was plotted against the applied load in the **Fig. 6 (a)**. The differences between the applied loads to the prediction loads are very small with the maximum of 12 N in F_Y direction and the error diminishes at higher applied loads. Further, the prediction error when moments are applied was also calculated and plotted against the applied moments and shown in **Fig. 6 (b)**. The differences between the applied moments to the prediction moments are also very small with the maximum of 4 N-m in F_Z direction and the errors were random. The prediction error of moments is smaller than prediction error of forces. From these results, it can be confirmed that the calibration was done correctly and precisely.

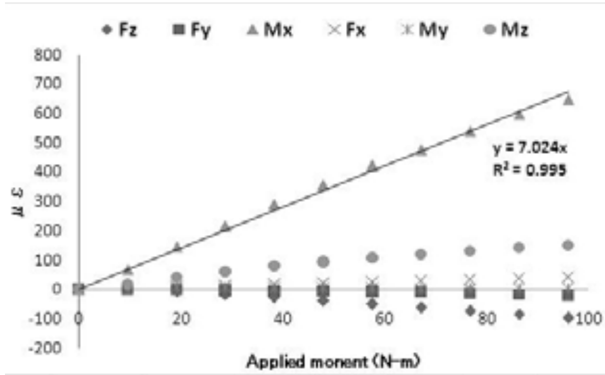
Preliminary Field Test

To see the sensor response to higher pull force, a 40 hp tractor was used to pull the plough in the same



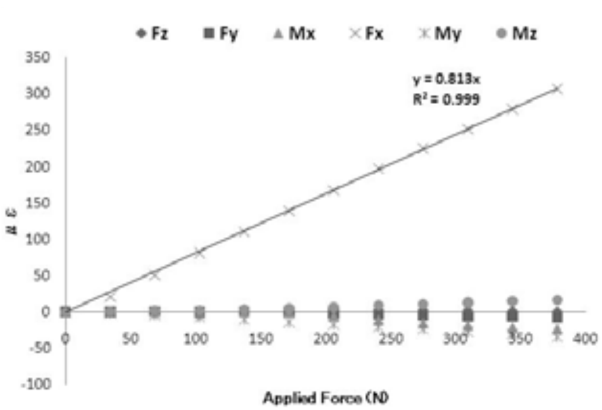
	Fz	Fy	Mx	Fx	My	Mz
correl	-1.00	-1.00	-1.00	0.42	-0.99	-0.62
slope	-0.845	-0.026	-0.047	0.001	-0.020	-0.022

(a) Calibration curves for Force (F_Z)



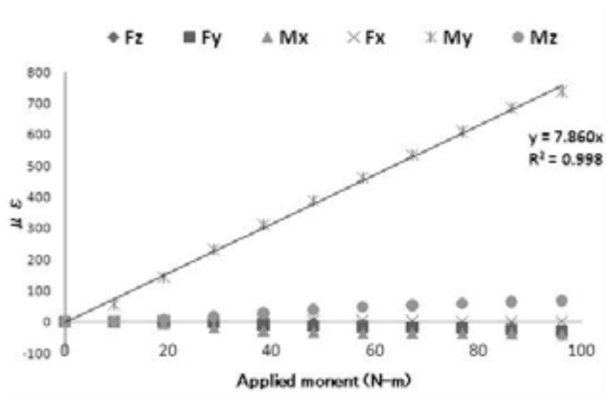
	Fz	Fy	Mx	Fx	My	Mz
correl	-0.99	-0.97	1.00	1.00	-0.15	0.99
slope	-0.920	-0.176	7.024	0.437	0.043	1.727

(d) Calibration curves for moment (M_X)



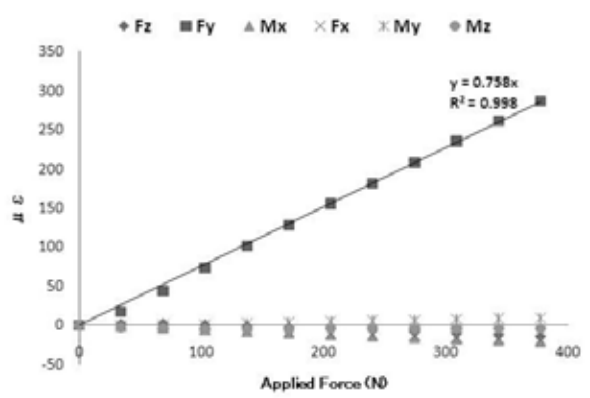
	Fz	Fy	Mx	Fx	My	Mz
correl	0.37	-0.92	-0.93	1.00	-1.00	0.99
slope	0.010	-0.017	-0.050	0.813	-0.086	0.042

(b) Calibration curves for Force (F_X)



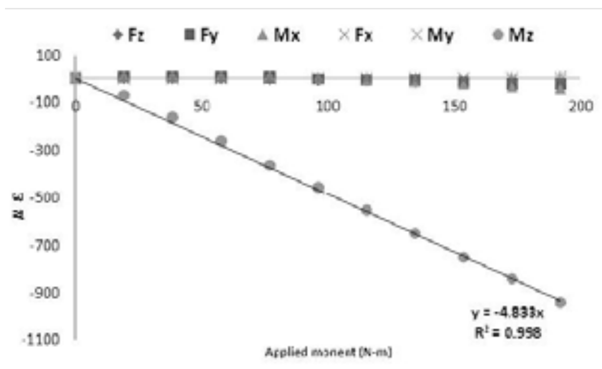
	Fz	Fy	Mx	Fx	My	Mz
correl	-0.85	-0.99	-0.93	-0.45	1.00	0.99
slope	-0.228	-0.293	-0.516	0.003	7.860	0.727

(e) Calibration curves for moment (M_Y)



	Fz	Fy	Mx	Fx	My	Mz
correl	-0.96	1.00	-1.00	-1.00	1.00	-0.38
slope	-0.031	0.758	-0.059	-0.048	0.025	-0.016

(c) Calibration curves for Force (F_Y)



	Fz	Fy	Mx	Fx	My	Mz
correl	-0.97	-0.91	-0.87	-1.00	0.96	-1.00
slope	-0.109	-0.091	-0.127	-0.036	0.015	-4.834

(f) Calibration curves for moment (M_Z)

Fig. 5

Fig.7 Plough being pulled by 40hp tractor

field with three different speeds for three trials (**Fig. 7**). The data on the 3 forces, 3 moments and tilt of the plough beam was collected. As shown in **Table 1**, the average pull force was 320 N with standard deviation of 145 N at of 0.36 km/h. While at higher speed of 1km/h and 1.36 km/h, it was 543 N and 558 N respectively. The average bending moment, MY, of plough beam was very low as the line of pull matches the pull force axis. This was possible as the height of attachment of the plough beam to the tractor was adjusted prior to the experiment. This also shows that the line of pull direction and pull force axis has to be matched. Base on these results, the sensor responded very well and can be used for actual field tests.

Table 1 forces and moment acting on the plow beam pulled by tractor

Speed (km/hr)		F_x (N)	F_y (N)	F_z (N)	M_x (N)	M_y (N)	M_z (N)
0.36	Average	-2.81	0.66	320.48	6.27	28.71	-2.97
	SD	14.58	9.72	145.05	8.41	30.43	3.37
	Maximum	63.95	36.48	786.38	43.91	122.22	6.84
	Minimum	-27.76	-25.81	66.54	-25.56	-19.5	-32.58
1	Average	13.92	-3.49	543.42	13.21	72.04	-10.38
	SD	19.77	9.81	181.03	8.23	28.82	6.47
	Maximum	82.09	25.83	945.66	44.17	132.55	8.62
	Minimum	-28.62	-27.72	96.75	-11.42	-3.9	-29.16
1.36	Average	52.45	25.05	558.14	24.46	99.34	-1.66
	SD	11.84	6.03	159.43	4.21	15.15	0.59
	Maximum	77.37	35.23	925.57	33.73	133.37	0.03
	Minimum	11.34	0.98	194.87	9.25	51.01	-3.37

Force Monitoring Program

The force-monitoring program was developed using Visual basic 6.0 programming to illustrate size and direction of acting force to the plough in 3 dimensions (**Fig. 8**). The monitoring program can help analyze the characteristic of the resultant force in the real time during test.

Conclusions

This is the first attempt to use the principle of two EOR and torsion bar in measuring various forces and moments acting on the animal plough in real time operation. Aluminum alloy 5,056 was found appropriate with design load of 2.1 kN (F) in pull direction, 1.05 kN (P) on the side forces and 1.05 kN-m (M) for moments. One EOR was placed horizontally while the other was placed vertically with torsion bar in the middle. This arrangement enables to measure the six axis forces and moments acting on the plough body directly and concurrently unlike the use of multi EOR for tractor studies. Further, calibration of the senor was done to remove the interference. Calibration constant derived by using the cross coupling coefficients method resulted with a maximum prediction error of 12 N on force channel. Based on the calibration results and the preliminary field tests results, the data acquisition system designed can be incorporated for the animal plough operations ensuring to measure the six axis forces and moments acting on the animal plough with good accuracy.

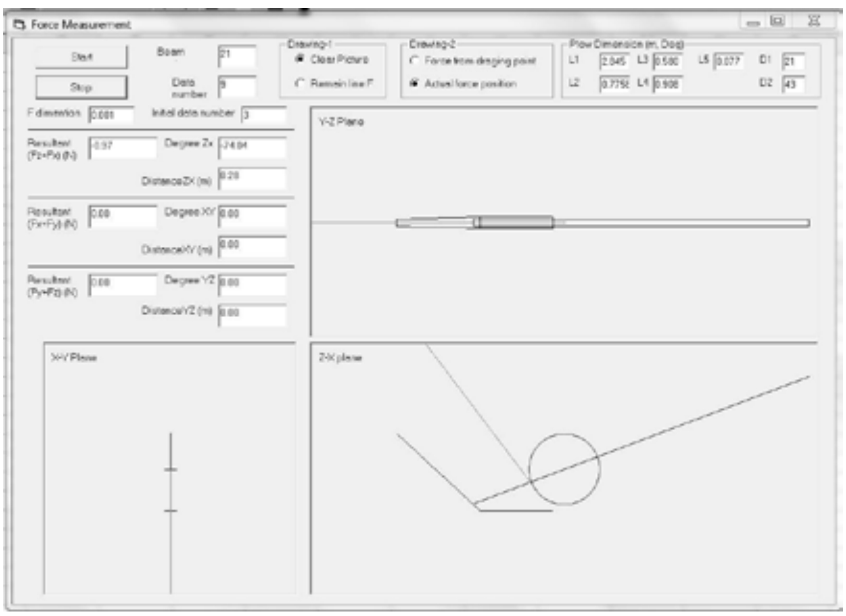


Fig. 8 Force monitoring program

Acknowledgments

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Energy use Pattern and Economic Analysis of Jute Fibre Production in India a case study for West Bengal

by

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Abstract

Production of jute, which is the main cash crop in eastern part of India, requires optimization of energy at all stages of production. The aim of this study was to examine direct and indirect resources of input energy in jut production. The study was conducted in West Bengal using a pre-tested questionnaire, 125 farmers were selected through a multistage stratified random sampling technique. The result revealed that Jute is mainly grown by marginal farmers (<1 ha) and small farmers (1-2 ha). The energy used in carrying out field operation in production was derived from human, animal and mechanical power. The availability of farm power was about 3.9 kW/ha and 5.1 kW/ha for marginal and small farmers respectively. The energy input per hectare of marginal and small scale farming was in the ratio of 1.0. The total energy input for marginal and small farm categories were 17,121 MJ and 17,060 MJ per hectare respectively. Fertilizer was the most energy consuming operation with about 48% of total energy inputs. It was also found that about 22%, 0.8% and 29% of total energy input were found from human, animal and mechanical power respectively. Benefit cost ratio was 1.24.

