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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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EDITORIAL

Half a year has passed since the Great East Japan Earthquake on 11th of March 2011. Many helping hands were held from various countries. As one of the citizens in Japan, I would like to express my sincerest gratitude to all the people who helped us.

During the extremely long history of Earth, there have been many tragic disasters. Some of them even terminated almost all the lives on Earth. The earthquake taught us many lessons; we have learned that we should always think about how to deal with unprecedented disasters.

After the Great East Japan Earthquake hit the eastern coast of Japan, one of the 50 nuclear plants in Japan, Fukushima Daiichi, was severely damaged by the tsunami. There were also hydrogen explosions, which spread radioactive materials into vast areas. It polluted forests, farms, and buildings. In Fukushima, nobody has been able to live near the nuclear plant, even up to right now. However, people of Fukushima, especially the farmers, have a strong will to rebuild their hometown and restart their agriculture by decontaminating radioactive pollution. People are anxious to introduce special agricultural machinery, such as a tractor to remove a few centimeters of surface soil precisely, or a special truck to load contaminated objects. Farmlands damaged by the salt of the tsunami need to be cleaned up and many agricultural machines are needed in this operation. This decontamination effort will be the main work of agricultural machinery manufacturers who lost their work after the earthquake.

Some of the agricultural products were also contaminated, and a part of them was accidentally shipped out. Regarding this, the government of Japan has given their best effort to check out all the radiation contamination of agricultural products and ship out safe food all around Japan. Related to the accident that permitted the shipment of contaminated products, there is a focus on the traceability of food. Many traceable foods are beginning to be sold in markets. Systems for traceability have been organized such as GAP. Because of the nuclear plant accident, they should add “radioactive materials” as a checking category from now on. Before the accident, people weren’t so much interested in radioactive pollution, and the pollution level was not checked precisely. We may have been eating some polluted food before the accident.

Regarding the accident of Fukushima Daiichi, we have been saving electricity this summer, as a countermeasure. There were creative ideas such as setting the cooling temperature of air conditioners 2 or 3 degrees higher. Thanks to the citizen’s cooperation, we have saved enough electricity to compensate for the electric power plants that cannot be used. Today, many Japanese citizens are very afraid of a Nuclear Power Plant, and many can not be operated since they need to be checked. Using nuclear electricity is one of the efficient ways to prevent increased carbon dioxide. However, if this type of power results in many dangerous accidents, we need to start thinking about using alternative energies. The demand for renewable energies, such as wind power, or biomass energy may grow rapidly from now on. The accident was a tragic one, but it gave us many important messages. This experience will be used to save other countries in the future. Japan may use more fossil fuels than before for some time to come since we need to activate more fired power plants to cover the loss of nuclear power plants. This is inevitable since renewable energies are very expensive for now. However, there is some research to create new biomass energy, such as creating energy from algae. People are looking forward to the coming day of introduction. Global food price is greatly rising because of the enormous amount of corn and wheat used for fuel. Renewable energy without using food is an urgent need, as well as promoting agricultural machinery to increase the land productivity.

Yoshisuke Kishida
Chief Editor

October, 2011

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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Farm Mechanization in Bhutan

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Abstract

There is a potential for further farm mechanization in Bhutan with immediate attention given to paddy. There is also mechanization potential for other root and cash crops like potatoes, oranges and apples. It can be said that there is a need for exploration of existing technology that would be beneficial to the country's need. Although, strong support from a Japanese grant (2KR) has existed for almost more than 20 years there continues to be a need for further studies to adapt the available technology for Bhutanese farmers.

Introduction

Bhutan is a small country landlocked between the China and India with land area of 38,394 sq km of which 72.5 % is forest cover (NSB 2006). It has a total population of 634,982 (Population and Housing census (2005)). The Rural-Urban population distribution is 2.4. The agricultural sector is the dominant sector with 63 % of the population that contributes 22.4 % of the gross domestic product (GDP) to Bhutan's economy. Of the total land area, 7.8 % is used for agricultural purposes. The average land holding of 90 % of the farming community and is less than 5 acres (1 acre = 0.4 ha), which is also associated with higher slope and small terraces such as shown in **Fig. 1**.

Farm mechanization alone cannot achieve a sustainable and better socio-economic situation. A coherent and a holistic policy approach from other sectors should be built into a creation of convenient and wholesome agricultural development. Setting up large scale industries in Bhutan is limited by resources and markets. The only viable solution for long-term sustainability of farming is to increase the labour productivity and alleviate drudgery and improve the outlook with improved technologies. It would be by either developing within the country or procuring from outside and introducing into the country. Farming is still done by primitive methods leading to higher cost of production that is economically not viable.

The present scenario of farm mechanization and intervention made in mainly paddy cultivation is presented in this paper along with a few recommendations.

Present Situation

Bhutan, being in a sub tropical zone, is suitable for all types of crop cultivation but has been limited due to geographic terrain. Rice cultivation is predominant in low land and is second to maize and potato cultivation in the whole country. The major crops grown along with the area covered and yield are shown below in **Table 1**.

Being subsistence in nature, farming in Bhutan is associated with drudgery and is labour intensive. Also, farming is still carried out with animal and human power. The average labour days of 72-95 per acre (180-237 per hectare) is much higher than in a country like Philippines (70-100 labour days

Fig. 1 Picture of a common rice field in Bhutan

Table 1 The major crop production, area and yield

Crop	Area (Acre)	Production (MT)
Paddy	46,585	54,325
Maize	53,938	90,566
Barley	2,789	1,421
Wheat	7,583	4,191
Potato	8,455	47,403

Source : MoA, Agriculture Stat. 2004

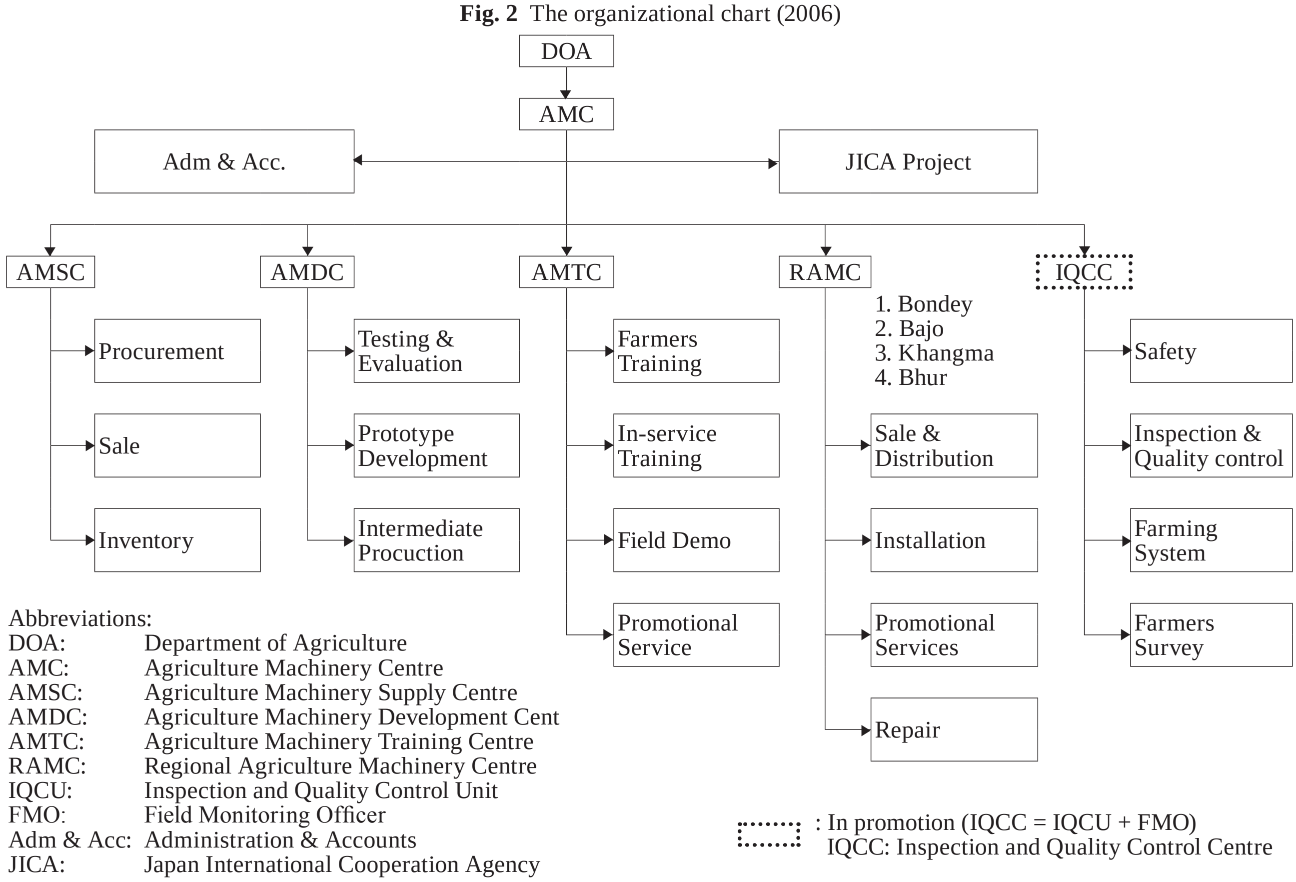
per hectare) (Kencho and Swinkle, 2003) for rice cultivation. Many households respond to the shortage of farm power by scaling down their activities, reducing the area under cultivation (by up to 50 %) and growing a limited range of crops. They struggle to keep pace with the seasonal calendar which results in taking short cuts in one season and are the normal ways of doing farming in Bhutan. However, some of the farming activities in some places have seen a great change. On top of the shortage of labour, the farming community is affected by the continuous rural to urban migration. The migration however, is not due to better employment opportunities in terms of the income and satisfactory jobs available elsewhere, but rather, to a large extent, due to the attraction towards modern amenities.

Strong support from the government is there for promotion of farm mechanization. The Ministry of Agriculture, through its “triple gem” concept, seeks to improve agriculture by enhancing productivity, improving accessibility and strengthening marketing. This concept is geared in support of the 10th plan objective of poverty reduction. Various service institutions with strong linkages have been set up like Research Centers and extensions in support of the farm mechanization program. Waving of taxes and duties for import of agricultural machinery from a third country is also there. Subsidy in some form like price for cash crop, transport on farm machinery, and financial support in the form of loans with a low interest rate of 12 % per annum (BDFC 2005) are provided to farmers for procuring farm machinery.

Besides, to have an efficient and effective promotion of a farm mechanization program, the Agriculture Machinery Centre (AMC) was established in 1983 with strong support from the Japanese Grant. Now the centre is facilitated with four Regional Agriculture Machinery Centres (RAMC), Agriculture Machinery Development Centre (AMDC), Inspection and Quality Control Centre (IQCC), Agriculture Machinery Training Centre (AMTC) and a Sales and Procurement unit (AMSC).

The four RAMCs functions as the main distribution centre for

Fig. 2 The organizational chart (2006)



technology transfer to the farming community. The RAMC provides main linkages between the AMC and the farming community. All the backup services like installation, repair, training, and sales required by the farming community are being provided through the RAMCs. As shown in **Fig. 2**, the regional centres (Bondey, Bajo, Khangma and Bhur) are spread throughout the country.

As more and more new types of machines flow into the country, the standardization of the farm machinery has become very important and especially that the safety aspects are carried out. This led to the inception of a new centre, the IQCC, in 2006. The centre functions as the governing body to provide quality assurance of the farm machinery that flows into the country.

The farm machinery, either received as grant aid (2KR) from Japan (96 % of the total population of the machinery) or procured from a third country (2 % of the total population of the machinery), are sold to the farmers by AMSC at the government approved subsidy. Subsidies are either in the form of price for 2KR machinery and indirect for others. Other subsidies are in the form of technical backstopping like training for machinery users. Various types of training for proper transfer of farming technology to the farming community are being imparted by the AMTC.

The role of R & D in the promotion of farm mechanization has been very important in Bhutan. Although, there has been very little research and development of small implements and tools until now, there has been much intervention for the promotion of machines and transfer of technology. The machinery that comes into the country is tested for quality, demonstrated to farmers and a few are modified to suit the local condition. Private firms have also assisted with technical guidance in conducting trials and making modification of machinery and tools for long term sustainability. With this R & D mechanism (**Fig. 3**), some machinery has been very popular in the country.

Interventions/Progress in Agricultural Mechanization

The interventions in Bhutanese farming is aimed at ending drudgery, saving costs and, improving yield through the use of suitable farm machinery, tools and implements and sustainable farming practices. Agricultural work is carried out by traditional methods using rudimentary tools and implements. Farming is characterized by back-breaking work with low productivity. The largest share of the intervention made in farm mechanization is through the 2KR Grant. Machinery received through the grant is sold at subsidy. The proceeds are either used for agricultural development or for the procurement of other farm machinery for resale to the farming community. Some of the machinery that has gained popularity in the country and highly demanded at present is shown in **Table 2**.

Status of Farm Mechanization

Farm operations are mostly done manually using human and animal power. A very small amount of mechanical power is available for farm operations.

Land Preparation

Breaking the land surface and loosening it to be readied for sowing and planting is the most difficult work. Traditionally land preparation is done by digging the surface with

Fig. 3 The R & D Mechanism for promotion of farm machinery in the country

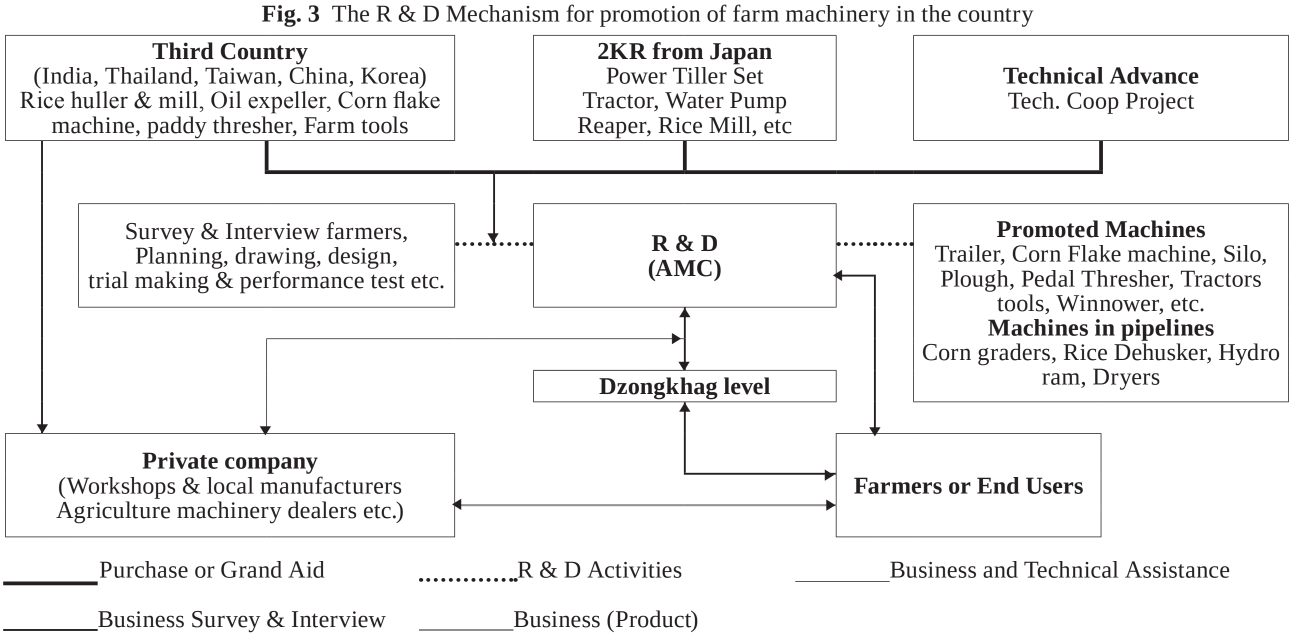


Table 2 Farm machinery, tools and implements supplied till from 1984 until Dec. 2006

Description	Total(nos)
Tractor	215
Power tiller	1,982
Power thresher	198
Power Reaper	88
Paddy transplanter	53
Water pump	216
Oil mill set	163
Rice mill	1,292
Flour mill	1,205
Corn flake machine	137
Pedal Thresher	1,287
Tools & Implements	363,143

Source : AMC, Data Manager, 2006

a spade or hoe or by ploughing with draft animals as shown in **Fig. 4**. It is very labour intensive and time consuming. Much of the drudgery is alleviated with the use of improved ploughs and machinery, such as the power tiller and tractor, while labour productivity is drastically improved. With the use of improved ploughs there is almost 2.5 man-days saved from the used of the traditionally plough. Use of the power tiller for plowing results in almost four times more area coverage than by ploughing with animal power (AMC pamphlet, 2006). Due to small terraces and steep slope (>18 %) use of tractors are restricted to the few low flat lands. There is very little noticeable impact on the use of tractors in the fields of Bhutan (See **Figs. 5** and **6**).

Seeding and Transplanting

Traditionally transplanting is done mostly by women as shown in **Fig. 7**. It is a hard job involving hours of bending to reach the ground as they plant the seedlings and sow in the seeds. Seeding is mostly done by broadcasting for seeds such as oilseeds and wheat. For paddy, nurseries are raised either traditionally (dry bed method) or by modern methods such as poly tunnels and greenhouses. Commonly, the seedlings are planted randomly into the prepared field. With the traditional method, rice transplanting consumes 18 % of the labour requirement (Kencho, 2003) that is highest in rice cultivation. New methods of transplanting with machines and line planting (**Fig. 8**) make the transplanting job much easier. It is, also, more efficient and labour saving.

Weeding

Weeding is a critical activity and a physically demanding job with a major determinant factor of final yields. Traditionally weeding is done manually by women using a hand hoe or uprooting manually as shown in **Fig. 9**. Chemicals are also used, when farmers can afford them. Also in a few paddy fields, weeding is done using a manual type rotor weeder (**Fig. 10**) making work easier and more efficient.

Spraying

Spraying is commonly used in fruit crops. It is done using spraying machines imported from other countries. Due to the ban on chemicals, spraying works are not very common in Bhutan.


Fig.4 Modified Bull plough


Fig. 5 Traditional plough

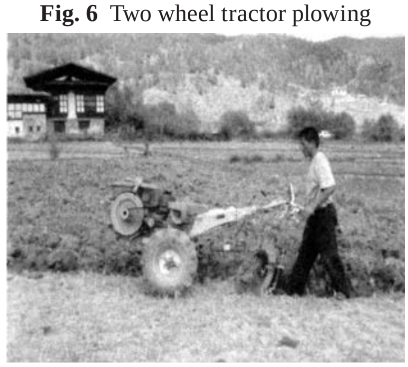


Fig. 6 Two wheel tractor plowing


Fig. 7 Manual Transplanting (random)

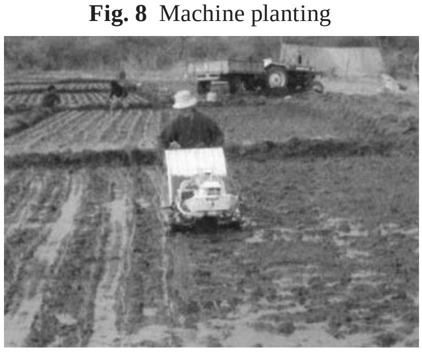


Fig. 8 Machine planting

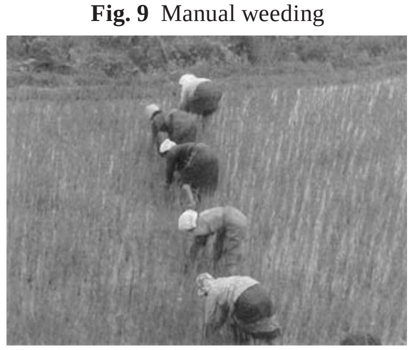


Fig. 9 Manual weeding

Harvesting

A study has shown that 14 % labour (Kencho, 2003) is required in paddy harvesting. This is very high compared to other countries. In fruit crops, hand picking is common. For other crops, the spade and sickle are common. In paddy and wheat, a serrated sickle is more efficient and has become popular among the Bhutanese farmers (**Fig. 11**). A few farmers have started using walking type reapers, as shown in **Fig. 12** this has shown to save 20 labourers. This technology is gaining popularity in Bhutan but, due to a lack of source for such a machine, the popularity and advantages are still not seen by many farmers. The combine harvester is normally not very feasible as the size of the terraces and slope is not suitable for such a machine.

Threshing

Threshing is done manually by treading with the feet, threshing with long sticks and beating on flat stones and logs (**Fig. 13**). Not only is this method physically exhausting, a substantial amount of grain is lost or damaged in the process. Many rice growing farmers have used the pedal thresher since its introduction. Study has shown that about 60 % of the total labour required for threshing has been saved by using a pedal thresher, as shown in **Fig. 14** (Rice cultivation in Bhutan, 2003). Power threshers are not very common as they are expensive and not readily available. Moreover, with small land holdings, especially with paddy fields, the average production does not justify owning the power threshers individually. Therefore, group users are encouraged, but the efficient and cheap machines are not available. Developments of a pedal thresher and a simple threshing machine are under way in the Research Division.

Post Harvest Operation

Post harvest operations like drying of cereal crops are done in the sun. In the traditional method, crops such as maize are stored and dried by hanging in the roof trust or in the attic of the Bhutanese house. This method is not safe from insects, pests and rodents but the farmers have no choice. Moreover, for efficient drying, mechanical dryers or improved dryers are not common in the country. Direct storage after harvesting is common, which damages the crops due to high moisture content. The most common methods of storage are use of wooden boxes (**Fig. 15**), bamboo baskets (**Fig. 16**), gunny bags, oil drums, plastic containers and mud structures. With this method, loss is as high as 30 % to 40 % and is very high compared to other countries. At present, research is underway with the introduction of forced air dryers and metal silos for storage in the farming communities.

For the milling operation, small scale rice mills, flour mills and oil mills are used. The machines are imported from India. Although they are not very efficient, they have gained much popularity throughout the country. At present, there are 3,000 micro enterprises with these

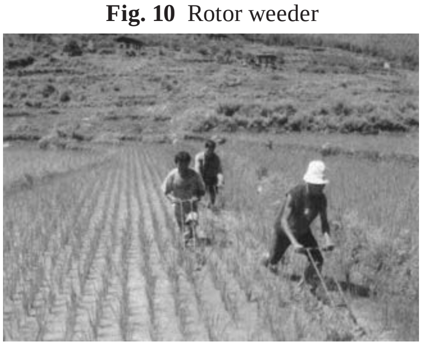


Fig. 10 Rotor weeder

Fig. 11 Sickle harvesting

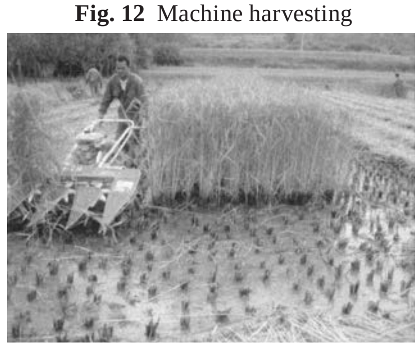


Fig. 12 Machine harvesting

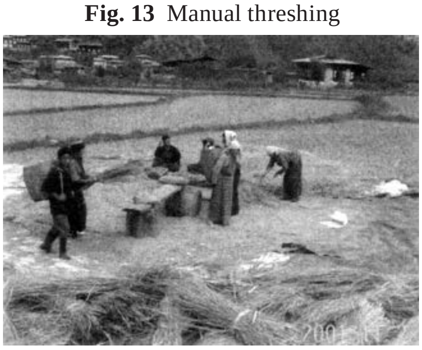


Fig. 13 Manual threshing

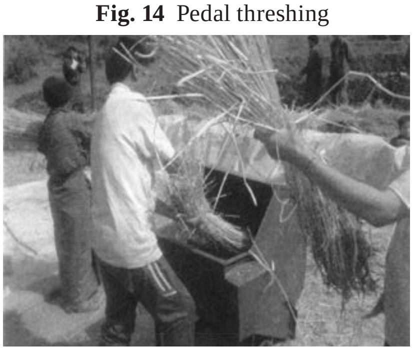


Fig. 14 Pedal threshing

Fig. 15 Storage by wooden box

processing units. There are very few traditional mills in the rural areas.

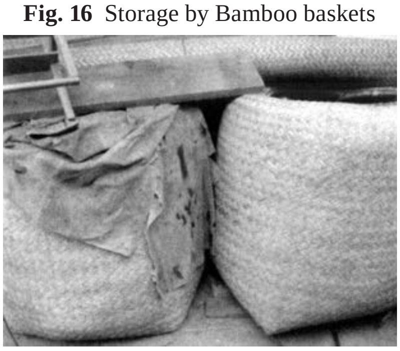
Manufactures and Workshop Facilities

Since farm mechanization is a new area in the country, there are very few local manufacturers. Fabrications like the metal silo, plow parts, small corn flake machines, pedal threshers, manual winnower, plow and hand tools are carried out at present. With very limited knowledge on farm machinery manufacturing, the private firm is mostly involved in importing the farm machines for supply to farmers. Repair workshops are very limited and repair work is done at government owned farm machinery repair workshops under the Ministry of Agriculture.

Conclusion and Recommendations

This paper has mainly focused on the mechanization of paddy cultivation that is prevailing in Bhutan. There is a potential for further farm mechanization. Although, paddy mechanization is presently prominent, there is also a potential for other root crops and cash crops like potatoes, oranges and apples. There is also a need for exploration of existing technology which would be beneficial to our country's need. Although, strong support by Japanese grants (2KR) for almost 20 years has been there, further studies must be done to make the available technology suitable to our farmers. A few of the recommendations that could be drawn from this paper are listed below.

Fig. 16 Storage by Bamboo baskets



- There is a need of a certification body to certify farm machines for quality control and standardization while importing.
- The private firms for import of farm machinery have to be encouraged. Better technology transfer mechanism needs to be established.
- R&D activity in machinery, and technology generation has to be upgraded.
- Upgrading of knowledge at various qualification levels through formal and informal education is very crucial at this developmental stage.
- Upgrading the knowledge of the farmers, the staff and the education system in the country must to done to bring in proper farm mechanization that can contribute to the economic growth of the country.

Although tremendous improvement in the quality of life in our farming community has been seen over 20 years due to the support of the grant, there is still lot of room for improvement. Level and appropriate choice of agricultural mechanization has to be carefully examined as it has direct effect on land and labor productivity, farm income, environment and the quality of life of farmers. Hence, basic farm mechanization requirements that cater to the needs must be met. These include such things as suitably for small farms, simple design and technology, versatility for use in different farm operations, affordability in terms of cost to farmers and, most importantly, the provision of support services from the government and the private sector. Thus, this paper further urges the reader to support and provide guidance for providing better quality life to the Bhutanese farmers.

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Mechanization and Economic Analysis of Wheat Production in Iran

by
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Abstract

Indicators have been used for determination and assessment of the status of wheat production in Iran. First, a descriptive analysis was performed on the production of wheat in the 2001-2008 period. The results revealed that, generally, production of wheat had a positive growth in this period. The Cobb-Douglas production function was estimated to identify the importance of inputs in the production to the wheat output. Different models were built to justify the production status of wheat. The survey was carried out with data obtained from The Ministry of Agricultural Jihad (MAJ).

Data included the mechanization ratio based on area of machinery use and number of wheat farmers who use agricultural machinery in the entire studied area. It also included the average cost of production for each operation, production characteristics of wheat such as economic indices, area of cultivated land for modeling wheat yield, land under cultivation of wheat (ha) and cost per unit of wheat production ($ kg^{-1}) as output. Agricultural mechanization has an important role in improvement of wheat production in Iran. Levels of mechanization in each agricultural operation have had different effects on yield improvement. The high value of R^2 of models showed the robustness of selected factors as input for modeling the desired output.

Introduction

The Iranian government has a long history of subsidizing wheat as a staple food. Wheat is one of the most valuable crops and an important commodity in Iran. The governments have followed a program of general subsidy on bread to support consumers in Iran. Within the production factors of wheat, because of semi mechanized structure of wheat farms, agricultural mechanization has an important role to change the status of its production in Iran.

Agricultural Mechanization embraces the use of tools, implements and machines for agricultural land development, crop production, harvesting, storage, and on-farm processing. It includes three main power sources: human, animal, and mechanical. The manufacture, distribution, repair, maintenance, management and utilization of agricultural tools, implements and machines is covered under this discipline with regard as to how to supply mechanization inputs to the farmer in an efficient and effective manner.

Mechanization technologies keep changing with industrial growth of the country, and socio-economic advancement of the farmer. Whereas, declining interest in agriculture of the landowners and non-availability of the agricultural labor for field operations may be one of the major socio-economic issues in highly industrialized nations, increasing land and labor productivity with dignity are the mechanization requirements of the developing countries. Mechanization technology is, therefore, location-specific and dynamic. The quality of inputs of mechanization, and consequently land and labor productivity in both situations, may differ considerably (Gifford & Rijk, 1980; Singh, 1997 and 2000; Singh & Chandra, 2002).

Acknowledgment

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Several authors have studied the status of mechanization with reference to the intensity of power or energy availability, and its impact in increasing the agricultural and labor productivity. Giles (1975) reviewed power availability in different countries, and demonstrated that productivity was positively correlated with potential unit farm power. The NCAER (1981) assessed the impact of tractorization on the productivity of land (yield and cropping intensity), and economic growth (income and employment). However, the trends for European and Asian countries were distinctly different. Binswanger (1982) defined the status of mechanization by the growth of mechanically power-operated farm equipment over traditional human and animal power operated equipment. Rijk (1989) reviewed the growth of mechanization in different Asian countries, and suggested computer software (MECHMOD) for the formulation of strategy for mechanization policy based on economics of use of animate and mechanical power for different field operations.

It is of utmost importance to examine whether the use of machines has been economical or not. Singh (1986) on the basis of a sample of 35 combine harvesters reported that the average area covered by a combine harvester of small size was 192.1 acres of wheat and 173.6 acres of paddy. With an average rate of Rs.210 per acre, annual gross return of Rs.76,203 was estimated while the annual fixed and operating costs were Rs.48,538, thus, showing a net profit of Rs.27,664 during 1984-85.

Screening products, populations, or territories for exceptional changes in the demand for products or services is an important management activity, whether to prevent losses or to take advantage of opportunities. In either event, managers must make decisions that interrupt normal operations and reallocate resources. To trigger such activity, time series monitoring has the purpose of automatically detecting outliers and structural changes in time series data, such as step increases or decreases, as soon as possible after they occur and with sufficiently few false alarms (Editorial, 2009).

Spatial and temporal changes in precipitation and temperature patterns will, thus, have major impacts on the viability of both dry land and irrigated farming (Benhin, 2008). The ability of crop simulation models to predict growth and yield as influenced by the environment, agronomic practices and crop traits suggests that such models can identify traits to increase yield potential (De Wit, 1965; Lu, 1993; Reynolds *et al.*, 1996). Hung and Tang (2006) studied the effects of the five key agronomic factors (sowing date, seedling density, Nitrogen application, Phosphate application and Potassium application) on wheat yield to build up the production management models. Their results indicated the differences in the importance of the respective factors to wheat yield among different ecological environments. In another study Knox *et al.* (2010) assessed the spatial and temporal impacts of climate change on irrigation and yield for sugarcane grown in Swaziland by combining the outputs from a general circulation model, a sugarcane crop growth model and a GIS. Al-Karablieh *et al.* (2002) forecasted wheat production in Jordan. Based on their work, the variables affecting wheat production in the selected region were the early monthly rainfall and cultivated areas of wheat. In the presence of these variables, temperature and number of rainy days have insignificant effect on the prediction of wheat output. Analysis showed that rainfall was the major factor in increasing wheat production.

The total wheat cropped area in Iran is currently more than 2,781,939 ha having increased from 2,162,064 ha in the 2001 (Anonymous, 2010); further irrigation developments are underway which will result in an additional 619,000 ha being cultivated. This will add pressure on already strained water resources, and is likely to lead to increased tensions. At present, wheat irrigation needs approximately 7,200 m^3 ha^{-1} depending on variety, soil and agro climate conditions. Iran has experienced ups and downs in wheat production. A negative relationship was observed between flour prices and the wheat production. However, surplus of wheat production was observed in only a few years. In such periods farmers suffered heavy losses due to inadequate marketing facilities in the country.

The objective of this study was to conduct a preliminary assessment of production factors effects on wheat production in Iran and then use technological factors for modeling wheat yield in the period of study (2001-2008).

Material and Methods

One way to know about what inputs are crucial in the production of wheat output is to calculate elasticities of wheat output with respect to these inputs. These elasticities can be found by estimating a production function with an appropriate functional form. To know what inputs are crucial in the production of wheat output, the study estimates Cobb-Douglas production.

The study proposes the following specification of production function:

$$In\ Y_i = \alpha_0 + \sum_{j=1}^{9} \alpha_j\ In\ (x_{if}) + e_i ..... (1)$$

Where Yi denotes wheat output per hectare the ith year, xij the vector of inputs used in the production process, α_0 constant term, α_j represents coefficients of cost inputs that are estimated from the model and ei is the error term. Log wheat output per hectare is assumed to be a function of different sets of factors such as cost of inputs and mechanization ratio in different stages of wheat production.

Two indices were used to provide information about the mechanization status of wheat farms of Iran for studying production systems of irrigated wheat. **Eqn. 2** shows the mechanization level of farms by dividing those agricultural operations done by farm machinery by the total area of the farms or, in other words, the total area of farms that needs mechanized operations.

$ML = A_m / TA \times 100$ ....(2)

where ML is the mechanization level, Am is the mechanized area of farms and TA is the total area of farms or all of farms that needs mechanization.

The second index used in this study was the Mechanization Ratio (MR) that introduced a proportion of mechanized farmers to the total number of wheat farmers. This index determines the distribution pattern of machinery users in crops. According to the some domestic cultures, distribution of farm machinery is so important because farmers in some regions like to maintain their independence and only do operations themselves and do not work on strange farms. This situation has negative effects on the agricultural system and prevents full capacity of agricultural machines to be employed. **Eqn. 3** shows the MR index.

$MR = M_f / TF \times 100$ ....(3)

This study on mechanization of wheat farming in Iran was conducted in the period of 2001 to 2008. The survey was carried out by means of data obtained from the Ministry of Agricultural Jihad (MAJ). Data were collected from all Iran provinces and included mechanization ratio based on area of machinery use, and the ratio of number of wheat farmers who used agricultural machinery to the entire studied area of farmers, average cost of production for each operation, production characteristics of wheat such as economical indices, and area of cultivated land for modeling wheat yield as output.

The coefficients that were obtained from estimating the Cobb-Douglas production function were important. They identified how much wheat output per hectare was influenced in percentage terms due to one percent change in the independent variable and these coefficients were used for finding predicted values of wheat output on the nationwide and aggregate level. Forecast needed two important pieces of information. These were a) future value of inputs used in wheat production and b) the parameters (elasticities) that link inputs to wheat output. The elasticity parameters were obtained from the estimated production function as mentioned above.