Introduction

The relation between agriculture and energy is very close. The level and pattern of energy use in agriculture, as well as its contribution to energy supplies depends on variety of agronomic and socio-economic factors. Energy use in agriculture has developed a hope to increasing populations with limited available arable land to have a better standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labour intensive practices, or both. Efficient and effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings.

In India, jute is growing in the North Eastern part as a rain-fed crop. It plays a predominant role in the country's economy particularly for the eastern and northeastern states, despite the fact that it accounts for hardly 1.4% of the total cropped area in this part of the country. Jute is cash crop and is mainly grown by marginal and small farmers and usually followed by rice. It is sown in April and may and harvested in July and August, while rice transplantation commences from July. In this country jute seed is produced as a crop separate to fibre crop. Total area under jute in India is about 0.8 million hectares, the major jute growing states are West Bengal, Assam, Orissa, Bihar, U.P. and Tripura. Jute grows better where a well distributed minimum rainfall of 1200 mm with high temperature and high humidity is available during April to August. It grows well in loamy and sandy loam type of soil with pH 6.0 to 7.5 (Mandal, 1991)

Energy consumption in crop production sector has great relevance to the energy system in India since energy is an important resource for agriculture. At the same agriculture is a resource for energy. Hence it is necessary to consider these relationships of energy uses by agriculture and energy from agriculture in a modeling frame work to assess the future demand of energy resources.

The analysis of these issues is prerequisite to the development of a sound energy policy for crop production system in West Bengal, which has to play a leading role in future to increase production and productivity.

Energy consumption per unit area in agriculture is directly related to the development of the technology in farming and the level of production. The inputs such as animate, seed, fertilizer, chemical, fuel, electricity and machinery take significant share of the energy supplies in the production system of modern agriculture. The use of intensive inputs in agriculture and access to plentiful fossil energy has provided an increase in food production and standard of living. Efficient use of the energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture as well as sustainability of rural living. Energy auditing is one of the most common approaches to examining energy efficiency and environmental impact of the production system (Hatirli *et al*., 2006; Kocturk and Engindeniz, 2009).

Agriculture, energy and global warming are closely related issues. First, the agricultural sector is an important user of fossil energy and it may reduce energy consumption through energy efficiency improvement. Second, it is a producer of biomass and the need for energy in agriculture, increase in population, fertilizer, chemicals, irrigation and energy need for mechanization production has made it compulsory for handling of non-renewable energy sources. Nevertheless, deterioration of agricultural areas, soil erosion and contamination of fresh water sources have brought about interrogating energy intensive agriculture systems in terms of sustainability (Pimentel, *et al*., 1999) by expanding the production of biomass, the agricultural sector offers scope for offsetting greenhouse gas emissions of fossil fuels. Third changes in land management may increase the carbon content of soil through carbon sequestration (Ierland and Lansink, 2003)

Objectives

i. Measure the quantity of energy inputs in jute production
ii. Find out source of energy and share in production
iii. Find out farm power availability
iv. Analyse the cost of production of jute

Materials and Methods

West Bengal has a geographic area of 8.87 million ha which constitutes 2.70% of the land area of the country. It lies between latitude 20° 31' and 27° 12' N and longitude 89° 50' and 89° 52' E. The state has two natural divisions: the north Himalayan and the south fertile alluvial Gangetic plain.

The 19 district of the state has varied altitude and climate. Climate varies from moist-tropical in the east to dry tropical in the south west and sub-tropical to temperate in the mountains of the north. The mean annual rain fall ranges from 1,200 mm to 1,500 mm. The soil type also varies according to their altitudinal and geographical situations. The minimum and maximum temperature varies from 11.2°C to 27.1°C and 23.3°C to 36.5°C respectively. The average relative humidity varies between 76.0 to 98.0%. Net sown area was 5.46 million ha.

The study was carried out in two districts of (24 Parganas (N) and Hoogly) of West Bengal. The villages were selected on the basis of multi-stage stratified sampling method to represent the area. The following parameters were also considered in the selection of a village. The population of the village should preferably by more than 1,000. The urban effect should not be prevalent in the village. Village should be well connected by road. The 125 jute growing farm families, covering all categories of landholdings from sixteen selected villages were contacted using a face to face questionnaire for collecting data.

A questionnaire on farm power sources, such as human, animal, prime movers, stationary engine/ electric motor, machinery and the energy inputs referred to direct and indirect, operational and commercial forms. The direct source of energy includes human, animal, fuel and electricity while the indirect source of energy consist seed, farm yard manure, agrochemicals, chemical fertilizers and machinery used in the production process. On the other hand, commercial energy consist fuel, electricity, agro-chemicals, chemical fertilizers, machinery and seed used in production operational energy includes human ,animal and power tiller. Renewable energy includes human, animal and seed while non renewable energy consist fuel, electricity, chemical, fertilizers and machinery in the process of jute production.

Operation wise as well as sources wise energy use patterns were studied under different farm categories. The energy data pertaining to seedbed preparation, sowing, fertilizer application, weeding & thinning, irrigation, harvesting, leaf removing and bundling, transportation, steeping fibre extraction and sun drying were obtained from the jute farmers. Since the pesticide proportion to total energy was insignificant, it has not been included in the energy consumption.

All inputs were converted to energy units using the energy coefficients reported on **Table 1**. These coefficients were adopted from literature sources that best fit to the Indian conditions (De, 2005; Grover, 2004). The mechanical energy was computed on the basis of specific fuel consumption and the machinery energy was calculated by using the following equation.

Machinery energy = [Ec × Wt × H] / A .... (1)

Where, Ec is the coefficient that is taken as 64.80 MJ/kg for electric motor and 68.40 MJ/kg for diesel engine, Wt is the weight of the farm machinery used per hour (kg), H is the hour of use of machinery (h) and A is the operational area (ha).

The energy productivity and specific energy were also calculated using the following formula as suggested by (Mittal and Dhawan, 1988; Singh *et al.*, 1997).

Energy productivity = Fibre Output (Kg/ha) / Energy Input (MJ/ha) .... (2)

Specific energy = Energy Input (MJ/ha) / Fibre Output (Kg/ha) .... (3)

Table 1 Equivalent co-efficient for various sources of energy

Energy source	Units	Equivalent energy, (MJ)
Human	Man-hour	1.96
		1 Adult woman = 0.8 Adult man
		1 Child = 0.5 Adult man
Animal	Pair-hour	10.10
Diesel	Litre	56.31
Electricity	kWh	11.93
Seed	Kg	14.70
FYM	Kg	0.30
Fertilizer	Kg	
(a) Nitrogen		60.60
(b) Phosphorus		11.10
(c) Potash		6.70
Agrochemical	Kg	
(a) Superior Chemical		120.00
(b) Inferior chemical		10.00
Machinery	Kg	
(a) Electric motor		64.80
(b) Prime mover other than electric motors		68.40
Farm Machinery excluding self propelled machines	Kg	62.70
Jute sick	Kg	18.4

Source: (De, 2005; Grover, 2004)

Result and Discussion

Socio-Economic Characteristics

The average size of operational land holdings was 0.5 ha in marginal farmers and 1.37 ha in small farmers, the overall average being 0.74 ha was observed. It was observed that jute is mainly grown by marginal and small farmers and found that about 87% of marginal farmers and about only 13% of small farmers were engaged in jute production (**Fig. 1**)

Fig. 2 show the land distribution pattern under jute cultivation. It is clear from the **Fig. 2** that marginal farmers had only 27% of land while small farmers had 73%.

It is clear from the **Figs. 3** and **4** that the marginal farmers had put 31% of their land holding to jute crop while the small farmers had 27% of their land holding to jute crop. This showed that farmers put nearly one third of their land holding to jute crop. **Figs. 3** and **4** also revealed that marginal farmers were putting more percentage of their total land area under jute crop than small farmers. This was due to the fact that they use jute stick as fuel for cooking. It was also observed that jute was mainly sown by traditional method of sowing; as only about 5% of total area was sown in line (**Fig. 5**). Which is the appropriate method of jute sowing for

Fig. 1 Categories of jute growing farmers

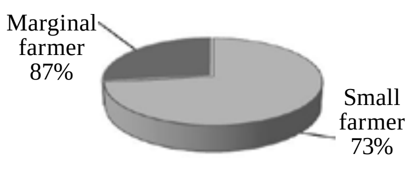


Fig. 2 Land holding distribution pattern under jute cultivation

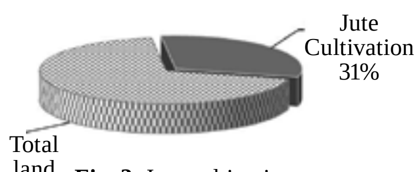


Fig. 3 Jute cultivation area among marginal farmers

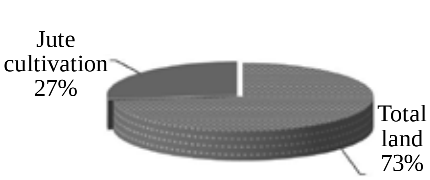


Fig. 4 Jute cultivation area among small farmers

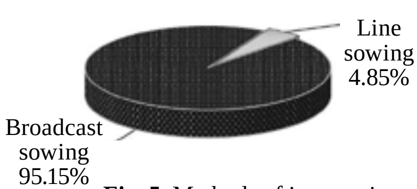


Fig. 5 Methods of jute sowing

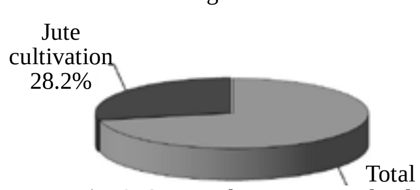


Fig. 6 Area under jute cultivation in West Bengal

Table 2 Amount of power available to two categories of farmers from different sources