Results and Discussion

A descriptive analysis was performed on irrigated wheat production in Iran. Economic analysis revealed that the mean of total cost of production was \$337.99 US ha^{-1} in the 2001-2008, which had an increasing rate. Cost per kg of wheat was \$0.10 US and gross return was \$196.75 US ha^{-1} in the same period. **Table 1** shows the descriptive statistics of wheat production. The production costs has been estimated to \$0.26 US kg^{-1} for the enterprises using direct plantation machines and to 0.31 US \$ kg^{-1} for the enterprises using conventional systems in Turkey (Duygu *et al*., 2010).

Fig. 1 shows the growing trend of area under wheat cultivation (ha) in the period. Increase in area of an irrigated crop indicates growth of that country to produce self food, especially wheat in Iran, which has a critical position in food security. **Fig. 2** illustrates changes of average production of wheat in Iran. This graph has a positive incline that shows growth of production. Production of wheat increased from 6,026,978.52 tons in 2001 to 10,575,037.03 tons in 2008. Yield (kg ha^{-1}) had a similar trend to production as that shown in **Fig. 3**.

The changes of the economical properties of wheat farming can be seen in **Fig. 4**. This Fig. shows the trend of gross value of production,

Table 1 Description of irrigated wheat production in Iran

Items	Year								
	2001	2002	2003	2004	2005	2006	2007	2008	Average
Gross value of production, \$ ha^{-1}	227.94	300.61	424.02	501.8	612.73	665.1	769.42	776.33	534.74
Total cost of production, \$ ha^{-1}	165.34	209.86	238.61	273.59	377.92	416.14	495.42	527.06	337.99
Gross return, \$ ha^{-1}	62.559	90.75	185.4	228.2	234.8	248.95	273.99	249.27	196.75
Cost per unit of wheat, \$ ha^{-1}	0.07	0.07	0.07	0.081	0.10	0.11	0.13	0.14	0.10
Area under wheat cultivation, ha	2,162,064.03	2,177,901.33	2,293,844	2,398,606	2,547,632	2,634,106.4	2,706,995.6	2,781,939	2,462,886.04
Production, ton	6,026,978.52	6,651,566.54	8,232,468.6	8,704,683.03	9,750,304.6	9,972,664.9	10,137,769.86	10,575,037.03	8,756,434.13
Yield, kg ha^{-1}	2,787.6	3,054.12	3,588.94	3,629.06	3,827.2	3,785.98	3,745.03	3,801.32	3,527.40

total cost of production and gross return in studied years. Gross value of production had a constant trend in the last year of the period. In this year gross return had a decreasing trend. Therefore, it was concluded that wheat farming in this year was not economically profitable. However, gross value of production had a good growth but, because of total cost of production in the same period, wheat farmers did not enjoy the profit of their farming.

Table 2 shows the average cost of production for each operation of wheat. Almost all wheat production costs are positive growth during the period.

Cost of different farming operations has been compared in **Fig. 5**. Water cost is the highest among farming operations. Iran is located in a semi-arid climate and water has an important role in irrigated crop production, thus, agricultural water supply for wheat production in most areas requires a high cost. Cost of seed and harvesting are placed in second and third place and because of using certified seed in wheat farms, wheat sensitivity and its effects on harvesting losses cannot be changed.

Fig. 1 Trend of changes in area under wheat cultivation

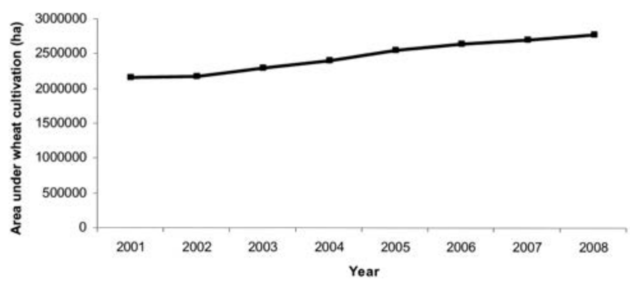


Fig. 2 Trend of changes in production (ton)

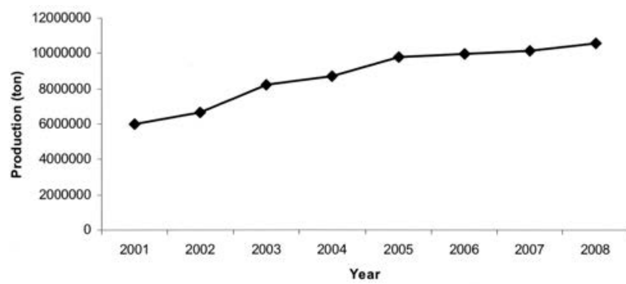


Fig. 3 Trend of changes in yield (kg ha^{-1})

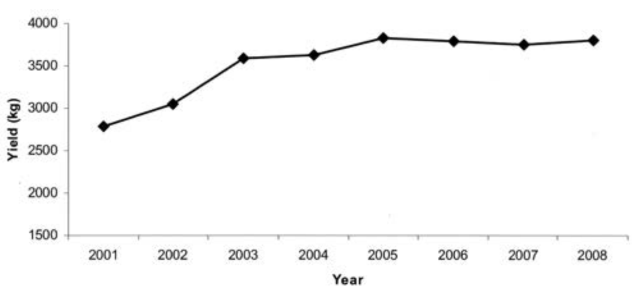


Fig. 4 Trend of changes in economical properties of irrigated wheat production ($ ha^{-1})

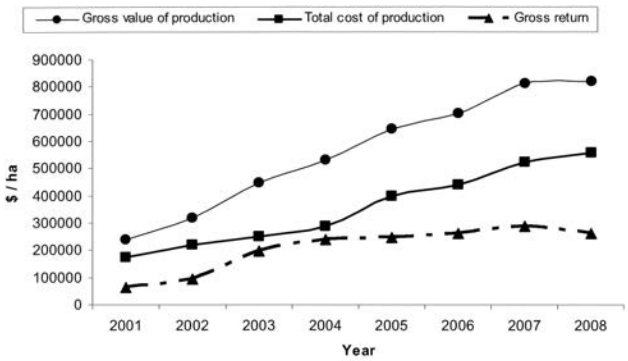


Fig. 5 Comparison of cost among different farming operations

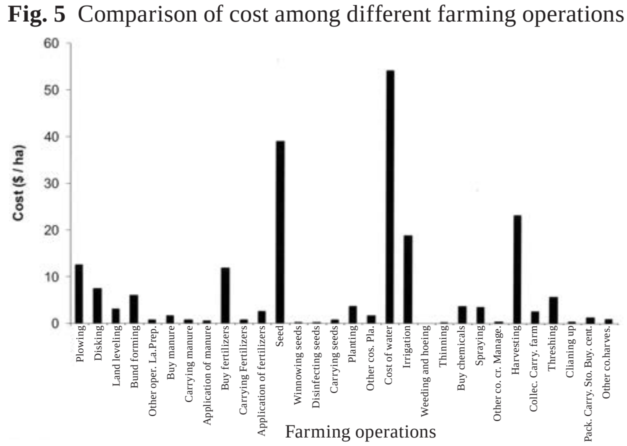


Fig. 6 Trend of agricultural operation costs in the period of study

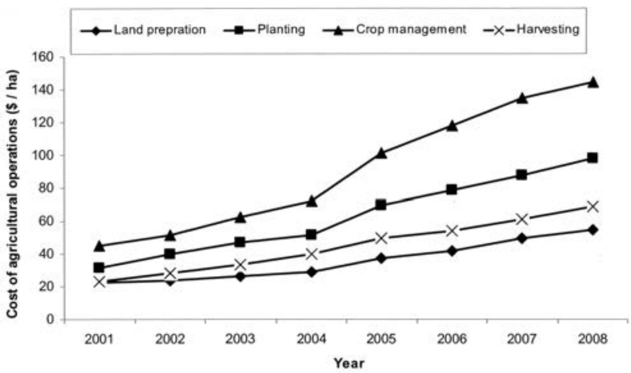


Fig. 6 compares the cost of agricultural operations in different years. According to this Fig., crop management has the highest cost among the other operations followed by planting, harvesting and land preparation in order, respectively. Crop management has a special situation in the agricultural sector of Iran. Consumption of chemicals and fertilizers is beyond the standards because of incorrect culture that is prevailing between farmers. Reformation is required in this case to decrease extra usage of these materials in farms that have negative effects both economically and environmentally. Crop management has grown faster in comparison to other costs, thus, it requires serious attention.

Table 3 shows the mechanization level (ML) of irrigated wheat farms in different operations per year in the specific period. **Table 3** indicates that ML in land preparation is better than the other operations. Agricultural operations have a different trend in ML in the period, illustrated in **Fig. 7**, but average percent of ML has a positive growth due to increasing number of machines per unit of area. ML of land preparation has reached its equilibrium and it

Table 2 Average cost of production for each operation for irrigated wheat ($)

Agricultural Operations	Year								
	2001	2002	2003	2004	2005	2006	2007	2008	Average
Plowing	8.50	9.09	9.67	10.55	13.35	14.89	16.21	18.02	12.53
Disking	4.56	4.86	5.87	6.11	7.75	8.82	10.68	11.12	7.47
Land leveling	1.82	1.94	2.16	2.28	3.27	3.41	4.90	5.42	3.15
Bund making	3.47	3.94	4.30	4.61	6.63	7.43	8.22	9.35	5.99
Other operations	0.35	0.43	0.45	0.50	0.74	0.58	1.05	1.27	0.67
Total of Land preparation	22.49	23.86	26.50	28.77	37.38	41.69	49.48	54.86	35.63
Purchase manure	0.55	0.97	1.36	0.94	1.61	1.87	2.55	2.88	1.59
Carrying manure	0.35	0.49	0.52	0.39	0.59	0.80	0.86	1.18	0.65
Application of manure	0.25	0.33	0.34	0.30	0.56	0.73	0.71	0.97	0.52
Purchase fertilizers	7.51	8.62	8.99	9.60	12.73	13.99	15.78	16.64	11.73
Carrying fertilizers	0.32	0.38	0.44	0.51	0.71	1.05	1.35	1.35	0.76
Application of fertilizers	1.31	1.60	1.90	2.02	2.74	2.91	3.14	4.37	2.50
Seed	17.93	23.63	29.05	32.95	43.80	49.66	54.76	60.17	38.99
Winnowing seeds	0.10	0.05	0.07	0.06	0.14	0.16	0.18	0.39	0.14
Disinfecting seeds	0.20	0.18	0.17	0.20	0.29	0.31	0.33	0.38	0.26
Carrying seeds	0.36	0.37	0.52	0.50	0.79	0.90	0.86	1.09	0.67
Planting	1.69	2.13	2.44	2.78	4.10	4.28	5.28	6.38	3.64
Other costs of planting	1.05	1.26	1.28	1.39	1.77	1.84	1.97	2.06	1.58
Total cost of planting	31.67	40.06	47.13	51.69	69.89	78.58	87.81	97.91	63.09
Cost of Water	28.04	31.15	39.08	45.09	58.73	68.57	78.60	82.43	53.96
Irrigation	8.29	9.58	11.19	13.13	21.74	25.01	28.36	32.62	18.74
Weeding and hoeing	0.01	0.03	0.02	0.02	0.06	0.07	0.07	0.03	0.04
Thinning	0.17	0.37	0.06	0.26	0	0.83	0	0	0.21
Purchase chemicals	2.01	2.27	2.39	2.61	3.53	3.99	5.79	5.83	3.55
Spraying	1.34	1.77	2.06	2.58	4.02	4.33	5.80	6.42	3.54
Other cost of crop management	0.06	0.27	0.26	0.21	0.37	0.38	0.39	0.66	0.32
Total cost of crop management	45.29	51.72	62.70	72.08	101.23	117.96	134.96	144.79	91.34
Harvesting	12.32	14.62	16.87	20.18	25.08	29.07	31.73	34.77	23.08
Collecting and carrying in farm	1.53	1.79	1.96	2.05	2.68	2.81	3.12	3.90	2.48
Threshing	3.81	4.55	5.04	4.95	6.59	6.22	6.46	7.60	5.65
Cleaning crop	0.31	0.22	0.23	0.21	0.26	0.26	0.28	0.45	0.28
Packaging and carrying to store and purchase centers	4.56	6.79	8.87	11.85	14.10	14.69	18.24	21.04	12.52
Other costs of harvesting	0.62	0.35	0.78	0.57	1.10	1.06	1.32	1.18	0.87
Total cost of harvesting	23.17	28.35	33.79	39.84	49.83	54.14	61.18	68.97	44.91

Table 3 Mechanization level (ML) per operation for irrigated wheat (%)

Agricultural Operations	Year								
	2001	2002	2003	2004	2005	2006	2007	2008	Average
Land preparation	40.63	40.56	41.53	41.22	39.14	40.38	43.79	44.53	41.47
Plowing	92.85	96.1	95.74	95.79	94.94	95.15	95.93	93.89	95.04
Disking	78.3	74.86	80.92	78.49	73.86	76.24	80.25	80.22	77.89
Land leveling	51.93	49.85	48.09	49.62	49.17	49.68	57.82	60.8	52.12
Bund forming	46.74	46.88	54.74	52.89	44.38	44.49	49.89	50.96	48.87
Farmyard manure application	0.6	1.94	0.72	0.77	0.26	1.05	3.04	0.75	1.14
Chemical fertilizer application	14.01	14.3	10.51	11.00	11.37	16.09	19.62	25.14	15.25
Planting	41.74	44.48	49.77	47.77	44.85	44.15	54.45	55.81	47.87
Crop management	9.13	11.23	10.42	12.45	12.84	11.76	15.68	15.13	12.33
Irrigation	1.14	3.1	0.04	0.56	0.8	0.22	2.31	1.46	1.20
Weeding and hoeing	0.08	0.06	0.09	0.01	0.12	0.02	0.46	0.01	0.10
Spraying	35.31	41.77	41.56	49.25	50.46	46.83	59.95	59.06	48.02
Harvesting	71.27	73.05	79.95	84.08	82.09	84.7	84.08	87.4	80.82
Harvesting by combine	63.52	63.48	74.73	79.53	75.66	77.64	78.01	80.16	80.16
Harvesting by mower	7.62	7.62	5.09	4.52	6.27	6.73	6.05	7.22	6.61
Harvesting by other machines	0.13	0.12	0.13	0.03	0.16	0.33	0.02	0.02	0.11
Post harvesting (Threshing)	17.29	15.91	12.13	10.47	13.45	13.34	9.85	10.61	12.88
Average	32.23	33.02	33.87	34.33	33.26	33.71	36.97	37.57	34.37

is constant. Most values of ML are related to the harvesting. Although the effective role and suitable situation of combines in Iran was satisfying, mechanized crop management needs to be expanded. Gradually, the use of separate threshing units has been declining.

The highest ML among agricultural operations of wheat belonged to plowing while weeding and hoeing are the non-mechanized operations. The present eight-year study illustrates the actual situation of mechanization status of the wheat crop in Iran. Manure application, irrigation and weeding and hoeing are the operations that require immediate consideration to improve their condition. In general, land preparation activities are in good condition, because of their characteristic needs to consume high amounts of energy. Combine harvesters are needed that would subsequently reduce wheat harvest losses in Iran. Improving the level of mechanization of operations is essential and inevitable and should be considered by policymakers of Iran. As can be seen in **Fig. 8**, the beginning and ending stages of the production process are better than the intermediate step (crop management). Wheat farmers in Iran play down the crop management step because of lack of knowledge that should be corrected.

Jamal and Rind (2007) designed a study to develop forecasting models for acreage and production of wheat in Pakistan. After evaluating the models, the best factors for justification of desired outputs were selected. They used the last year's wheat area, wheat production, lentil area, lentil production, rapeseed and mustard area, rapeseed and mustard production, total rainfall for the month of August, total rainfall for the month of September and October and the total rainfall for

Fig. 7 Trend of ML in 2001-2008

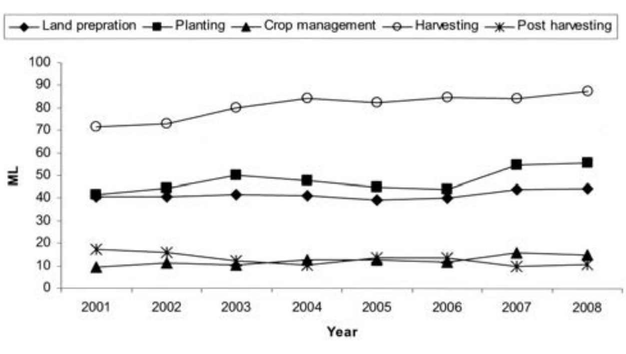


Fig. 8 Comparison of ML among agricultural operations

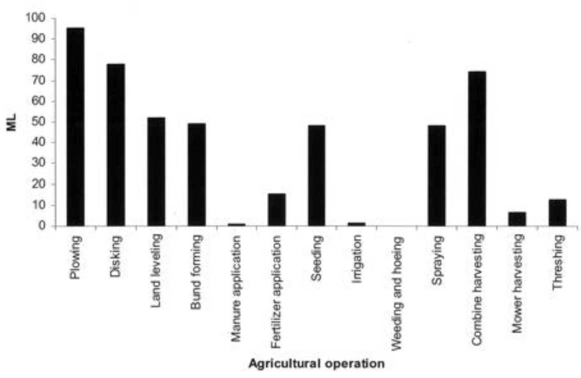


Table 4 MR for each operation of irrigated wheat

Agricultural Operations	Year								
	2001	2002	2003	2004	2005	2006	2007	2008	Average
Land preparation									
Plowing	90.18	91.89	92.55	92.73	94.43	94.32	94.63	95.18	93.23
Disking	63.43	62.68	64.48	63.54	60.97	62.73	66.07	65.46	63.67
Land leveling	31.94	34.34	31.43	37.76	38.01	40.83	44.95	43.18	37.80
Bund forming	30.52	31.98	33.09	33.06	34.07	36.36	39.99	39.87	34.86
Farmyard manure application	0.43	0.60	0.52	0.26	0.56	0.77	1.22	0.67	0.62
Chemical fertilizer application	5.92	5.84	3.77	4.64	6.42	9.37	9.57	10.78	7.03
Planting	22.84	24.08	24.11	27.58	29.69	32.64	35.59	35.69	29.02
Crop management									
Irrigation	0.17	0.20	0.11	0.21	0.07	0.18	0.21	0.32	0.18
Weeding and hoeing	0.15	0.21	0.21	0.05	0.11	0.02	0.28	0.08	0.13
Spraying	21.26	22.75	22.79	29.00	33.89	35.94	39.16	39.21	30.50
Harvesting									
Harvesting by combine	40.93	40.87	46.86	53.36	55.25	57.14	58.69	61.33	51.80
Harvesting by mower	9.05	9.15	7.73	8.18	8.99	9.34	9.84	10.63	9.11
Harvesting by other machines	0.17	0.21	0.07	0.07	0.21	0.35	0.11	0.12	0.16
Post harvesting (Threshing)	22.27	18.19	19.54	15.70	24.45	23.31	19.20	20.66	20.41
Average	24.23	24.49	24.80	26.15	27.65	28.80	29.96	30.22	27.04

the month of November and December for modeling the area of wheat production. The variables used for wheat production for modeling included average nitrogen fertilizer used, average DAP fertilizer used, manures, number of ploughs, total rainfall for the month of November and October and November, total rainfall in the month of April and mean maximum temperature in the month of April.

Mechanization Ratio (MR) is an important indicator in the study of a regional effect on the indigenous cultures of the machine operating system. In most areas of Iran, farmers are not willing to easily give machinery service to other farmers so tractors and agricultural machines ownership are as an independence factor for the farmer and his family. In most cases, agricultural machines of a farmer, after finishing the work of his farm until the next year remain useless, but he avoids working for other farmers that he knows as his competitors. Distribution of farm machinery is not uniform in all areas of the country. Also, different operation distribution viewpoints of agricultural machine owners are in various positions. **Table 4** shows the amount of MR for each operation of irrigated wheat production. As can be seen in this table, MR has a swing in various operations during the period but has an overall growth. A graphical display of **Table 4** can be seen in **Fig. 9**. Like in the process of ML, harvest operations are allocated to the highest values. The operation process of land preparation, a constant during the study, has apparently reached a stable condition. Crop management and planting will grow with a gentle slope. Mechanization ratio of post harvesting is variable and fluctuates constantly.

A study in Egypt revealed that

Fig. 9 Trend of MR in the 2001-2008

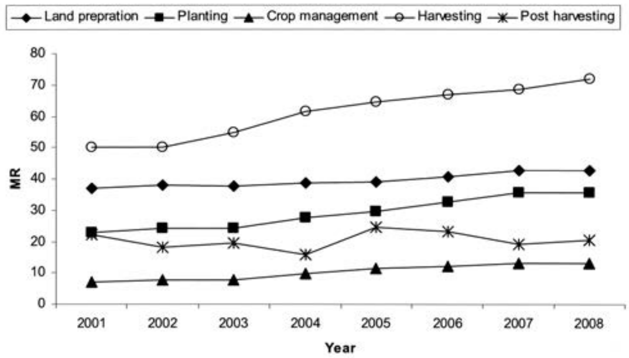
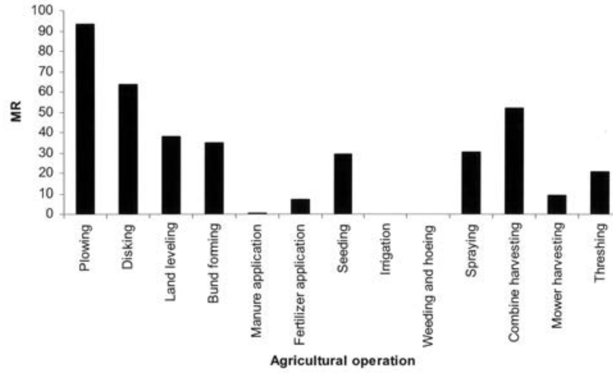


Fig. 10 Comparison of MR among agricultural operations



tractors are used by virtually all wheat farmers (99 percent), albeit for an average of just three-quarters of a day over the wheat season. Despite high usage in wheat farming, tractors are owned by only 14 percent of wheat farmers; the remainder rent. Wealthier and larger farmers are more likely to own a tractor than poorer households (Kherallah *et al.* 1999).

Clearly mean MR value of various operations can be compared in **Fig. 10** easily. Plowing and disking operations have the highest values of MR from diagram 10 so we can conclude that virtually no wheat farmers use mechanized irrigation and weeding and hoeing. MR of harvesting is about 50 % while its ML is nearly 70 %. This means that owners of combine and other harvesting machines have a good cooperation to do other farms work of harvesting and this condition is very desirable.

Table 5 Data sets for modeling wheat production in Iran

Inputs	Output
ML of agricultural operations (%)	Yield (kg ha^{-1})
MR of agricultural operations (%)	Yield (kg ha^{-1})
ML of agricultural operations (%)	Area under cultivation of wheat (ha)
MR of agricultural operations (%)	Area under cultivation of wheat (ha)
MR of agricultural operations (%)	Cost per unit of wheat production ($ kg^{-1})
ML of agricultural operations (%)	Cost per unit of wheat production ($ kg^{-1})
Cost of inputs ($ ha^{-1})	Yield (kg ha^{-1})

Table 6 Modeling effect of ML on wheat yield as output

Coefficients[a]

Model (No.1)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	6.559	1.386		4.730	0.009**
Land preparation	−1.900	0.480	−0.694	−3.961	0.017*
Planting	0.750	0.239	0.663	3.134	0.035*
Harvesting	1.317	0.169	0.819	7.805	0.001**
R Square	0.981				
Adjusted R Square	0.967				
Durbin-Watson	1.959				

a. Dependent Variable: Yield *Significant at 5 % level **Significant at 1 % level

There are differences among the MR and ML, as can be seen in **Fig. 11**, in each operation. Mechanization Ratio is related to the number of farm machinery owners and has a specific capacity limited by national conditions governing agricultural growth potential. It is ideal to be able to get the full mechanization of the farms that they are 100 percent mechanized. The difference among the current value of MR and its ideal value can be reduced by using systems of agricultural machines exploitation as much as possible. Improving the system of agricultural machinery usage can increase the level of mechanization and will show its positive results on improving wheat yield. Black borders in **Fig. 11** shows the growth of indigenous cultures in sharing agricultural machines. This sharing is not uniform for all operations. If the difference of ML and MR for each of the operations increase this shows that the potential in the agricultural machinery is operating properly.

Trend of changes in ML and MR show a little growth in the specific period. **Fig. 12** shows the trend of ML and MR. Due to sharing machinery in wheat farms, ML is in a higher position than MR.

Various sets of input data for modeling wheat production were used. Totally, seven models for the study of wheat production in Iran were built as their profile can be seen in **Table 5**. Each of the seven models will be discussed subsequently.

Table 6 shows elasticities of the dependent variable (wheat output per hectare) with respect to the in-

Fig. 11 Differences between mean amount of ML and MR

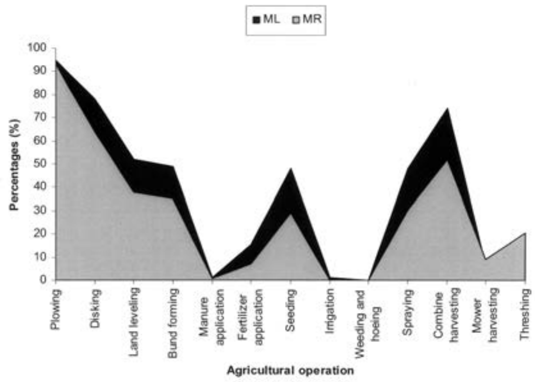


Fig. 12 Changes in trend of ML and MR in 2001 to 2008

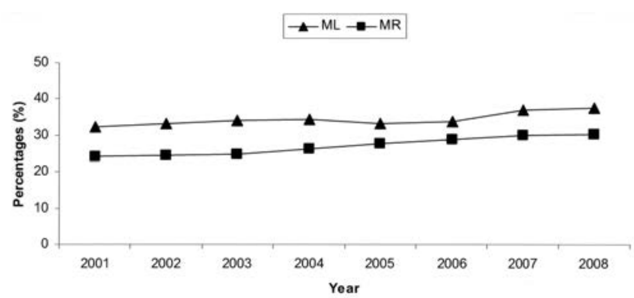


Table 7 Modeling effect of MR of agricultural operations on yield as output

Coefficients[a]

Model (No.2)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	5.841	26.671		0.219	0.847[n.s]
Land preparation	−0.391	11.377	−0.182	−0.034	0.976[n.s]
Planting	−0.611	8.234	−0.929	−0.074	0.948[n.s]
Crop Management	0.132	2.950	0.284	0.045	0.968[n.s]
Harvesting	1.394	1.703	1.674	0.819	0.499[n.s]
Post harvesting	−0.073	0.285	−0.089	−0.256	0.822[n.s]
R Square	0.840				
Adjusted R Square	0.441				
Durbin-Watson	1.956				

a. Dependent Variable: Yield

Table 8 Modeling effect of ML of agricultural operations on land under wheat cultivation as output

Coefficients[a]

Model (No.3)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
Land preparation	5.375	3.563		1.508	0.271[n.s]
Planting	0.738	0.886	0.325	0.833	0.493[n.s]
Crop Management	−0.177	0.550	−0.189	−0.323	0.778[n.s]
Harvesting	0.280	0.159	0.517	1.757	0.221[n.s]
R Square	1.328	0.458	0.997	2.902	0.101[n.s]
Adjusted R Square	0.955				
Durbin-Watson	0.843 2.724				

a. Dependent Variable: Land under cultivation of wheat

dependent variables (the set number 1, ML of agricultural operations). This set includes ML of agricultural operations as input and wheat yield as output of the Cobb-Douglas production function. Based on the output of this model, ML of harvesting has the greatest effect on wheat yield. The standardized coefficient (Beta) indicates the importance and influence of each input on the output. Only significant factors were used in model 1 (**Eqn. 4**).

$$In\ wheat = 6.559 - 1.9\ In(X_{LP}) + 0.75\ In(X_p) + 1.317\ In(X_H) + ei \quad (4)$$

Hussain *et al.* (2006) used the total number of irrigations, seed rate (kg acre-1), fertilizers (number of DAP bags per acre) and soil fertility (Nitrogen in percentage available in the soil). Their results showed that wheat yield was positively related to the seed rate, DAP and Nitrogen but negatively related to the number of irrigations.

Table 7 shows the relationship of MR of various operations and wheat yield, and **Eqn. 5** shows the Cobb-Douglas production function of this model. The results indicated that the proportion of wheat farmers who have agricultural machinery to all of wheat producers has no significant effect on wheat output. It was concluded that distribution of agricultural machines among farmers is not fair and this allocation trend cannot affect or improve the yield of wheat in Iran. As can be seen in **Table 7**, based on standardized coefficients, the ratio of harvester owners in wheat production has the maximum effect on wheat output because of the crucial role of cereal combines in the harvesting period. Wheat is too sensitive to falling grains on the ground in the harvest period. Thus, reaching harvester combines in time on farms is so important. There are combines in Iran which support wheat farms of the country from south to north. They start harvesting wheat at the first of harvesting season (April) from southeast regions of Iran and gradually move into the northern farms.

$$In\ wheat = 5.841 - 3.91\ In(X_{LP}) - 0.611\ In(X_p) + 0.132\ In(X_{CM}) + 1.394\ In(X_H) - 0.073\ In(X_{PH}) + ei \quad (5)$$

Wheat development due to its impact on self-sufficiency is very important. Identity factors affecting the development of wheat farming can help policy makers in planning the increase of crop areas. Level of mechanization in various agricultural operations is the first factor that can be effective in developing wheat. The timeliness of operations has assumed greater significance in obtaining optimal yields from different crops, which has been possible via mechanization. Harvest mechanization level influence on increasing wheat fields over other operations in the years has been studied. Planting operations had minimal impact. Based on the determination coefficient of the Cobb-Douglas model built (0.95) with increasing levels of farm mechanization in wheat fields further areas can be brought under wheat cultivation. **Table 8** describes the profile of Model No. 3 and its Cobb-Douglas function is given in **Eqn. 6**.

$$In\ Land\ under\ cultivation\ of\ wheat = 5.375 - 0.738(X_{LP}) - 0.177\ In(X_p) + 0.280\ In(X_{CM}) + 1.328\ In(X_H) + ei \quad (6)$$

Wheat development is dependent on agricultural machinery. As can be seen in **Table 9**, MR of three farming operations from five operations has significant effect on development in wheat. Harvest in this model is also most effective. Appropriate distribution of combines is a very decisive factor in creating new farms. In most cases one to one correspondence between an agricultural machine and its owner is established. A limited percent of machinery owners are partners. Increase in the number of machines per farm, particularly related to land preparation, harvesting and post-harvest are concerns which policy-makers of the mechanization sector must consider. Each farmer has limited capabilities and limitations may prevent the development of land owned by him. Conditions must be provided so that any farmer who has his work developing is not stopped for lack of access to agricultural machinery. Land preparation and harvesting machines have a lot of depreciation. Thus, special attention is needed to develop the presence of these machines in the wheat production process.

In Land under cultivation of wheat $= 10.639 + 0.506\ In(X_{LP}) + 0.495\ In(X_H) + 0.061\ In(X_{PH}) + ei$ ....(7)

Kaur *et al.* (2010) has concluded that wheat area, plant protection chemicals and fertilizers are the significant determinants of output in the semi-hilly region. Only the area under wheat is significant in the central region and irrigation and fertilizers influence positively the yield of wheat in the south-western region of Punjab, Pakistan. MR of various operations has significant effect on cost per unit of wheat. The R Square of Model No. 5 (0.99) shows that the model could well justify per unit cost of wheat. It can be seen from the Cobb-Douglas function (**Eqn. 8**) that mechanization ratio of planting and harvesting are not entered in this model. On the other hand it is most significantly related to the MR of land preparation.

Ghadiryanfar *et al.* (2009) studied combine availability on harvesting cost in wheat production of Iran. They compared the mean of operation costs in each province of Iran using the Duncan test. Their results showed that the cost of wheat harvested in provinces decreased with an increase in the number of combine harvesters in the provinces. Therefore, for decreasing the harvesting cost in Iran provinces, it is necessary to distribute more combine harvesters.

Kamrul *et al.* (2010) investigated technical inefficiency of wheat production in some selected areas of Bangladesh. They found that average technical efficiency of wheat production in Bangladesh was 16 percent. Also education and training on wheat farm operators was found to have significant effect on yield and technical efficiency of wheat production (**Table 10**).

In Cost per unit of wheat production $= -16.813 + 3.4021\ In(X_{LP}) + 0.400\ In(X_{CM}) + 0.348\ In(X_{PH}) + ei$ ....(8)

Model No. 6 will express the effect of mechanization on wheat costs. As can be seen in **Table 11** none of MR items have significant impact on cost per unit of wheat production as output. So, it can be concluded from this phenomenon that the level of mechanization of operations that are done in an area is not enough to improve the economic situation of wheat farms. Mechanization level of harvesting, post harvesting and crop management are the most effective factors on cost of one kg of wheat produced in Iran.

In Cost per unit of wheat production $= -34.652 + 3.5901\ In(X_{LP}) - 0.846\ In(X_P) + 1.222\ In(X_{CM}) + 3.643\ In(X_H) + 1.249\ In(X_{PH}) + ei$ ....(9)

These results indicated that increasing the cost of harvest operation increases the yield. This means

Table 9 Modeling effect of MR of agricultural operations on land under wheat cultivation as output

Coefficients[a]

Model (No.4)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	10.639	0.258		41.292	0.000**
Land preparation	0.506	0.107	0.284	4.747	0.009**
Harvesting	0.495	0.042	0.717	11.847	0.000**
Post harvesting	0.061	0.018	0.090	3.445	0.026*
R Square	0.997				
Adjusted R Square	0.995				
Durbin-Watson	2.286				

a. Dependent Variable: Yield *Significant at 5 % level **Significant at 1 % level

Table 10 Modeling effect of MR of agricultural operations on cost per unit of wheat production as output

Coefficients[a]

Model (No.5)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	−16.813	1.406		−11.961	0.000**
Land preparation	3.402	0.421	0.633	8.088	0.001**
Crop management	0.400	0.093	0.343	4.304	0.013**
Post harvesting	0.348	0.058	0.169	6.042	0.004**
R Square	0.997				
Adjusted R Square	0.995				
Durbin-Watson	1.882				

a. Dependent Variable: Yield *Significant at 5 % level **Significant at 1 % level that use of better harvesting machines reduces losses in grain harvesting operations. Higher qualitiy will, certainly, have higher costs, thus, increasing the cost of harvesting increases the wheat yield. Therefore, improvement of wheat harvest machine quality should be considered in macro planning of the agricultural sector since good programs in reducing grain losses in the harvesting operation has been done. Results of model No. 7 indicate that the cost of land preparation on yield of wheat, also, is effective. Considering that the coefficient of land preparation is negative, this reveals that increasing the cost of this operation decreases wheat yield. So, it can be concluded that the cost of land preparation is now more than required. Any additional actions to be done on the farm will have to pay more money. It is concluded that the number and volume of land preparation operations is extreme and should be adjusted to reduce adverse effects on wheat yield (**Table 12**).

$$In\ Yield = 7.344 - 0.666\ In(X_{LP}) + 0.846\ In(X_H) + ei \quad (10)$$

Higher levels of mechanization are preferred by farmers to ensure timeliness, to increase yield of crops, and to reduce the cost of cultivation, provided the farm size is large enough to use the machine and sufficient labor at reasonable wages are not available when required. To maximize profit, alternative mechanization technologies are adopted using animate and mechanical power sources to accomplish different field operations for different crops (Singh, 1992, 1997; Singh & Chandra, 2001; Singh & Singh, 2003; Government of India, 1961, 1971, 1981, 1991). Farm mechanization has been helpful to bring about a significant improvement in agricultural productivity. Thus, there is strong need for mechanization of agricultural operations. The factors that justify the strengthening of farm mechanization in the country can be numerous. The productivity of farms depends greatly on the availability and judicious use of farm power by the farmers. Agricultural implements and machines enable the farmers to employ the power judiciously for production purposes. Agricultural machines increase productivity of land and labor by meeting timeliness of farm operations and increase work output per unit time. Besides its paramount contribution to the multiple cropping and diversification of agriculture, mechanization also enables efficient utilization of inputs such as seeds, fertilizers and irrigation water.