	Power available (kW/ha)	
Sources / Parameters	Marginal farmer	Small farmer
Human power	0.447	0.547
Bullock power	0.087	0.24
Stationary engine power	1.78	1.91
Electric motor power	0.44	1.10
Power tiller power	1.17	1.29
Total	3.924	5.087

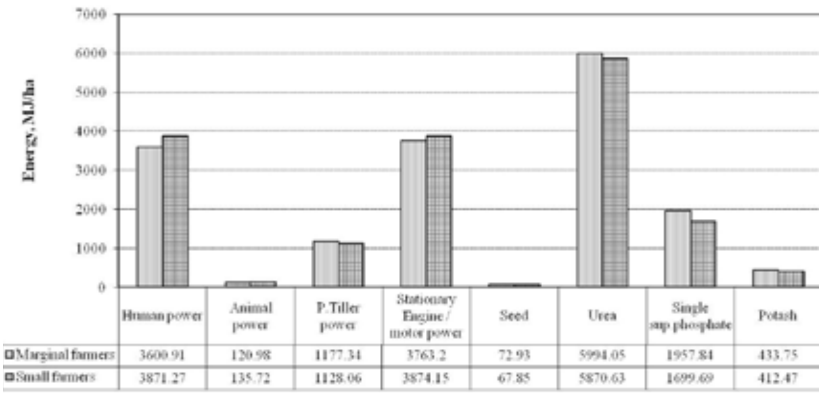


Fig. 7 Source wise energy use pattern for the production of jute

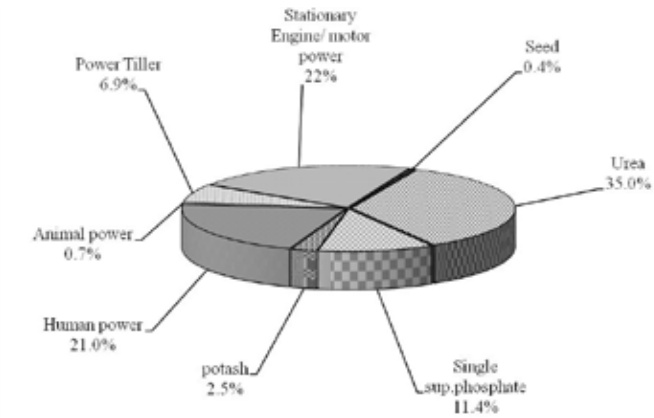


Fig. 8 Share of energy resource use in cultivation of jute (Marginal farmers)

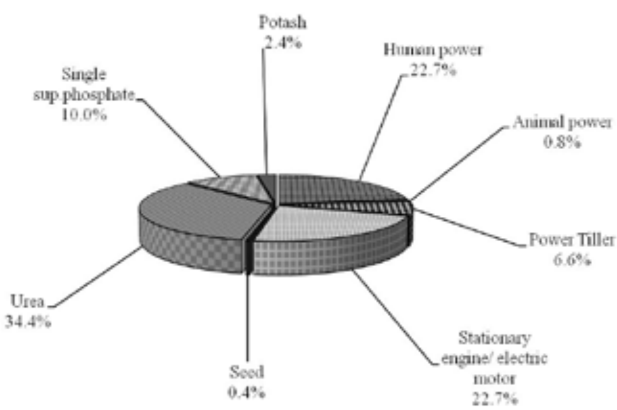


Fig. 9 Share of energy resource use in cultivation of jute (small farmers)

maintain plant population as well as ease of intercultural operations. It was also observed that only 28% of total cultivated area was under jute cultivation in West Bengal (**Fig. 6**)

Farm Power Availability

Table 2 revealed that the total availability of farm power sources for small farmer was higher (5.1 kW/ha) as compared to marginal farmer (3.9 kW/ha). This was due to the fact that small farmers had more numbers of power tiller, electric motor as well as bullock power compared to marginal farmers.

Energy Use Pattern in Jute Production

Energy use pattern by different categories of farmers for production of jute has been plotted in **Fig. 7**. It is clear from **Fig. 7** that marginal farmers were using more quantity of fertilizer and power-tiller power as to compare small farmer, while small farmers use higher amount of human power, animal power and stationary engine / electric motor compared to marginal farmers. It is also observed that the total input energy for production of jute was 17,121 MJ/ha and 17,060 MJ/ha for marginal farmers and small farmers respectively (**Fig. 7**). The total input energy for marginal farmer was higher compared to small farmers. This was due to the fact that marginal farmers were using higher amount of fertilizer as compared to small farmers.

Percentage of energy source used in the cultivation of jute for two categories of farmers is shown in **Figs. 8** and **9**. It is clear from **Figs. 8** and **9** that fertilizer was the major source of energy and contributing to about 49% (urea 35%, single super phosphate 11.4% and potash 2.5%) and about 46% (urea 34%, SSP 10% and potash 2%) of total input energy for marginal and small farmers respectively. It was found that marginal farmers were using higher amount of fertilizer as compared to small farmer. This was due to the fact that marginal farmers had tiny field compared to small farmers. It was observed that marginal and small farmers used almost same amount of energy obtained from stationary engine /electric motor (22%) as well as from seed (4%). It was also observed that human energy was the other major resource of energy contributing 21% and 22.7% of total input energy for marginal and small farmers respectively. The higher human power for small farmers was due to the fact that they used waged labour while marginal farmers used his family members. **Figs 8** and **9** also revealed that small farmers were using less amount of power tiller (6.6%) and higher amount of animal power (0.8%) as compared to marginal farmers 6.9% and 0.7% power tiller and animal power respectively. This was due to the fact small farmers were performing field operation by using animal power while marginal farmers were performing field preparation by using hire power tiller (**Table 2**).

Fig. 10 shows the source-wise energy requirement for the overall production of jute. It is clear from the **Fig. 10** that total input energy was about 1,7091 MJ/ha, among the different sources of energy the major component of energy input was chemical fertilizer about 48% of total input energy followed by stationary engine / electric motor and human power both contribute almost same amount of energy about 22% for the production of jute. It was also observed that among the chemical fertilizer use of urea was highest and contributing to about 35% of total input energy followed by single super phosphate about 11% and potash about 2%.

It was also observed that direct source of energy was higher (52%) as compared to indirect source of energy about 48% of total energy required in jute production (**Fig. 11**). The **Fig. 12** shows that the most of the energy was consumed in the form of non-renewable energy of about 77% of total input energy in jute production. The use of commercial energy was maximum about two third of total input energy for both marginal and small farmers respectively. While operational energy was about 29% for marginal and 30% for small farmers (**Figs 13** and **14**).

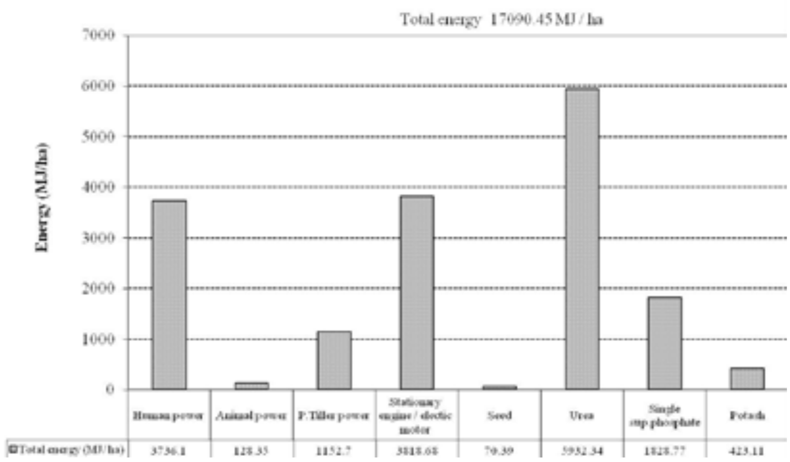


Fig. 10 Source wise energy requirement for the production of jute

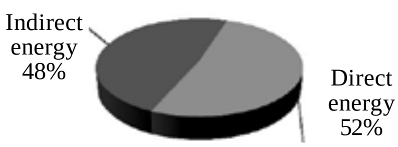


Fig. 11 Direct and indirect source of energy used in jute production

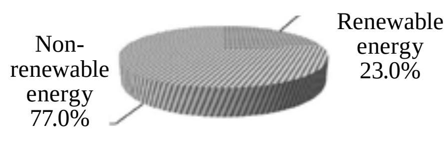


Fig. 12 Renewable and non renewable source of energy used in jute production

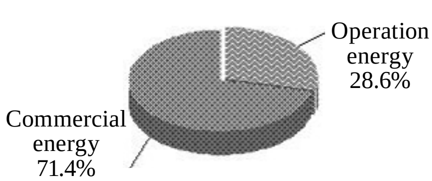


Fig.13 Share of commercial and operational energy of Marginal Farmers

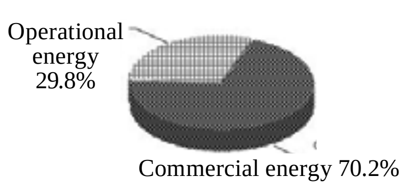


Fig. 14 Share of commercial and operational energy of Small farmers

Human Energy Utilization Pattern in Jute Production

It is clear from the **Figs 15** and **16** that weeding and thinning were the major human energy consuming operation for both marginal and small farmers and varied from about 37% to about 40% of total human energy input for the production of jute followed by fibre extraction varied between 19% to 21%, transportation and keeping it in water for retting varied from 11% to 14%, harvesting 10% to 11% and leaf removing and bundling 6% to 7% among marginal and small farmers. Sowing, plant protection and fertilizer application were required least and almost same amount of human energy.

Fig. 17 reveals that small farmers required more human energy in land preparation, sowing, fertilizer application, irrigation, weeding and thinning, transportation and keeping it in water for retting, while marginal farmers used more human energy in plant protection, harvesting, leaf removing and bundling and fibre sun drying and transportation. This was due to the fact that small farmer used animal power for land preparation and waged labour for most of the operations, while mar-

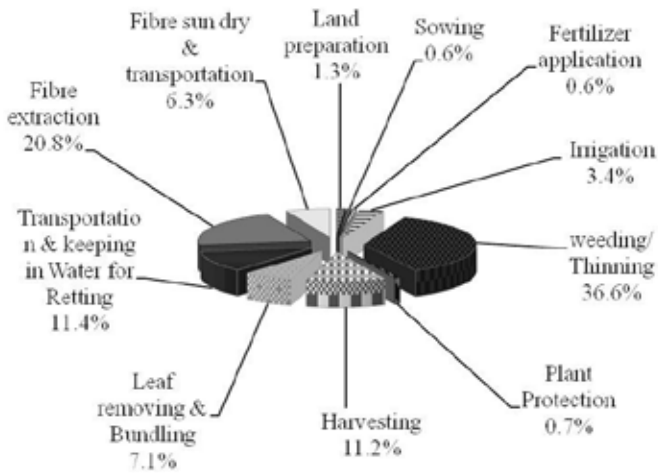


Fig. 15 Share of human energy input in jute production for marginal farmers

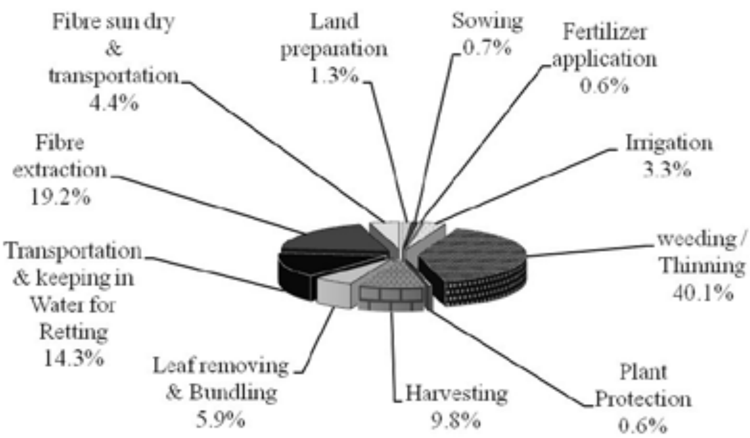


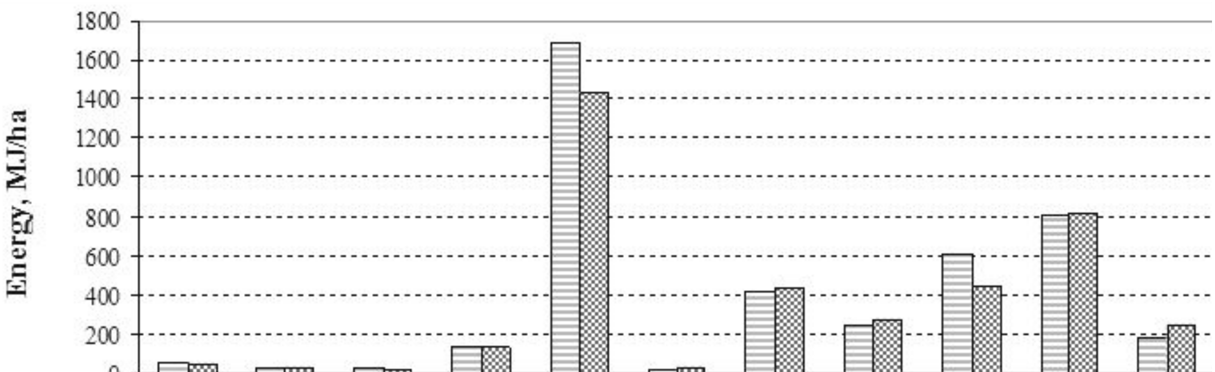
Fig. 16 Share of human energy input in jute production for small farmers

ginal farmers performed most of the operations by family members.

The average fibre yield was about 28.75 q/ha. On assessment of the effect of land holding on energy input , it is observed that marginal farmer were using higher amount of input energy and get maximum yield 29.1 q/ha as compared to small farmers about 28.4 q/ha. Jute cultivation also produced large amount of biomass in terms of jute stick as a byproduct of jute fibre which in terms of energy is about 112.24 GJ/ha. The energy productivity of main product for marginal and small farmers was almost same 0.17 kg/MJ and specific energy for marginal and small farmers was 5.9 MJ/kg and 6.0 MJ/kg respectively.

Cost Analysis in Production of Jute

It was found that jute production was highly labour intensive crop as **Fig. 18** shows the cost analysis of different energy input sources for the production of jute. It is clear from the **Fig. 18** that human power component was the major source of cost consuming to a tune of about 74% of total cost of cultivation followed by irrigation which was in the form of stationary engine/



	Land preparatio n	Sowing	Fertilizer applicatio n	Irrigation	weeding/ Thinning	Plant Protectio n	Harvestin g	Leaf removing &	Transport ation & keeping in	Fibre extraction	Fibre sun dry & transporta
Small farmers	54.21	31.56	26.34	137.20	1690.50	23.27	412.82	248.68	603.92	808.50	183.75
Marginal farmers	49.47	24.19	23.44	132.05	1430.45	28.87	439.96	275.85	447.57	813.69	246.78

Fig. 17 Operation-wise human energy requirement for the production jute

electric motor about 14%, chemical fertilizer about 6% and land preparation in terms of power tiller and animal power accounted 5.4% of total cost of jute production. Among the chemical fertilizer singe super phosphate consuming higher cost as compared to urea. The human power requirement was the major component of cost of cultivation because jute is such a crop in which most of the operations were performed by human labour such as weeding and thinning, transportation to retting site, steeping in water and fibre extraction. It was observed that among the operations maximum human energy and cost consuming operation was weeding and thinning which account about 37% of total cost of cultivation followed by fibre extraction about 21%, transportation and keeping it in water for retting about 12% and harvesting about 11% (**Fig. 19**). Sowing consuming least cost and energy this is due to the fact that jute was generally sown by broadcast method of sowing. The total cost of cultivation was found about Rs 25,795 per hectare and benefit cost ratio was 1.24.

Conclusions

Jute is mainly grown by marginal and small farmers. The total numbers of 125 jute growing farm families were selected. Among them 87% were marginal farmers and only 13% were small farmers. The total availability of farm power sources for marginal and small farm categories was 309 kW/ha and 5.1 kW/ha respectively. The research result revealed that total energy requirement for marginal and small farmers was 17,121 MJ/ha and 17,060 MJ/ha respectively and overall average energy requirement for jute production was 17,091 MJ/ha.

The energy input of chemical fertilizer were about 49% and 46%; mainly nitrogen has the biggest share in the total energy inputs for marginal and small farmers respectively. On an average direct and indirect source of energy was about 52% and 48% respectively while the non-renewable form of energy input was about 77% of the total energy input used in jute production compare to 23% renewable source. Among the operations, weeding and thinning was the major energy consuming operation for both marginal and small farmers and it varied from 37-41% of total human energy input followed by fibre extraction and varied from 19-21% respectively for the production of jute. The specific energy for marginal and small farmers was 5.9 MJ/kg and 6.0 MJ/kg jute fibre respectively. The average energy produced from the byproduct of jute fibre as jute stick biomass was about 112.24 GJ/ha. The research result revealed that jute production was highly labour intensive crop and about 74% of total cost of jute production was consumed by human power followed by irrigation which is in terms of stationary engine/ electric motor (about 14%). The benefit cost ratio was 1.24.

The above study revealed that if sowing of jute and post harvest operations are mechanized then there will be considerable reduction in total energy requirement and also cost of jute production.

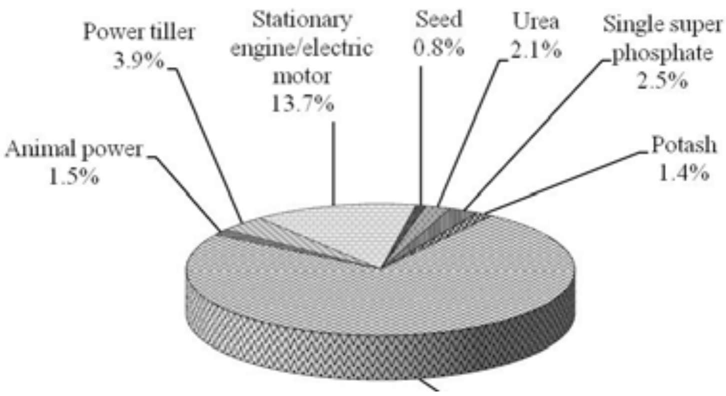


Fig. 18 Share of cost of different components in jute production

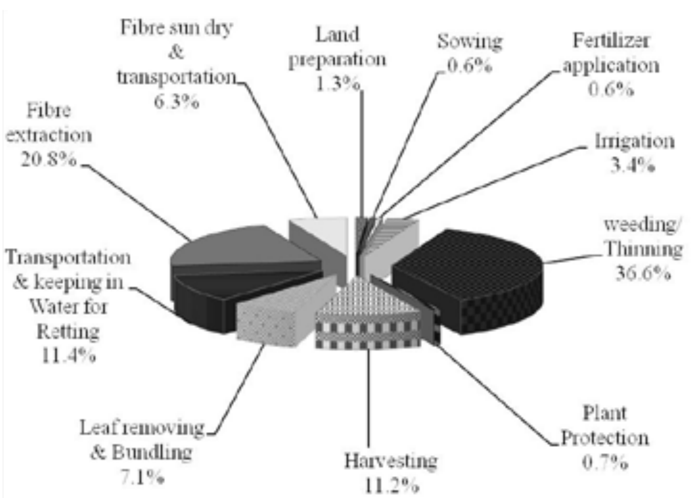


Fig. 19 Share of human energy input operation wise in jute production

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Animal Drawn Improved Sowing Equipment for Mustard in Terraces of Sikkim in India

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Abstract

The sowing of mustard is in practice by broadcasting and followed by leveling with traditional leveler (*dande*) in all the four districts of Sikkim in India. The five sowing equipment were evaluated for sowing of mustard. The animal drawn equipment included single row improved mustard seed drill, two row improved seed drill, single row improved multi-crop planter, improved multi-purpose tool frame with seeding attachment and sowing under zero till condition by two row improved seed drill. Their performances were compared with traditional sowing practice which saved costly seeds (8.5%) due to sowing in line.

The seed drill hopper bottom was provided mild steel plates having 5 mm holes at the centre for mustard seed rate control. The sowing by single row unit and two row sowing units indicated work rate of 300-350 and 650-770 m^2/h (at 300 mm row spacing), respectively. The maximum net saving in sowing of mustard (US $ 47.72/ha) was with zero-till using two row improved seed drill but yield (10.7 q/ha) was lower in comparison to other methods of mustard sowing. The highest work rate (780 m^2/h) was in the sowing of mustard by animal drawn two row improved multi-purpose tool frame with seeding attachment followed by two row improved seed drill. The draft values for all improved equipment varied from 226 N to 370 N which were within the limit of draught developed by an average pair of bullocks in Sikkim.