Table 11 Modeling effect of ML of agricultural operations on cost per unit of wheat production as output

Coefficients[a]

Model (No.6)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	−34.652	12.854		−2.696	0.114[n.s]
Land preparation	3.590	3.197	0.523	1.123	0.378[n.s]
Planting	−0.846	1.983	−0.299	−0.427	0.711[n.s]
Crop management	1.222	0.575	0.746	2.125	0.167[n.s]
Post harvesting	3.643	1.651	0.904	2.206	0.158[n.s]
R Square	0.936				
Adjusted R Square	0.776				
Durbin-Watson	2.616				

a. Dependent Variable: Cost per unit of wheat production

Table 12 Modeling effect of cost of inputs on wheat yield as output

Coefficients[a]

Model (No.7)	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
(Constant)	7.344	0.121		60.537	0.000[n.s]
Land preparation	−0.666	0.159	−1.913	−4.202	0.008[n.s]
Harvesting	0.846	0.140	2.757	6.056	0.002[n.s]
R Square	0.953				
Adjusted R Square	0.953				
Durbin-Watson	3.434				

a. Dependent Variable: Cost per unit of wheat production

Conclusions

The objective of this study was to conduct a preliminary assessment of production factors effects on wheat production in Iran. Secondly, technological factors were used for modeling wheat yield in the period of study (2001-2008). To investigate irrigated wheat production systems, two indices (mechanization level and mechanization ratio) were used that provide information about farm mechanization status. Total cost of production was $337.99 US ha^{-1}, which showed an increasing trend in growth of total cost of production in the specific period. The chart of average production revealed a positive incline so that wheat production was increased from 6,026,978.52 tons in 2001 to 10,575,037.03 tons in 2008. Yield (kg ha^{-1}) had a similar trend to production. According to the importance of water in Iran with semi-arid climate for irrigated crop production, irrigation was the most costly among farming operations.

This eight-year study illustrated the actual situation of mechanization status of wheat in Iran. Mechanization Level (ML) of agricultural operations showed different trends in the specific period. Although the effective role and suitable situation of combines in Iran was satisfying, mechanized crop management needs to be expanded. Gradually, the use of separate threshing units has been declining. Another important indicator in the study of regional effect on the indigenous cultures of the machinery operating system was Mechanization Ratio (MR). The highest level of both ML and MR among agricultural operations of wheat belonged to plowing.

Mechanization Ratio, which related to the number of farm machinery owners, was limited by national conditions governing agricultural growth potential, and the country had a specific capacity. It was ideal to be able to get the full mechanization of the farms that they were 100 percent mechanized. The difference between the current value of MR and its ideal value can be reduced by exploiting the use of agricultural machines as much as possible. Improving the systems of agricultural machinery usage can increase the level of mechanization and will show its positive results on improving wheat yield.

Various sets of input data were used for modeling wheat production and, totally, seven models were built for analyzing Iran wheat status. For this purpose inputs used in wheat production are linked to wheat output by parameters obtained from the Cobb-Douglas production function for the period years. The results showed that the first and second most important inputs in ranking in wheat production were mechanization level in various operations and cost of land preparation and harvesting. Assessment of cost per hectare as output showed the most significant effects in mechanization ratio of land preparation, crop management and post harvesting, respectively. The first factor in developing wheat that could be effective was the level of mechanization in various agricultural operations. Harvest mechanization level influence on increasing wheat fields over other operations in the years was studied. Based on the determination coefficient of the Cobb-Douglas model (0.95) with increasing levels of farm mechanization in wheat fields, further area can be brought under wheat cultivation. Appropriate distribution of combines is a very decisive factor in creating new farms. Increase in the number of machines per farm, particularly related to land preparation, harvesting and post-harvest must be considered by policymakers of the mechanization sector. Also, land preparation cost is effective on wheat yield. Considering the negative coefficient of land preparation, revealed that cost increase decreases wheat yield. Another interpretation is that the cost of land preparation is now more than required.

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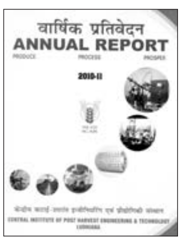
BOOK



CIPHET Annual Report (2010-11)

The executive summary of the annual report 2010-11 is as under

http://www.ciphet.in/

About Ciphet

The Central Institute of Post-Harvest Engineering and Technology (CIPHET) was established on 29 December 1989 at the PAU Campus, Ludhiana, Punjab, India as a nodal institute to undertake lead researches in the area of the post-harvest engineering and technology appropriate to agricultural production catchment and agro-industries.

The institute's second campus was established on 19 March 1993 at Abohar, Punjab, India. Which is primarily responsible for conducting research and development activities on fruits and vegetables, and commercial horticultural crops. CIPHET is also headquarters for two All India Coordinated Research Projects (AICRPs) viz. AICRP on Post-Harvest Technology (PHT) at 38 Centres and AICRP on Applications of Plastics in Agriculture (APA) at 11 Centre's.

Effect of Crop, Machine and Operational Parameters on Peak Cutting Force for Harvesting Fodder Maize

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Abstract

The efficiency of a reciprocating type cutter bar is influenced by the dynamic cutting force exerted by the cutter bar on the crop. The appropriate crop, machine and operational variables that influence the force required for cutting fodder maize stalks were identified. For recording the dynamic force required for cutting the maize stalk, a cutter bar test rig was developed. The investigation used two cutter bar stroke lengths viz., 76.2 and 90.0 mm, three cutter bar speeds viz., 1.5, 1.75 and 2.0 ms^{-1}, four diameters viz., 10, 15, 20, and 25 mm and three maize stalk moisture contents (completely dry forage, semi dry and green forage). The peak cutting force requirement was directly proportional to diameter and inversely proportional to maize stalk moisture content and cutter bar speed. The cutter bar with stroke a length of 90.0 mm registered 6.3 to 28.7 percent reduction in peak cutting force as compared to 76.2 mm stroke length for the selected levels of cutter bar speed, diameter and maize stalk moisture content. The peak cutting force of 272.4 N was registered for combination levels of 71.2 percent moisture content, 25 mm stalk diameter, 2.0 ms^{-1} cutter bar speed and 90.0 mm stroke length.

Introduction

Harvesting forage at optimum maturity is crucial for ensuring quality and productivity of fodder crops. Standing crops of cereals, oilseeds, fodder, fibre and other similar vegetative crops are cut mechanically by a reciprocating cutter bar. The efficiency of a reciprocating type cutter bar is influenced by the dynamic cutting force exerted by the cutter bar on the crop. The quality of cutting of the stalk is highly influenced by the cutter bar speed. The most significant features of the reciprocating cutter bar are stroke length and operational speed of the cutter bar knife. Other than the stroke length of the cutter bar knife and operational speed, the most important factor affecting dynamic force required for cutting the stalk is the diameter and moisture content. In the present investigation, the effect of machine and crop variables viz., stroke length of cutter bar, cutter bar speed, diameter and moisture content on peak cutting force was analyzed.

Review of Literature

The resistance of the crushed and cut plants depends on the rigidity, diameter and, moisture content of the stalk and the density of the growing plants (Czeslaw Kanafojski, 1972). The force required for shearing forage is affected by forage species, maturity and moisture content (Ige and Finner, 1976). Mohsenin (1986) found that the ultimate shear strength is inversely proportional to dry matter density. The moisture content, stem diameter and shear strength are relevant properties to cutting. With increase in cutting speed, stalks are cut without flattening and the resistive force decreases (Prasad and Gupta, 1975; Das, 1998; Devnani, 1998, Jekendra, 1999 and Pandey, 1998). The cutting process is greatly influenced by physical and rheological properties of crops in harvesters. The increased speed also results in high inertia force of the cutter bar and machine vibration, which in turn limits the speed of cutter bar (Devnani, 1998).

Methods and Materials

Uniformity of cut and cutting efficiency depends upon the stroke length of the cutter bar knife. The stroke length of the cutter bar knife determines the amount of space between the knives for the flow of the stalk during the operation. The quality of cutting stalk and power required for the cutting operation are highly influenced by the speed of the cutter bar. The most important crop factor affecting dynamic cutting force required for cutting crop stalk is the diameter of crop stalk. The moisture content of the stem has a direct correlation with the force required for cutting in addition to the diameter of the stalk.

Hence, the following variables were selected for investigating the dynamic force required for cutting maize fodder crop using a cutter bar test rig.

Stroke Length of cutter bar (L)	2 levels
76.2 mm	L_1
90.0 mm	L_2
Cutter bar speed (S)	3 levels
1.50 ms^{-1}	S_1
1.75 ms^{-1}	S_2
2.00 ms^{-1}	S_3
Stalk diameter (D)	4 levels
10 mm	D_1
15 mm	D_2
20 mm	D_3
25 mm	D_4
Moisture content in wet basis (M)	3 levels
Completely dried crop	M_1
Semi-dry crop	M_2
Green crop	M_3

A cutter bar test rig was developed for recording the dynamic force required for cutting fodder maize crop stalks (**Figs. 1** and **2**). The rig consisted of a main frame, cutter bar assembly, power transmission, variable speed drive, load cell and high speed data acquisition system. A total of 216 randomly replicated experiments were conducted using the test rig with selected levels of variables. The data acquired during cut could be displayed as a force - time curve on a personal computer (McRandal and McNulty, 1978). The dynamic force, as sensed by the load cell, was exported to the Excel spread sheet where the force-time curve was converted into a force-distance curve. The number of readings obtained in one revolution of crankshaft (N) was calculated from the curve obtained from the PICOLOG software. The rotation angle between successive readings (Δ) was calculated using the following expression.

$$\Delta = 360/N \qquad (1)$$

Fig. 1 Cutter bar test rig

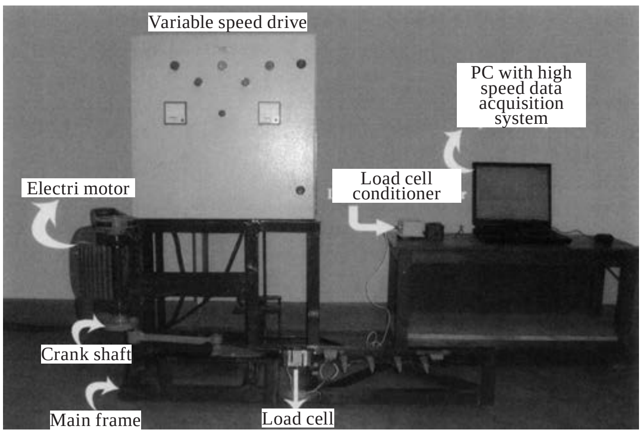


Fig. 2 Load cell connected to wearing plate of cutter bar

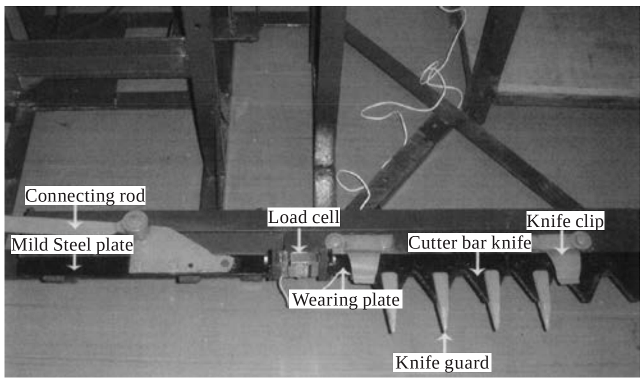


Fig. 3 Typical Force - Time curve

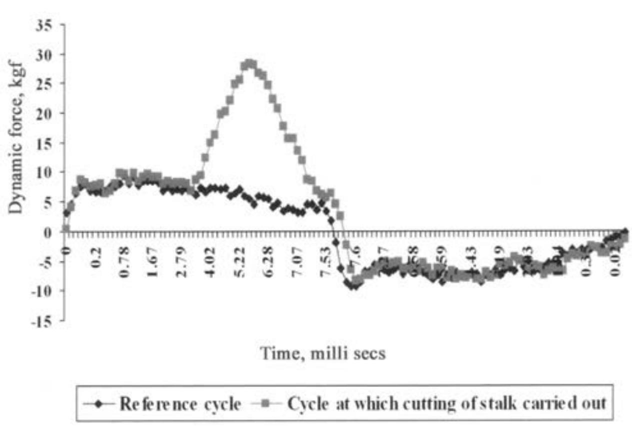
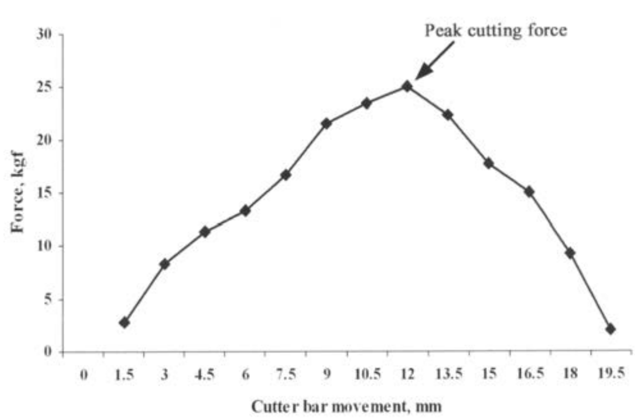


Fig. 4 Typical force-distance curve



where,

N = Number of data obtained for one revolution of the crankshaft.

The movement of cutter bar between successive readings was calculated using the following expression.

Movement of cutter bar =

$$r - r \times \cos [\Delta \times (\pi / 180)] \quad \ldots(2)$$

where,

r = Radius of the crankshaft, mm.

The force-distance curve for which the cycle of stalk cutting was carried out was compared with the reference cycle (idle stroke) to calculate the force required for cutting the stalk. The typical comparison curve is shown in **Fig. 3**. From the curve, the force required for cutting was obtained by subtracting the inertial forces and frictional force of idle reciprocation from the gross dynamic cutting force. The force calculated for each position of the cutter bar was plotted as a force-distance curve as shown in **Fig. 4**. The peak cutting force (PFc) required for harvesting the selected maize fodder crop was recorded for all treatments.

Results and Discussion

The effect of machine and crop variables viz., stroke length of cutter bar, cutter bar speed, diameter and moisture content of the maize stalk on peak cutting force required for harvesting maize are discussed and presented below.

The relationship between peak cutting force and cutter bar speed for 76.2 mm stroke length (L_1) is depicted in **Fig. 5**. Increase in cutter bar speed from 1.5 (S_1) to 2.0 ms^{-1} (S_3) resulted in 20.8 to 29.6 percent reduction in peak cutting force for the selected levels of diameter and moisture content of the maize stalk. This may have been due to the fact that, at low cutter bar speeds, the stalks became flattened and crushed and the cutting process was accompanied by large resistive forces. With increase in cutter bar speed, the stalks were cut without flatten-

Fig. 5 Effect of cutter bar speed on peak cutting force at selected levels of diameter and moisture content of maize stalk for 76.2 mm stroke length of cutter bar (L_1)

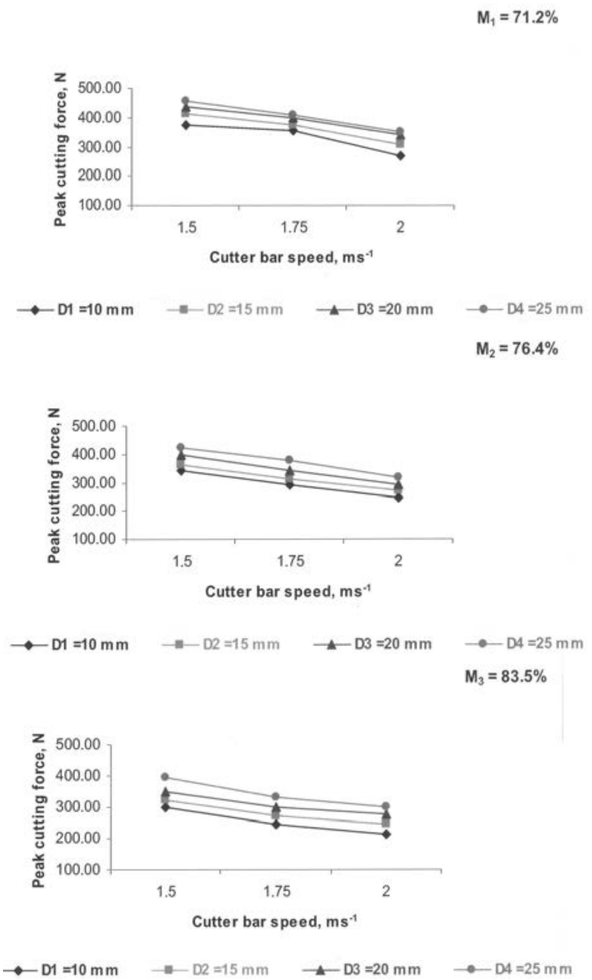
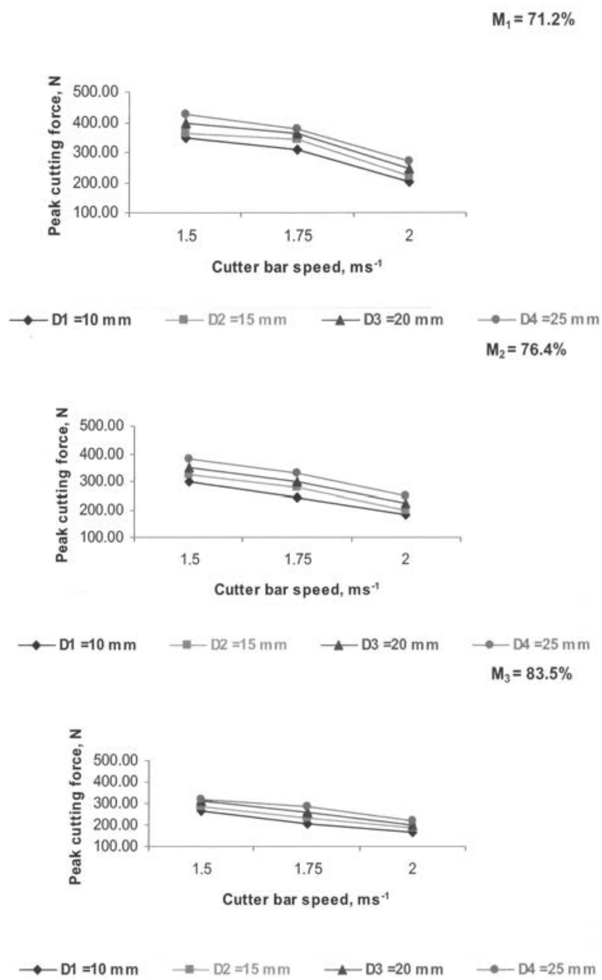


Fig. 6 Effect of cutter bar speed on peak cutting force at selected levels of diameter and moisture content of maize stalk for 90.0 mm stroke length of cutter bar (L_2)



ing or crushing and the resistive forces decreased. The peak cutting force increased by 15.5 to 41.1 percent with increase in diameter from 10 (D_1) to 25 mm (D_4). Increase in moisture content from 71.2 (M_1) to 83.5 percent (M_3) resulted in 15.0 to 44.9 percent reduction of peak cutting force required for the selected levels of diameter of maize stalk and cutter bar speed. This was attributed to the fact that, as the moisture content of stalk reduced, the cells dried out and the stem shrunk. For a given cross sectional area, the cutting resistance was more when the moisture content was less. Hence, the peak cutting force decreased with increase in moisture content. The minimum value of peak cutting force required for harvesting 10 mm diameter maize stalk with 83.5 percent moisture content (M_3) was 212.42 N at 2.0 ms^{-1} cutter bar speed (S_3), whereas the maximum value of peak cutting force of 455.11 N was 1.5 ms^{-1} cutter bar speed for harvesting 25 mm diameter (D_4) with 71.2 percent moisture content (M_1).

For 90.0 mm stroke length cutter bar (L_2), the relationship between peak cutting force and cutter bar speed is illustrated in **Fig. 6**. Increase in cutter bar speed from 1.5 ms^{-1} (S_1) to 2.0 ms^{-1} (S_3) led to 30.9 to 42.1 percent reduction in peak cutting force for the selected levels of diameter of stalk and moisture content of crop. The minimum cutting force of 168.59 N was 2.0 ms^{-1} (S_3) for 10 mm diameter and 83.5 percent stalk moisture content. Increase in moisture content from 71.2 (M_1) to 83.5 (M_3) percent resulted in 17.4 to 50.4 percent reduction in peak cutting force for the selected levels of stalk diameter and cutter bar speed. The peak cutting force was higher for stalks with lower moisture content because the strength of the outer stem layer (stem wall) increased with reduction in moisture content, which increased the stiffness of the stem wall.

Effect of Stroke Length

Comparing **Figs. 5** and **6**, shows that the cutter bar with stroke length of 90.0 mm (L_2) gave lower values of cutting force than that of 76.2 mm stroke length (L_1) at all cutter bar speeds, diameters and moisture contents of the stalk. The overall reduction in peak cutting force varied from 6.3 to 28.7 percent with 90.0 mm stroke length (L_2) as compared to 76.2 mm (L_1).

The resistance offered to cutting by the stalk was the sum of the edge resistance and shearing resistance. The edge resistance was constant due to the pressure exerted on the edge area. The frictional resistance due to sliding of the crop against the edge chamfer depended upon the angle of chamfer, angle of friction between knife and chamfer and the normal force acting on the tapered cutting edge (Bosai *et al.*, 1990). It can be expressed as:

$$P = P_0 + N \sin(\gamma + 2\varphi) / \cos^2 \gamma$$

Where,

P = Resistance to cutting

P_0 = Resistance offered by the stalk for knife penetration

N = Normal pressure force due to cut stalk fibers acting on the face of the wedge

γ = Wedge angle

φ = Angle of friction

Cutting force normal to the knife edge was constant for a given knife and stem. When cutting edge was perpendicular to direction of travel, force of cutting was equal to the force exerted on the cutting edge. However, when the cutting edge was inclined to the direction of travel by knife edge angle (α), only the component of cutting resistance along the direction travel constituted the cutting force encountered by the knife.

i.e. cutting force

$P^1 = P \sin \alpha$

When $\alpha = 90^o$

$P^1 = P \sin 90^o = P$

When $\alpha = 59^o$ (value of knife edge angle for 76.2 mm stroke length of knife)

$P^1 = P \sin 59^o = 0.857 P$

When $\alpha = 54^o$ (value of knife edge angle for 90.0 mm stroke length of knife)

$P^1 = P \sin 54^o = 0.809 P$

The cutting force P^1 would be reduced by 5.6 percent for 90.0 mm stroke length than 76.2 mm stroke length of cutter bar.

For a given value of normal cutting resistance P, the cutting force required to overcome the resistance of the crop depended on knife edge angle (α) of cutter bar. Since cutting force required was 5.6 percent lower for 90.0 mm stroke length (L_2) than that of 76.2 mm stroke length (L_1), the peak cutting force required for harvesting the maize stalk with similar conditions was lower.

Statistical analysis of the data (ANOVA) was performed to assess the significance of the variables viz., moisture content (M), cutter bar speed (S), stroke length (L) and stalk diameter (D) on peak cutting force. The results indicated that there was significant difference among the treatments. The individual effect of the variables viz., moisture content of stalk (M), cutter bar speed (S), stroke length (L) and stalk diameter (D) were significant at the one percent level of probability. In the treatment effect, the order of significance was highest for cutter bar speed (S) followed by stroke length (L), moisture content (M) and diameter of stalk (D) on peak cutting force. This confirmed the earlier discussion that the cutter bar speed (S) had a significant effect on peak cutting force.

Conclusions

A cutter bar speed from 1.5 to 2.0 ms^{-1} with a 76.2 mm stroke length resulted in 20.8 to 29.6 percent reduction in peak cutting force for the selected levels of diameter and stalk moisture content. The peak cutting force required for harvesting maize stalk increased by 15.5 to 41.1 percent with an increase in diameter from 10 to 25 mm. Increase in moisture content of from 71.2 to 83.5 percent resulted in 15.0 to 44.9 percent reduction of peak cutting force for the selected levels of diameter of stalk and cutter bar speed. For a 90 mm stroke length, reduction of 30.9 to 42.1 percent in peak cutting force was observed with an increase in cutter bar speed from 1.5 to 2.0 ms^{-1} for the selected levels of diameter and moisture content. Increase in moisture content from 71.2 to 83.5 percent resulted in 17.4 to 50.4 percent reduction of peak cutting force required for the selected levels of stalk diameter and cutter bar speed. The cutter bar with a stroke length of 90.0 mm registered 6.3 to 28.7 percent reduction in peak cutting force as compared to that of 76.2 mm stroke length for the selected levels of cutter bar speed, diameter and moisture content.

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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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Effect of Heat Treatment on the Physical Properties for Some Oil Seed: **T. Z. Fouda,** Prof., and Head of Agric. Eng. Dept., Fac. of Agric., Tanta U. EGYPT; **M . Salem,** Prof., and Head of Food Tech., same; **A. Omnia**, Grad. St. Food Tech. Dept., same.

This work was carried out to investigate the characterization of Canola, Linseed, Nigella and Roselle seeds under using different heat treatments (dry heat at 85 ºC for 10 and 20 min, seaming for 10 and 20 min). The study was revealed to the following main points:

• The dimension including length, width, thickness and the weight of 1,000 seeds of studied seeds was slightly decreased by dry heat treatment while the steam treatment was increased the dimension of studied seeds.

• The results revealed that, Some physical properties of the canola seeds, linseeds, nigella seeds and roselle seeds were considered such as the weight of 1,000 seeds (seed index) was 5, 8, 4 and 35g and bulk density was 1.57, 1.48, 1.58 and 1.16g/cm^3, respectively. The seeds dimensions including length, width and thickness were (1.95, 1.85 and 1.71mm), (4.40, 2.38 and 0.10 mm), (3.01, 1.51 and 1.09 mm) and (5.19, 4.21 and 2.64 mm), respectively.

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Imporoving Engine Cooling System: **Samir M. Younis**, Professor of Agricultural Engineering, Faculty of Agriculture, Alexandria University, Alexandria, EGYPT.

Fan spacing fan coverage and hub to fan diameter ratio ware studied on the efficiency of engine cooling system. The best fan performance could be obtained with modified fan 40 % at 100 % coverage and 10 cm spacing from the radiator and the engine fan, the power required to operate the fan was reduced by 35 %. Some empirical thermal equations were obtained to relate resistance to air flow in terms of the well known numbers as Reynolds, Randal and Nusselt Numbers.

Algorithmic Approach for Overhauling of Modern Bulldozers thorough Management Techniques (PERT/CPM)

by

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Abstract

Due to sudden breakdowns with farm machinery, the work in the field gets adversely affected. The knowledge of time and cost involved in a particular repair activity of farm machinery is essential to decide whether to continue the interrupted work and to assess whether or not it is possible to complete field operation within the stipulated time. PERT and CPM techniques have been applied to analyze the major overhauling of modern bulldozers. These techniques identified forty two subsystems or activities. The technique finalized 10 critical activities and expected completion of all events required 192 h with a variance of 8 h. The analysis revealed that the probability of completing the overhauling ranged from 0.299 to 0.331 for completion duration of 185 to 200 h, respectively.

Introduction

With the increase in agricultural mechanization, bulldozers have assumed an important role in Indian farming especially due to adoption of intensive cultivation. The bulldozer is used for fairly long periods for field operations. Due to change in terrain and other natural causes, repairs are invariably required in the bulldozer. There were as many as forty two systems in a bulldozer with each system having a number of components. Hence need for repair arose due to normal wear and tear of the components as well as due to unforeseen conditions in the field.

Due to sudden breakdown in a bulldozer, the work in the field gets adversely affected. The knowledge of time and cost involved in a particular repair activity is essential to decide whether to continue the interrupted work and to assess whether or not it is possible to complete the field operation within the stipulated time. In the present paper, an analysis is done on the types of repairs, time required for each type of repair work and minimization of cost involved in the whole repair work by applying the modern management techniques of PERT (Programme Evaluation and Review Technique) and CPM (Critical Path Method).

Research work on maintenance of tractor and other farm machinery has focused mainly on the average life time and repair costs. William *et al.* (1981) developed a method to accurately estimate the total cost of owning and operating farm machinery. The method adopts a depreciation schedule that is based on replacement price of the equipment. Ward *et al*. (1985) have estimated that the wear out life of a tractor is 12,000 hours and that after 6,000 hours of work a two wheel drive tractor has an accumulated repair cost equivalent to 70 percent of the original purchase price. Dwarika

Table 1 Major overhauling of a modern bulldozer

Description	Activity name	Activity duration, h	Preceding activity
Disconnect the U frame from the Chassis.	A	1	--
Removal of the centre and corner blades.	B	2	A
Reconditioning the centre and corner blades.	C	16	B
Repairing the shovel and 'U' frame.	D	24	A
Assembling the centre and corner blades in the shovel and 'U' frame.	E	2	C, D
Disconnect the master pin of the track chain.	F	1	A
Removal of the recoil spring assembly.	H	6	F
Dismantling the idler wheels, welding, grinding and reassembling.	I	24	O
Removal of the carrier rollers.	J	4	H
Dismantling, welding and turning the carrier rollers and roller shafts	K	24	J
Removal of the roller frame from the unit	L	8	H
Dismantling the track rollers and shaft	M	2	R
Inspection and reconditioning the shafts	N	32	M
Welding the track rollers, turning etc.	O	56	M
Removing the sprocket wheel from the frame	P	8	Z
Welding and grinding the sprocket wheels	Q	24	P
Checking the bellow seal, bearing etc. and adjusting	R	8	P
Assembling carrier rollers and shaft	S	4	K. N
Assembling the track rollers and shaft	T	16	O
Welding and cleaning the roller frame	U	16	M
Assembling the rollers in the roller frame	V	6	T. U
Fitting the carrier rollers in the roller frame	W	2	N
Assembling the sprockets in the main frame	X	8	C. R
Fitting the roller frame in the unit	Y	8	V
Fitting the recoil spring, stand etc.	Z	6	Y
Fit the idler wheel in the frame and check the alignment	AA	8	I, Z
Removal of the grouser plates from the chain	AB	24	F
Dismantle the chain assembly	AC	16	AB
Welding and surface grinding of the chain links	AD	40	AC
Welding the grouser plates and reconditioning	AE	24	AC
Assembling the chains	AF	16	AE, AD
Assembling the grouser plates	AG	24	AF
Assemble the chain assembly in the frame	AH	4	AG, AA, X
Removing and overhauling of fuel injection pump to Larson and Toubro and get back Dynamo, starter repairs etc.	AI	48	A
Dismantling cylinder head, cleaning, crack checking bottom surface checking, valve grinding lapping, etc. and assembling Head	AJ	32	AI
Removal of the radiator, oil cooler etc. and reconditioning	AK	16	L
Removal of the Block from the chassis and dismantling the piston, connecting rod, min and connecting rod bearing etc. and cleaning, removal of clutch and cleaning	AL	24	AK
Piston liner inserting, crank shaft grinding, main and connecting rod bearing setting, ring gap checking small end bush bearing etc.	AM	48	AL
Assembling the piston, connecting rod, main and connecting rod bearing etc. assembling the Head ad tightening etc.	AN	32	AN, AJ
Repairing the main clutch, stearing clutch and assembling	AO	24	AL
Assemble the block to the chassis and fixing the radiator, oil cooler pump, injectors, Dynamo starters etc.	AP	24	AO, AN
Assembling the U frame with chassis alignment and adjustment, starting engine idle run, rectification of defects and final delivery	AQ	32	E, AH, AP

Dhish *et al.* (1988) estimated that the life of a tractor is 10 to 12 years.

Wendl (1990) evaluated the repair costs for tractor to be 33,000 DM after 9,000 hours of work without taking tyre replacements into account. He hypothesized that approximately 65 percent of total repair costs could be attributed to five different groups of components. Nosachinho (1990) developed a method for accounting of the operating time of tractors between repairs.

Recently operations research technique have been applied in the analysis of farm machinery. Binder *et al.* (1990) have developed a post optimality algorithm which gives detailed information on the effects of a machinery change on all relevant tractor and labour resources. The information is useful for investigating complete machinery interactions. Adam (1990) used reliability analysis to study tractor system failure. He employed a time between failure (TRF) analysis to estimate reliability levels. Using 120 tractors of 4 makes, he found that the power drive was the more failed system in all makes.

Materials and Methods

The present study was carried out at the Tractor Workshop, Department Agricultural Engineering, Government of Tamilnadu, Coimbatore, India. The authors by their personal experience analysed the overhauling of the bulldozer. First the entire bulldozer system was divided into 42 sub systems or activities.

For each activity, three time estimates viz., Optimistic (t_o), pessimistic (t_p) and most likely (t_m) were estimated. The expected time of repair for each action was computed by using the following formula.

$t_e = t_o + 4t_m + t_p / 6$ ....(1)

The PERT calculations and the critical path were identified as per the procedure suggested by Gillet (1976). The expected time of completion of the major overhauling was computed by the formula.

$E (T) = \sum E (T_l)$ ....(2)

where, $E(T_1)$ is the expected completion time of the 1th critical activity.

It is well known that PERT method takes in to account the variability in the time duration of each activity. The variance of the completion time of an activity is estimated by the formula.

$\partial^2 = [(t_p - t_o) / 6]^2$ ....(3)

The variance in the completion time of a project (say ∂^2) is obtained by adding the variance of completion times of critical activities. The mean and the variance of the total time of completion, say, T can be used to find out the probability of several activities, which can be assumed to be independent random variables, by Centre Limit Theorem (Hogg and Craig, 1978). T will follow, approximately, a normal distribution with mean T and variance ∂^2. If ST is the scheduled time of completing the major overhauling then

$P (T < ST) = P (T - T) / T < (ST - T) / \partial_T = P (Z < Z_0)$............(4)

where Z is the standard normal variable with mean 0 and variance 1 and Z_0 is a known constant given by

$Z_0 = (ST - T) / \partial_T$

In a similar manner the probability of completing a critical event I by a scheduled time ST1 can be worked out as

$P (T < ST_i) = P (T_i - T_i) / \partial_T < (ST_i - T_i) / \partial_T = P(Z < Z_0)$

where, T_i and ∂_T^2 are, respectively, the sum of expected time duration and variance of the completion time of activities up to and including the 1th activity.

Results and Discussion

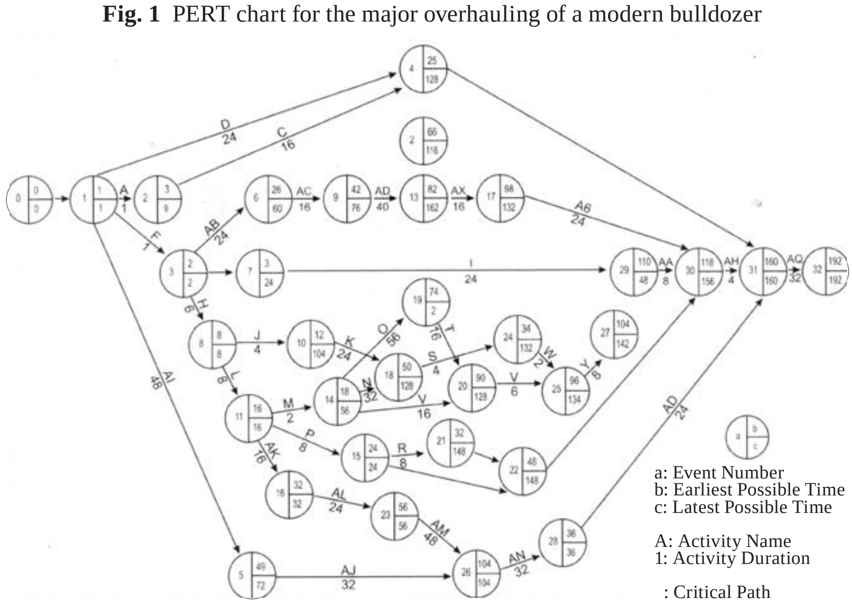
The PERT chart for overhauling the bulldozer and the critical activities is shown in **Fig.1**. The PERT technique identified 15 critical activities. The PERT chart for the major overhauling of a bulldozer was drawn. The critical path consists of the following activities.

A-F-H-L-AK-AL-AM-AN-AP-AQ

Table 2 Expected completion time of overhauling

Activities in critical path	A	F	H	L	AK	AL	AM	AN	AP	AQ	Total
Duration, h	1	1	6	8	16	24	48	32	24	32	192

Fig. 1 PERT chart for the major overhauling of a modern bulldozer



The expected completion time of overhauling was 192 hours. The total variance of completion time was 8 hours. The largest variance was associated with activity AM viz., piston liners inserting, reboring, crankshaft balance and crack checking. The analysis revealed the probability of completing the overhauling ranged from 0.299 to 0.331 for completion duration of 185 to 200 hours.

Conclusion

The PERT technique was applied to the major overhauling of modern bulldozers. The technique identified 10 critical activities and estimated that the overhauling work had an expected duration of 192 h with a variance of 8 h. The probability of completing activities in the critical path had to be properly watched. The analysis revealed that the probability of completing the overhauling ranged from 0.299 to 0.331 for completion duration of 185 to 200 hours.

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NEWS

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Design of a Grain Cleaning Machine for Small Farms

by

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Abstract

A grain cleaning machine is designed and tested for small growing farm entities and farms of Uzbekistan. Unlike the well-known machines, a rolling rubbing device for placing the grain from not threshed heaps is considered in design in order to segregate the grain from unthreshed ears of wheat separated out during grains volume cleaning in the course of cleaning by masticating them with rollers that rotating against each other.

The designed grain cleaning machine together with required operation performances has low amount specific metal content and less energy intensity. The weight of machine is 305 kg and consumes power in amount of 2.7 KW at work performance of 350 kg/hour.

On the basis of implemented pilot research it is determined that the best mastication of not threshed ears by least damage of grain is achieved at a rotation frequency of the first roller at 600 rpm, and the second roller within 800-1,200 rpm and at backlashes between rollers of 2-3 mm. For achievement of qualitative clearing of grain lots at minimum loss of grain it is necessary to choose the following intervals of parameters and the operation modes: frequency of sieve fluctuations is 100...150 rpm; amplitude of fluctuations sieve is 30...50 mm; an angle of slope sieve is 8...11.

Introduction

At present time the great changes are being implemented in the agriculture infrastructure of Uzbekistan. Because of low efficiency, all large-scale farms are reorganized and their lands are divided to farmers and farms. Today, manufacturers of products for agriculture, together with other effects, influence the cultivation of grain-cereal such as wheat, barley and rye. According to the contract conditions, one-half of the produced grain remains for the needs of workers and farms. The total annual yield amounts 2.5-2.8 million tons of grain (Tulepov, 2009). Cleanliness of the grains is about 91-94 % with about 4 % not threshed heaps, 1.0-1.2 % pieces of stalks, 2.0-2.3 % easy impurity and 1.0-1.5 % weed seeds (Astanakulov *et al*., 2008). It is known that before storage or processing grain should be cleared of weed impurities and pieces of stalks. Weed impurities causes fungi, reduces grain quality and does not allow long grain storage. This also reduces the quality at received flour machines.

Until now in Uzbekistan, for preliminary cleanings of grain, OVP-20A, OVC -25 and "Petkus-vibrant" K-521 have been intended for large-scale enterprises, have great volume and weight, consumes more power, and also have a good selling price. Besides, the design of these machines does not provide for the wearing through of not threshed heaps during cleaning and, as a result, 4-5 % of grain goes to the waste (Astanakulov *et al*., 2006).

The above-stated defect of these machines does not allow their use by farmer and farms as compared to large-scale enterprises. On this basis, the Uzbek Scientific and Research Institute of Mechanization and Electrification of Agriculture has developed a machine for primary cleaning of the grain that would meet the needs of small farmers and farms. The technological process of the designed machine, together with the grain cleaning, includes grinding of the not threshed heaps. This research is undertaken for the purpose to study the technological process of proposed grain-cleaning machine and, also, to identify the parameters and indicators of work in the final process.

Materials and methods

The technological scheme of machine is developed on the basis of the technical project and initial requests and produced an experimental sample (**Figs. 1** and **2**). The grain-cleaning machine has following dimensions: length- 1,500 mm; width- 800 mm; heigh- 1,100 mm.

The machine consists of bunker (1), soaking up channel (2), a fan (3), an electric motor (4), top and bottom sieves (5) and (6), sieve drive mechanism (7) and rubbing rollers (9). These operating parts are mounted on a frame of the machine (8).

Technological process of grain-cleaning machine is proceeded in the following manner. The grain lots accumulated in storage bin (1) through rollers (9) and arrived on the inclined aspiration channel (2). The fan (3) cleared the grains of easy impurity before they arrived on the top surface sieve (5). On the top sieve, large impurities such as pieces of a stalk and not threshed heaps could not fall through while the grain fell through the apertures and arrived on the bottom of the sieve. On the bottom sieve, small impurities and weed seeds fell through the smaller apertures while the grains were held back. The sieves were oscillated by a drive mechanism (7). After grain cleaning, the clean grain and the thrash were deposited and collected separately. In the process of experimental research of the developed machine, influence of parameters and the modes of operation of working bodies on completeness of heaps mastication and grain damage on quality of clearing and grain loss are studied.

In order to conduct experiments grain heaps, containing the grain of 90.3 %, not threshed heaps of 4.7 %, easy impurity of 2.3 %, part of a stalk of 1.2 % and weed seed of 1.5 %.

Results and Discussion

Process of mastication of not threshed heaps. **Table 1** shows the completeness of heaps mastication at a constant rotation frequency of the first roller (600 rpm) with an increase in rotation frequency the second roller from 600 rpm to 1,200 rpm. With an increase in completeness, the mastication is simultaneously increased, due to the grain damage. With a rotation frequency of the first and the second roller of 600 rpm completeness of heaps mastication is 36.1 %. With an increase in rotation frequency of the second roller to 800 rpm completeness heaps mastication it is intensively increased and reached on 64.2 %. At an increase in rotation frequency of the second roller of 1000 rpm and 1,200 rpm, completeness of heaps mastication increased much more and it reached 85.4 % and 94.6 %, respectively.

At identical rotation frequency of 600 rpm of the first and the second roller there is no observed grain damage. With increase in rotation frequency of the second roller from 800 rpm to 1,000 rpm grain damage is increased slightly from 0.3 % to 0.5 %. And, with an increase in rotation frequency from 1,000 rpm to 1,200 rpm grain damage is essentially increased reaching from 0.5 % to 1.3 %. At 1,200 rpm the damage amounts four times more than that for rotation of 800 rpm and on three times more than frequencies of rotation of 1,000 rpm.

At a rotation frequency of the second roller of 1,000…1,200 rpm,

Table 1 Influence of frequency of rotation wearing through roller on completeness heaps mastication and grain damage

Frequency of rubbing roller rotation, rpm	600	800	1,000	1,200
Completeness of cereals wearing through, %	36.1	64.2	85.4	94.6
Grains damage, %	0	0.3	0.5	1.3

Fig. 1 Schematic view of grain cleaning machine

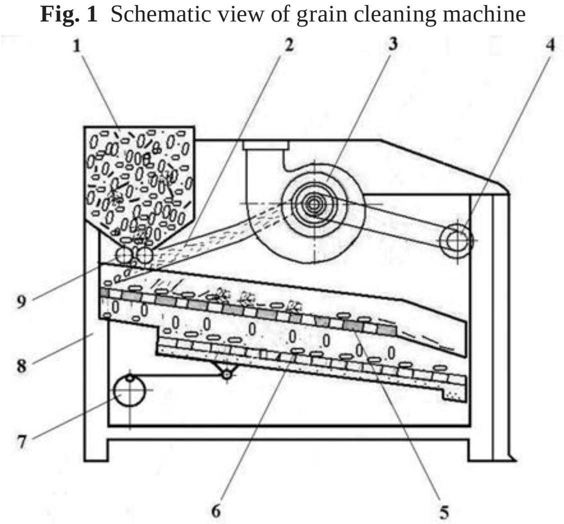
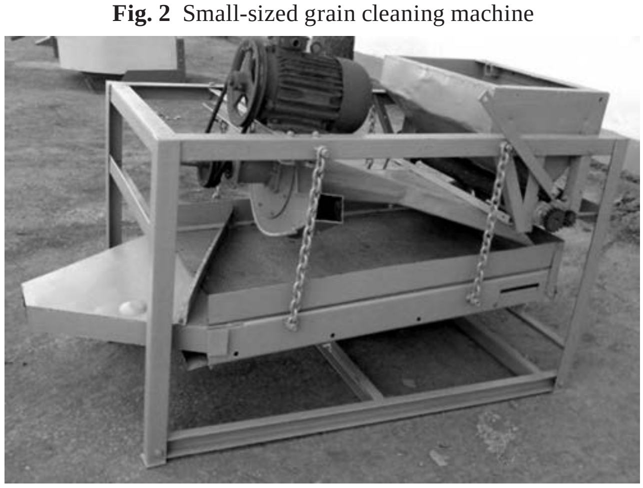


Fig. 2 Small-sized grain cleaning machine



completeness of the heaps mastication were up to standard of an initial request, and admissible damage of grain is at a frequency of roller rotation of 800…1,000 rpm.

Backlash influence between rollers on completeness of heaps mastication and on grain damage showed that completeness of heaps mastication decreased much more with an increase in a backlash from 1 mm to 4 mm (**Table 2**). Including, if at a backlash between rollers of 1 mm, completeness of heaps mastication is 93.9 % at a backlash of 2 mm and decreased on 84.1 %, and at backlashes between rollers of 3 and 4 mm, accordingly on 77.6 and 72.8 %.

Simultaneously, with a decrease in completeness of heaps mastication, grain damage decreased also. If at a backlash between rollers of 1 mm grain damage is much more than others then, at a backlash between rollers of 2 mm, this indicator essentially decreased and amounts 0.4 %, and at a backlash of 3 mm it made 0.1 %. At a backlash between rollers of 4 mm grain damage is not observed.

Analysis showed that, on the best indicators when completeness of heaps mastication is reached, backlashes at 3 mm and 4 mm gave the best grain damage.

Process of cleaning grains. After optimum frequencies of rotation of rollers and backlash spacing were determined, the influence of frequency and amplitude of fluctuations and, also, angle of sieve slope on cleanliness and grain losses were studied.

From (**Table 3**), it is visible that, with increase in frequency of fluctuations, sieve cleanliness of grain increased. At a frequency of sieve fluctuations of 100 rpm, cleanliness of grain amounts 97.6 % and at frequency of fluctuations of 125 rpm and 150 rpm this indicator reached 98.1 and 98.6 %. At an increase in frequency of sieve fluctuations from 150 rpm to 200 rpm, cleanliness of grain had almost identical significances and made, accordingly, 98.7 and 98.5 %.

However, with improvement of cleanliness, of grain losses were, simultaneously, increased. At sieve fluctuations of 100 and 125 rpm, of loss of grain is insignificant (0, 1 and 0, 3 %) and, with increase in frequency of fluctuations from 150 to 200 rpm, this indicator is intensively increased and reached from 0.9 % to 3.1 %. It is almost 10 times higher the indicator at frequencies of fluctuations of 100 rpm and 125 rpm.

At frequency fluctuations from 100 to 150 rpm, cleanliness of grain shall amount 98…99 %, and losses of grain 0.1…0.9 %. Therefore, for definition of optimum parameters and modes of operation of the grain cleaning machine, it is necessary to choose these intervals of frequency of fluctuations.

Dependence between quality indicators and amplitude of fluctuations sieves (on eccentricity radius) shows by changing the amplitude of fluctuations from 10 mm to 50 mm. cleanliness of grain changes. By increasing the amplitude of fluctuations from 10 mm to 30 mm cleanliness of grain is increased. From 97.4 to 98.5 % cleanliness improves 1.1 %; however, at further increase in amplitude of fluctuations from 30 mm to 50 mm cleanliness of grain changed only slightly to 98.5 and 98.7 %.

Change of losses of grain with amplitude of fluctuations has another character. If, with increase in amplitude of fluctuations from 10 to 30 mm, loss of grain decreases from 0.4 % to 0.1 % at an increase in amplitude of fluctuations from 30 to 50 mm, grain losses are increased and reach 0.1 % to 1.1 %.

The best cleaning and the least losses of grain results were with amplitude of fluctuations of 20 …30 mm.

The grain cleanliness and grain losses increased as angle of sieve increased from 5 to 17 degrees. The best sieve slope angle amounts between 5 and 11 degrees.

Conclusion

1. There is a possibility of allocation of grain from not threshed heaps

Table 2 Backlash influence between rollers on completeness of heaps mastication and grain damage

Space between roller, mm	1	2	3	4
Completeness of cereals wearing through, %	93.9	84.1	77.6	72.8
Grain damage,%	2.8	0.4	0.1	0

Table 3 Influence of frequency, amplitude of fluctuations, and angle of slope sieves on work quality indicators for the grain cleaning machine

Title of rate values	Frequency of sieves fluctuations, rpm				
	100	125	150	175	200
Cleanliness of grain	97.6	98.1	98.6	98.7	98.5
Grain losses	0.1	0.3	0.9	1.3	3.1
	Range of sieves fluctuations, mm				
	10	20	30	40	50
Cleanliness of grain	97.4	98.1	98.5	98.7	98.6
Grain losses	0.4	0.2	0.1	0.5	1.1
	Angle of sieves slope, degree				
	5	8	11	14	17
Cleanliness of grain	95.4	97.0	98.6	99.2	99.5
Grain losses	0.1	0.1	0.4	1.0	2.1

separated by grain weight by rubbing their rollers, rotating against each other.

2. For the best rubbing of not threshed heaps with the least damage of grain, rotation frequency of the first roller should be 600 rpm, and rotation frequency of the second roller within 800-1,200 rpm, at a backlash between rollers of 2-3 mm.
3. For achievement of qualitative clearing of grain lots at minimum loss of grain it is necessary to choose following intervals of parameters and modes of operation for the grain cleaning machine: frequency of sieve fluctuations of 100...150 rpm; amplitude of sieve fluctuations of 30...50 mm; angle of sieve slope of 8...11.
4. The developed grain cleaning machine, together with required qualities of work, has low metal consumption and power consumption. The weight of machine amounts 305 kg and consumes 2.7 KW of power energy at an operation rate of 350 kg/hour.

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Internal Air Flow Characteristics of a Head-feed Combine -1

—Analysis of the Air Velocity in the Grain Separation Tunnel—

by

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Abstract

This study analyzed the air velocity in the grain separation tunnel wherein the non-material components were separated to have a full understanding of the separation wind flow. The velocity of the separation wind in the head-feed combine was measured using a five-hole pressure probe. The inlet air velocity ranged from 5.0 to 25 m/s; and that of the center over the first cross-flow auger ranged from 1.7 to 12.8 m/s. The air velocity at the front and rear positions over the chaff sieve were 1.5 to 5.0 m/s and 3.0 to 9.4 m/s, respectively. The air velocity at the straw rack ranged from 0.8 to 8.4 m/s.

The air velocity of the separation wind depended on the number of revolutions of the main separation fan. The air velocities of both sides of the main separation fan were faster than the air velocity at the center. The air velocity distribution pattern (AVDP) of the separation wind was U-type and affected the rear parts including the first cross-flow auger and the sorting sieve.

The AVDP of the first cross-flow auger showed a high correlation with that of the inlet part at a 5 % significance level.

Introduction

With the decrease in the working population in rural areas, aging of society, harvesting by custom work and lack of full-time-farming promotion policy, the workability of the head-feed combine and its high performance and efficiency are needed. Therefore, the technical development for improving the separation performance is essential.

In the head-feed combine, the crops are cut in the cutting unit and conveyed to the threshing unit, wherein they are separated into grains and straws. The straws are discharged to the rear side of the combine, and the foreign substances in the grains are separated through the wind and gravity separation processes in the separation and cleaning unit. Grains from unthreshed heads that have not been cleaned undergo reprocessing wherein the grains are threshed from the heads and rachis branches, and are conveyed to the separation unit for their cleaning. After the separation process, grains are conveyed to the grain tank through the first cross-flow auger and grain auger. The grains are discharged using the grain sack or grain conveyor through the discharge auger.

In Korea, the head-feed combines are often used to harvest rice or barley. The precision of grains is the most influential factor in evaluating the quality of the crops, which in turn is mostly influenced by the separator. The separator consists of two machines such as the oscillating separator for gravity separation, and the wind separator for wind separation. Its structure differs from manufacturer to manufacturer. It basically consists of the grain pan, which uniformly spreads out the grains in the threshing unit to ease the separation; the grain sieve, which acts as a diaphragm wherein only the grains are separated from empty heads fallen by the wind of the winnowing machine; and the straw rack, which separates the foreign substances from the grains and blows them outside. In the separator, which consists of such complex factors, the inner air flow characteristic of the separation wind determines the precision of the grains. The factor that influences the inner air flow of the separation wind is the grain separation wind tunnel. The precision of the separation can be improved by increasing the efficiency of the separation wind via the grain separation wind tunnel optimization.

Lee *et al*. (1975) developed a shattering/separation machine that could improve the precision and efficiency of the threshing machine to obtain objective data. A study was also done to establish a method using the developed shattering/separation machine for analyzing the separation performance of the threshing machine. Kim *et al*. (1994) theoretically identified the process where the grains are separated from foreign substances by the mechanical vibration and wind in the separation unit of the combine. He also manufactured a testing machine that has a packaging function to present a separation model for the head-feed combine. Kawase *et al*. (2000) presented an optimal design guideline that can improve the efficiency of the winnowing machine that generates the separation wind, as well as the optimal wind tunnel designed at the outlet part of the winnowing machine. Nonami *et al*. (2003) reported an optimization of the separation wind tunnel shape using a water model (by realizing the air flow using the water flow) to clarify the air flow and optimize the wind tunnel shape.

In the first report of this study, 3D wind velocity variation was measured and analyzed in the separation wind flow field created in the separation space. For the second report, the variation of the wind direction in the separation space will be analyzed.

Materials and Method

Test Equipment

Machine Used in the Experiment

A four-row head-feed combine (DSM72G, Daedong, Korea) was used in this study. **Table 1** shows its specifications. The four-row type was used because it was currently the most widely distributed type of head-feed combine in Korea. This head-feed combine consisted mainly of the cutting unit, the conveying unit, the threshing unit, the separation unit, the storage unit, the driving unit, and the engine unit. The sorting sieve of this combine consisted of the grain pan, which spreads out the grains on the separation plate and the chaff sieve, where the separation was done through the wind. It was 1,550 mm long and 665

Table 1 Specifications of the head-feed combine

Model No.	DSM72G, Daedong		
Dimen-sions	Length (mm)		4,445
	Width (mm)		1,910
	Height (mm)		2,635
	Weight (kg)		3,130
Engine	Model		E4DE-TDE
	Type		4 cycle, 4 cylinders
	Displacement (cc)		2,955
	Power (kW) / Speed (rpm)		53/2,700
Trans-mission	Center distance of crawler (mm)		1,030
	Width of crawler (mm)		450
	Length of ground contact (mm)		1,580
	Average pressure of ground contact (kg/cm^2)		0.20
	Speed change type		HST
	Traveling speed (m/sec)	Forward	0-2.26
		Reverse	0-2.26
Reaping parts	Reaping width (mm)		1,485
Thre-shing parts	Threshing drum	Diameter × width (mm)	427 × 900
		Speed (rpm)	505
Grain tank capacity (L)	1,400		

Table 2 Air flow measuring points in the head-feed combine

Measure-ment part	Measure-ment point	X Coordi-nate (cm)	Y Coordi-nate (cm)	Z Coordinate (cm)
Inlet parts	1	220	40	100, 150, 250, 365, 480, 580, 630
	2	220	−30	100, 150, 250, 365, 480, 580, 630
	3	220	−80	100, 150, 250, 365, 480, 580, 630
	4	220	−110	100, 150, 250, 365, 480, 580, 630
1st cross-flow auger	5	500	60	100, 150, 250, 365, 480, 580, 630
	6	500	−20	100, 150, 250, 365, 480, 580, 630
2nd cross-flow auger	7	740	100	100, 150, 250, 365, 480, 580, 630
	8	780	30	100, 150, 250, 365, 480, 580, 630
Chaff	9	530	260	100, 150, 250, 365, 480, 580, 630
	10	570	260	100, 150, 250, 365, 480, 580, 630
	11	620	260	100, 150, 250, 365, 480, 580, 630
	12	760	260	100, 150, 250, 365, 480, 580, 630
Straw rack	13	900	270	100, 150, 250, 365, 480, 580, 630
	14	1,000	270	100, 150, 250, 365, 480, 580, 630

mm wide, and had an oscillating speed of 405 rpm. The winnowing fan was a four-winged fan with a diameter of 348 mm and an adjustable revolution frequency of 950 rpm to 1,550 rpm. Its linear velocity ranged from 17.3 to 28.2 m/s. The sieve was manually adjusted within a range of 15-31 mm. **Fig. 1** shows the harvesting flow in a head-feed combine and the separation space in detail.

Separation Wind Measurement System

The measurement system consisted of a five-hole pressure probe (S5H-1, SDD, Korea, referred to as "FHPP") for the measurement of the wind velocity and direction, a manually adjustable 3D holder for fixing the FHPP, a differential pressure gauge (SD-332, SDD, Korea) for measuring the pressure generated from the FHPP, a data collector that collected and processed the pressure data output of the differential pressure gauge, a notebook computer for storing the data, and the operation software for this system. As shown in **Fig. 2**, the FHPP has a diameter of 3.5 mm and a length of 990 mm. The 940 mm-long portion was reinforced with an 8 mm diameter tube. The differential pressure gauge had a measurement accuracy of ±0.5 %, a resolution of 1 Pa, and a measurement range of 0-1,000 Pa. The wind velocity measurement range was 0-40 m/s, and the measurement range of the pitch angle and the yaw angle was ±45º.

Experimental Method

Measurement Points

To realize the optimal design for the separation wind tunnel, the separation wind was measured by using the aforementioned equipment. **Fig. 3** shows the separation wind measuring points and the names of the parts of the separation space in the combine. **Table 2** shows the x and y coordinates, with the winnowing fan axis as the reference point, and the z axis (depth), with the lateral side of the combine as the reference point, for the measurement of the separation wind. To analyze the separation wind flow characteristics in the separation space, the separation wind was measured at four points in the separation wind inlet part, two points over the first cross-flow auger, two points over the second cross-flow auger, four points over the chaff sieve, and two points over the straw rack. In addition, the separation wind was measured at seven points by depth, with the lateral side of the combine as the reference point. Thus, the separation wind was measured at a total of 98 points.

Measurement Method

Fig. 4 shows the actual measurement of the separation wind at each point. The separation wind was measured at a total of 98 points in four steps, while the number of revolutions of the winnowing fan was changed to 1,100, 1,300, 1,400, and 1,550 rpm. The number of revolutions of both the winnowing fan and the combine engine were changed. A total of 392 measurements were made, with the opening of the chaff sieve set at the standard value for harvesting rice. **Fig. 5** shows the flowchart for the collection of the

Fig. 1 Schematic diagram of the separation space in the head-feed combine

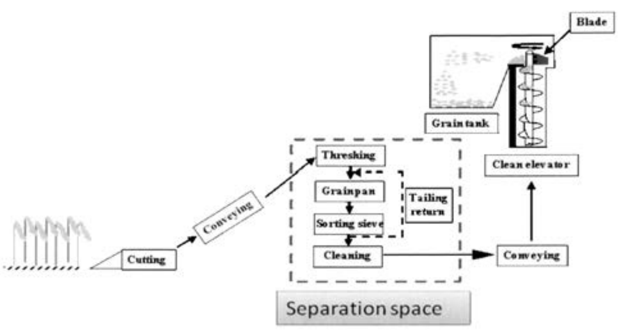


Fig. 2 Geometrical feature of the straight-type five-hole pressure probe

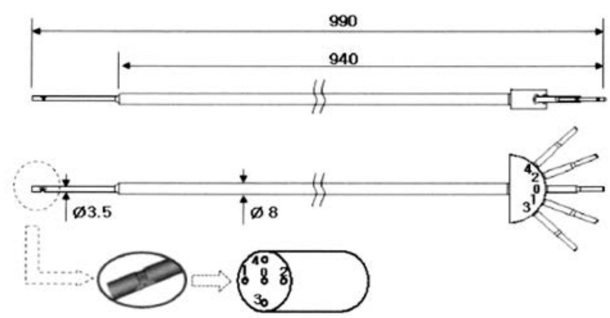


Fig. 3 Air flow measuring points in the head-feed combine

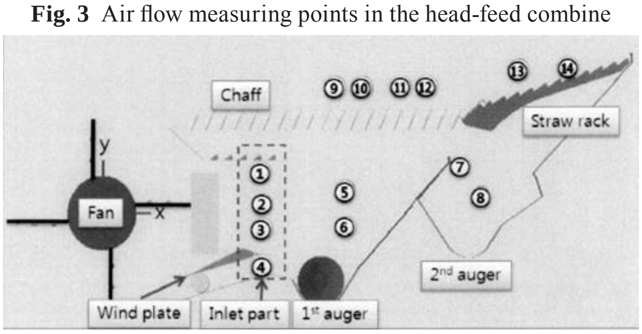


Fig. 4 Air flow measurement scene with the head-feed combine

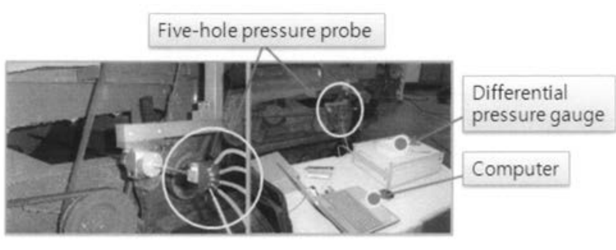


Table 3 Air velocity of each position in separation tunnel according to the fan revolution

		1,100 (rpm)				1,300 (rpm)				1,400 (rpm)				1,550 (rpm)			
		Min. (m/s)	Max. (m/s)	Ave. (m/s)	C.V. (%)	Min. (m/s)	Max. (m/s)	Ave. (m/s)	C.V. (%)	Min. (m/s)	Max. (m/s)	Ave. (m/s)	C.V. (%)	Min. (m/s)	Max. (m/s)	Ave. (m/s)	C.V. (%)
Inlet parts	1	5.0	17.5	10.6	42.3	5.6	20.5	12.5	43.4	6.1	21.6	13.3	42.4	7.0	23.6	14.6	40.9
	2	6.0	18.0	12.3	38.0	8.0	21.5	14.9	35.5	7.0	22.8	14.9	40.9	10.0	25.0	16.5	32.8
	3	7.1	16.4	10.9	28.9	8.4	19.5	12.9	29.4	6.9	19.9	13.4	32.7	9.4	22.3	15.4	30.0
	4	12.6	14.2	13.1	4.3	14.8	17.1	15.5	5.3	14.8	18.3	16.5	6.4	16.6	20.2	18.3	6.7
1st auger	5	1.7	5.7	3.3	43.8	2.1	6.5	3.7	40.6	2.2	5.8	3.7	36.6	2.2	6.4	4.1	37.4
	6	7.6	10.1	8.8	11.5	8.4	12.1	10.6	13.1	8.9	12.8	10.9	11.7	10.1	14.7	12.2	14.0
2nd auger	7	-	-	-	-	-	-	-	-	0	2.7	0.9	129	0	3.0	1.6	73.1
	8	1.2	2.5	1.6	27.4	1.2	2.1	1.7	22.7	1.3	1.9	1.6	17.7	1.6	2.4	1.7	19.3
Chaff	9	1.5	4.2	2.7	43.0	1.6	3.9	2.3	38.2	1.7	4.2	2.6	35.3	1.5	4.8	2.7	41.8
	10	1.4	3.0	2.2	27.4	1.7	4.0	2.7	30.0	2.2	4.4	3.0	27.2	2.4	5.0	3.5	24.6
	11	3.0	6.7	4.2	33.1	3.4	6.7	4.6	27.5	3.6	7.1	4.8	27.9	4.0	7.3	5.3	27.3
	12	3.8	6.4	5.2	16.0	4.9	9.0	6.8	22.4	5.2	8.3	6.8	14.6	5.7	9.4	7.7	15.7
Straw rack	13	3.4	5.8	4.6	18.0	4.4	6.5	5.5	14.2	4.2	6.7	5.7	16.5	4.9	8.4	6.8	16.2
	14	1.2	4.9	3.1	51.1	0.8	6.1	3.7	61.6	1.1	6.2	3.9	58.3	1.2	7.2	5.7	37.3

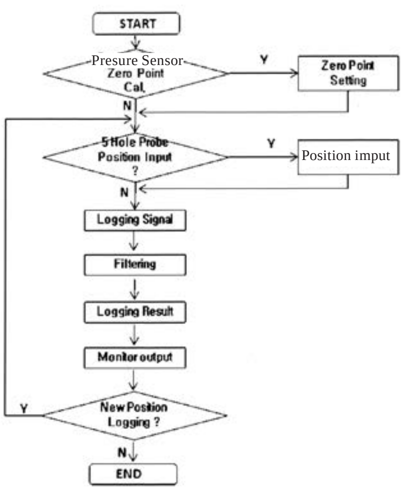
Table 4 Correlation coefficient between the inlet air velocity and the air velocity at each part of the combine harvester

		1st cross−flow auger		2nd cross−flow auger		Front of chaff		Rear of chaff		Straw rack	
		Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13	Point 14
Inlet Parts	1	0.948**	0.776*	0.439	−0.359	0.830*	0.924**	0.512	−0.016	−0.040	−0.379
	2	0.936**	0.939**	0.733*	−0.161	0.634	0.765*	0.378	−0.068	0.052	−0.185
	3	0.861**	0.839**	0.984**	−0.315	0.496	0.564	0.198	−0.203	−0.238	−0.111
	4	−0.397	0.000	−0.158	0.327	−0.798*	−0.769*	−0.776*	−0.481	0.135	0.814*

**: 1 % significant level, *: 5 % significant level, number of samples: 7

measurement data. When this system was implemented, the pressure in the differential pressure gauge was set at point zero. When the tester entered the measurement points of the FHPP and the measurement button was pressed, the pressure was measured at a rate of 50 times a second. This process was repeated and after the average data of each point was analyzed in this study.

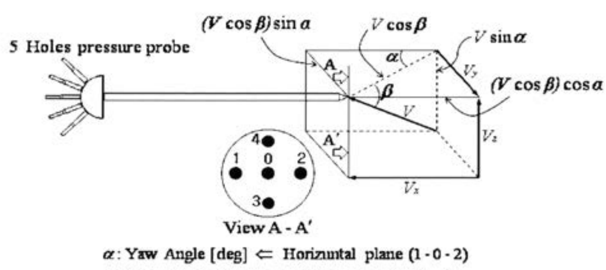
Fig. 5 Signal processing method



3D Wind Velocity Calculation

The wind velocity was calculated using **Eqn. 1**, with the five pressure values obtained from the measurement in the actual flow field. **Eqn. 2** represents the pressure, and **Eqn. 3** represents the 3D wind velocity components. **Fig. 6** shows the 3D velocity components that were obtained by decomposing the FHPP velocity vectors according to the yaw angle and the pitch angle.

Fig. 6 Velocity decomposition of the five-hole pressure probe (Kim *et al.*, 2006)



The yaw angle and pitch angle coefficients were first calculated with the five pressure values measured from each measuring point. Then the five pressure coefficients (Cp_i) that satisfied the yaw angle and the pitch angle were calculated, and the measured pressure (P_i) and the corresponding values were substituted into **Eqn. 1** to obtain the velocity vectors.

$$V = \sqrt{2/p} \times (p_{i,max} - P_{i,min}) / (Cp_{i,max} - Cp_{i,min}) \quad (1)$$

$$p_s = p_{i,max} \times Cp_{i,max} \times (1/2\ pV^2) \quad (2)$$

$V_x = V cos\beta \times cos\alpha$, $V_y = V cos\beta \times sin\alpha$, $V_z = V sin\alpha$ ....(3)

Results and discussion

Separation Wind Velocity and the Coefficient of Variation

Table 3 shows the minimum, maximum, average, and coefficient of variation of the separation wind velocity by measuring points/positions and the number of revolutions of the winnowing fan. The separation wind velocity by measuring positions and points showed significant differences. The inlet part showed a wind velocity of 5.0-25 m/s, and a coefficient of variation of 4.3-43.8 %. For the inlet part, the difference between the upper and lower parts of the wind plate was significant. Regardless of the number of revolutions of the winnowing fan, the velocity was faster at the lower part of the wind plate, and the coefficient of variation at point 4 was smallest because of the narrower tunnel at the upper part than at the lower part. The separation wind velocity at the position over the first cross-flow auger ranged from 1.7 to 12.8 m/s, and the coefficient of variation was 11.5-43.8 %, indicating a significant wind velocity change.

At point 7 over the second cross-flow auger, the separation wind was very weak at about 0 m/s, which indicated that the measuring point was not influenced by the separation wind. The wind velocity at point 8 was weak because of the eddy flow.