Keywords: broadcasting, work rate, seed rate, zero-till drill, draught animal.

Introduction

Sikkim has the lowest percentage of population below the poverty line (8.17%) across all Indian states. The 450 villages coming from 176 gram panchayats of the state are dependent upon animal based farming utilizing 58,700 bullocks (Tiwari and Rautaray, 2011). The average annual utilization of animal power is for 43 days and is limited to tillage operation in all the four districts (Gangtok, Namchi, Gyalshing and Mangan). To maintain the highest growth rate (31.8%) among all states, the present agricultural land (11% of total area of Sikkim) needed selective farm mechanization for all cultivation operations in terraces (Suryavanshi *et al*., 2012). The small size, low cost, light weight proven designs of seed drills are available which have found acceptability during frontline demonstrations. The developed improved sowing equipment suitable for all major crops (except paddy) in terraces have high capacity and are light in weight (below 20 kg). These cost effective and energy efficient equipment ensure savings in labour, time and cost of operation in addition to saving of costly seeds. The area under oilseeds in north eastern hill region is 0.4 million ha with production of 0.26 million tonnes. In Sikkim, the net sown area, total production and yield of mustard and rapeseed are 6,000 ha, 4,500 tones and 0.7 t/ha respectively (Tiwari, 2012).

The two row animal drawn seed drill (Mahakal) developed by CIAE, Bhopal used agitator and orifice for seed metering inside the seed box. This equipment provided work rate of 0.10 ha/h. The mustard seeds were metered using fluted roller of 2 × 2 mm size on seeding attachment fitted on CIAE design multi-purpose tool frame. The seeding attachment showed work rate of 1,200 m^2/h (Singh *et al*., 1996). Animal drawn two row inclined plate planter was developed and tested for mustard in black cotton soils at CIAE, Bhopal which had effective field capacity of 0.14 ha/h (Pandey *et al.*, 2004). The wooden vertical rotor with cells on periphery was provided on two row seeding equipment developed at CIAE Bhopal which showed work rate of 1000 m^2/h for sowing mustard (Pandey *et al.*, 2006). Acharya N.G. Ranga University, Hyderabad developed two row seed cum fertilizer drill employing rotor for metering different crops seeds. For mustard, the equipment provided an effective field capacity of 0.15 ha/h (Pandey *et al.*, 2004). If total area under the mustard and rapeseed in Sikkim is sown using improved sowing equipment (seed drill/planter) it could be mechanized using 4,000 units costing US $ 40,000 which have the scope to use in sowing for other crops also.

The objective of comparative evaluation of improved sowing equipment for mustard is to help Department of Agriculture, Government of Sikkim for finalizing subsidized and cost effective equipment which may be adopted for promoting line sowing of mustard crop replacing present practice of manual hand broadcasting of costly seeds followed by leveling using traditional wooden leveler (*dande*) for partial covering of seeds under terrace condition.

Material and Methods

The sowing of mustard in all the four districts of Sikkim is performed by manual broadcasting after two operations of ploughing by traditional plough and seeds are partially covered using traditional wooden leveler (*dande*). The seed rate used by farmers ranged 8-10 kg in traditional practice of manual broadcasting of seeds in terrace condition. The time taken in broadcasting practice is 35 h/ha including covering of seeds by traditional leveler. Five animal drawn improved sowing equipment were evaluated in terraces for mustard sowing. The selected animal drawn sowing equipment were single row improved seed drill, two row improved seed drill, single row planter, two row sowing attachment on multi-purpose tool frame and two row improved zero till seed drill. The single row planter and sowing attachment were equipped with plastic hopper fitted with vertical plastic rotor having cells on periphery for seed metering. In single row seed drill, two row seed drill and two row zero till seed drill, the seeds flow was controlled by inserting mild steel plate having orifice in the centre of opening. The furrow openers were shoe type on seed drills which were able to sow the seeds after making narrow openings in terrace. The zero till sowing of mustard after rice harvest was performed by fitting inverted T type furrow openers and fluted rollers having small flutes for small seeds metering of mustard.

The multi-purpose tool frame with seeding attachment (overall dimensions of 730 × 700 × 960 mm and weight of 19.8 kg) consisted of two plastic seed boxes, main frame of hollow round galvanized iron pipe having various holes for fitting two tines for opening narrow furrows in ploughed land, plastic tubes and power drive cum ground wheel (**Fig. 1**). The vertical rotors with cells at the periphery were provided for metering of mustard seeds.

The animal drawn single row improved seed drill of 22 kg weight and overall dimension of 700 × 700 × 460 mm was developed for sowing mustard crop (**Fig. 2**). The seed box was provided with mild steel sheet (120 × 50 × 0.5 mm) having a 5 mm hole in the centre to pass seeds through it. The metered seeds by fluted roller were dropped behind shoe type furrow opener through plastic tube into soil. The furrow openers were attached to the square main frame made of angle (35 × 35 × 5 mm) of 700 mm length. The transport cum support wheels were provided for adjusting the depth of operation. The drive to the metering mechanism was provided through ground drive wheel by chain and sprocket arrangement.

The animal drawn single row improved planter (**Fig. 3**) of 11.2 kg weight consisted of galvanized iron main frame, single moulded plastic hopper of 2 kg capacity, shoe type furrow opener, two ground wheels and vertical plastic rotor with cells on its periphery. The power was transmitted through chain and sprockets (from 18 to 12 teeth) from the ground drive wheel of 450 mm to seed metering shaft. The overall dimensions of light weight, cost effective and energy efficient unit was 450 × 430 × 660 mm. The seed feed shaft of square shape was made of


Fig.1 Seeding attachment on multipurpose tool frame


Fig. 2 Sowing of mustard seed by single row seed drill


Fig. 3 Single row animal drawn planter

aluminum.

The animal drawn two row mustard drill of weight 23.7 kg and overall dimension of 730 × 700 × 960 mm was developed to achieve higher work rate and variable row spacing for sowing of mustard seeds (**Fig. 4**). This sowing equipment after removing mild steel plates with holes inside seed box can be used for other crops having medium size seeds (buckwheat, wheat, soybean, black gram etc.) by employing the same fluted rollers (2 nos.) for seed metering. The two shoe type furrow openers were fitted on main frame which was made of hollow square section. The depth of operation was changed by selecting proper holes in hitch for fitting beam. The square hollow bars with holes, welded at ends of main frame also served as transport cum depth wheel. The equipment had provisions for changing of seed rate, row spacing and depth of operation for sowing small and medium size seeds sowing in friable soil condition.

For development of animal drawn two-row improved zero till seed drill, inverted T type furrow openers were fitted on main frame which opened a narrow opening for metering seeds through plastic tubes (**Fig. 5**). For seeds metering, aluminum fluted rollers (10 flutes) were employed which got seeds passed through holes (5 mm size) made in the mild steel plate fixed on the opening inside the seed box.

The sowing equipment were calibrated before use on terraces for the required seed rate of 6 kg/ha for mustard. The soil, crop seeds and equipment performance parameters were recorded during testing and average of five readings was calculated for all parameters. The results of the study are reported in **Table 1**. The performance of animal drawn sowing equipment on terraces in Sikkim was compared with traditional practice of manual broadcasting of mustard seeds.

Results and Discussion

The two row improved multipurpose tool frame with seeding attachment was tested at bullock speed of 2.36 km/h (**Fig. 1**). The draft, effective field capacity and field efficiency were 314 N, 0.082 ha/h and 58%, respectively. The draft required to operate the equipment was 88 N more than draft of 226 N for single row planter. The cost of operation was worked out as $ 6.82/ha.

The animal drawn single row improved seed drill (**Fig. 2**) showed work rate of 350 m^2/h and covered 800 m^2 area in terraces previously prepared by use of animal drawn improved wedge plough and planker. It was tested in terraces at soil moisture content (dry basis) of 21.3% and bullock speed of 2.25 km/h at recommended seed rate of 6 kg/ha and row spacing of 300 mm under hill farming. The effective field capacity and field efficiency were 0.035 ha/h and 52%, respectively. The draft value was 275 N. The cost of operation and labour requirement were $ 15.97/ha and 28.5 man h/ha respectively. The effective field capacity (350 m^2/h) of single row seed drill was 54.54% lower as compared to two row improved zero-till seed drill and it was 50% lower as compared to work rate (700 m^2/h) of two row improved seed drill (**Table 1**). The draft value was the highest (370 N) for sowing of mustard using two row improved seed drill at bullock speed of 2.26 km/h and with of operation of 600 mm.

The animal drawn single row improved planter (**Fig. 3**) was evaluated at recommended seed rate in terrace (6 kg/ha) at row spacing of 300 mm which showed work rate of 480 m^2/h at friable soil moisture content (dry basis) of 19.6%. The average bullock speed, depth of operation and width of operation were 2.50 km/h, 43 mm, 300 mm respectively. The labour requirement and cost of sowing was worked out as 21 man-h/ha and US $ 11.65/ha considering 1 $ equivalent to Rs 67.11, respectively (**Table 1**).

The two row improved zero till seed drill (**Fig. 5**) showed work rate of 770 m^2/h at bullock speed of 2.2 km/h. The draft value was 340 N and cost of operation was $ 7.25/ha. The observed seed rate was 6.72 kg/ha and plant emergence after 20 days of sowing was 62/sq. m (**Table 1**).

The work rate (770 m^2/h) of animal drawn two row improved zero till seed drill was 9.09% higher as compared to mustard sowing by two row improved seed drill. The observed seed rate was maximum (6.72 kg/ha) for sowing of mustard using two row improved zero till seed drill. The cost of operation for sowing mustard was the lowest (US $ 7.25/ha) for zero-till condition and the yield was also the lowest (1.25t/ha) for zero-till condition sowing of mustard. The cost of operation for two ploughing by improved wedge plough were added in working out

Fig. 4 Improved two row seed drill

Fig. 5 Two row zero till seed drill in operation

net savings in sowing operations by improved equipment other than zero till condition.

There was saving of US $4.82/ha in cost of operation and 9 man h/ha in labour requirement using seeding attachment on multi-purpose tool frame over sowing using single row planter. The plant emergence/ m^2 after 20 days was found 11.11% higher for sowing by multi-purpose tool frame seeding attachment over single row planter (**Table 1**). The net savings in cost of operation by two row zero till seed drill were 79.13%, 87.78%, 71.39% and 85.72% over sowing of mustard using single row improved planter, two row seeding attachment on multi-purpose tool frame, single row improved mustard seed drill and two row improved mustard seed drill, respectively.

The labour requirement was minimum (13 man-h/ha) for sowing under zero tilling condition and maximum (28.5 man h/ha) for single row mustard drill. The yield (8.8 q/ha) of mustard crop sown by traditional practice (manual broadcasting followed by leveling using traditional leveler for covering of seeds) was minimum as compared to sowing by improved sowing equipment in the study. The traditional practice of sowing is manually broadcasting of seeds followed by partial cover-

Table 1 Performance parameters of different mustard sowing equipment

Parameters	Sowing by animal drawn equipment					Traditional practice of manual broadcasting
	Single row planter	Multi-purpose tool frame with two row seeding attachment	Single row mustard drill	Two row mustard drill	Two row zero till seed drill	
Previous crop grown	Rice	Rice	Rice	Rice	Rice	Rice
Previous field operations	Improved wedge plough followed by clod crusher cum leveler	Improved wedge plough followed by clod crusher cum leveler	Improved wedge plough followed by clod crusher cum leveler	Improved wedge plough followed by clod crusher cum leveler	-	Traditional wooden plough followed by traditional leveler (Dande)
Area of terrace, m^2	1,600	1,650	800	1,200	1,200	1,600
Seed rate, kg/ha	6.25	6.6	6.5	6.65	6.72	7.5
Soil moisture content (dry basis), %	19.6	20	21.3	20.4	20.8	20.2
Width of operation, mm	300	600	300	600	600	-
Depth of operation, mm	43	40	46	48	35	20
Speed of operation, km/h	2.5	2.36	2.25	2.26	2.2	1.8
Draft, N	226	314	275	370	340	-
Effective field capacity, ha/h	0.048	0.082	0.035	0.07	0.077	0.065
Field efficiency, %	64	58	52	57	64	84
Cost of operation, US $/ha	11.65	6.82	15.97	7.97	7.25	9.61
Labour requirement, man-h/ha	21	12	28.5	14.28	13	15.4
Saving over traditional practice,						
Labour, %	-	22.07	-	7.27	15.58	-
Time, %	-	22.07	-	7.27	15.58	-
Cost of operation, %	-	29	-	17.05	24.49	-
Plant emergence (after 20 days) per m^2	132	136	76	88	72	105
Yield, t/ha	1.5	1.58	1.4	1.44	1.25	0.85

1 US $ equivalent to Rs 67.11

ing using traditional leveler (*dande*) and is 29% costlier as compared to animal drawn improved sowing attachment fitted on tool frame. There were net saving of 22.07%, 7.27% and 15.58% in labour and time of sowing using sowing attachment on multi-purpose tool frame, two row improved seed drill and two row zero till seed drill, respectively over traditional practice of sowing. The animal drawn two row improved seed drill and animal drawn two row improved zero-till seed drill showed net savings of 17.05% and 24.49% respectively in cost of operation as compared to manual broadcasting of mustard seeds (**Table 1**).

Conclusions

The following conclusions can be drawn from the study:

i. The work rate of single row improved planter (weight of 11.2 kg) was 480 m^2/h and cost of operation was US $11.65/ha.

ii. The draft values for single row mustard planter and two row seeding attachment on tool frame were 226 N and 314 N, respectively.

iii. The effective field capacity of two row seeding attachment on tool frame was 820 m^2/h and the cost of operation was $ 6.82/ha.

iv. The work rates of modified single row seed drill, two row modified mustard drill and two row modified zero till drill were 350, 700 and 770 sq m/h, respectively.

v. The draft values for modified single row, two row and two row zero till seed drill for mustard sowing were 275, 370 and 340 N, respectively.

vi. There was net savings in cost of operation of 79.19%, 87.78%, 71.39% and 85.72% for mustard sowing under zero till condition using two row seed drill as compared to single row improved planter, two row seeding attachment on tool frame, single row improved mustard seed drill and two row improved seed drill.

vii. The labour requirement (13 man-h/ha) was minimum for two row zero till seed drill sowing of mustard and was maximum (28.5 man-h/ha) for single row mustard drill.

viii. The traditional practice of sowing by manual broadcasting of seeds and followed by partial covering using traditional leveler (*dande*) was 29% costlier as compared to sowing by animal drawn improved sowing attachment fitted on tool frame.

ix. There were net saving of 22.07%, 7.27% and 15.58% in labour and time of sowing using sowing attachment on multi-purpose tool frame, two row improved seed drill and two row zero till seed drill, respectively over traditional practice of sowing.

x. The animal drawn two row improved seed drill and animal drawn two row improved zero-till seed drill showed net savings of 17.05% and 24.49%, respectively in cost of operation compared to manual broadcasting of mustard seeds.

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A Tractor Drawn Vegetable Transplanter for Handling Paper Pot Seedlings

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Abstract

A tractor operated 3-row multi-stack vegetable transplanter (MSVT) for planting vegetable seedlings raised in paper pots was developed. Each multi-stack planting unit comprised three sets of metering wheel and slotted plate, a seedling delivery tube, a furrow opener and a soil covering device. The vegetable transplanter carried 180 pots at a time. The average field capacity of the transplanter for transplanting chili seedlings at 600 mm × 450 mm seedling spacing was found to be 0.111 ha/h at a forward speed of 2 km/h resulting in a saving of 87.14% and 87.5% labor; 87.71% and 87.20% of operating time over the conventional method of manual transplanting of pot seedlings and bare root seedlings, respectively. The transplanter could plant 72 pot seedlings per min in each row with 4% missed planting, 9% tilted planting and 84% soil covering efficiency. The cost of transplanting with MSVT was found to be around $275 per hectare.

Key words: vegetable transplanter, paper pot seedlings, labor saving, operating cost

Introduction

Adoption of mechanized vegetable cultivation practices along with other improved crop production practices is the need of the time (Clarke, 1997; Saxena and Dhawan, 2006). Manual transplanting of seedlings is time consuming; expensive and labour-intensive and often results in non-uniform plant distribution (Parish, 2005; Kumar and Raheman, 2008; Manes *et al.*, 2010). Various attempts have been made to develop tractor-mounted 2-row and 3-row semi-automatic vegetable transplanters for bare-root and plug seedlings (Anon., 2006; Manes *et al.*, 2010). Pocket-type metering devices have been provided in the transplanters for bare-root seedlings. The field capacity and labor requirement have been reported to be 0.082 to 0.092 ha/h and 44.4 man-h/ha, respectively at a forward speed of 0.8 to 1.0 km/h. Rotary cup-type metering devices have been provided in the transplanters for plug and pot seedlings. They had a field capacity of 0.14 ha/h and labor requirement of 28.6 man-h/ha when operated at a forward speed of 1.4 km/h. Field capacity of these machines was lower due to lesser speed of operation as feeding of seedlings to the metering unit was done manually. A vegetable transplanter with array type metering device powered by hand tractor using pot seedlings was developed (Kumar and Raheman, 2011). Its field capacity was 0.026 ha/h when operated at 0.9 km/h. The quality of transplanting was reported to be satisfactory for all the above mentioned transplanters but their field capacity was lower and the metering mechanism was bit complicated.

From the review of literature it was found that the existing automatic vegetable transplanters require either plug or pot seedlings. As initial investment on production of plugs is high and mechanisms employed for the removal of seedlings from the tray are complex, use of pot seedlings seems to be a better option due to their ability to degrade, lower cost and ease in preparation (Kumar and Raheman, 2008). The advantage of potted plants is that the gravitational fall of seedlings can be applied to automate the transplanting operation with reduced complexity in metering device. Paper pots made with newspaper were used for raising seedlings (Ueno *et al.*, 2002; Furuki *et al.*, 2003; Kumar and Raheman, 2010). Suitable metering mechanism for handling paper pots was essential to carry out

Fig. 1 Seedlings raised in double layer polyethylene-covered unheated greenhouse with the ready-to-plant paper pot seedling of chili

mechanized transplanting of vegetable seedlings. Hence, an attempt was made to design and develop a suitable metering unit for handling paper pot seedlings in a vegetable transplanter.

Selections of Pot Seedlings and Number of Stacks

Paper pot seedlings of chili pepper (Capsicum annuum) grown in aluminum trays in a double layer polyethylene covered unheated greenhouse with the ready-to-plant seedling are shown in **Fig. 1**. Each seedling was grown in a cylindrical paper pot of volume 82 cm^3 filled with mix comprising farm yard manure (FYM), soil and sand in the proportion of 80:10:10. The volume of pot and the proportion of ingredients in the soil-based FYM amended mix were based on the outcome of the experiments conducted in two different seasons (Nandede, 2013). The average dimensions of pot i.e. diameter and length were found to be 50.8±3.0 mm and 40.0±2 mm. The maximum weight of pot with potting mix was found to be 68 g, 71 g and 77 g at 6%, 9% and 12% moisture content (db), respectively.

Development of MSVT

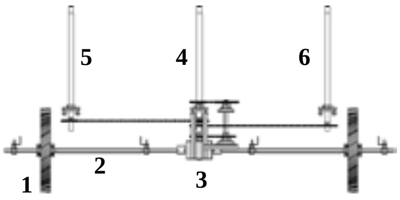
The developed tractor drawn vegetable transplanter consisted of multi-row planting units. Each planting unit comprised metering wheels, slotted plates, seedling delivery tubes, ground wheels, furrow opener, soil covering device, a power transmission system and a three point hitching attachment. It was attached to the three point linkages of the tractor for easy lifting and lowering. The planting units were powered by ground wheel with the help of a transmission system. The drawbar power of the tractor was utilized for pulling the planting unit in the field. The number of rows of seedlings to be planted by the MSVT was decided based on maximum number of furrow openers it can pull, width of the existing seeding/planting machines used in India, dimensions of the paper pot and space requirement of the individual multi-stack planting unit. Diameter of the metering wheel was decided based on the row to row spacing of the vegetable seedlings. Maximum width of operation of most of the seeding equipments used for Indian field conditions are below 2.5 m. Considering all the above factors, it was decided to develop a 3-row vegetable transplanter using paper pot seedlings. Hence, the width of machine was around 2.2 m as each planting unit required 0.74 m space after keeping sufficient clearance between two adjacent planting units.