At points 9 and 10, which were located at the front part over the sorting sieve, the wind velocity was 1.5-5.0 m/s, and the coefficient of variation was 24.6-43.0 %. At points 11 and 12, which were at the rear part over the sorting sieve, the wind velocity was 3.0-9.4 m/s. There was a change in the scattering loss when the number of revolutions of the winnowing fan excessively increased, considering that the final average velocity of the grains was about 7 m/s (Nonami *et al.*, 2002).

The wind velocity of points 13 and 14 over the straw rack ranged from 0.8 to 8.4 m/s, and the coefficient of variation ranged from 14.2 to 61.6 %, indicating a very large wind velocity change.

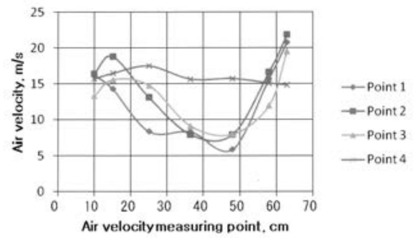
The wind velocity increased with the increase in the number of revolutions of the winnowing fan. At the inlet part, the wind velocity was higher at the points closer to the left and right sides and lower at the points around the center, therefore, a method was needed to increase the wind velocity at the center.

Change in the Separation Wind Velocity Distribution Pattern in the Separation Tunnel

Fig. 7 shows the separation wind velocity measuring points in the separation space and their distribution pattern. The wind velocity was represented by the number of revolutions of the winnowing fan, and the average velocity of each number of revolutions was calculated to derive the regression curve and the regression equation. The separation wind distribution at the inlet part (points 1 to 3) had a U-shaped pattern, wherein the wind velocity was highest at both sides and decreased as the measuring point approached the center. This seemed to indicate that the wind volume was relatively high at both sides, as there were inlets for the separation wind.

Meanwhile, the wind velocity at point 4 was relatively more uniform than at the other points. This indicated that the wind velocity was not influenced much by the wind volume, as the tunnel was relatively narrow because of the wind plate. The wind velocity patterns of points 5 and 6 over the first cross-flow auger were U-shaped, similar to those at points 1, 2, and 3 at the inlet part. On the other hand, the wind velocity was not uniform at point 7 over the second cross-flow auger, especially, when the number of revolutions of the winnowing fan was high. It showed a pattern that was relatively similar to the patterns at points 1, 2, and 3 at the inlet part. The pattern by position of the wind velocity at point 8 differed from

Fig. 7 Average air velocity pattern at each part of the grain separation tunnel



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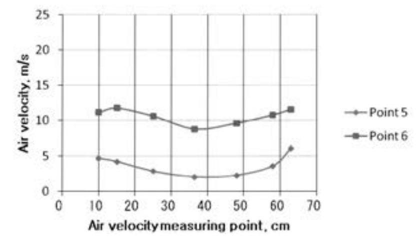
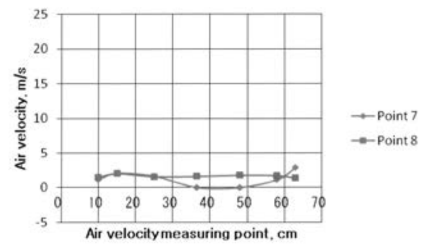


< b. Over the 1st cross-flow auger >



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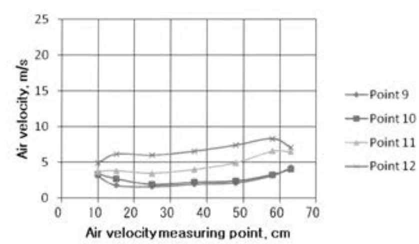
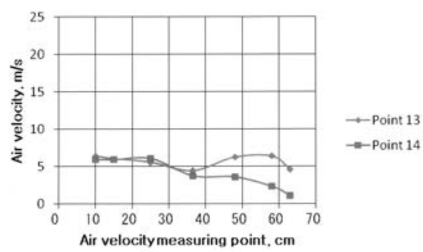


< d. Over the sorting sieve >



< e. Over the straw rack >

that at the other parts because of the eddy flow. At points 9 and 10 at the front part over the sorting sieve, the wind velocity patterns were similar to the wind velocity pattern at the inlet part (points 1, 2, and 3). This indicated that the inlet wind velocity influenced the part over the sorting sieve which can greatly influence the wind separation of grains.

The increase in the wind velocity was biased towards one side as the measurement depth increased at points 11 and 12 at the rear part over the sorting sieve. The wind velocity was biased to the left side at the rear part of the combine, maybe because of the initial wind velocity pattern. That is, the inlet wind velocity was high at the left side, and this phenomenon was stronger at the part that was further back. This represented the importance of the initial wind velocity pattern at the inlet part.

In the wind velocity pattern at point 13 at the straw rack, the left and right distributions were relatively uniform, unlike those at the inlet part (points 1, 2, and 3). The wind velocity pattern at point 14 at the straw rack was less influenced by the inlet wind velocity as the measuring point approached the rear of the combine. This indicated that an additional auxiliary winnowing fan was needed to maintain the existing grain separation performance so that the longer threshing unit and the sorting sieve can be used for larger combines.

The separation wind distribution had U-shaped patterns, which had large differences between those at the sides and the center. The initial wind velocity pattern at the inlet part (points 1, 2, and 3) influenced point 5 over the first cross-flow auger and points 9, 10, 11, and 12 over the sorting sieve at the rear part. The wind velocity pattern at point 4 at the inlet part influenced point 6 under the first cross-flow auger and point 13 in front of the straw rack. Thus, the wind velocity pattern at the inlet part influenced the rear part, and, therefore, the separation wind pattern must be made uniform to improve the separation performance.

Correlation between the Wind Velocity Values at the Inlet Part and at Each Measuring Point

Table 1 shows the correlation between the average inlet wind velocity values according to the measuring points/positions, the change in the number of revolutions of the winnowing fan, and those over the first cross-flow auger, the second cross-flow auger, and at the front and rear positions over the sorting sieve and at the straw rack according to the changes in the number of revolutions of the winnowing fan. The measurement results showed that the average wind velocity near the first cross-flow auger had a strong positive correlation with all the points except for point 4 at the separation wind inlet part at the 5 % significance level, indicating that the wind velocity of the inlet part greatly influenced the wind velocity near the first cross-flow auger.

The average wind velocity at point 7 near the second cross-flow auger had a strong positive correlation with the points except for points 1 and 4 at the separation wind inlet part at 5 % significance level, which also indicated that the wind velocity at the position was influenced by the wind velocity of the inlet part in the same manner as that over the first cross-flow auger. The wind velocity at point 8 was not influenced by the inlet wind velocity because the grain scattering prevention cover blocked the separation wind flow.

At the front part over the sorting sieve, the average wind velocity had positive or negative correlations at the 5 % significance level with all the points except for point 3 at the inlet part. This indicated that the points were influenced by the inlet wind velocity. It seemed that points 1 and 2 showed a positive correlation at the front part over the sorting sieve because they were influenced much by the wind velocity at the upper part of the inlet. The average wind velocity at the front part over the sorting sieve showed a negative correlation with point 4 at the separation wind inlet part.

The average wind velocity at the rear part over the sorting sieve showed a correlation only with point 4 at the separation wind inlet part and point 11 at the rear part over the sorting sieve. This indicated that the inlet wind velocity did not greatly influence that of the rear part over the sorting sieve.

The average wind velocity showed a correlation only with point 4 at the inlet part and point 14 at the straw rack, indicating that the inlet wind velocity did not greatly influence that of the part near the straw rack.

Conclusions

In this study, a five-hole pressure probe was used to measure the separation wind velocity in the combine and its pattern was analyzed according to the measuring points. The following results were obtained.

1. The wind velocity increased with the increase in the number of revolutions of the winnowing fan. At the inlet part, the wind velocity was higher at the points closer to the left and right sides and lower at the center.
2. The separation wind velocity distribution in the separation space showed U-shaped patterns, which involved a difference between the wind velocity values at the side and at the center. The initial wind velocity pattern at the inlet part influenced the wind velocity patterns at the rear part, except for some points.
3. The average wind velocity pattern at the first cross-flow auger had a strong positive correlation with all the points except for point 4 at the separation wind inlet part at a 5 %

significance level, indicating that the wind velocity of the inlet part greatly influenced that at the first cross-flow auger.

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■■

(*Continuation*) Internal Air Flow Characteristic of a Head-feed Combine -2

— Analysis of the Air Direction in the Grain Separation Tunnel —

by
Choung-Keun Lee

Abstract

The report of the first study presented the results of the analysis of the air velocity in the grain separation tunnel of a head-feed combine. This paper reported the measurement using a five-hole pressure of yaw and pitch angles of the separation wind. It aimed to analyze the patterns of the yaw and pitch angles in the grain separation tunnel. The inlet yaw angle ranged from −9.0 to 5.7 degrees and the coefficient of variation ranged from 57 to 110 %. The inlet pitch angle ranged from 14.8 to 55.3 degrees and the coefficient of variation ranged from 8.9 to 43.6 %. The yaw angle at the inlet part showed diverse distribution patterns depending on the measuring point. The yaw angle pattern over the sorting screen was biased towards the right side except at point 10. The pitch angle pattern at the inlet part was similar to the U-shaped air velocity pattern.

Introduction

In the previous report (Lee, 2011), the separation wind velocity at the measuring positions and points was measured using a five-hole pressure probe (FHPP) to examine the wind flow in the separation space and to analyze the patterns for diverse measuring points. The results showed that the separation wind velocity greatly varied according to the measuring points and positions, while that of the inlet part of the separation space, where the winnowing fan was located, influenced the rear part of the separation space. To improve the separation performance, the appropriate separation wind velocity, as well as the appropriate yaw angle and pitch angle, were needed.

The yaw and pitch angles of devices including the blower, suction fan, propeller, and screw were important because their changes generally influenced the performance of the device such as its flow rate and static pressure.

Kang *et al*. (2005) numerically analyzed the changes in the flow rate and static pressure in the axial-flow-type turbo fan according to the change in the pitch angle, and proved that the static pressure almost linearly increased according to the change in the pitch angle from 44 to 54 degrees (the established pitch angle), under the impeller operating conditions. It was also proven that the air volume of the fan at a pitch angle of 59 degrees was higher than that of a pitch angle of 54 degrees, the established design angle, by 13 % and the static pressure by 33 %.

Han *et al.* (2006) analyzed the effect of diverse pitch angles (0, 10, 15 and 20 degrees) on the performance of the centrifugal-axial-flow-type fan. They aimed to improve the flow rate and static pressure of the in-line duct fan and reduce noise. With the increase in the pitch angle, the velocity component that was axial to the overall flow increased, and the best air volume performance was obtained when the pitch angle was 15 degrees.

There has been no study yet on the effect of the yaw angle and the pitch angle of the separation wind in the separation space of the head-feed combine. Also, there has been no preliminary study on the change in the yaw angle and the pitch angle even without the subjects to be separated in the separation space.

Hence, this study was conducted with the following objectives: 1) to measure the variations in the yaw angle and the pitch angle of the separation wind when there was no subject to be separated in the separation space of the head-feed combine, and 2) to analyze the correlation of the yaw angle and the pitch angle patterns with each measuring point and position.

Materials and Method

Machine Used in the Experiment and Experimental Methods

A four-row head-feed combine (DHS70G, Daedong, Korea) was used in this study. The separation wind measurement system was the same as that of the first study. The measuring positions, points, and methods were also the same as those in the previous report, and the yaw angle and the pitch angle, which represent the wind direction at each position and point, were measured (Lee, 2011).

Here, the yaw angle means the angle which the separation wind direction moves in the up and down direction. The pitch angle means the angle which the separation wind direction moves right and left direction.

Calculation of the Yaw Angle and the Pitch Angle

To calculate the yaw angle (á) and the pitch angle (ß), the non-nulling correction method was used to find the values of á and â that satisfied the yaw coefficient (C_{pa}) in **Eqn. 1**, and the pitch coefficient ($C_{pß}$) in **Eqn. 2** from the calibration map using the pressure values measured from the flow field. These were based on the calibration map of the FHPP, which was obtained according to the yaw angle and the pitch angle in the uniform classification of the wind tunnel with a constant velocity (Kim *et al*., 2006 and 2008).

$$Cp_\alpha(\alpha,\beta) = \frac{p_1 - p_2}{p_0 - \frac{1}{4}(p_1 + p_2 + p_3 + p_4) + p_\sigma} = \frac{Cp_1 - Cp_2}{Cp_0 - \frac{1}{4}(Cp_1 + Cp_2 + Cp_3 + Cp_4) + Cp_\sigma} \quad \text{.......(1)}$$

$$Cp_\beta(\alpha,\beta) = \frac{p_3 - p_4}{p_0 - \frac{1}{4}(p_1 + p_2 + p_3 + p_4) + p_\sigma} = \frac{Cp_3 - Cp_4}{Cp_0 - \frac{1}{4}(Cp_1 + Cp_2 + Cp_3 + Cp_4) + Cp_\sigma} \quad \text{.......(2)}$$

In the above equations, p_i and Cp_i represent the five pressure values and pressure coefficients that were simultaneously obtained from the FHPP. The standard variations of the pressure values and pressure coefficients are given in **Eqns. 3** and **4**, respectively.

$$p_\sigma = \sqrt{\sum_{i=0}^{4}(p_i - \frac{1}{5}\sum_{i=0}^{4} p_i)^2} \quad \text{.......(3)}$$

$$Cp_\sigma = \frac{p_\sigma}{\frac{1}{2}\rho V^2} = \sqrt{\sum_{i=0}^{4}(Cp_i - \frac{1}{5}\sum_{i=0}^{4} Cp_i)^2} \quad \text{...(4)}$$

The relational expression of the static pressure and pressure coefficients are given in **Eqn. 5**.

$$p_i = p_s + Cp_i(\alpha,\beta)\cdot\frac{1}{2}\rho V^2 \quad \text{.......(5)}$$

Results and Discussions

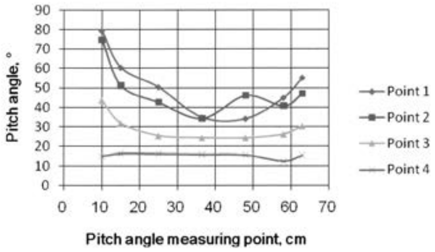
Separation Wind Yaw Angle and the Coefficient of Variation

Table 1 shows the minimum, maximum, average, and coefficient of variation of the yaw angle with the measuring points/positions and the number of revolutions of the winnowing fan. The average change in the inlet yaw angle was −9.0 degrees to 5.7 degrees, and it did not greatly change according to the number of revolutions of the winnowing fan, unlike in the case of the pitch angle. However, according to the measuring position, it ranged from −33.1 degrees to 42.9 degrees, indicating that the yaw angle greatly changed according to the positions. The coefficient of variation of the inlet yaw angle was 57-110 %. In the case of the pitch angle, the yaw angle at point 4 showed a relatively stable distribution, which could be the effect of the wind plate. The yaw angle at point 5 over the 1st crossflow auger had a minimum value of 9.2 degrees, which was higher than that at the inlet part, and was biased towards the right side. However, the yaw angle at point 6 had a minimum average of 0 degrees and the change was smaller than that in the inlet yaw angle. This could be due to the

Table 1 Yaw angle according to the fan revolution

		1,100 (rpm)				1,300 (rpm)				1,400 (rpm)				1,550 (rpm)			
		Min. (°)	Max. (°)	Ave. (°)	C.V. (%)	Min. (°)	Max. (°)	Ave. (°)	C.V. (%)	Min. (°)	Max. (°)	Ave. (°)	C.V. (%)	Min. (°)	Max. (°)	Ave. (°)	C.V. (%)
Inlet parts	1	−10.2	40.7	5.6	99	−10.7	40.8	5.0	104	−14.3	39.7	4.2	94	−11.5	42.9	5.7	110
	2	−4.8	13.0	2.7	106	−4.6	13.1	4.2	98	−5.1	12.1	1.2	100	−3.0	12.6	2.8	94
	3	−25.1	17.7	−5.3	79	−33.1	17.1	−6.2	89	−32.2	18.0	−9.0	95	−30.5	17.1	−6.9	99
	4	−7.6	5.9	0.7	57	−9.0	6.1	−0.4	87	−9.5	4.2	−1.2	87	−9.4	4.3	−1.6	85
1st auger	5	−0.7	34.7	18.5	75	−11.7	26.3	9.2	70	3.9	31.2	17.5	61	−2.3	32.7	18.2	66
	6	−2.5	7.6	2.6	63	0.3	7.2	3.9	63	−2.4	3.2	0	60	−2.0	4.5	0.7	71
2nd auger	7	-	-	-	-	-	-	-	-	−41.6	14.4	−7.0	145	−21.0	13.6	−3.1	82
	8	−40.0	20.8	−10.6	93	−38.2	17.0	−17.3	64	−33.6	7.4	−13.6	72	−39.6	38.8	−3.9	96
Chaff	9	−21.2	35.7	12.2	59	−36.2	24.0	2.2	85	−36.8	26.7	5.2	84	−10.5	34.6	9.7	91
	10	−15.9	10.2	−2.4	58	−15.3	11.4	−2.3	55	−30.2	11.4	−4.5	101	−21.5	10.6	−3.5	80
	11	−3.8	32.3	11.4	82	−9.4	21.0	8.4	46	−3.2	21.3	8.6	83	−4.7	20.0	6.0	80
	12	−3.7	19.2	6.6	72	−9.4	13.6	4.9	58	−11.7	11.5	2.8	48	−11.7	15.4	2.8	45
Straw rack	13	−11.8	3.7	−3.2	105	−14.8	3.1	−5.9	77	−13.3	17.5	−2.0	95	−18.7	8.6	−4.6	87
	14	−22.2	9.6	−2.9	91	−31.7	11.3	−1.2	147	−38.2	10.4	−3.6	188	−20.7	3.7	−8.7	78

Fig. 1 Average yaw angle pattern at each measuring point



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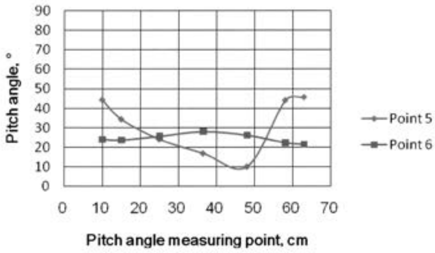

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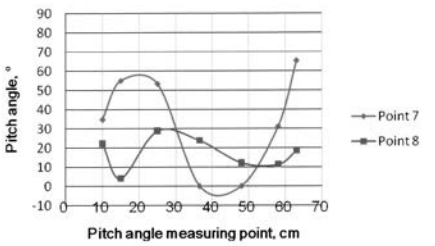

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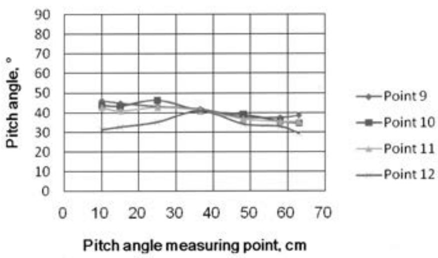
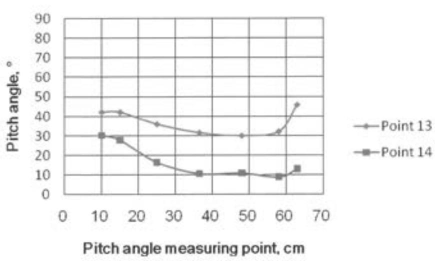


< d. Over the sorting sieve >



< e. Over the straw rack >

relatively stable yaw angle at point 4 at the inlet part. At the position over the 2nd cross-flow auger, point 7 was 1,400 rpm and 1,500 rpm, while point 8 was biased towards the left side. The average yaw angle at the position over the sorting sieve was from −4.5 degrees to 12.2 degrees, and its coefficient of variation was 45-101 %, which was generally more stable than at the inlet part. This meant that the chaff sieve, again, made the separation wind steady in a manner similar to that with the pitch angle change.

The change in the yaw angle over the straw rack was from −1.2 degrees to −8.7 degrees, and its coefficient of variation was 77-188 %, indicating that the yaw angle greatly changed according to the positions.

The right-side bias of the yaw angle was observed at the inlet part and over the 1st cross-flow auger, the 2nd cross-flow auger, and the sorting sieve. It seemed that this had to be addressed to improve the separation performance.

Change in the Separation Wind Yaw Angle Distribution Pattern in the Separation Tunnel

Fig. 1 shows the separation wind yaw angle at the inlet part based on the number of revolutions of the winnowing fan, as well as the regression curve and the regression equation using the average yaw angles based on each number of revolutions. **Table 2** shows the correlation between the average inlet yaw angles according to the measuring points/positions and the change in the number of revolutions of the winnowing fan, and those over the 1st cross-flow auger, the 2nd cross-flow auger, at the front and rear positions over the sorting sieve, and at the straw rack, according to the change in the number of revolutions of the winnowing fan. At point 1, the yaw angle pattern at the inlet part greatly changed with the change in the depth. The most stable yaw angle distribution was at point 4 within ±5 degrees. The variation was high at point 5 over the cross-flow auger according to the measuring point, but point 6 showed a relatively stable distribution within ±5 degrees, as in the case of point 4, and a correlation with points 3 and 4 at a 5 % significance level. Points 7 and 8 over the 2nd cross-flow auger did not show a uniform distribution, as in the pitch angle. The distribution pattern of the yaw angle over the sorting sieve was biased towards the right side, except for that at point 10. Point 11 had a negative correlation with point 2, and point 12 with point 1, at a 1 % significance level. This significance was not observed for wind velocity and the pitch angle. This might have been due to the structural characteristics of the separation space rather than on the effect of the inlet yaw angle.

At the position over the straw rack, the patterns of points 13 and 14 were similar, and had no change in their yaw angles according to the depth. This might have been due to the separation wind with non-uniform yaw angles that passed through the straw racks. The pitch angle at point 14 showed a correlation with the pitch angles at points 3 and 4 at the inlet part at a 5 % significance level.

The yaw angle changed according to the depth and the measuring point. Therefore, to minimize this phenomenon and to improve the separation performance, the blades which guide the yaw angle toward a specific direction were needed at the wind plate, under the sorting sieve and at the 1st cross-flow auger.

Separation Wind Pitch Angle and the Coefficient of Variation

Table 3 shows the minimum, maximum, average, and coefficient of variation of the pitch angle by the separation wind yaw angle measuring points/positions and the number of revolutions of the winnowing fan. The separation wind pitch angle showed marked dif-

Table 2 Correlation coefficient of the yaw angles at the inlet and at each part in the combine harvester

		1st cross−flow auger		2nd cross−flow auger		Front of chaff		Rear of chaff		Straw rack	
		Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13	Point 14
Inlet parts	1	−0.760*	0.168	−0.540	0.497	0.374	0.243	0.040	−0.883**	−0.555	0.698
	2	0.403	0.581	0.039	0.088	−0.212	−0.601	−0.831*	−0.116	0.629	0.461
	3	0.692	0.807*	−0.139	−0.102	−0.227	−0.156	−0.548	0.139	0.389	0.765*
	4	−0.112	0.825*	−0.615	0.423	−0.015	−0.036	−0.458	−0.646	−0.033	0.824*

**: 1 % significance level, *: 5 % significance level, number of samples: 7.

Table 3 Pitch angle according to the fan revolution

		1,100 (rpm)				1,300 (rpm)				1,400 (rpm)				1,550 (rpm)			
		Min. (º)	Max. (º)	Ave. (º)	C.V. (%)	Min. (º)	Max. (º)	Ave. (º)	C.V. (%)	Min. (º)	Max. (º)	Ave. (º)	C.V. (%)	Min. (º)	Max. (º)	Ave. (º)	C.V. (%)
Inlet parts	1	34.0	79.1	51.2	30.4	18.0	79.7	47.0	43.6	34.6	77.2	51.7	28.0	43.1	81.4	55.3	24.5
	2	32.5	72.3	46.8	26.9	35.9	73.2	48.0	25.3	31.5	76.3	47.6	30.3	37.5	77.6	50.3	26.0
	3	21.3	41.9	27.7	25.6	21.4	42.7	27.9	26.3	24.1	44.2	30.4	22.4	25.5	45.6	31.6	22.1
	4	12.1	16.2	14.8	9.4	12.3	16.3	15.2	9.3	12.4	16.3	15.4	9.2	12.8	16.7	15.6	8.9
1st auger	5	14.1	48.3	33.6	39.9	5.8	46.2	30.2	54.0	14.6	45.8	31.4	39.8	0.9	46.0	30.2	55.6
	6	19.9	24.1	22.8	11.2	20.5	28.3	24.8	10.5	20.3	27.8	24.7	10.2	19.9	29.2	25.7	12.8
2nd auger	7	-	-	-	-	-	-	-	-	0	66.8	26.6	126	0	69.5	41.8	71.4
	8	0.2	43.6	14.8	103	1.1	27.3	15.0	73.7	5.0	38.0	16.9	68.4	2.1	47.0	22.6	85.2
Chaff	9	35.4	47.9	42.9	10.9	30.4	45.6	40.3	12.8	36.7	45.5	41.0	7.1	37.9	45.5	41.4	7.2
	10	35.0	45.0	40.1	9.2	34.4	53.7	40.7	16.3	33.6	48.5	40.8	12.0	34.1	46.3	40.3	12.1
	11	31.7	43.5	39.3	9.8	35.6	42.5	39.4	8.4	34.3	41.9	39.1	8.1	31.0	43.6	39.3	11.6
	12	29.8	42.4	34.8	11.8	26.7	39.8	33.1	12.3	28.7	41.2	34.0	11.1	30.7	40.0	33.3	9.6
Straw rack	13	27.9	47.3	36.9	20.0	28.4	43.2	35.9	15.7	30.7	46.7	37.2	17.1	32.6	45.9	38.3	15.0
	14	8.6	36.2	22.4	42.6	2.2	28.2	12.9	84.7	3.5	30.5	14.9	70.8	7.9	32.5	17.1	56.1

Table 4 Correlation coefficient between the inlet pitch angle and the pitch angle at each part of the combine harvester

		1st auger		2nd auger		Front of chaff		Rear of chaff		Straw rack	
		Point 5	Point 6	Point 7	Point 8	Point 9	Point 10	Point 11	Point 12	Point 13	Point 14
Inlet parts	1	0.712*	−0.491	−0.176	0.038	0.695	0.335	0.408	−0.618	0.792*	0.871**
	2	0.470	−0.305	0.249	−0.014	0.590	0.310	0.341	−0.574	0.570	0.824*
	3	0.625	−0.375	0.340	0.017	0.650	0.252	0.367	−0.538	0.686	0.839**
	4	−0.489	0.482	0.103	0.216	0.491	0.586	0.550	0.237	0.254	0.342

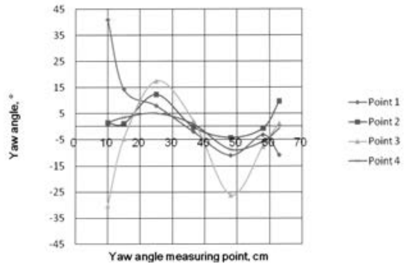
**: 1 % significance level, *: 5 % significance level, number of samples: 7.

ferences based on the measuring positions and points. The average change in the inlet pitch angle was 14.8-55.3 degrees, indicating that the separation wind blows upward to improve the cleaning efficiency at the sorting sieve and at the rear of the separation space. The coefficient of variation was 8.9-43.6 %, and was relatively low at 1,550 rpm of the winnowing fan. At point 4, the average minimum pitch angle was 14.8 degrees and the maximum coefficient of variation was 15.6 %, indicating the most stable distribution. This might have been brought about by the installation of the wind plate at about 15 degrees upward on the separation space floor. The average pitch angle over the 1st cross-flow auger was from 30.2 degrees to 39.9 degrees, which was smaller than the inlet pitch angle, and the pitch angle at point 6 showed a constant value of 22.8 degrees to 25.7 degrees, unlike at point 6. This could have been due to the effect of point 4 at the inlet part, which showed a relatively stable pitch angle change. At the front and rear parts over the sorting sieve, the average pitch angle was from 33.1 degrees to 42.9 degrees, and the coefficient of variation was 7.2-16.3 %. Thus, the variation of the pitch angle was lower than the variations at the other points, and its coefficient of variation was also relatively constant. At the straw rack, the average pitch angle was 12.9-38.3 degrees, which was smaller than that over the 1st cross-flow auger or the sorting sieve. The coefficient of variation was 15-84.7 %, with a relatively large change according to the number of revolutions of the winnowing fan.

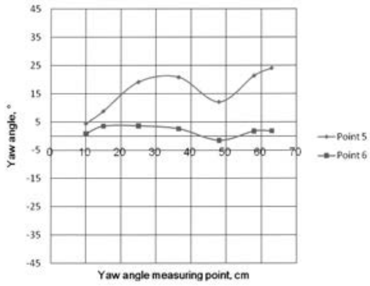
Change in the Separation Wind Pitch Angle Distribution Pattern in the Separation Tunnel

Fig. 2 shows the separation wind

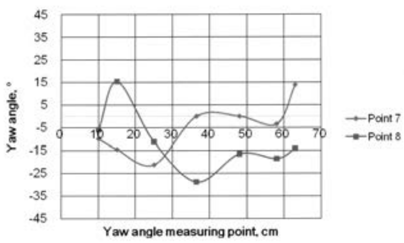
Fig. 2 Average pitch angle pattern at each measuring point



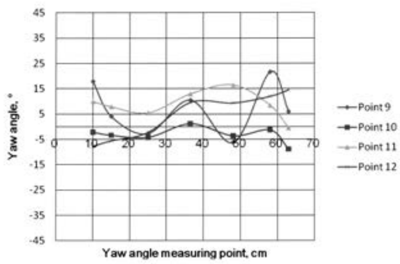
< a. Inlet parts >



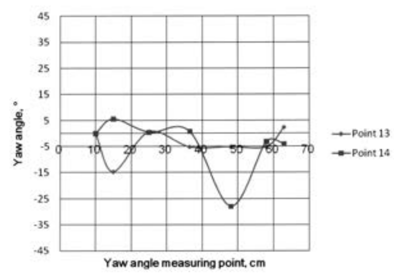
< b. Over the 1st cross-flow auger >



< c. Over the 2nd cross-flow auger >



< d. Over the sorting sieve >



< e. Over the straw rack >

pitch angle based on the number of revolutions of the winnowing fan, and the regression curve and the regression equation using the average pitch angles based on each number of revolutions. **Table 4** shows the correlation between the average pitch angle at the separation wind inlet part according to the measuring points/positions and the change in the number of revolutions of the winnowing fan. It also showed the average pitch angle over the 1st cross-flow auger, the 2nd cross-flow auger, at the front and rear positions over the sorting sieve, and at the straw rack, according to the change in the number of revolutions of the winnowing fan. The pitch angle distribution at the inlet part (points 1 to 3) had U-shaped patterns, as in the case of the wind velocity, wherein the pitch angle was highest at both sides and decreased as the measuring point approached the center. This may be due to the wind volume that was relatively high at both sides, as there were inlets for the separation wind at both sides of the winnowing fan.

The pitch angle at point 4 was relatively more uniform than that at the other points, as in the case of the wind velocity. The pitch angle at point 4 was not influenced much by the wind volume, since the tunnel was relatively narrow at the position because of the wind plate.

The pitch angle of point 5 over the 1st cross-flow auger showed U-shaped patterns that were similar to those at points 1, 2, and 3 at the inlet part, and showed a correlation with point 1 at a 5 % significance level. Point 6 had a relatively uniform pattern because it was influenced by point 4 at the inlet part.

The pitch angle was not uniform at point 7 over the 2nd cross-flow auger, especially when the number of revolutions of the winnowing fan was high. It showed a pattern that was relatively similar to the patterns at points 1, 2, and 3 at the inlet part, but it did not show any significant correlation. The pattern by position of the pitch angle that was measured at point 8 differed from that of the other parts possibly because of the eddy flow.

The front and rear parts over the sorting sieve showed constant values within 33.1-42.9 degrees. This might have been due to the separation wind with the pitch angle that was formed at the inlet part, passing between the uniformly spaced chaff sieves of the sorting sieve. The chaff sieve could be installed at an angle of 27-60 degrees, and it was installed at an angle of 42-49 degrees, which was used to harvest barley and rice.

The inlet pitch angle slightly diminished when the wind passed between the chaff sieves of the sorting sieve at the front and rear parts over the sorting sieve.

The pitch angle pattern at point 13 at the straw rack had a symmetrical pattern, and had a correlation with point 1 at the inlet part at a 5 % significance level. The pitch angle pattern at point 14 was similar to the pitch angle patterns at points 1, 2, and 3 at the inlet part, and had a correlation with them at a 5 % significance level.

The pitch angles of the separation wind in the separation space showed U-shaped patterns at the inlet part, except for the pitch angle at point 4, but unlike in the case of the wind velocity, they did not have similar patterns at the rear, except for the position over the 1st cross-flow auger and at point 14 at the straw rack. This indicated that the change in the pitch angle was greatly influenced by the components in the separation space. In addition, the change in the pitch angle based on the measuring depth was significant, as with the wind velocity, and it seemed that the change in the pitch angle at the left and right sides had to be reduced to improve the separation performance.

Conclusions

This Study Led to the Following Conclusions:

1. The average change in the inlet yaw angle was −9.0 degrees to 5.7 degrees, and the coefficient of variation at the inlet part was 57-110 %. The position over the sorting sieve showed a yaw angle of −4.5 degrees to 12.2 degrees, and a coefficient of variation of 45-101 %.
2. The yaw angle pattern at the inlet part greatly changed according to the change in the depth at point 1. At point 4, however, the yaw angle distribution pattern was most stable within ±5º. The yaw angle distribution pattern over the sorting sieve was biased towards the right side, except at point 10.
3. The average change in the inlet pitch angle was from 14.8 degrees to 55.3 degrees, and the coefficient of variation was 8.9-43.6 %. At the front and rear parts over the sorting sieve, the average pitch angle was from 33.1 degrees to 42.9 degrees, and the coefficient of variation was 7.2-16.3 %. Thus, the variations in the pitch angle were lower than those at the other points, and the coefficient of variation was also relatively constant.
4. The inlet pitch angle distribution had U-shaped patterns, as in the case of the wind velocity, wherein the pitch angle was highest at both sides and decreased as the measuring point approached the center. The front and rear parts over the sorting sieve showed constant values of 33.1 degrees to 42.9 degrees.

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NEWS

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December 2nd- 3rd, 2011

Nong Lam University, Hochiminh City, Vietnam

INTERNATIONAL WATER EXHIBITION: The Organizing Committee is pleased to inform you that the International Workshop on Agricultural and Bio-systems Engineering will be held at Nong Lam University, Hochiminh city, Vietnam on December 2nd- 3rd, 2011. This workshop is co-organized by Nong Lam University, the Kyushu Branch of JSAM (Japanese Society of Agricultural Machinery), Mie University (Japan) and Sung Kyung Kwan University (Korea) andmainly sponsored by The Viet Nam Ministry of Education and Training.