Components of the MSVT

The purpose of the metering wheel is to carry the pot seedlings in a circular array and feed the pot seedlings in upright orientation to the lower metering wheels or seedling delivery tube through the slot provided in the slotted plate. Each metering wheel had 21 conical shaped cups attached at the outer periphery of the MS ring at a centre to centre distance of 75 mm. It carried 20 pot seedlings. Overall diameter and height of the bottom and middle metering wheels were 590 mm and 160 mm, respectively as compared to 576 mm and 85 mm for top metering wheel. Height of the top metering wheel was kept lower than the middle and bottom metering wheels to facilitate easy refilling of seedlings. A slotted plate made from aluminum sheet of size 600 mm × 600 mm × 4 mm was cut to form a donut of outer diameter 600 mm and inner diameter 400 mm. A slot of width 65 mm and length 100 mm was made on this plate along the path of movement of pot seedlings to allow them to drop to the lower metering wheels/seedling delivery tube. Width and length of the slot were decided based on the size of pot and gravitational falling speed of the pot seedling. Slotted plate was placed at the bottom of each of the metering wheel. Three metering wheels along with slotted plate were fixed to a common rotating shaft at a height of 160 mm. Shaft of the planting unit and slotted plates were supported by four studs arranged at 90° to each other with the help of horizontal flat support (planting unit frame). Metering wheel, slotted plate, common shaft and studs with flats for horizontal support together were called as planting unit. The overall dimensions of each multi-stack planting unit were 725 mm × 678 mm. Three such units were fixed on a main frame of the machine by providing sufficient gap between two planting units for three point hitch attachment. Overall dimensions of the frame were 2180 mm × 690 mm × 853 mm. Main frame of the machine supported the three sets of multi-stack planting units, furrow openers, soil covering device, a power transmission system and three point hitch attachment of the MSVT.

Power transmission system

The power transmission system coordinated rotary speed of the planting unit shaft with forward speed of the tractor to get the desired seedling spacing of 450 mm. It consisted of a pair of ground wheels, reduction gear box, chain and sprocket. The shaft of the planting unit was driven by a pair of ground wheel shaft through a gear box (8:1) and was kept between ground wheel shaft and the multi-stack planting unit shaft. The output shaft of the gear box was driving a shaft provided for changing seedling spacing and that shaft was used to drive the central planting unit shaft, which in



1. Ground wheel; **2**. Shaft of ground wheel; **3**. Gear box; **4**. Shaft of central planting unit; **5**. Shaft of left planting unit; **6**. Shaft of right planting unit; **7**. Shaft for changing the plant spacing

Fig. 2 Overall View of power Transmission System of MSVT

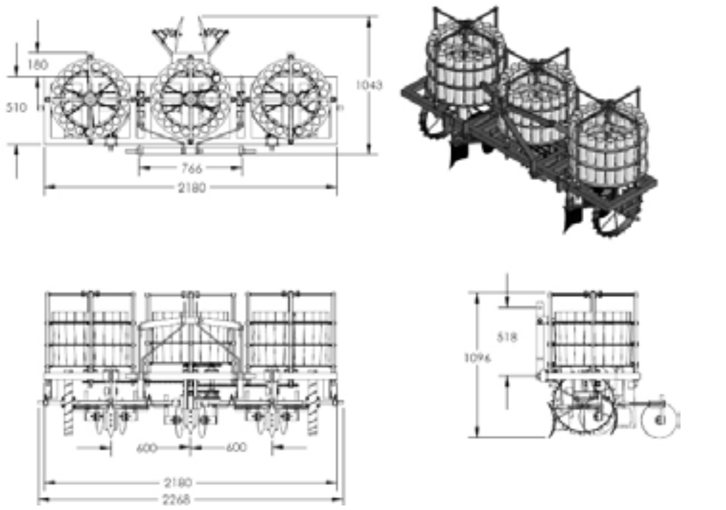


Fig. 3 Isometric view along with schematic diagram of MSVT

turn drove the left and right planting unit shafts using chain and sprocket. An overall view of power transmission system of the MSVT is shown in **Fig. 2**.

Furrow opener, soil covering device and seedling delivery tube

Reversible shovel type furrow opener with face width of 50 mm was selected. It was fitted on the shank using plow bolts. Rectangular boots and 'C' shaped clamp were attached behind the furrow opener to support the middle and lower end of the seedling delivery tube. A pair of discs converging at the rear end was used as soil covering device. Provisions were made to vary the tilt angle, disc angle and depth of operation of the discs. The shank of the furrow opener was fitted to the main frame using a bracket made from angle iron and bolts. The seedling delivery tube was made of PVC pipe of outer diameter 75 mm and wall thickness 2 mm. It was provided at the seedling discharge point i.e. lowest slotted plate of all the multi-stack planting units.

All the components of the MSVT were assembled together on a main frame. Power transmission system was fixed on vertical supports taken from the frame. Three point linkage attachments were provided by taking support from front and back laterals of the main frame. An isometric view along with schematic diagram of the MSVT is shown in **Fig. 3**. An overall view of the tractor drawn 3-row MSVT is shown in **Fig. 4**.

Performance Evaluation of Msvt Under Actual Field Conditions

The tractor drawn 3-row MSVT was evaluated for transplanting paper pot seedlings of chili at 600 mm × 450 mm seedling spacing in three well prepared plots each of size 32 m × 16 m. The soil was lateritic sandy clay loam having bulk density of 1,200 kg/m^3 and moisture content of 9.0±2% (db). Twenty-eight days old pot seedlings of average height 100±10 mm and moisture content of potting mix around 7% (db) were selected. The tractor was operated at an average forward speed of 2 km/h. Pre-experimental trials were undertaken to adjust the working of planting unit, furrow openers, soil covering device and depth adjustment to ensure that pots were planted in upright orientation at appropriate depth in the furrow with sufficient amount of soil covering the pot seedlings. A mark was made on the position control lever of the tractor hydraulic system to set the depth of operation of the furrow opener at 80 mm.

A total of 180 seedlings with 60 seedlings in each multi-stack planting unit were carried at a time. The tractor was operated along the length of the selected plot. During the operation, time lost for placing the pot seedlings in the planting unit, turning, engagement and disengagement of depth adjustment levers were recorded. The total time required for transplanting each plot was noted. The actual field capacity, field efficiency, percent wheel slip and fuel consumption of tractor were determined. After the completion of operation in each plot, the number of missed plantings, tilted plantings and correctly planted seedlings were counted. The amount of soil covering both correctly planted and tilted seedlings were recorded separately as sufficiently soil-covered, partially soil-covered and excessively-soil covered seedlings. After the operation, tilted seedlings were placed in upright orientation

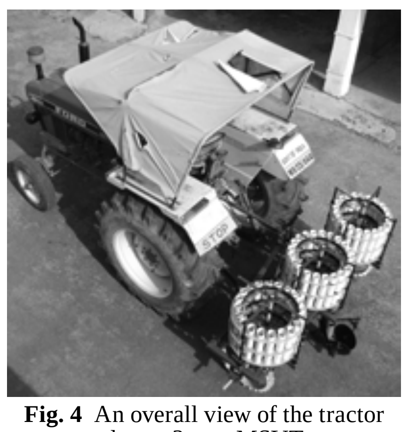


Fig. 4 An overall view of the tractor drawn 3-row MSVT

in the furrow. Sufficient amount of soil was covered around all the pot seedlings. The labor required for the correct placement and soil covering of the seedlings was recorded. All the seedlings were immediately watered. The population of established plants was recorded two days after transplanting. Labor required for filling the missing seedlings were noted down. The cost of mechanical transplanting using MSVT was then calculated.

For the purpose of comparison, chili seedlings were manually transplanted at 600 mm × 450 mm spacing in two plots of same size as used for MSVT using pot seedlings and bare-root seedlings. When bare-root seedlings were used, slightly older seedlings were preferred. Hence, 32 days old bare root seedlings were used. The performance of transplanting using MSVT and manual method of transplanting were compared in terms of field capacity, labor requirement, quality of planting and cost of operation.

Results and Discussion

Field Capacity and Labor Requirement

Field performance, quality of work and cost of transplanting using MSVT are compared with manual method of transplanting of paper pot seedlings (MTP) and bare-root seedlings (MTB) and are given in **Table 1**. While operating the MSVT at an average forward speed of 2 km h^{-1}, the percent wheel slip of tractor was found to vary between 8 to 10% with an average fuel consumption of 4.49 l/h. The mean depth of placement of pot seedlings was 60 (±15) mm. The field capacity of the MSVT was found to be 0.111 ha/h with a field efficiency of 30.83%.

The conventional manual transplanting required 210 and 250 man-h/ha for paper pot and bare-root seedlings, respectively. The mechanical transplanting by MSVT resulted in a saving of 87.14% and 87.71% of labor and time, respectively over the manual transplanting of paper pot seedlings and a saving of 87.50% and 89.20% in labor and time, respectively for manual transplanting of bare-root seedlings. Saving of labor and time in the range of 70 to 93% and 75 to 78%, respectively were reported for the tractor operated 2-row semi-automatic vegetable transplanters as compared to manual vegetable transplanting in India (Satpathy and Garg, 2008; Singh, 2008; Manes *et al.*, 2010).

Quality of Transplanting

The quality of transplanting as indicated by the seedling planting rate, percent missed planting, percent tilted planting, overall planting efficiency, soil covering efficiency, percentage of seedlings with partial soil coverage and with excess soil coverage for the MSVT is given in **Table 2** for the individual plots. It indicated that the developed MSVT had an average planting rate of 72 pot seedlings per min in each row. The reported planting rate in the semi-automatic vegetable transplanters for bare-root seedlings varied from 35 to 45 seedlings per min (Anon., 2006; Singh, 2008; Satpathy and Garg, 2008). Fully automatic transplanters have planting rate above 60 seedlings per min (Suggs *et al.*, 1987; Shaw, 1997; Tsuga, 2000) and 32 seedlings per min for walk behind type hand tractor operated automatic vegetable transplanter (Kumar and Raheman, 2011). Average percentage missed planting that occurred due to damage of pots within the machine during metering of pot seedlings of chili was found to be 4.07% and around 7% of the total pot seedlings planted by the developed MSVT was found tilted. Overall planting efficiency of the MSVT was found to be around 96%.