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Greenhouse Glazing Material Effect on Evaporative Cooling for Tomato Production under Summer Conditions

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Abstract

The influence of greenhouse glazing material on an evaporative cooling system based on cooling pads and an extracting fan was studied in a 32 m^2 tomato greenhouse located in the eastern area of coastal delta, Egypt. Two different glazing materials; fiberglass reinforced plastic (FRP) and double layer polyethylene sheets (PE) were used. Tomato plants were transplanted on 21 April, 2007 into 60 plastic pots in each greenhouse with a plant density of 3.25 m^2. At transplanting, the evaporative cooling system was automatically activated when the two greenhouse air temperature reached to 28 ºC. Air temperature, relative humidity, wind speed, and total solar radiation entering the greenhouse were measured and recorded on a data-logger to analysis their correlation with the tomato crop yield response. A mathematical model was developed to simulate microclimate on and around the leaf surface for greenhouse tomatoes. Air temperature and relative humidity inside the two greenhouses were 28.5 ºC and 29.8 ºC, 53.3 % and 55.7 %, respectively, during summer months at and around noon. Furthermore, the data revealed generally high uniformity of the microclimatic conditions within the greenhouse, in the lengthwise (east-west) and vertical directions. However, due to short length of the greenhouse (8 m), small temperature gradients (lower than 2 ºC) were observed from pads to fan. It was concluded that, due to the optimal level of microclimatic conditions inside the two greenhouses with an evaporative cooling system, they produced a fresh yield of 8.796 and 7.356 kg/m^2, respectively. Thus, the fiberglass greenhouse increased the fresh yield by 19.58 % as compared with the polyethylene greenhouse. It was also concluded that in order to obtain completely uniform microclimatic conditions throughout the volume of the greenhouse, and high effectiveness of evaporative cooling, it was desirable to install shading black net on the roof of greenhouse.

Introduction

High air temperature (T > 45 ºC) and vapour pressure deficit (VPD > 3 kPa) are currently observed in greenhouses during summer In Egypt. These conditions are responsible for the decrease in fresh yield and quality of protected cropping. High summer temperatures result in the need for constant heat removal from the greenhouse. This may be accomplished by replacing the existing air in the greenhouse with cooler air from outside the structure. If outside temperature is low enough, and temperature inside the greenhouse is not too high, warm air may be passively (natural thermal buoyancy) exhausted through roof vents. This system is most effective in winter, spring, and fall. It is limited in its effectiveness for summer cooling since the incoming solar radiation load and outside air temperature may be too high for the

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capabilities of this system during summer months in most other climates (Papadakis *et al*., 1996; and Sethi and Gupta, 2004). The high heat loads (high values of outside air, dry and wet bulb temperature associated with high intensity of solar radiation) during the summer months and the aim of achieving the desired growing conditions (solar radiation, air temperature, and relative humidity in the greenhouse as required for growth), are stimulating the use of evaporative systems to cool greenhouse (ASHRAE, 1995; Arbel *et al*., 1999; Kittas *et al*., 1999). Willits (2003) and Toida *et al.* (2006) showed that, in the extreme environmental locations where summer ambient air temperature generally exceeds 40 ºC, evaporative cooling, which can lower the inside air temperature significantly below the ambient air, is the most efficient system for greenhouse cooling. These systems are based on conversion of sensible heat into latent heat through the evaporation of water, which is supplied mechanically.

Evaporative cooling in a commercial greenhouse equipped with a pad-fan system for use during the summer period in arid countries was studied by Jamal (1994) and Jain and Tiwari (2002). Improving the cooling efficiency and covering the roof of the greenhouse with external shading would save appreciable amount of energy and water consumption. The cooling performance was achieved up to 80 % and the temperature of the greenhouse was lowered by 10 ºC as compared to the outside air (Abdel-wahab, 1994 and Kittas *et al*., 2001). Jain and Tiwari, 2002) reported greenhouse air temperature to be 4-5 ºC lower as compared with the outside conditions.

When an evaporative cooling pad was used, both air and canopy temperatures declined with increasing airflow rates up to 0.13 m^3 m^{-2} s^{-1}, the highest level considered. With no evaporative pad cooling, the evapotranspiration coefficient was predicted to range from 1.75 for an outside temperature of 36.8 ºC and an outside humidity ratio of 3.3 g kg^{-1} to 0.8 for an outside humidity ratio of 29.9 g kg^{-1} at the same temperature. With evaporative cooling, the coefficient was predicted to range from 0.6 to 0.8 at the same outside temperature and the same range of outside humidity ratios (Kittas *et al*., 2003; Willits, 2003 and Fuchs *et al*., 2006).

The objectives of this study were to examine the factors that influence the level and uniformity of the microclimatic conditions obtained in a greenhouse during the summer months with forced ventilation using a fan-pad system under two different greenhouse glazing materials using corrugated fiberglass reinforced plastic (FRP) and double layer polyethylene sheet (PE).

Materials and Methods

Greenhouse Facilities and Plant Material

The experiments were conducted during the Summer of 2007 in two experimental gable-even-span greenhouses orientated in the East-West direction and situated at the University of Mansoura (Latitude and longitude, respectively, are 31.045 ºN and 31.37 ′E) in the eastern area of the coastal delta, Egypt. The geometrical characteristics of each one were 8 m long, 4 m wide, and 3.25 m high, with a net floor surface area of 32 m^2 and a volume of 87.7 m^3. The rafters were tilted at 27 degrees to minimize the side effects of wind load and intensity of solar radiation on the roof of the greenhouse during summer months. The two greenhouses (G_1 and G_2) were covered with two different glazing materials; 800 µ thick corrugated fiberglass reinforced plastic (FRP) and a double layer of polyethylene sheet (PE) of 140 µ (as an inner layer) and 200 µ (as an outer layer). The greenhouse facility used in this research work had the ratio of cover surface area to the total greenhouse surface area of 2.685. To alleviate the natural heating load from the solar radiation entering the greenhouse during the period of measurements (Summer 2007), and otherwise to increase the cooling effect of the fan-pad cooling system, a shading black net screen (60 %) was used to cover only the gable roof of the two greenhouses.

One extracting fan (single speed, direct driven, 60 cm diameter, and 8000 m^3/h discharge) was located on the leeward side of each greenhouse with cooling pads (cross-fluted cellulose pads, 2.4 × 1.0 m) mounted in a vertical fashion on the side toward the prevailing winds. The cooling process by ventilating was mostly used when the ambient air temperature outside the greenhouse was lower than 20 ºC. But when the air temperature outside the greenhouse rose above 20 ºC, the evaporative cooling system was used.

During this experiment, the pot system was used as an agriculture system for protecting the tomato crop. Each greenhouse was equipped with 60 plastic pots (30 cm high and 28 cm diameter) arranged in five rows (each row having twelve pots). These pots contained a mixture of three different types of soil; clay soil (pasteurized at 105 ºC for 20 minutes), pure yellow sand, and Irish peat moss with ratio of 1: 1: 1. In addition to this mixture, half kilogram of compost as an organic substance was added to each pot mixture (for the purpose of bio-agriculture system).

A drip irrigation system was employed for watering the pots of tomato plants, and installed inside the greenhouses throughout this experimental work. Twelve drippers (long-bath GR 4 liter/hr discharge) were alternatively distributed uniformly with 50 cm dripper spacing throughout each row of plants. One hundred and twenty tomato plants

(Ebesia variety) were transplanted on 21 April, 2007 into 60 plastic pots in each greenhouse with a plant density of 3.25 m^2.

Measurements and Data Acquisition Unit

The solar radiation, air temperature, air relative humidity, and wind speed outside the greenhouses were measured and recorded using meteorological station (WatchDog model 550) which was installed just above the greenhouses. Another meteorological station (WatchDog model 550) for internal microclimate variables was installed within the centre of greenhouse 2 at a height of 1.8 m above the ground surface. The internal microclimate variables included global solar radiation just above the canopy of tomato plants (2.25 m) inside the two greenhouses using two disk solarimeters, dry-bulb air temperatures, air relative humidity, air temperature just leaving the cooling system, and ground surface temperature. A 12 channel data-logger (Digi-Sense Scanning Thermometer Type) was also used for taking and storing readings from the different sensors (thermocouples type K, with an accuracy of ± 0.2 ºC). They were uniformly distributed and located inside the two greenhouses on the centerline of longitudinal and lateral directions. An infrared thermometer (Raytek, Rayner ST60) was also used to measure the temperatures of the cover materials and the leaf surface of plants. The data were displayed on the video screen and updated by a scan of all the sensors every one minute. The time interval for data recording was 60 min. with data acquisition every one minute for integrated measurements. The calibration of all sensors and the logger was completed successfully at the beginning of the experimental work. Two microclimate control boards were attached to the extracting fans in the two greenhouses. They switched the fans ON and OFF whenever the air temperature inside the greenhouses increased above 28 ºC and dropped below 28 ºC, respectively.

Calculations

A microclimatic energy balance was developed to predict the ambient air temperature inside the greenhouse as shown in **Fig. 1**. It was simulated by several sources of heat energy that affect the greenhouse microclimatic conditions (Wang and Boulard 2000 and Bartzanas *et al.*, 2002). The heat energy balance on the two greenhouses was determined by limiting heat energy input (Q_i) to solar radiation available inside, if the heat energy absorbed by the bare area of the greenhouse floor (Q_g), heat energy consumed in evapotranspiration process (Q_{ev}), and total heat losses by conduction, ventilation, and thermal radiation (Q_{loss}) were known or measured. Thus, the heat energy balance was computed from the following formula:

$Q_i = Q_g + Q_{ev} + Q_{loss}$, Watt ... (1)

The heat energy input from the solar energy (Q_c) was obtained by measuring the solar radiation flux incident on a horizontal surface (I_i) in W m^{-2} just above the canopy of plants and the floor surface area of the greenhouse (A_f) in m^2, as:

$Q_i = I_i A_f$, Watt....................... (2)

The solar energy absorbed by the floor surface (Q_g) was obtained by determining the bare area of greenhouse floor (A_b) in m^2, and the absorptivity of the floor surface (α_g), as:

$Q_g = I_i A_b \alpha_g$, Watt .... (3)

The heat energy consumed in the evapotranspiration process (Q_{ev}) was calculated by determining the rate of evapotranspiration to solar radiation (R) that ranged between 0.48-0.52 according to growth stage (Nelson, 1996), ratio of floor surface area covered by tomato plants to the total floor surface area (F), and the solar energy available inside the greenhouse (Q_i), as:

$Q_{ev} = R F Q_i$, Watt................. (4)

The total heat energy loss by conduction and convection, ventilation, and thermal radiation were computed from the following equation:

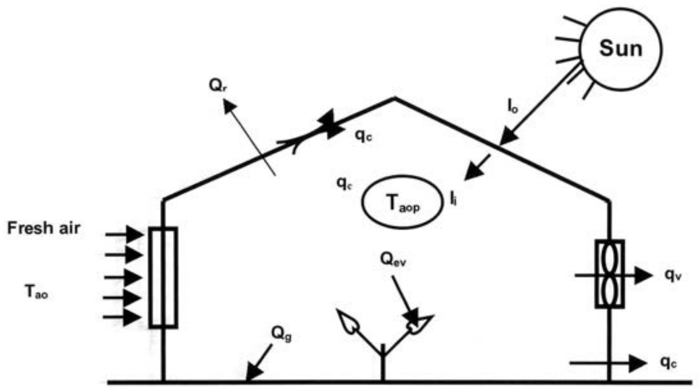
$Q_{loss} = q_c + q_v + q_r$, Watt .... (5)

The heat losses from the greenhouse by conduction and convection were determined by limiting the heat transfer to conduction and convection, if the overall heat transfer coefficient (U_o) in W m^{-2} $°C^{-1}$ total surface area of the greenhouse cover (A_c) in m^2, and inside (T_{ai}) and outside (T_{ao}) air temperatures in ºC were known or measured. The procedure did not require the separation of the conduction and convection components. It could be calculated from the following formula:

$q_c = U_o A_c (T_{ai} - T_{ao})$, Watt .... (6)

The heat energy loss by forced ventilation (q_v) could be calculated by determining the rate of extracting fan discharge (V) in m^3 s^{-1}, density of air (ρ) in kg m^{-3}, specific heat of air at constant pressure (C_p) in J kg^{-1} $°C^{-1}$, and temperature differ-

Fig. 1 Schematic diagram of the greenhouse microclimatic energy balance



ence between inside and optimal air temperature inside (T_{aop}) in ºC, as:

$$q_v = V \rho C_p (T_{ai} - T_{aop}), \text{ Watt} \quad (7)$$

The heat energy loss by thermal radiation (q_r) could be computed by the mean emittance factor of the inside substances (ε), average transmissivity coefficient at long wave radiation (τ), Stefen-Boltzmann constant (σ) in W m^{-2} k^{-4}, and absolute temperature difference between inside air and the sky (T_{sky}) in ºK, as:

$$q_r = \varepsilon \tau \sigma A_f (T_{ai}^4 - T_{sky}^4), \text{ Watt} \quad (8)$$

$$T_{sky} = 0.0559 (T_{ai})^{1.5}, \text{ }^oK \quad (9)$$

To understand the air exchange between the inside and outside of greenhouses and to validate the results of theoretical computation with that measured, experimental methods are essential for use. The energy balance on the greenhouse during daylight through the experimental period is represented by **Eqn. 1**. A mathematical model was developed and used to compute the hourly average heat energy balance on the greenhouse during daylight. It could be rewritten in finite difference form and solved for the greenhouse air temperature (T_{ai}) at each hour with respect to the optimal temperature (T_{aop}), and input and output energies, as:

$$T_{ai} = T_{aop} + (1000 / mC_p) (Q_i - Q_g - Q_{ev} - q_c - q_r), \text{ }^oC \quad (10)$$

The effectiveness of the evaporative cooling system could be computed by determining the cooling effect (T_{dd}, temperature difference between outside and inside) and wet-bulb depression (T_{wd}, temperature difference between dry- and wet-bulb of outside air) as follows (ASHRAE, 1995):

$$\eta_{ev} = (T_{dd} / T_{wd}) \times 100, \% \quad (11)$$

For the rest of this experimental work, the greenhouse covered with corrugated fiberglass reinforced plastic, and the greenhouse covered with double layer polyethylene sheets are referred to as G_1 and G_2, respectively. Data were statistically analyzed using Excel 5.2 program. Linear regression analysis was used to examine the relationship between the different microclimatic factors.

Results and Discussion

The effectiveness of the evaporative cooling system (fan-pad system) under different glazing materials was investigated in particular for the hottest days during the experimental period. The intensity of solar radiation, air temperature and air relative humidity inside the two greenhouses were compared with that data outside as an important measure of the effectiveness of the fan-pad cooling system. Data were measured and collected for a period of 166 days at Mansoura. The hourly average data are summarized and listed in **Table 1**. During this time, the fan-pad system was automatically operated by the control board according to the optimal set-point temperature inside (28 ºC).

Table 1 Typical data of microclimatic conditions outside and inside the greenhouses

Solar time	Solar Radiation, Wm^{-2}			Ambient air temperature, ºC			Air relative humidity, %		
	I_o	I_i (G_1)	I_i (G_2)	T_{ao}	T_{ai} (G_1)	T_{ai} (G_2)	RH_o	RH_i (G_1)	RH_i (G_2)
23.92	0.0	0.0	0.0	22.7	23.8	25.4	84.7	72.0	77.0
0.92	0.0	0.0	0.0	22.3	23.6	25.1	87.4	73.5	78.7
1.92	0.0	0.0	0.0	22.0	23.5	24.8	88.8	74.2	79.5
2.92	0.0	0.0	0.0	21.5	23.1	24.6	89.9	74.8	80.1
3.92	0.0	0.0	0.0	21.2	22.9	24.5	90.5	75.1	80.5
4.92	0.0	0.0	0.0	21.0	22.7	24.2	91.2	75.5	80.9
5.92	66.7	17.7	14.1	21.6	23.3	25.8	92.4	76.2	81.7
6.92	235.6	107.4	94.7	23.2	24.1	27.3	89.9	74.8	80.1
7.92	445.9	229.6	205.6	25.4	25.3	27.9	83.3	71.3	73.9
8.92	646.4	344.4	309.5	27.3	26.4	28.8	72.7	65.7	68.1
9.92	748.7	402.7	362.3	28.9	27.3	29.5	63.2	60.6	63.8
10.92	850.8	458.8	412.7	30.1	27.8	29.9	55.8	57.0	59.5
11.92	900.2	486.1	436.9	31.0	28.3	30.5	50.5	54.1	56.6
12.92	861.8	464.8	418.0	31.7	28.7	30.8	47.3	52.2	54.7
13.92	759.5	408.5	367.5	32.1	28.9	31.4	45.7	51.4	53.8
14.92	599.6	319.4	287.1	31.9	28.8	31.1	45.8	51.7	54.0
15.92	414.3	213.4	191.0	31.3	28.5	30.2	47.9	52.5	55.3
16.92	206.8	94.3	83.1	30.0	27.9	29.3	52.5	54.9	57.8
17.92	69.6	18.5	14.7	28.0	26.8	28.2	58.9	58.3	63.6
18.92	0.0	0.0	0.0	26.0	25.7	27.0	66.4	62.3	66.4
19.92	0.0	0.0	0.0	25.0	25.2	26.7	71.9	65.1	69.3
20.92	0.0	0.0	0.0	24.2	24.7	26.3	75.8	67.3	71.7
21.92	0.0	0.0	0.0	23.5	24.4	26.0	79.3	69.2	73.8
22.92	0.0	0.0	0.0	23.0	24.2	25.8	82.3	70.8	75.6

Actual solar radiation data recorded outside (I_o) and inside (I_i) on a clear day ranged from near zero to about 1000 W m^{-2}. The lowest values during the experimental period were in the range of 25-110 W m^{-2}, which occurred just after sunrise and prior to sunset. They varied from day to day and during the month according to the sky cover (clouds), solar altitude angle, and solar incident angle. The actual solar radiation recorded inside the two greenhouses was lower than that outside, due to the reflectance, absorptance and transmittance factors of the two different covering materials and shading black net screen. The hourly averages of solar radiation recorded outside and inside the two greenhouses were 523.5, 274.3, and 245.9 W m^{-2}, consequently, the effective transmittance of the covering materials was, on the average, 52.4 % and 46.97 %, respectively.

The air temperature in G_2 varied between 24.5 and 31.4 ºC, whereas the air temperature in G_1 ranged from 22.7 to 29.8 ºC. The hourly average air temperatures recorded outside and inside the two greenhouses at and around noon (critical period) were 31.4, 28.5, and 29.8 ºC, respectively. Accordingly, the data showed that the fan-pad cooling system was an effective method for lowering air temperature of the greenhouse as inside air temperatures in the two greenhouses were lowered 2.9 and 1.6 ºC, respectively, at that period. Compiled information from many researchers (Nelson, 1996; Arbel *et al*., 1999; Kittas *et al*., 2003 and Sethi and Sharma, 2007) showed that air temperature inside the greenhouse without cooling system was frequently between 11-20 ºC higher than those outside, in spite of open ventilators.

Therefore, the fan-pad cooling system could lower inside air temperatures between 13.9 to 22.9 ºC and 12.6 to 21. 6 ºC, respectively, as compared with any greenhouse without a cooling system. In spite of the solar radiation entering G_2 during the experimental period was lower than that entering G_1, the air temperature in G_2 was higher than that in G_1, since the fiberglass cover reflected and transmitted long-wave thermal radiation greater than the polyethylene cover. This phenomenon could be attributed to the high level of thermal trapping (greenhouse effect) that occurred in G_2, and may be due to radiometric thermal properties of polyethylene cover. The radiometric thermal properties of the covering material play a very important role in the case of thermal trapping. As a consequence, the average transmittance coefficient to long-wave thermal radiation of the covering materials (FRP and PE) is 0.55 and 0.29, respectively (Papadakis *et al*., 2000). The air temperatures at the level of the tomato canopy were uniform in the two greenhouses, because the inside air was continuously moved by the extracting fans. This is in agreement with the data published by Kittas *et al.* (2003) and Sethi and Sharma (2007) where they stated that, as the air inside the greenhouse is continuously moving, air temperatures are uniform, humidity surrounding the leaf surface is reduced, and carbon dioxide levels are, thus, decreased. The temperature of the tomato plant leaves recorded during the majority of daylight time was lower than the inside air temperature which prevented occurrence of plant thermal stress and, consequently, reduced the risk of plant water stress and fungal diseases.

The air relative humidity in the two greenhouses during the daytime ranged from 48.0 % to 58.6 % and from 50 % to 61.4 %, respectively, whereas, the outside relative humidity was in the range 38.5-49.0 %. Most protected cropping grows best within a fairly restricted range, typically 55 % to 70 % relative humidity for many species (Nelson, 1996 and Ozturk and Bascetincelik, 2003). Low humidity increases the evaporative demand on the plant to the extent that moisture stress can occur, even when there is an ample supply of water to the root system. The water loss from the plant added to the inside air is often determined by the difference in water vapor concentration between inside the leaf and outside, and by the resistance to movement of water molecules from inside the leaf to outside. The resistance varies according to the length of the path that water molecules must traverse, and the size of the stomata opening. As the leaf temperature is reduced due to evaporative cooling, the internal vapor pressure of the leaf is lowered and thus the water loss from the plant is less, and vice versa. With the fan-pad cooling system, lowering of the dry-bulb temperature will generally raise the air relative humidity. Furthermore, water is always being added to the air in the greenhouse from transpiring plants and evaporating water from cooling system. The solar radiation entering the greenhouse is often utilized to evaporate free water from the leaf, rather than raising leaf temperature and increasing water loss from the plant into inside air. When non-saturated air comes in contact with free moisture and the two are thermally isolated from an outside heat source, there is a transfer of mass and heat. Because of the vapor pressure of the free water surface is higher than that of the unsaturated air, water transfers in response to the differential. The transfer involves a change of state from liquid to vapor, requiring heat of vaporization. In spite of the pad face air velocity of the fan-pad cooling system used with the two greenhouses was on the average 1.8 m/s, the air relative humidity inside G_2 was greater than that in G_1. This may be due to high thermal trapping that occurred in G_2, which demanded cooling operation for a long time. Due to all the reasons discussed above, the air relative humidity in G_1 was lower than that in G_2 by 3.1 %.

The effectiveness of the cross-fluted pads as a cooling media was experimentally examined from April to September 2007. Cooling capacity is dependent upon the volume of air flow and the saturation efficiency. Saturation efficiency is, in turn, dependent strongly upon such factors as length of cooling operation period, air velocity through the pad, water temperature in the cooling system, and water flow rate through the cooling media. The daily average effectiveness of the fan-pad cooling system inside the two greenhouses (1 and 2) during the experimental period was, on the average, 72.0 % and 73.6 %, respectively. Accordingly, the cooling system of G_2 was, on the average, more efficient than the cooling system of G_1 by 1.6 % because the cooling operation period in the G_2 was longer than that in G_1. Consequently, the water temperature of cooling system (2) was always lower than that in cooling system (1). The effectiveness of the fan-pad cooling system varied during the experimental period, according to the outside air relative humidity and dry-bulb temperature. When the exterior air relative humidity decreased lower than 30 %, more cooling effect was achieved making the cooling system more efficient. Substantial temperature decreases were obtained when the outside air relative humidity was less than 30 % and outside air was higher than 35 ºC. Therefore, the two cooling systems achieved a cooling effect that ranged between 6.4 and 4.0 ºC at air relative humidity that ranged between 30.5 and 60.2 %, respectively. Cooling effect (degree of cooling) and, consequently, evaporative cooling efficiency was strongly dependent upon the wet-bulb depression that mainly affected by air relative humidity and water temperature in the cooling system. Therefore, the greatest value of cooling effect for G_1 and G_2 (6.4 ºC and 6.5 ºC, respectively) and cooling efficiencies (80.0 % and 81.3 %, respectively) were achieved with the greatest value of wet-bulb depression (8 ºC) and lowest value of air relative humidity (30.5 %). Whereas, the lowest value of cooling effect for G_1 and G_2 was 0.8 ºC and 0.9 ºC, respectively, with cooling efficiencies of 38.1 % and 42.9 %, respectively and were recognized with the lowest value of wet-bulb depression (2.1) and greatest value of air relative humidity (75.3 %). To determine and examine the best model to correlate cold air temperature just leaving the pad cooling system (T_{idd}) in G_1 and G_2, and wet-bulb depression (T_{wd}) all the data were used in regression analysis and plotted in **Fig. 2**. This analysis revealed a highly significant linear relationship between these parameters. The linear regression equations for the best fit were:

$$T_{idd}\ (G_1) = 29.09 - 0.7200\ (T_{wd})$$
$$T_{idd}\ (G_2) = 29.09 - 0.7355\ (T_{wd})$$

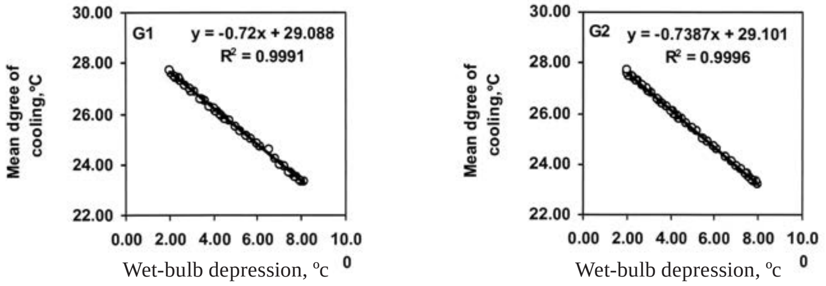
The above equations are, definitely, the numerical expression of the data, which showed that the fan-pad cooling system for G_1 and G_2 was reduced by the dry-bulb air temperature recorded outside by 0.72 and 0.74 of the wet-bulb depression, respectively. Therefore, the previous equations can be rewritten as follows:

$$T_{idd}\ (G_1) = T_{odd} - 0.7200\ (T_{wd})$$
$$T_{idd}\ (G_2) = T_{odd} - 0.7355\ (T_{wd})$$

Thus, the y-intercept is equal to the mean dry-bulb temperature of outside air, whereas, the slopes are equal to the mean efficiencies of cooling systems. These models predict the cold air temperature just leaving the cooling pads for the two greenhouses and show enough accuracy for use in hot climatic conditions. This is in agreement with the data published by Aldrich and Bartok (1990) when they reported that, most cooling systems reduced the dry-bulb temperature of outside air 0.7 to 0.8 of the wet-bulb depression. Finally, the fan-pad cooling system in G_2 consumed 166.8 kWh of electrical energy by the extracting fan, whereas, the cooling system in G_1 consumed 104.8 kWh. This obvious difference was due to fact that the extracting fan of G_2 was operated for a long time period per day throughout the growing season, to reject the excessive heat energy accumulated inside the greenhouse, and to provide an optimal level of microclimatic conditions in G_2. Furthermore, the air temperature in G_2 rapidly increased just after sunrise as compared with G_1 (Anna *et al.*, 2003).

The arithmetical model of energy balance that was marked out previously revealed that there are many factors affecting microclimatic conditions of the greenhouse during daylight. These factors and their influence on thermal energy balance were solar radiation inside the greenhouse (Q_i), solar radiation absorbed by the bare floor surface area (Q_g), solar radiation consumed in the evapotranspiration process (Q_{ev}), and total heat energy losses (Q_{loss}). The solar radiation absorbed by the bare floor area in the two greenhouses represented, respectively, 29.12 % and 27.43 % of the total

Fig. 2 Air temperature just leaving the cooling system plotted against wet-bulb depression for the two greenhouses



solar radiation entering the greenhouses, Whereas, the evapotranspiration process from the plants in the two greenhouses during the experimental period represented 30.27 % and 28.85 % of the solar radiation entering the greenhouses, respectively. The total heat energy losses by conduction from the greenhouses during daylight, sensible and latent heat due to forced ventilation, and thermal radiation were examined. They were represented 38.07 % and 39.94 % of the total solar radiation entering the two greenhouses, respectively. The data of the mathematical model showed that the difference between input and output heat energies yielded the accumulated heat energy in various substances inside the two greenhouses. It also revealed that, the ratio of output heat energy to the input heat energy presents the validation of the model of heat energy balance. The validation of the model which described the relationship between the input and output heat energies for the two greenhouses was 97.46 % and 96.22 %, consequently, about 2.54 % and 3.78 % of the total input heat energy was accumulated, respectively.

Statistical validation of the model was also performed by comparing the measured and predicted air temperatures to determine how well the model statistically simulated the fan-pad cooling system performance. The predicted air temperature (T_{aip}) of the model was plotted against the air temperature recorded inside the two greenhouses (T_{aim}) as shown in **Fig. 3**. Regression analysis showed a highly significant linear relationship between the predicted and measured data. The regression equations for the best fit were:

$$T_{aip}\ (G_1) = 1.0389\ (T_{aim})$$

$$T_{aip}\ (G_2) = 1.0377\ (T_{aim})$$

The coefficient of determination (R^2) denotes the percentage of variation in the measured air temperature explained by the variation in the predicted air temperatures. There is a good agreement between the obtained results from the mathematical model and those obtained experimentally. In general, the results of the mathematical model are valid in the wide range of air temperatures.

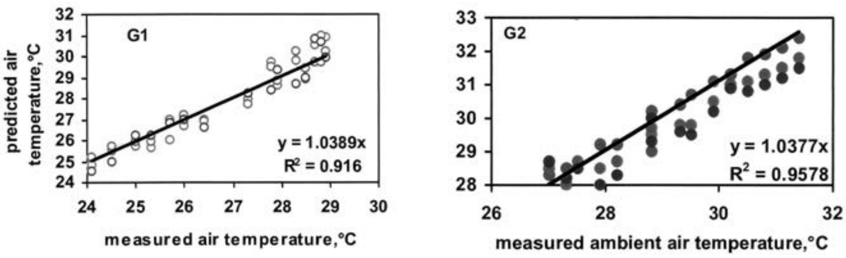
For the duration of the experimental period, the weekly average number of leaves of the tomato plants in G_1 and G_2 were 3.2 and 2.8 leaves/week, respectively. Therefore, the weekly average stem length of tomato plants in G_1 and G_2, respectively, was 12.6 and 11.0 cm/week. Accordingly, G_1 increased the growth rate of plants on the average by 14.55 % as compared with G_1. This variation could be attributed to the reaction rates of various metabolic processes, absorption rate of nutrient elements, and release of water by root system, which were strongly affected by the inside air and relative humidity. The air temperatures recorded in the two greenhouses were a little over the optimal daylight temperature (28 ºC) particularly at the critical period (from 10 to 15) during the hot summer season. A linear increase of the air temperature with distance in the two greenhouses and parallel decrease in the air relative humidity were evidently observed during the experimental period. These changes were expressed in an air temperature increase of 1.7 and 2.5 ºC, and 12 % and 15 % decrease in air relative humidity, over the distance of 8 m between the cooling pads and extracting fans in the two greenhouses, respectively. Due to the reasons discussed previously, the number of fruits being seated on the plants inside the two greenhouses was on the average 18.76 and 15.70 fruits/plant, respectively. Accordingly, G_1 increased the rate of fruit set, on the average, by 17.83 % as compared with G_2. Therefore, the fresh yield of the tomato crop per square meter inside the two greenhouses was 8.796 and 7.356 kg, respectively.

Conclusion

This research work examined the factors that influence the level of the obtained climatic conditions and their degree of uniformity in the two greenhouses equipped with a fan-pad cooling system and covered using two different glazing materials (fiberglass reinforced plastic (FRP) and double layer of polyethylene sheets (PE)). The factors tested were; solar radiation entering the greenhouse, air temperature inside the greenhouse, and air relative humidity and their effect on the growth rate, fruit set, and fresh yield of tomatoes crop during the summer season of 2007. From this study the following conclusion were drawn as:-

1. The hourly average solar radiation recorded outside and inside the two greenhouses during the experimental period were 523.5, 274.3, and 245.9 W m^{-2}, respectively. Consequently, the effective transmittance of the FRP and PE glazing materials with shading black net screen was 52.40 % and 46.97 %, respectively.
2. The air temperature recorded in the two greenhouses at and around noon (critical period) was, on the average, 28.5 and 29.8 ºC, respectively.
3. The fan-pad cooling system was

Fig. 3 Predicted air temperature versus measured air temperature



an effective method of lowering the air temperature of the greenhouse as inside air temperatures in the two greenhouses were lowered 2.9 and 1.6 ºC, respectively.

4. A linear increase of the air temperature with distance in the two greenhouses, and a parallel decrease in the air relative humidity were observed during the experimental period.
5. Cooling effect of the fan-pad cooling system was strongly dependent upon the wet-bulb depression that was mainly affected by air relative humidity and water temperature in the cooling system.
6. There was a good agreement between the results from the mathematical model and those obtained experimentally. In general, the results of the mathematical model are valid (96.8 %) in the wide range of solar radiation, air temperature, and air relative humidity conditions which occurred in Egypt at midday during the summer.
7. The fresh yield of the tomato crop per square meter in the two greenhouses, was, respectively, 8.796 and 7.356 kg. Consequently, G_1 was more productive than G_2 by 19.58%.

Finally, it can be concluded that the greenhouse equipped with fan-pad cooling system and covered with FRP glazing material was an effective method of providing and maintaining desirable conditions inside the greenhouse under hot and humid weather conditions.

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Development of a Hydraulic Trainer Bench for Educational Purposes

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Abstract

In response to feedback from academia and industry stating the need for training in hydraulics to our graduates, the Department of Agricultural Engineering at the Faculty of Engineering, University of Khartoum successfully designed and developed an educational hydraulic trainer bench. It included basic hydraulic system components such as pumps, actuators, valves, hoses and a cooler and a reservoir as well as a heat exchanger. A steering unit was also incorporated to for demonstration purposes. The performance parameters of the power unit, the actuators and system temperature were measured and their specifications were checked to verify the procedures and measuring techniques.

Introduction

The transmission and control of power by means of fluid under pressure is becoming increasingly used in all branches of industry. Over half of all industrial products incorporate fluid power systems in their basic designs. The major advantages of hydraulic systems are the flexibility, safety of operation, use of relatively small components and ease of installation and maintenance. A properly designed fluid power system eliminates the need for complicated systems of gears, cams, and levers. The Department of Agricultural Engineering at the Faculty of Engineering, University of Khartoum received significant feedback from Sudanese industry stating the need for training in hydraulics and pneumatics.

Objectives

The main objective of this work was to design and develop a comprehensive hydraulic trainer bench for educational purposes. For ease of operation and exchangeability of parts, the proposed trainer bench should be simple in design, construction and operation.

Materials and Methods

The major components in the hydraulic circuits were: reservoir (tank), filter, electric motor, hydraulic pump, pressure gauge, relief valve, oil cooler, check valve, manually operated valve 4/3 closed center directional control valve (DCV), flow control valve, hydraulic cylinder and load (spring). Other components used to perform the tests included hydraulic tester (to apply load), pressure gauge, temperature gauge, flow meter and a tachometer. In the following paragraphs the different tests performed together with procedures followed are presented.

Hydraulic Circuits and Tests Performed

Pump testing was carried by connecting the hydraulic tester to the circuit downstream from the pump as shown in **Fig. 1**. Before testing, oil pressure was released from the

system by disconnecting the oil pressure hose between the pump and the control valve. The oil pressure hose was then connected to the hydraulic tester inlet and the outlet port was connected to the reservoir. Testing was then carried out by slowly closing the tester load valve to load the system in steady increments of 15 bars up to a level just under the system's maximum pump pressure, which is equivalent to system relief valve setting. The corresponding oil flow was recorded as

Table 1 Hydraulic pump test results

Pressure (bar)	0	15	30	45	60	75	90	105	120	135	150
Flow (l/min)	19	19	17.5	17.3	17	17	16.8	16.5	16	0	0

shown in **Table 1**. **Fig. 2** shows plot of the data.

Verification of Pump Performance Parameters:

Pump performance parameters including pump delivery, drive power, torque at the pump shaft, input power, and volumetric and torque efficiencies were evaluated. The pump used in the experiment had a displacement of 14.1 cm^3/rev @ 1,400 rpm and maximum allowable pressure of 150 bars. The volumetric and overall efficiencies ranged from 85 % to 97 %, and from 80 % to 90 %, respectively.

Pump Delivery in the Proposed Bench could be Calculated by the following Formula:

$$Q_p = \eta_{vol.p} \times D_P \times N_p / 1000 \quad (1)$$

where

Q_p = pump delivery, L/min

D_P = Displacement of pump, cm^3/rev

N_p = pump speed, rpm

$\eta_{vol.p}$ = Volumetric Efficiency, 0.85-0.97

Knowing the pump displacement, pump speed and average volumetric efficiency of 91 %, the computed pump delivery was 17.96 L/min.

The Shaft Power of the Pump was Calculated Using the following Formula:

$$P_{EL} = p \times D_P \times N_p / 6 \times 10^5 \times \eta_{overall} \quad (2)$$

where

P_{EL} = Electrical Motor power output (power input to pump), kW

p = operating pressure, bar,

D_P = pump displacement, L/min,

$\eta_{overall}$ = pump overall efficiency, (0.8-0.9) and

N_p = pump speed, rpm

With an average overall pump efficiency of 85 %, the computed drive power was 5.8 kW (7.7 hp).

The Torque at the Pump Shaft was Given by the Following Formula:

$$T_p = D_p \times P_p / 2\pi \times \eta_{overall} \quad (3)$$

where

T_p = Torque at pump shaft, N m,

D_p = pump displacement, cm^3/rev,

P_p = operating pressure, bar and

$\eta_{overall}$ = pump overall efficiency, 0.8-0.9

The computed torque at pump shaft was 396 N m.

Pump Hydraulic Power was Calculated by the following Formula:

$$P_{HY} = Q_p \times P / 600 \quad (4)$$

where

Q_p = flow rate of pump, L/min and

P = pump pressure, bar

Considering a pump flow rate of 17.96 L/min and pump pressure of 150 bars, **Eqn. 4** yields an output power of 4.49 kW (5 hp).

Fig. 1 Pump testing configuration

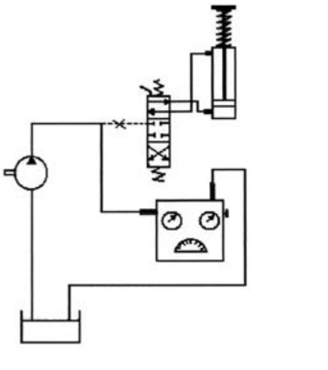
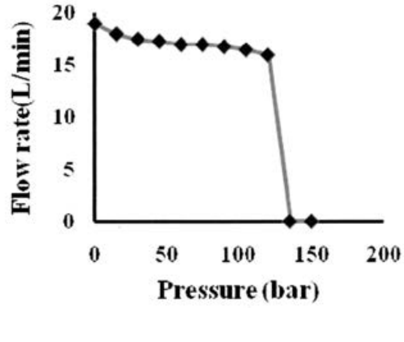


Fig. 2 Pump flow rate versus pressure



The Pump input Power was Calculated by the following Formula:

$$P_{IN} = P_{HP} / \eta_{overall} \quad (5)$$

With a pump hydraulic power of 4.49 kW, and average overall efficiency of 85 %, the computed input power was 5.282 kW (7.08 hp).

The Torque Efficiency of the Pump was Calculated Using the following Formula:

$$\eta_T = \eta_{overall} / \eta_V \quad (6)$$

With a pump average overall efficiency of 85 % and pump average volumetric efficiency of 91 %, the computed torque efficiency of the pump was 93.4 %.

Pump tests showed that the pump flow rate decreased as pump pressure increased. The maximum pump pressure was in the vicinity of 150 bars and the pump flow was reduced to zero (relief valve fully open). Maximum flow rate was 19 L/min at a pump pressure of zero (no load). These results of a maximum pressure of 150 bars and a maximum flow rate 19 L/min of the tested pump were in agreement with the specifications of the maximum pump pressure of 150 bars and maximum flow of 17.96 L/min. Thus, the pump was successfully tested and, the circuit could be used to test any hydraulic pump.

Hydraulic Motor Circuit Configuration and Test

The hydraulic motor circuit (as shown in **Fig. 3**) consisted of gear pump driven by a 7 hp 3 phase electric motor, a gear-type hydraulic motor, a heat exchanger, a double solenoid 4/3 DCV, hydraulic pressure gauge, a filter and reservoir, two sets of relief valves, a check valve and restrictor valve and hydraulic hoses 0.5 inch diameter. The hydraulic tester was also included. Knowing D_p and $\eta_{vol,p}$ and pump displacement in terms of load flow rate, (Q_m) was expressed by:

$$D_p = Q_m \times 1000 / N_p \times \eta_{vol,m} \quad (7)$$

where

D_p = pump displacement, cm^3/rev,

Q_m = flow rate required by motor,

L/min and

$\eta_{vol,m}$ = motor volumetric efficiency (0.85-0.97)

With a pump displacement of 14.1 L/min, pump shaft speed of 1,400 rpm and average motor volumetric efficiency of 91 % the computed load flow rate was 17.96 L/min. Motor displacement was calculated by the following formula:

$$D_m = Q_m \times 1000 \times \eta_{vol,m} / N_m \quad (8)$$

where

Q_m = motor flow rate, L/min,

D_m = motor displacement in cm^3/rev,

N_m = motor shaft speed, rpm and

$\eta_{vol,m}$ = Motor volumetric efficiency (0.85-0.97)

With a load flow rate of 17.96 L/min, motor shaft speed of 1,220 rpm and motor volumetric efficiency of 91 %, **Eqn. 8** gives motor displacement 13.39 cm^3/rev.

To perform a motor test, the tester was connected downstream from motor as shown in **Fig. 3**. Before testing, oil pressure was released from the system by disconnecting the pressure line between the motor and the control valve as the figure shows. The pressure line from the hydraulic motor output was connected to the inlet port of the hydraulic tester and the outlet port was connected to the reservoir. The motor was then loaded slowly by closing the tester load valve. Readings of motor speed were taken every 3 L/min flow rate from 5 L/min to 17 L/min. Load pressure was held constant at 150 bars as supplied from pump. Test results are given in **Table 2** below. From the motor test results, the motor speed (as theory postulates) was increased linearly as the motor flow rate was increased. Maximum flow rate was 17 L/min at a motor speed of 380 rpm. Based on the results of a maximum pressure of 150 bars and maximum flow rate 17 L/min, the displacement of the motor was 0.04 L/rev, which was in agreement with the information provided by the manufacturer of the motor.

Table 2 Hydraulic motor test results

Flow (l/min)	17	14	11	8	5	0
Speed (rpm)	380	353	274	200	120	0
Displacement (l/rev)	0.0447	0.0397	0.0401	0.4000	0.0417	0

Cylinder Circuit Description and Test

The cylinder circuit consisted of a gear pump, double acting cylinder, heat exchanger, manually operated 4/3 DCV, pressure gauge, filter and reservoir. There were two sets of relief valves. A check valve and a restrictor valve were used to control the travel speed.

Cylinder testing was made by connecting the hydraulic tester to the cylinder circuit as shown in **Fig. 4**. The cylinder was loaded slowly by closing the secondary relief valve. The test was made by loading the cylinder in increments of 10 bars, pressure from 0 to 150 bars and recording the corresponding spring compression (X) and lapsed time using a stopwatch. The data are shown in **Table 3**.

$$V = X / T \quad (9)$$

where

V = Piston speed, m/sec,

X =Spring compression, meters and

T = Lapsed time, seconds

Knowing pressure and cylinder area, the force is given by:

$$F = P \times A / 10 \quad (10)$$

where

F = load, kN,

P = pressure, bar and

$$P_{power} = F \times V, kW \quad (11)$$

The Spring Stiffness was Calculated by flowing Equation:

$$\delta = F / X \quad (12)$$

where

δ = spring stiffness and

F = load, KN

Actual stiffness calculated from actual data was found to be 144.910 kN/m. Based on the results obtained, the hydraulic cylinder was successfully tested.

Hydraulic Oil Overheating:

A major problem that adversely affects performance of hydraulic power circuits in Sudan is oil overheating due to harsh working environment. A heat exchanger, therefore is an essential component to avoid overheating and hence degra-

Fig. 3 Setup for testing the hydraulic motor and the schematic hydraulic circuit

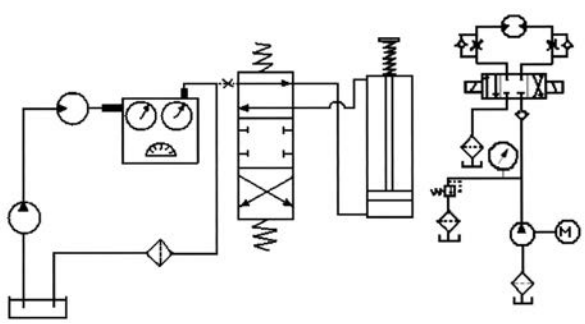
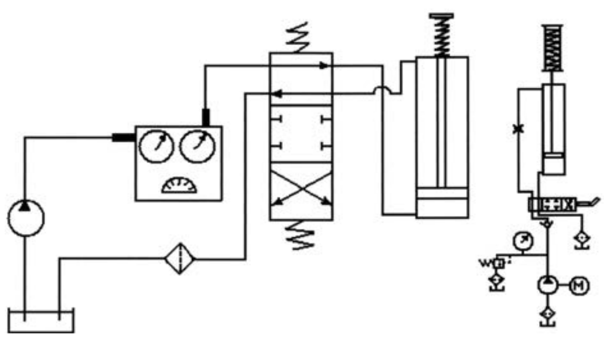


Fig. 4 Setup for testing the hydraulic cylinder and schematic circuit



dation of the hydraulic fluid; a problem that may be tackled in many ways among which is increasing the size of the reservoir or including a suitable heat exchanger or cooler in the circuit. Inclusion of a heat exchanger was adopted and temperature readings with and without the inclusion of the heat exchanger were taken as pressure was increased up to the pump maximum pressure specified by the manufacturer. Data below gives the readings.

Description of the Steering Circuit

Fig. 6 shows the steering circuit. It consisted of a gear pump, a 4/3 DCV, a double acting cylinder, a double rod rack, a tie rod, a heat exchanger, a filter and a reservoir. Furthermore, the hydraulic tester was also incorporated for simulation purposes. Although data regarding the performance of the steering unit was not collected, the unit worked satisfactorily when the pump was operated. The model, thus, could serve as a demonstration tool.

Conclusions

1. A trainer bench circuit (as shown in **Fig. 7** was successfully tested That cold be used as a demonstration tool for educational purposes.

Fig. 5 Pump pressure versus temperature with and without cooling system

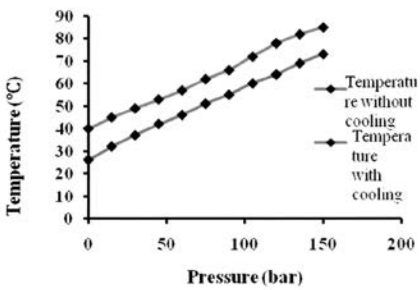


Fig. 6 View of the final trainer bench

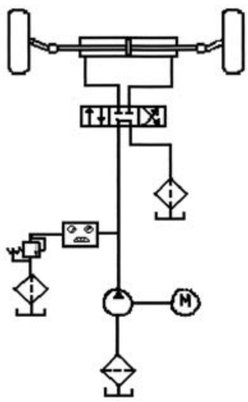


Fig. 7 Schematic diagram of the steering circuit

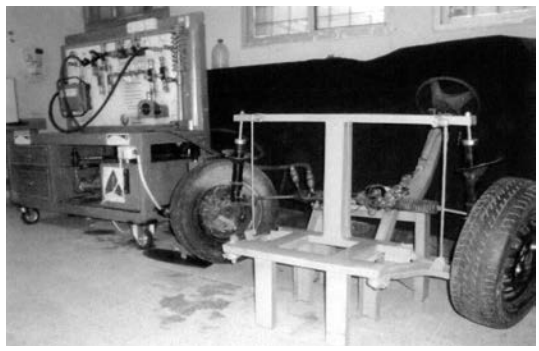


Table 3 Hydraulic cylinder test results

Pressure (bar)	Flow (l/min)	Spring deflection (m)	Time (sec)	Cylinder speed (m/s)	Load (KN)	Power output (kW)	Stiffness (kN/m)
0	19	0	0	0	0	0	0
10	18.8	0.013	1.5	0.009	1.964	0.017	151.038
20	18.5	0.024	1.22	0.0197	3.927	0.077	163.625
30	18.1	0.040	1	0.04	5.891	0.236	147.263
40	17.9	0.058	0.8	0.073	7.854	0.569	135.414
50	17.7	0.075	0.7	0.107	9.818	1.052	130.900
60	17.617.6	0.084	0.65	0.129	11.781	1.522	140.25
70	17.5	0.095	0.6	0.158	13.745	2.176	144.679
80	17.3	0.107	0.56	0.191	15.708	3.001	146.804
90	17.2	0.125	0.47	0.266	17.672	4.7	141.372
100	17	0.136	0.34	0.4	19.635	7.854	144.375
110	16.8	0.148	0.31	0.477	21.599	10.312	145.936
120	16.5	0.160	0.29	0.552	23.562	12.999	147.263
130	10	0.163	0.28	0.582	25.526	14.859	
140	0	0.170	0.28	0.607	27.489	16.69	
150	0	0.170	0.28	0.607	29.453	17.882	

Table 4 Variation of hydraulic oil temperature with and without heat exchanger as pump pressure increased

Pressure (bar)	0	15	30	45	60	75	90	105	120	135	150
* Temperature (ºC)	40	45	49	53	57	62	66	72	78	82	85
** Temperature (ºC)	26	32	37	42	46	51	55	60	64	69	73

*: test carried without installing the cooler into the circuit.
**: test carried with the cooler system installed in the hydraulic circuit.

2. The system facility was designed to demonstrate hydraulic pump, motor, and cylinder and testing of each of the components easily.
3. A heat exchanger was successfully incorporated with the hydraulic circuit and tested.
4. A hydraulic steering model was successfully designed and developed for educational proposes. The developed circuit and identification component of the hydraulic system gave an indepth understanding and allowed coherent viewing of the circuit configuration, parameters, settings and components.
5. Hydraulic pump testing such as pump flow rate versus pump pressure and pump pressure versus temperature with and without a cooling system were successfully carried out and their various models developed.
6. Hydraulic motor flow rate versus motor speed was successfully tested and a model was developed.
7. Hydraulic cylinder tests such as pump flow rate versus pressure, load pressure versus deflection, power versus load and deflection versus load were successfully carried out and their various models developed.

Recommendations:

For completion of the hydraulic trainer bench it is recommended that the following needs to be done:

1. Upgrade the hydraulic trainer bench by adding hydrostatic transmission and breaking systems.
2. Develop a computer program to simulate the performance of the circuits of the hydraulic trainer bench.
3. Develop a programmable logic control (PLC) to control and operate some hydraulic circuits.
4. Develop an interactive computer program to perform the calculations necessary to design any hydraulic circuit including hydrostatic transmission.
5. Complementary to the hydraulic trainer bench, it is suggested that a computer controlled pneumatic trainer bench be developed and tested.

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Development and Evaluation of a Power Tiller Operated Planter for Maize

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Abstract

A three row, power tiller operated planter was developed for planting of maize seeds. The major components were main frame with hitching unit, hopper, metering unit, furrow opener and power transmission unit. The planter was evaluated in the laboratory and in the field for planting of maize. Field performance tests revealed that the average draft requirement for the planter was 483 N, which was well within the capacity of a 9-12 hp power tiller. An average field capacity of 0.17 ha/h was obtained for continuous operation of the planter at an average speed of 1.93 km/h for planting maize. The field efficiency of the planter was observed to be 65.4 %, which was in the prescribed range of 65-75 % for a row crop planter. The average depth of placement of seed was 68 mm. The cost of the planter was Rs. 8,400/- and hourly cost of operation was Rs. 131/-. The man-h requirement for planting one hectare of land was 5.88. The cost of planting by planter was Rs. 770/- per hectare as compared to Rs. 1100/- required for manual planting. The savings in man hours and cost of planting were quite substantial and justified the use of the planter.

Introduction

Maize (Zea mays) is a major food grain crop of India grown widely over all the country. The total area under maize is 6.31 million hectare with a production of 10.85 million tons and a production of 1,721 kg per ha (www.indiancommodity.com). The productivity of this crop can be improved through the adoption of viable technologies in the mechanization of maize cultivation suitable to Indian conditions. Maize seed is traditionally sown in line by hand dropping behind the plough. The manual method of hand dropping of seed behind the animal drawn plough, and hand dibbling are highly labour intensive. The benefits of row crop drilling over broadcasting are well established for most cereals, pulses and oilseed crops. The seed to seed spacing in row crop drilling is difficult to maintain. For crops, where tillering does not take place, planting with proper spacing is recommended for higher yield (Sahoo and Srivastava, 2004). Hence, planting of seed in the desired fashion is a need based operation in crop production as it aids in maximizing yield. The labour intensive operation of weeding can also be mechanized easily in the planted crop.

The small and scattered land holdings and poor socio-economic conditions of the farmers of India, has confined the mechanization level to draft animal operated implements for various agricultural operations. However, the feeding and management cost of these draft animals are so high compared to the productivity level by the use of these animal drawn implements that it becomes a real problem for the farmers to keep the draft animals. The power tiller is popular among the farmers of eastern India since it is suitable for dry tillage as well as for wet puddling for cultivation of paddy. But the annual use of a power tiller through these tillage operations is not enough to make it economically viable. Annual use can be increased by developing suitable matching equipment for the power tiller to carry out different farm operations. There is a need to develop precision equipment which can meter seeds and plant them at predetermined depth with uniform seed to seed and row to row spacing. It is also essential to save labour, time of operation, cost of operation and costly seeds. A number of tractor drawn planters have been developed in India and are commercially available for different individual crops like cotton, maize, groundnut and soybeans (Pandey, 1997). But these are costly and not accessible to the small and medium farmers. So, a study was undertaken to develop a power tiller operated planter suitable for planting maize seeds. Keeping this in view, the present work on development and performance evaluation of a power tiller operated planter for maize was undertaken.

Materials and Methods

A 3 row, power tiller operated planter was developed in the Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Bhubaneswar. The major components are main frame with hitching unit, hopper, metering unit, furrow opener and power transmission unit (**Figs. 1** to **4**). The specifications of the planter are presented in **Table 1**.

Main Frame with Hitching Unit

The main frame was made form 35 × 35 × 5 mm mild steel angle iron with an over all size of 1330 × 660 mm. The main frame had a tool bar, which consisted of a 5 mm thick mild steel square section 35 × 35 mm. The individual seed hoppers for each row were fixed on the tool bar with bushings to facilitate positioning according to the row spacing. The main frame was attached to the hitch bracket of the power tiller rigidly by means of a hitching pin. The main frame also facilitated adjustment of furrow openers according to the row spacing.

Hopper

The planter consisted of three hoppers with 6,000 cm^3 volumetric capacity. The hoppers were made of 1 mm thick mild steel sheet. It was fabricated with consideration given

Fig. 1 Schematic diagram of power tiller operated planter (rear view)

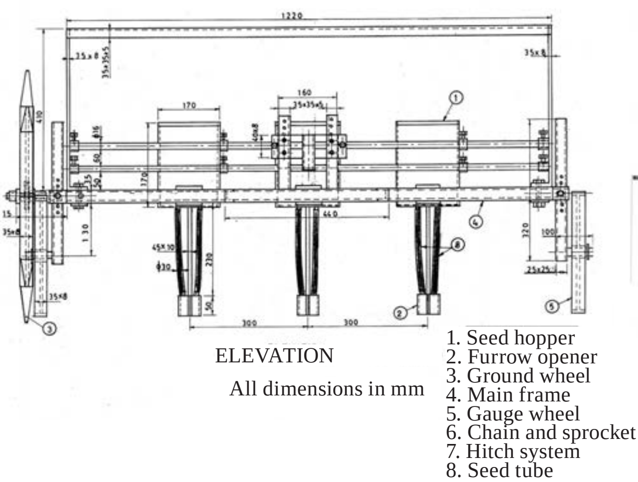

Fig. 2 Schematic diagram of power tiller operated planter (side view)

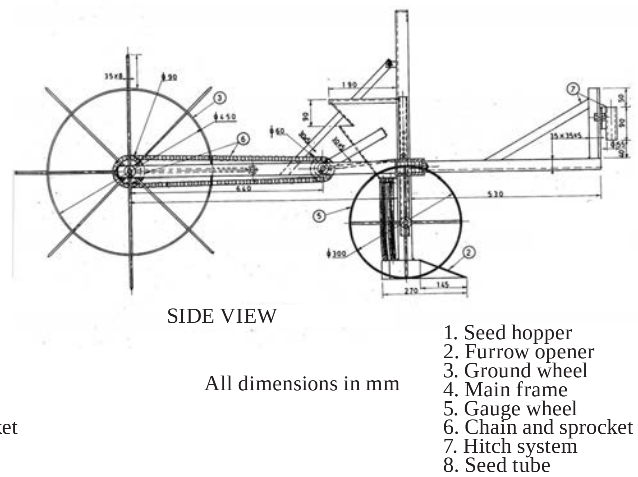

Fig. 3 Field evaluation of the power tiller operated planter (rear view)

Fig. 4 Field evaluation of the power tiller operated planter (side view)

to the required volumetric capacity, angle of repose and seed bulk density. The slope of the hopper walls, which was required to be more than the angle of repose of the seed, was 45 degrees. The cross section was trapezoidal. A sliding plate was provided to maintain the depth of seed layer in the pick up chamber irrespective of the filling of main chamber.

Metering Unit

An inclined plate type metering unit having metering plates with cells of proper size and shape was designed and developed for maize seeds. The plates were made of cast aluminum 120 mm diameter. They had eight L-shaped cells at the periphery. The number of cells on the plate depended on the plant to plant spacing in a row and on the transmission ratio between the ground wheel and the metering plate. The seed plate was mounted at an angle of 60 degrees with the horizontal so that the extra seed dragged along were dropped before reaching the seed outlet of the hopper.

Table 1 Specifications of power tiller operated planter

Component	Specifications
Overall size (Length × Width × Height)	1,800 × 1,430 × 690 mm^3
Number of rows	3
Row spacing	250 mm to 450 mm (Adjustible)
Plant spacing	450 mm
Seed metering	Inclined plate type
Number of seed hopper	3
Hopper capacity	6,000 cm^3 each
Number of furrow opener	3
Type of furrow opener	Shoe type
Power transmission	Chain sprockets, bevel gear
Speed ratio (Ground wheel : Seed plate)	1 : 0.52
Power source	9-12 H.P. power tiller
Field capacity	0.17 ha/h
Weight	115 kg

Seed Tube and Furrow Opener

The seed tube and furrow opener were developed with consideration given to the optimum depth of seed placement. The seed tube was made of 25 mm diameter plastic pipes with 2 mm wall thickness. The height of the seed delivery spout was close to the ground to achieve seed spacing uniformity. The 200 mm length shoe type furrow opener provided the outlet for both seed and fertilizer. The shank height of the furrow opener was 280 mm. The furrow opener was bolted to the main frame with rigid clamps that could be adjusted in the horizontal direction. The depth of operation of the furrow opener was controlled by vertical adjustment of gauge wheels provided on each end of the main frame with respect to the bottom of the furrow opener. Seed were covered by the flow of loose soil during operation. Hence, there was no need for covering device.

Ground Wheel

The speed of the seed plate was governed by the ground wheel diameter and the transmission ratio. The diameter of the ground wheel was 450 mm, which matched the specified range (350-450 mm) of RNAM test code. The wheel rim was 35 mm wide and 5 mm thick flat mild steel. Lugs of 75 × 35 mm were provided, on the periphery of the wheel for better traction. The ground wheel had 8 spokes made of 10 mm diameter MS rod.

Power Transmission Unit

Power transmission was achieved from the drive wheel to the main shaft of the metering device through a chain-sprocket arrangement. The sprockets were mild steel with a ground wheel sprocket 49 mm diameter and 13 teeth and a main shaft sprocket 94 mm diameter and 25 teeth for a speed ratio of 0.50. Chains from the drive sprocket to the ground wheel were 12 mm pitch were. Power was transmitted from the main shaft to the seed plate by a two bevel gears. The speed ratio between the ground wheel and seed plate could be varied to achieve different plant to plant spacing by altering the sprockets of the power transmission system.

Fertilizer Box

A fertilizer box was provided on the front side of the main frame with a fluted roller metering mechanism.

Performance Evaluation of the Planter

The planter was evaluated in the laboratory and in the field. In the laboratory calibration, row to row variation in seed metering and uniformity of seed delivery over a sand bed were evaluated (IS: 6316-1971).

The test plots were prepared into fine tilth by rotatilling twice followed by a leveling operation. Experiments were conducted in sandy loam soil having sand, silt and clay in the ratio of 81.24, 7.80 and 10.96 %, respectively. The planter was operated by the power tiller in straight rows in the experimental plots. Observations were recorded on time taken to cover the area, actual depth of seed placement, speed and draft. Recommended agronomic practices were followed in raising the crops. Germination percentage was recorded on the seventh day after sowing. Performance of the planter was compared with the manual method of planting of maize. The performance of the planter was indicated by draft, field capacity, field efficiency and field machine index.

Results and Discussion

Laboratory Calibration

Row to row variation in seed metering and uniformity of seed delivery were studied in the laboratory. Tests were conducted with full, ¾ and ½ filled hopper. The results indicated that variation of seed discharged from the average of three rows, was statistically non-significant for all the three hopper fill conditions (**Table 2**).

An overall average of 85.5 maize seeds was delivered in 25 revolutions of the ground wheel as indicated by the laboratory tests. The maximum deviation of seed discharge of any row from the average was observed to be less than 2 %. All the deviations were within the range of 7 % set by Indian standards. No difference in metering was observed with different hopper capacity. This was due to the partition of the hopper by the sliding plate. The depth of seed layer in the pick up chamber was maintained at a constant level at any hopper fill condition. Hence, a non-significant difference was observed in the number of seeds discharged at different hopper fills.

The seeding uniformity was also evaluated by using the sand-bed test. A null-hypothesis, using the `t' test indicated that the variation of seed dropped from the mean among the three rows was non-significant (**Table 3**).

An average of 11.9 seeds was placed per 5 m length of bed. The maximum deviation of the number seed dropped in any of the rows from the average was 2.52 %. Hence, it could be concluded that the planter performed satisfactorily in metering the maize seeds among the rows.

Field Performance Test

Field performance tests were conducted on the experimental farm of OUAT, Bhubaneswar to obtain actual data on over-all performance of the machine. The performance data of the planter are presented in **Table 4**.

The planter had an average draft requirement of 482 N over three plots. A medium size power tiller of 9-12 hp (VWH 130) could easily operate the planter. An average field capacity of 0.17 ha/h was obtained for continuous operation of the planter for planting maize at an average speed of 1.93 km/h (**Table 4**). A field efficiency of 65.4 % was observed, which was in the prescribed range of 65-75 % (Kepner *et al*., 1987). The major loss in efficiency was due to the turns at the head land and adjustment of the planter position before a run so that required spacing was maintained with the planted rows of the previous pass. No breakdown, repairs and adjustment of components during the operation were observed. The average depth of placement of maize was 6.8 cm and seeds were placed in the range of 4-8 cm depth. The average spacing between seeds was 42 cm and was in the range of 0-70 cm. However, after germination, the average plant spacing was 44.4 cm as compared to the recommended plant spacing of 45.0 cm. The variation between seed spacing and plant spacing was due to the germination of 90.2 % at field condition. The field machine index was as high as 75.48 % with an average of 71.88 %. This was due to the rectangular size of the test plot and less turning time at the head land.

The average plant spacing on the 21st day was 48.2 cm. This was due to the non-emergence of some seed in the field. The number of plants over a meter length was 2.07 as compared to the theoretical 2.22 plants over that length. The number of plants per square meter was approximately 4.6 as compared to the recommended 5 plants per square meter (**Table 5**).

The yield was 34.5 q/ha for ma-

Table 2 Seed distribution of maize (Ganga-5) in row at different hopper capacity

Hopper capacity	Average number of seed discharged in 25 revolutions of ground wheel			
	Row 1	Row 2	Row 3	Average
Half hopper				
Average	83.1	80.6	84.3	82.7
Maximum deviation from average, %	+0.48	−2.53	+1.93	
‘t’ on basis of average	0.22 (NS)	1.09 (NS)	1.03 (NS)	
Three-fourth hopper				
Average	87.6	83.1	84.9	85.2
Maximum deviation from average, %	+ 2.81	−2.46	−0.35	
‘t’ on basis of average	1.26 (NS)	1.30 (NS)	0.14 (NS)	
Full hopper				
Average	86.7	89.4	90.1	88.7
Maximum deviation from average, %	−2.25	−0.79	+1.58	
‘t’ on basis of average	1.20 (NS)	0.47 (NS)	1.03 (NS)	

NS : Non-significant

Table 3 Sand bed test for seeding uniformity

Parameter	Number of seed per 5 m length of bed			
	Row 1	Row 2	Row 3	Average
Mean	11.6	12.0	12.0	11.9
Maximum deviation from average, %	−2.52	+0.84	+0.84	
‘t’ on basis of average	0.23 (NS)	0.12 (NS)	0.15 (NS)	

NS : Non-significant

chine planting as compared to 28.2 q/ha for manual planting. However, the average yield per plant was higher for machine planting as compared to manual planting. This was due to higher plant population in manual planting that resulted in less yield per plant.

The cost of the planter was Rs. 8,400.00 and the hourly cost of operation was Rs. 131.00. The cost of operation of the planter per hectare was Rs. 770.00 and the cost of manual planting was Rs. 1,110.00 per hectare. Thus, the cost of manual planting was 43 % higher than the machine planting. The break-even point was 27.37 hours per year and the payback period of the planter was 150 hours.

Conclusions

On the basis of the results obtained from the laboratory calibration and field trials of the power tiller operated planter, the following conclusions were drawn:

1. The deviations from the average of seed discharge among the rows at different hopper fill conditions were within the range of 3 % and statistically insignificant.
2. In the sand bed test, the variation of seed dropped from the mean among the three rows was statistically insignificant.
3. The effective field capacity of the planter was 0.17 ha/h for planting of maize with a field efficiency of 65.4 %.
4. The saving in man hour requirement and cost of planting were quite substantial and justified the use of a planter for planting of maize.

Table 4 Field performance data of power tiller operated planter

Performance parameters	Values
Seed variety	Ganga-5
Soil moisture content, % d.b.	14.26
Soil bulk density, g cm^{-3}	1.13
Seed rate, kg/ha	18.4
Germination, %	90.2
Width of coverage, mm	1,350
Row spacing, mm	450
Average operating speed, Km/h	1.93
Average depth of seed placement, mm	68
Average field capacity, ha/h	0.17
Average field efficiency, %	65.4
Average field machine index, %	71.88
Labour requirement, man^{-h}/ha	5.88
Average draft, N	483

Table 5 Machine planting versus manual planting

Parameters	Machine planting	Manual planting
Average plant spacing, cm	48.2	32.0
Number of plants per m^2	4.60	7.80
Number of plants per meter	2.22	3.12
Yield, q/ha	34.5	28.2
Time requirement (h/ha)	5.88	50 man^{-h} + 16 bullock^{-h}
Cost of operation (Rs/ha)	770.00	1,100.00

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Impact of Arable Land Management and Tillage on Soil Water and Solute Balance in the Sub-Humid Climate of North-East Germany

by
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Abstract

Efficient water use and intelligent water management are essential for sustainable agricultural production. Long-term soil hydrological measurements were used to quantify deep drainage rates and nitrate losses from arable land managed under various farming regimes (integrated, integrated with irrigation, ecologic and low input) and tillage systems (plough and no till) in the Pleistocene region of Northeast Germany from 1994 to 2007. As dependent on the management system, the nitrate concentration varied between 40 and 150 mg l^{-1}. In connection with annual deep drainage rates between 100 mm and 200 mm during the study period, the annual nitrogen loss varied between 14 and 41 kg ha^{-1}. Differences in nitrogen loss observed between the farming systems were low, but yields increased and nitrogen losses decreased as a result of irrigation throughout the variants. No-till treatment resulted in reduced nitrate leaching (18 kg ha^{-1}) as compared with the tillage systems with plough and tooth cultivator (27 kg ha^{-1}).

Introduction

Land management practice is a decisive factor for the quantities of ground water recharge and solute leaching (Benson *et al*., 2006, Köhler *et al*., 2006), which constitute two fundamental aspects of land use characterised by potentially conflictive ecologic implications. Efficient water use and intelligent water management are essential for NE Germany as a sub-humid region marked by an annual water balance deficit between 80 and 250 mm (Dyck and Peschke, 1989, Müller *et al*., 1996). Throughout that region, measures are in demand to support groundwater recharge. To meet this claim, knowledge is required about suitable land management systems providing ground water recharge sustainable in quantity and quality. Starting in 1993, the impact of arable crop and soil management on deep drainage and solute leaching has been studied by the use of soil hydrological measuring installations under field experiments.

Material and Methods

Site and Soil Characteristics

The investigations were carried out at the ZALF Müncheberg V4 experimental field. Seepage-disposed sandy soils are dominant. Müncheberg is located in a Pleistocene end moraine landscape in NE Germany about 50 km east of Berlin and 40 km west of the Oder river, the Polish border. Soils are formed on Pleistocene parent material, clas-

Acknowledgement

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sified as Haplic Albeluvisol (Eutric, Arenic) (WRB 2006). The climate is sub-humid. Measured annual precipitation largely varied over the study period 1994-2005. It ranged from 418 mm in 1999 to 760 mm in 2002. Average annual precipitation was 543 mm and thus a little lower than the long-term average (562 mm).