The soil covering efficiency of the vegetable transplanter was found to be around 84%. About 9% of the pot seedlings were covered with excess amount of soil and about 7% of the pot seedlings were partially covered

Table 1 The average values of field, seedling and operational parameters

Parameter	Chili
Effective size of field, m^2	32 × 16
Type of soil	Lateritic sandy clay loam soil
Moisture content of soil, % (db)	9±2
Bulk density of soil, kg/m^3	1310±50
Seedling age, weeks	4
Height of seedlings, mm	100±10
Moisture content of pot mix, % (db)	6±1
Forward speed, km/h	2
Slip of driving wheels of tractor, %	8-10
Row to row spacing, mm	600
Seedling spacing in rows, mm	450±15
Depth of placement of pot, mm	60±15
Average fuel consumption, l/h	4.50
Average actual field capacity, ha/h	0.111
Theoretical field capacity, ha/h	0.36
Average field efficiency, %	30.83
Labor requirement, man-h/h	27

Table 2 Quality of transplanting of MSVT

Parameter	Value
Seedling planting rate, seedlings/min/row	72
Percent missed planting, %	4.07
Percent tilted planting, %	6.56
Overall planting efficiency, %	95.93
Soil covering efficiency, %	84.17
Partially soil covered seedlings, %	6.95
Excess soil covered seedlings, %	8.88

with soil. The variation in soil covering by the furrow closure device might be due to non-uniform soil condition and failure of pot seedling to fall in upright orientation. There was almost uniform distribution of seedlings in the field during manual transplanting of pot seedlings. Around 28% of the seedlings were excessively covered with soil and 6% of the seedlings were tilted after transplanting.

Cost Economics of the MSVT

Comparison of field performance and cost economics of MSVT with manual method of transplanting of paper pot seedlings (MTP) and bare-root seedlings (MTB) are given in **Table 3**. The total cost of material, fabrication and assembling of the MSVT was found to be $482.3. The initial cost of tractor was considered as $8,842 with 1,000 hours as annual use of tractor. Assuming appropriate rate of depreciation, interest on investment, housing, insurance and taxes and calculating the cost of fuel, lubricants, operator wages, repair and maintenance charges, the cost of operation of tractor per hour amounted to $5.7. The useful life of the developed MSVT was taken as 10 years. It was assumed that the use of tractor for transplanting of vegetables was the additional annual use besides 1,000 hours of annual use considered for other operations. The total cost of transplanting using the developed tractor drawn 3-row MSVT was calculated considering the production cost of seedlings. The cost of preparation of paper pots was $5.9 per 1,000 pots (Nandede, 2013).

The cost of transplanting of vegetable seedlings using the developed MSVT at various levels of annual use (h/year), manual transplanting of pot seedlings and manual transplanting of bare-root seedlings is presented in **Table 3**. As the annual use of the developed MSVT increased, its cost of operation decreased. The cost of operation for 100, 200, 300 and 400 h of annual use was found to be $280.0, $274.4, $272.0 and $270.3 per ha, respectively. The cost of operation with MSVT was found to be 2.79 to 2.68 times higher than the conventional method of transplanting with bare root seedlings. The cost of preparation of paper pots with mix was the major component of the cost of operation of MSVT using paper pot seedlings. It accounted for about 77 to 81% of the total cost of mechanical transplanting and 72% of the total cost of manual transplanting with pot seedlings. The higher cost of mechanical transplanting in the present study could be attributed to the higher cost of preparation of paper pot seedlings and lower field efficiency (30.83%).

Table 3 Field performance and cost economics of the MSVT

Particulars	MSVT				MTP	MTB
Field capacity, ha/h	0.111				0.0095	0.008
Labor requirement, man-h/ha	26.79				210	250
	for annual use of					
	100 h	200 h	300 h	400 h	303.5	100.5
Cost of operation, $/ha	280	274.4	272.0	270.3		
Cost of paper pots, $/ha	217.5					-
Cost of paper pots as the percentage of total cost of transplanting, %	77.65	79.24	79.97	80.46	72.03	-

MTP - Manual transplanting of paper pot seedlings.
MTB - Manual transplanting of bare-root seedlings.

Conclusions

The developed tractor drawn multi-stack vegetable transplanter (MSVT) for individual paper pot seedlings saved 87.14% and 87.71% labor and 87.5% and 89.20% in time during transplanting of vegetable seedling over manual transplanting of pot and bare root seedlings, respectively. Besides this, it increased the annual use of tractor on farms. The cost of operation was 2.72 times higher than that of conventional manual method of transplanting bare-root seedlings. Being the first prototype, field capacity and field efficiency of the MSVT were low. Efforts are being made to increase the field capacity and field efficiency by reducing the time involved in placing pot seedlings in the planting units and turning of the machine.

Acknowledgements

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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.

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Development of Web Application to Determine the Cost Economics of Agricultural Machinery

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Farm mechanisation accelerates faster agricultural growth through efficient use of machines by ensuring timeliness of agricultural operations, reducing cost of operation and by reducing human drudgery. Farm Machinery ownership and operating costs represent a substantial portion of total crop production expenditure. Cost economics becomes important for the farm machinery managers to control the machinery costs per hectare. Manual procedure of determining the cost economics of agricultural machinery is a time consuming process and finally making a smart decision whether to buy a farm machine or to go for custom hiring is a cumbersome process. Therefore, a web application was designed for the naive users to help the users in making the decision. The user is asked to enter the basic data pertaining to the farm machine and the software decides whether to acquire a farm machine or to go for custom hiring. The cost of operating a farm machine can be computed with ease by using the web application. Further, break-even-point, payback period and benefit-cost ratio can also be determined with a single click.

ERRATA

We mistook Dr. M. K. Ghosal's photo for Dr. M. Din's photo, and vice versa in Vol. 47 No.3 (p. 54). The right identities as below. We apologize to them and all our readers for our mistakes.

The title of their manuscript:
Design and Development of Cup in Cup Feed Metering Seed Drill for Seed Pattern Characteristics Study of Paddy Seeds

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EVENT CALENDAR

◆ **AGRICONTROL 2016**
—The 5th IFAC Conference on Sensing, Control and Automation for Agriculture—
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August 25-27, 2016, Jakarta INDONESIA
http://www.inagritech-exhibition.net/#axzz3zFynVBGC

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September 2016, Szeged HUNGARY

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October 12-14, 2016, Des Moines, Iowa, USA
https://www.eventbrite.com/e/2016-borlaug-dialogue-and-global-youth-institute-oct-12-15-registration-26211502309

◆ **10th CIGR Section VI Symposium**
—Food: the tree that sustains life—
October 24-27, 2016, BRAZIL
http://www.ufrgs.br/sbctars-eventos/xxvcbcta/en/

◆ **ICAS VII**
—International Conference on Agricultural Statistics (FAO)—
October 26-28, 2016, Roma, ITALY
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http://www.ciame.net/

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◆ **BICET 2016**
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http://www.itb.edu.bn/bicet2016/

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—India's Largest Agri Show—
December 14-18, 2016, Pune, INDIA
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◆ **XXXVII CIOSTA & CIGR Section V Conference**
June, 13-15, 2017, Palermo, ITALY
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NEWS

◇ Yoshisuke Kishida's Celebration Party Was Successfully Held

As we mentioned in the previous issue, the President and Chief Editor of AMA, Yoshisuke Kishida, was awarded the decoration of KYOKUJITSU SHOJUSHOU (THE ORDER OF THE RISING SUN, GOLD RAYS WITH ROSETTE) from Emperor of Japan. The celebration party was held on September 16th at the Palace Hotel Tokyo. More than 300 people attended the party including foreign visitors. The visitors from overseas made warm speeches. They were Dr. Gao Yuanen from China, Dr. Bill Stout from U.S., Dr. Gonchigdorj Enkhbayar from Mongolia and Dr. Oleg S. Marchenko from Russia. We sincerely thank all of them for their thoughtfulness.

About 90 people from more than 30 countries gave him celebratory messages. We also thank all of them for their kind words.

Mr. Kishida said, "On the occasion of this honorable event, I am newly resolved to make further contribution for the development of agricultural mechanization in the world."

Mr. and Mrs. Kishida with the decoration

The party's hall

Dr. Gao Yuanen from China

Dr. Bill Stout from U.S.

Dr. Gonchigdorj Enkhbayar from Mongolia

Dr. Oleg S. Marchenko from Russia

■■

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

(Vol.45, No.4, Autumn, 2014-)

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INSTRUCTIONS TO AMA CONTRIBUTORS

The Editorial Staff of the AMA requests of articles for publication to observe the following editorial policy and guidelines in order to improve communication and to facilitate the editorial process:

Criteria for Article Selection

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

a. are written in the English language;
b. are relevant: to the promotion of agricultural mechanization, particularly for the developing countries;
c. have not been previously published elsewhere, or, if previously published are supported by a copyright permission;
d. deal with practical and adoptable innovations by, small farmers with a minimum of complicated formulas, theories and schematic diagrams;
e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
f. are printed, double-spaced, under 3,000 words (approximately equivalent to 6 pages of AMA-size paper) ; and those that
g. art: supported by authentic sources, reference or bibliography.
h. written on CD-R.

Rejected/Accepted Articles

a. As a rule, articles that are not chosen for AMA publication are not returned unless the writer(s) asks for their return and are covered with adequate postage stamps. At the earliest time possible, the writer(s) is advised whether the article is rejected or accepted.
b. When an article is accepted but requires revision/modification, the details will be indicated in the return reply from the AMA Chief Editor in which case such revision/modification must be completed and returned to AMA within three months from the date of receipt from the Editorial Staff.
c. The AMA does not pay for articles published.
d. Complimentary copies: Following the publishing, three successive issue are sent to the author(s).

Procedure

a. Articles for publication (original and one-copy) must be sent to AMA through the Co-operating Editor in the country where the article originates. (Please refer to the names and addresses of Co-operating Editors in any issue of the AMA). However, in the absence of any Co-operating Editor, the article needs to be sent to Co-operating Editor in the writer's neighboring country.
b. Contributors of articles for the AMA for the first time are required to attach a passport size ID photograph (black and white print preferred) to the article. The same applies to those who have contributed articles three years earlier. In either case, ID photographs taken within the last 6 months are preferred.
c. The article must bear the writer(s) name, title/designation, office/organization, nationality and complete mailing address.

Format/Style Guidance

a. Article must be sent on CD-R with MS DOS format (e.g. Word Perfect, Word for DOS, Word for Windows... **Absolutely necessary TEXT FORMAT**) along with two printed copys (A4). Or it must be sent by E-mail with Word File and PDF File attached.
b. The data for graphs and photographs must be saved into piecemeal data and enclosed (attached) with the article.
c. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features:
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   (iii) an abstract following ii) above;
   (iv) body proper (text/discussion);
   (v) conclusion/recommendation; and a
   (vi) bibliography
d. The printed copy must be numbered (Arabic numeral) successively at the top center whereas the disc copy pages should not be number. Tables, graphs and diagrams must likewise be numbered. Table numbers must precede table titles, e.g., "Table 1. Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Figure 1. View of the Farm Buildings".
e. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
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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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