Measurement Concept

According to Gee and Hillel (1988), water and solute movement through the vadose zone should be compartmentalised into: (i) movement through the root zone, and (ii) movement below the root zone (**Fig. 1**). Fluxes within the root zone are spatially and temporally variable. Fluxes below the root zone may be transient or steady-state (Gee and Hillel, 1988, Schindler and Mueller, 1998). Infiltration and evapotranspiration result in spatially and temporally variable hydraulic and concentration gradients (Gee and Hillel, 1988). Despite average annual evapotranspiration exceeding precipitation in sub-humid environments over the long term, net downward fluxes below the root zone are possible during periods when precipitation exceeds evapotranspiration. Consistently high demand for water by plants may result in minimal deep drainage causing water content and matric potential below the root zone to approach a quasi-steady state in response to the long-term soil water balance. The basic idea was to detect drainage flow preferably below the root zone where soil water movement is directed predominantly downwards, changes in the soil hydrologic status will proceed slowly and continuously, and rainfall events or fluctuations of evapotranspiration will not produce distinct changes in soil water content and tension.

For this reason, continuous measurement of tensions and water content values was carried out under grassland and arable plots, usually at 3 m, and 5 m depth at forest sites. At arable sites the instruments were buried to enable agricultural equipment to pass over the measuring plots. Based on soil tension measurement at two depths, the proof may be given directly from the hydraulic gradient for downward water movement or, where required, periods of capillary rise may be detached.

Short Description of the Method (Schindler and Müller, 1998):

Over time, the soil at measuring depth was considered as being a pipe of various filling. Soil water content was taken as an indicator for the filling level. Transformation of the filling level (soil water content) into flux (drainage flow rate v) was undertaken by the Darcy equation ($v = K(\Theta) \times i$) containing a nonlinear scaling factor, the hydraulic conductivity function $K(\Theta)$ being dependent on water content (Θ), and the hydraulic gradient (i) as the driving force. Daily drainage flow rates (v) were calculated based on water content measurements and the hydraulic conductivity function $K(\Theta)$ calibrated to the water balance.

Management Systems

In the study period, three management systems were practised and investigated at the Müncheberg V4 experimental field (**Fig. 2**) in three distinct stages. From 1994 to 1998 different farming systems were tested. At the integrated (IO), integrated with irrigation (IB) and the low-input system (EO) mineral nitrogen fertilizer was applied. At the ecologic farming system (OO) exclusively organic nitrogen fertilizer (manure and slurry) was used. From 1999 to 2000 a break was inserted, cultivating lucerne grass LG (alfalfa) at all plots. In 2001 tillage experiments started. The effect of different tillage systems (P: plough in combination with tooth cultivator, NT: no-till) on yield and the soil water and solute balances was analysed. **Fig. 3** provides an overview of the average

Fig. 1 Measurement concept

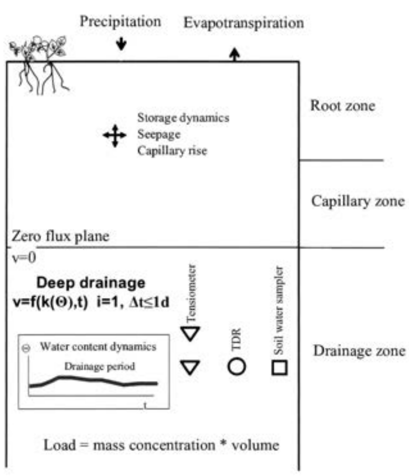


Fig. 2 Experimental field Müncheberg

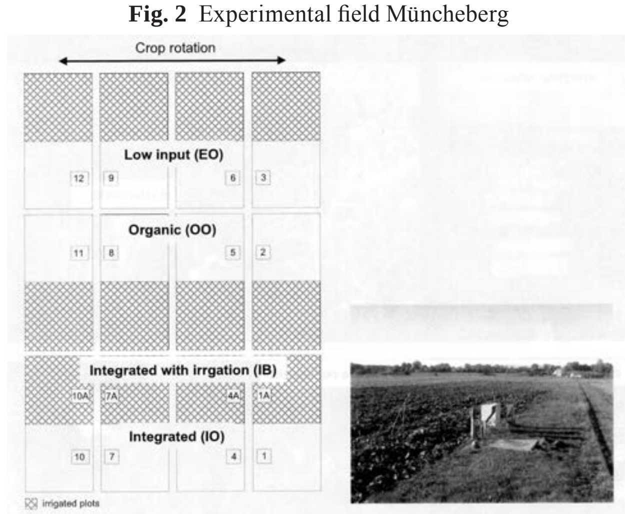
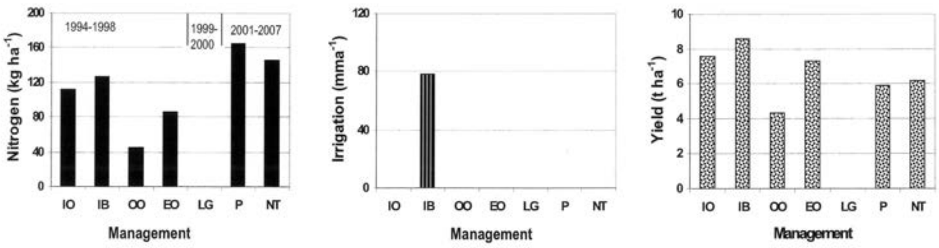


Fig. 3 Average annual management data, Müncheberg V4 experimental field, 1994-2006



Installation of the Müncheberg Experimental Field

Fig. 4 Installation of TDR, tensiometers and soil water samplers below plough horizon at the Müncheberg experimental field

annual nitrogen fertilizer input, annual irrigation rate and yield of the management systems as an average of the replications.

Crop Rotations were:

1994-1998:
- Sugar beet, winter wheat, winter barley and winter rye with catch crop

1999-2000:
- Lucerne grass at all plots

2001-2005:
- Plough: Winter wheat, winter barley, winter rape, triticale, winter rye + oil radish, potato
- No-till: Winter wheat + oil radish, corn, winter rye + oil radish, pea, winter barley, winter rape

Results and Discussion

Deep Drainage Dynamics and Arable Management Effects

In-situ temporal soil water content and calculated seepage dynamics were calculated for the period 1995-2005. Measurements of the soil water content allowed for a temporally highly disintegrated analysis of soil hydrologic conditions below the root zone. Periodic processes of seepage flow formation in the winter half-year, characterised by rising soil water content or falling soil water tension and subsequent soil drainage during the vegetation period were clearly visible. Individual periods were well distinguished. Seepage periods start mostly between January and March followed by soil drainage during summer and autumn time.

Results confirm the hypothesis of the well-balanced, slow and continuous progression of the soil water content in the deeper vadose zone below the root zone down to 3 m depth (Kutilek and Nielsen, 1994, Schindler and Müller, 1998). Daily changes in measured values allowed for the assumption of quasi steady-

Table 1 Deep drainage depending on management

Mangement	IO	IB	OO	EO	LG	P	NT
Drainage rate (mm a^{-1})	161	191	180	154	130	191	158
RMS (mm a^{-1})	50	47	33	38	18	68	49

Table 2 Nitrate leaching rates in dependence on management

Mangement	IO	IB	OO	EO	LG	P	NT
Drainage rate (mm a^{-1})	41	37	36	36	14	27	18
RMS (mm a^{-1})	16	9	12	16	7	15	7

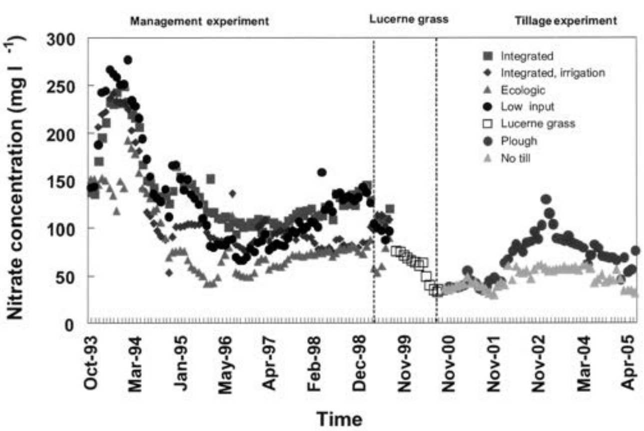
RMS: Root mean square, IO: integrated, IB: integrated with irrigation, OO: ecologic, EO: low input, LG: lucerne grass, P: plough, NT: no till

state conditions within intervals of 1 day. As the result of high variation in annual precipitation and land management effects, the variation of annual deep seepage rates appeared high (**Table 1**). Results differed as follows between the farming systems (stage 1994-1998). The integrated system with irrigation IB (191 mm a^{-1} and RMS 47 mm a^{-1}) produced the highest seepage rates followed by the ecologic farming system OO (180 mm a^{-1} and RMS 33 mm a^{-1}), which, in turn, had the lowest yields (see **Fig. 1**). The integrated system without irrigation IO (161 mm a^{-1} and RMS 50 mm a^{-1}) and the low-input system EO (154 mm a^{-1} and RMS 38 mm a^{-1}) produced nearly the same deep seepage rates and quite the same yields, too. However, the differences were not significant. The lowest deep seepage rate was calculated with 130 mm a^{-1} and RMS 18 mm a^{-1} under lucerne grass (stage 1999-2000), but precipitation turned out to be remarkably low (436 mm a^{-1}) in this period. Results of tillage experiments were valid for the stage 2001-2005. Tillage with plough (191 mm a^{-1} and RMS 68 mm a^{-1}) produced higher deep seepage rates than the no-till system (158 mm a^{-1} and RMS 49 mm a^{-1}). Differences, however, were not significant again.

Nitrate Concentration and Nitrate Leaching

Fig. 5 shows the dynamics of nitrate concentrations under the practised and tested arable management systems as an average of the replications from 1993 to 2005. Nitrate concentrations at all Müncheberg measurement plots decreased until 1995, after which they levelled-off. Obviously, the initial nitrate dynamics were a consequence of the preceding agricultural activities on that site. Since 1995 the nitrate concentrations in seepage water have been reflecting the effect of the investigated farming systems. Lowest nitrate concentrations were observed at the ecologic farming system, where the nitrate concentration varied between approximately 50 and 80 mg l^{-1}. Highest nitrate concentrations (100-130 mg l^{-1}) were analysed under the integrated system without irrigation, where the nitrogen input was nearly twice as high as at the ecologic system. Most fertilizer was applied at the integrated system with irrigation. This treatment, however, displayed nitrate concentrations similar to the ecologic system, between 80 and 100 mg l^{-1}. In all cases, nitrate concentrations consistently exceeded the 50 mg l^{-1} drinking water threshold. Starting in 1999, as soon as lucerne grass was growing, the nitrate concentration at all measurement plots decreased continually and levelled-off at approximately 45 mg l^{-1} in 2000. With the beginning of the tillage experiments in 2001, nitrate concentrations in seepage water altered again. At ploughed plots concentration increased continually to reach its maximum of 140 mg l^{-1} in 2003. Afterwards the concentration decreased continually and approached the values of no-till plots in 2005. Reason for this dramatic increase, after changing the management, could have been mineralization processes of the organic matter. At no-till plots the nitrate concentration varied just a little over the observation period (2001-2005) and remained at the low level of 40 to 60 mg l^{-1}.

Fig. 5 Dynamics of the nitrate concentration in seepage water at 3 m depth, Müncheberg V4 experimental field



Nitrogen leaching rates were calculated based on nitrate concentration and deep seepage rates. The differences of annual nitrogen leaching rates between the farming variants were small and not significant (**Table 2**). In the study period 1994-1998 the average annual nitrogen leaching rates varied between 41 kg N ha^{-1} (RSM 16 kg ha^{-1}) at the integrated plots IO (without irrigation) and 36 kg N ha^{-1} (RSM 12 kg ha^{-1}) at the ecologic variant (OO). Leaching rates of the low-input variant EO (36 kg N ha^{-1}, RSM 16 kg ha^{-1}) and the integrated variant with irrigation IB (37 kg N ha^{-1} and RSM 9 kg ha^{-1}) did not differ much from the ecologic system. However, irrigation had a noticeable effect on yield and nitrogen intake. The lowest fertilizer input and the lowest yields occurred at the ecologic treatment. Nevertheless, this treatment caused nitrogen leaching rates similar to those of the other treatments. Nitrogen leaching under lucerne grass (1999-2000) was strongly reduced (14 kg N ha^{-1} and RSM 7 kg ha^{-1}) compared to the previous management. Tillage with plough in combination with tooth cultivator (27 kg N ha^{-1} and RSM 15 kg ha^{-1}) produced increased nitrogen leaching as compared with the no-till variant (18 kg N ha^{-1} and RSM 7 kg ha^{-1}). However, The differences were not significant.

Conclusions

The effect of the investigated farming systems (integrated, integrated with irrigation, ecologic and low input) on nitrate dynamics was surprisingly small. The expected advantage of ecologic farming (Freyer, 2003, Pacini *et al*., 2003, Stark *et al*., 2006) could not be confirmed. However, these results agreed with findings of Böhm *et al*., 2009. As ecologic treatment produced the lowest yields, it did not show noticeably lowered nitrogen leaching. Irrigation, in turn, provided a noticeable effect on yield and nitrogen intake, but nitrogen leaching did not significantly differ from the ecologic treatment. No-till treatment displayed lower nitrate leaching than the tillage system with plough and tooth cultivator but mineralisation processes could have influenced this result. Also, the differences of deep seepage and nitrate leaching rates between the tested farming systems were small and not significant.

Summarizing we can Conclude:

1. High yields and a sustainable, soil and water protecting arable management requires a fertilization consistent with the plant demand. Exceeding fertilization does not markedly increase the yield but has strong negative pollution impacts of ground and surface waters.
2. Irrigation improves the fertilizer uptake and increased yields. Consequently the solute leaching is reduced.
3. Underdose fertilization reduces yields due to limited nutrient uptake; however, the solute leaching is not reduced compared to a sustainable management practice.

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Evaluation of some Soil Quality Indices under Two Soil Tillage Systems in a Tropical Region of South East Mexico

by

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Abstract

A five year field experiment was conducted to assess the interaction between soil tillage levels, maize-sorghum-legume rotation and two levels of chemical fertilization at the rain feed tropical region of south-east Mexico. The purpose of this research work was to asses this interaction over the variation of some soil quality indices and the effect on the productivity of the soil-grain yield. The treatments for soil tillage were zero till and the intensive traditional soil tillage of the region. Crop rotations employed were five years maize (mmmmm), five years sorghum (sssss), two rotations; (smsms) and (msmsm) and two intercropping of legumes (f)-cereals, (fsfsf) and (fmsmf). Ninety two and 136 units of nitrogen were the two levels of fertilization and were applied only to the cereals. The evaluated soil index in the first and fifth year were organic matter (mo), water infiltration rate (ir), aggregate stability (as), ph, biomass microbiana (mb), nitrogen soluble nitrogen, soil density (sd), soil depth (sd), electrical conductivity (ec) and availability of nutrients. In general terms, the best grain yield for both sorghum and maize were obtained with the no till treatment although no big differences were observed between them. The five year sorghum mean yield under no till with fertilization levels 1 and 2 were 3.6 and 4.5 Mg/ha, whereas, with conventional tillage these were just 3.1 and 4.1 Mg/ha, respectively. The grain yield of maize with level 2 of nitrogen, with zero and traditional till were 5.1 and 4.6 Mg/ha; however, with nitrogen level 1 there were no apparent advantages of the first treatment (3.8 Mg/ha in both cases). The type of crop rotation and soil tillage level mainly affected the chemical soil index at 0 to 5 cm depth. However, no effect occurred with the way of handling crop residues and with the levels of chemical fertilization. The main values of electrical conductivity were attributed to an increase in the solubility of some elements. It was also observed that, under no till, there was an increase of the levels of soluble carbon.

Introduction

The degradation of many agro ecological systems worldwide has been caused in great measure by the employment of more and more intensive agricultural production practices. Simultaneously, it has been incorporated into the production and over exploitation of more fragile natural resources without any consideration of agro ecological impact. Both situations are necessary to satisfy the growing demand of foods that cause the population's constant increment, and to generate utilities, demanded by the actual economic system. The development of the sustainable concept in the last decade has come to light because of alerts in relation to the human impact on the degradation of the natural resources. At the moment it is accepted without extensive discussion that it is not possible to continue with the rate of present degradation without seriously committing the future of humanity. Although it seems iterative, it is necessary to remember once again that the necessity to produce food will be an indispensable requirement while there is human life on the face of the earth. The destruction of the capacity of production of the agricultural systems or their drastic decrease would mean the disappearance of a significant part of human beings. Recently society has taken progressive consciousness of this problem and has introduced numerous alternatives dedicated to reduce the impact of the production activities related to the agro ecological systems, among which are different types of alternative agriculture such as conservation tillage and many others.

It is interesting to emphasize, before beginning the development of this topic, the change that has come into focus to analyze and to look for solutions to problems that are generated in agriculture. In the past the focus was on minimized analysis and is the one that has prevailed and still prevails. This form of study consists of using an actual farm and divide it into each of the parts that compose it to understand how it is constituted and the way it operates. Nowadays, the focus of the analysis requires that it be more and more holistic; that is to say integral. It is required to understand how a certain system works (function), how it is organized (components), the relationships that exist among them (communication, flows), what its limits are and what the entrances and exits are since, in almost all the cases, there are open systems.

A part of the specialist's attention in ecological systems has been centered in the systems of agricultural production, which are integrated by three main components: the plant, the soil and the environment. The three are related to the stability of the agro ecological system.

The production of biomass (fixation of atmospheric carbon by means of the reaction of photosynthesis) with the economically useful part being the product of the interaction that happens among all the factors associated with these components. Some of those factors are not controlled by the system, such as the quantity of rain water or the amount of radiation, which are considered as inputs to the system. However, the quantity of mulch residuals that are in the soil are dependent and controlled by the system and they contribute, after their decomposition, to increase the reserves of carbon. In contrast, the aerial residues that are controlled by the system, can not become part of the reservoir of carbon in the soil. Because of external agents, the farmer decides if they will be incorporated or not. The identification and understanding that the components are the structure of the system and function in a fundamental way to be able to intervene and guide in the direction that best impacts soil productivity.

The impossibility of measuring each aspect related to the system has made it necessary to define indicators and indices that allow a simple evaluation directed towards certain changes related to the dynamics of the system. It is interesting to point out that, in spite of the efforts carried out in this sense, a consent does not exist about indices and indicators that should be used to evaluate the soil conditions when related to tillage practices.

The amount of carbon in the soil is related to numerous properties. It is fundamental for soil fertility and much of the biological components (soluble carbon is required as an energy source for many microorganisms) for both chemical and physical properties. The decomposition of the organic matter for the microbial biomass and the fauna (mulch mineralization) constitutes a way to give essential elements for growth (it contributes to the chemical). The residual molecules of such processes of relatively high stability (humus) have an important paper in the structuring of the same one (apparent density, field capacity, porous space to retain the soil solution so that the roots of the cultivations grow; this is a relationship with the physical aspects). Low Concentrations of carbon in the soil associate with problems of low fertility, soil erosion rate and, in general, degradation processes. In contrast, the accumulation of organic matter (carbon) is considered as an indicator of good fertility and of appropriate physical and biological characteristics for grain production. Besides the mentioned functions related to grain production, the soil is considered as one of the main reservoirs of this element (CO_2) in nature. It is possible to use the soil capture of atmospheric carbon dioxide (CO_2) that is responsible partly for the call for global change. This is action that the country is committed to and is one of the 20 bigger originators of this gas in the world. Plus, even nowadays, it is possible to aspire to the possibility that the accumulation of carbon in the soil can surrender economic fruits. There are experiences in Mexico where the capture of each ton of carbon dioxide means that farm producers have an additional income of $9 USA dollars per hectare.

The conservation tillage systems allow integration of a series of advantages. On one hand, they contribute to the reduction of the rate of degradation of the soil, to the reduction of the consumption of fossil fuels, to the increase the levels of carbon dioxide in the soil and to the improvement of soil fertility and, in general, the sustainability of the agricultural productive systems. For the other side, they can constitute a mechanism to trap atmospheric carbon dioxide temporarily. It is necessary, however, to develop efficient indicators that allow measurement of the wanted changes that are made.

The objective of this research was to integrate an analysis of the effect of soil cultivation practices on the level of carbon dioxide and certain indices that can be used as good indicators to address the speed of the degradation-improvement processes and the sustainability of different agro ecological systems.

Experimental Method

In this section an experience related to the action is described for the first 5 years after the establishment of an experiment, with a series of treatments that are described as follows. The experiment was conducted at a location representative of a humid sub tropical climate in the southeast of Mexico, with an annual half precipitation of more than 1,200 mm of rain. The ph of the soil was near to the neutrality and its fertility was considered high. The treatments consisted of situations that simulated common production systems in the region. Crop combinations were (M = corn and sorghum = S) and rotations (MS, SM), with two crop cultivation practices (conventional = C and zero = Z), leaving the crop residuals on the surface (R) or without them (B). The sorghum and corn, starting from the first year, received two doses of nitrogen fertilization (92 and 138, kg/ha) applied in rows. Phosphorus (P) was not applied because the level of original (P) level was considered high (50 ppm P-Olsen). The weed control was made with Glifosato in pre seeding for zero tillage and for the conventional farm an application Atrazina + Metalochlor after seeding.

The experimental treatments represented a range of common conditions in the traditional systems of production for the two evaluated tillage systems. The most exhaustive system of exploitation was located on one end with the conventional system of farm and livestock shepherding with the residuals. With the other one, the zero tillage system was used, leaving all the crop residuals over the surface. Detailed evaluations of the production of biomass were made the first three years after establishment (2003, 2004, 2005) and grain production from the first to fifth years. In the third and last year some indicators of soil quality were also evaluated (chemical, physical and biological) along with accumulation of organic matter in the soil profile at the end of the fifth year.

Experimental Results

In **Tables 1** and **2** the results of sorghum and corn production are presented under traditional and conservation tillage practice conservation, with retention or removal of the crop residuals, for the period 2003-2007, as well as the yield average. These productions were

Table 1 Grain yield of sorghum from 2003 to 2007

Treatments[1]		yield					
Crop rotation 2003-2007	Tillage and crop residues	2003	2004	2005	2006	2007	Mean
			— Mg/ha—		Level 1 of nitrogen		
SSSSS	ZR	4.9	4.7	2.7	3.7	2.3	3.7
	ZB	5.5	4.0	3.4	3.0	1.7	3.5
	CR	5.5	3.8	3.9	5.4	1.6	4.0
	CB	5.8	4.3	3.4	3.1	1.5	3.6
Mean		5.4	4.2	3.4	3.8	1.8	3.7
MSMSM	ZR	-	4.4	2.4	3.0	1.9	2.9
	ZB	-	4.4	3.3	2.9	1.0	2.9
	CR	-	4.3	3.1	3.8	1.2	3.1
	CB	-	4.6	3.4	4.0	1.0	3.2
FSFSF	ZR	-	4.3	4.8	5.7	1.4	4.1
	ZB	-	4.1	4.6	4.3	1.2	3.6
	CR	-	2.7	4.2	5.0	0.8	3.2
	CB	-	3.1	4.7	3.9	0.8	3.1
Mean			3.6	4.6	4.7	1.1	3.4

Second part.

Treatments[1]		Grain Yield					
Crop rotation 2003-2007	Tillage and Residues	2003	2004	2005	2006	2007	Mean
			— Mg/ha—		Level 2 of nitrogen		
SSSSS	ZR	5.5	5.1	4.0	6.0	4.5	5.0
	ZB	6.0	4.5	4.1	3.9	3.1	4.3
	CR	5.7	3.9	4.5	5.6	4.3	4.8
	CB	5.8	5.2	4.2	4.1	2.8	4.4
Mean		5.8	4.2	4.2	4.9	3.7	4.6
MSMSM	ZR	-	4.6	4.5	3.6	3.9	4.1
	ZB	-	4.6	4.7	4.1	3.1	4.1
	CR	-	4.6	4.4	6.1	1.8	4.3
	CB	-	4.6	4.0	4.3	2.3	3.8
FSFSF	ZR	-	4.2	5.0	5.4	3.6	4.6
	ZB	-	4.1	5.1	4.6	3.1	4.2
	CR	-	2.6	4.9	6.2	1.9	3.9
	CB	-	3.5	4.3	3.9	2.3	3.5
Mean			3.6	4.8	5.0	2.7	4.1
Tillage	Z						4.5
	C						4.1
Residues	R						4.0
	B						3.7

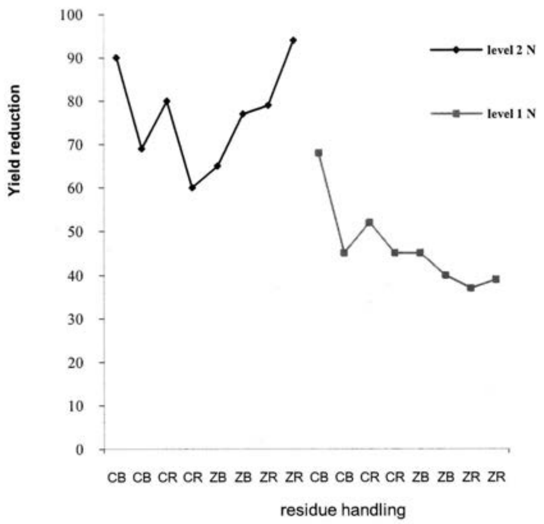
[1]Rotation; Sorghum=W, maize=M, F=bean; tillage system cero= Z, Traditional= C, residues handlind with = R bare soil = B

Table 2 Grain Yield of Corn from 2003 to 2007.

Treatments[1]		Grain Yield					
Crop rotation 2003-2007	Tillage and Residues	2003	2004	2005	2006	2007	Mean
			— Mg/ha—		**Level 1 of nitrogen**		
MMMMM	ZR	6.5	4.3	1.2	2.1	1.4	3.1
	ZB	6.5	4.6	2.4	3.2	1.4	3.6
	CR	6.3	5.5	2.5	4.9	2.0	4.2
	CB	6.1	5.3	2.9	3.5	2.2	4.0
Mean		6.3	4.9	2.3	3.4	1.8	3.7
SMSMS	ZR		6.2	4.6	4.9	2.2	4.5
	ZB		6.7	2.7	4.4	1.5	3.8
	CR		5.3	4.8	4.8	2.4	4.3
	CB		6.1	3.8	5.4	2.3	4.4
Mean			6.1	4.0	4.9	2.1	4.3
FMFMF	ZB		5.1	5.4	5.4	2.3	4.6
	CB		2.0	5.1	4.3	2.1	3.4
Mean			3.6	5.3	4.9	2.2	4.0
					Level 2 of nitrogen		
MMMMM	ZR	7.2	6.5	4.7	4.7	2.2	5.1
	ZB	7.4	6.1	4.8	4.0	1.7	4.8
	CR	6.3	6.3	5.4	5.7	2.6	5.3
	CB	6.2	6.4	5.0	5.1	2.5	5.0
Mean		6.8	6.3	5.0	4.9	2.3	5.0
SMSMS	ZR		8.7	7.6	6.6	3.8	6.7
	ZB		7.7	5.3	5.7	1.9	5.2
	CR		6.0	6.2	5.1	2.7	5.0
	CB		6.1	6.6	5.3	2.6	5.2
Mean			7.1	6.4	5.7	2.8	5.5
FMFMF	ZB		5.1	6.4	6.3	2.2	4.8
	CB		3.0	6.5	4.9	2.0	3.4
Mean			4.0	4.6	5.6	2.1	4.1

[1]Crop rotation; Sorghum=W, maíze=M, tillage systems Zero= Z, traditional= C, Residues handling with = R and bare soil =B

Fig. 1 Grain yield reduction with differnet N levels



achieved under rain fall conditions.

The yields of both cultivations in the period 2003-2007 were very variable. For sorghum these went from 1.0 to 6.1 Mg/ha and for corn the yield was 1.4 to 8.7 Mg/ha. In all the cases a tendency of the yields was to diminish with the time, with the largest decrease for corn. Such results were attributed to factors related with the climate with a shortage or excess of rainfall during the growing season.

The treatments that received nitrogen fertilization (NF) (level 2) produced higher yields, consistently, than those with level 1 nitrogen (N), indicating that the (N) nutrition required special attention under conditions similar to the experimental ones. Still, in the case of leguminous plants, one was included in the crop rotation (**Fig. 1**).

In general, for both sorghum and corn, the highest yields were obtained with the treatment of zero tillage, although a big difference could not be observed among them. The sorghum with zero tillage, with the levels 1 and 2 of (NF), yielded 3.6 and 4.5 Mg/ha as an average during the 5 years of the experiment, whereas, with conventional tillage systems this was only 3.1 and 4.1 Mg/ha, respectively. The yield averages of corn with (NF) level 2 and zero and conventional tillage were 5.1 and 4.6 Mg/ha. However, with nitrogen level 1, there were no apparent advantages compared with the first treatment (3.8 Mg/ha in both cases). The inclusion of a legume in the crop production system did not always give an increment on grain yields. This could be due to the extraction of water required for cultivation after the grain crop that affected the moisture residual of the soil and possibly some other physical characteristics of the following crop that influenced the crop negatively. In contrast, the presence of leguminous plants in the rotation in years with good rain fall was almost always in more yields and was attributed to a higher nitrogen and water availability.

It was observed in the handling of crop residuals that those treatments where the residuals were conserved over the surface produced more gain than those treatments where it was moved. The 5 year production average with and without residuals, independent of the tillage treatment and (FN) level, were 4.0 and 3.7 Mg/ha for sorghum and 5.3 and 4.6 Mg/ha for corn, respectively, that which shows the advantage of maintaining the crop residuals. It contributes it to improve the structure of the soil and to the supply of nutrients as the residuals are mineralized.

The Physical and Chemical Indicators

Some physical and chemical properties of soil were measured after the fifth year of applying the described treatments. These were used as indicators of the soil quality. The concept of soil quality is synonymous of health of the soil. Man's intervention in the soil, either with productive purposes or land escape, produces transformations that change the balance of water, organic matter and nutrients that generate erosion and compaction as related to the original condition. Such change must be measured to avoid the degradation of the resource. The indicators of quality give an idea of the changes related to the soil like the effect of human intervention. The indicators allow analysis of the current situation of a system and the identity of the critical points with regard to sustainability; analysis of the possible impacts before an intervention and help to determine if the use of the resource is sustainable. The indicators are a tool for making decisions. Healthy soil makes energy consumption smaller, equipment and machinery wear out less, less fertilizer is required, the cultivations settled down and surrender more, there are less problems with pests and disease and crops produce better quality. Efforts to maintain and improve crop quality will produce advantages for the farmers and the country.

Table 3 presents some indicators proposed to evaluate the quality of the soil and the affected process. However, the indicators of soil quality can vary for differences in the material parental, topographical and climatic conditions, position in the landscape, organisms of the soil and type of vegetation. The measurement of the quality of the soil should, especially, detect changes that can happen in one period between 3 to 10 years. Any change that is detected that guides to an indicator in a negative address has to be corrected to avoid the occurrence of irreversible damages such as those observed in many agro ecological systems of the country.

The rotation type and the nature of the soil tillage practices affected, in general, most of chemical indi-

Table 3 Selected soil quality index and processes being impacted

Soil Indicator	Process being affected
Organic Matter	Recycled Nutrients, pesticides and water retention, soil structure.
Water Infiltration rate	Soil erosion, nitrogen lixiviation; efficiency of water use.
Aggregates	Soil structure, soil erosion resistance, seed emergence, water infiltration rate.
pH	Soil fertility, pesticides soil absorption and mobility.
Biomass	Organic activity, nutrients mobility, degradation of pesticides
Nitrogen	Available N, N potential lixiviation, mineralization rate.
Soil Density	Root penetration, biological activity.
Soil depth	Rooting Volume, availability of water and nutrients.
Electric conductivity	Water infiltration rate, soil structure.
Soil fertility	Plant growing rate, environmental pollution.

Table 4 Some chemical indicators of soil quality after 5 years of having established the treatments in the depth 0 to 5 cm of the profile

	Soil Quality Index						
Main Treatments	pH	CE dSm^{-1}	K cmol kg^{-1}	NT %	MO %	C %	CS Abs
Depth 0 a 5 cm							
Crop rotation	6.3ab2	0.12 ab	1.18ab	0.11a	2.2a	1.26	0.252a
MMMMM	6.0a	0.16b	1.48ab	0.11a	2.2a	1.29	0.320b
SSSSSS	6.3ab	0.14ab	1.22ab	0.12a	2.0a	1.15	0.310ab
MSMSM	6.5b	0.14ab	0.96a	0.11a	2.0a	1.17	0.270ab
SMSMS	6.3ab	0.13ab	1.74b	0.13a	2.2a	1.26	0.300ab
FSFSF	6.6b	0.12ab	1.19ab	0.11a	2.0a	1.14	0.270ab
SFSFS	6.2a	0.11a	0.99a	0.11a	1.7a	0.97	0.240a
FMFMF	6.5b	0.12ab	1.16 ab	0.11a	2.0a	1.14	0.230a
Tillage							
Z	6.3a	0.14a	1.37a	0.12a	2.3a	1.32a	0.309a
C	6.4a	0.12b	1.13b	0.10b	1.8b	1.05b	0.250b
Crop residues							
R	6.3a	0.14a	1.33a	0.12a	2.1a	1.23	0.311a
B	6.3a	0.13b	1.20a	0.11a	2.0a	1.15	0.256b
Levels of Nirogen							
N^1	6.4a	0.13a	1.25a	0.11a	2.1a	1.22	0.270a
N^2	6.2a	0.14a	1.26a	0.11a	2.0a	1.15	0.288a

[1]Crop rotation (M = maize; S = sorghum; F = beans), tillage (Z = Zero, C = conventional); residues handling (R = with residues, B = bare soil), N_1 = 92 kg , N_2 = 136 kg

cators for treatments in the depth 0 to 5 cm. The zero tillage system produced higher values of electric conductivity, interchangeable potassium, total nitrogen, organic matter and soluble carbon than the traditional farm. The higher values of electric conductivity are attributable to an increase in the solubility of some elements. An interesting aspect is the increase of the soluble carbon. This seems to be an early indicator of favorable changes in the soil and was reflected in an increase of the microbial activity measured through the biomass. The levels of C-biomass and N-biomass in the soil of the different treatments presented the following order: zero tillage with retention of residues> zero tillage without crop residues > conventional tillage with residues> conventional tillage without residuals. The microbial biomass stood out as a much more sensitive indicator than the organic carbon to evaluate the different cultivation practices in the first years after the establishment of the experiment. The changes in deeper soil depth were imperceptible after 5 years. **Table 4** shows some changes of chemical properties of the soil, mainly in the soil depth from 0 to 5 cm.

Table 5 Some physical Index of Soil Quality after 5 Years

Treatments	Da 0 a 50 mm	Soil moisture[4] 0 a 50 mm	Soil resistance 150 a 210 mm	Soil Resistance 210 a 360 mm
	$g\ cm^{-3}$	$cm^3\ cm^{-3}$	KPa	KPa
ZR	1.5a[1]	13.9	1985a[1]	1615b
ZB	1.3a	9.9	2037a	1848a
CR	0.9b	7.0	1147b	1673b
CB	0.9b	6.8	1206b	1815a
DMS[2]	0.3		138	
Cv[3]	17.5		5.7	

Table 5 gives some physical soil quality indicators after 5 years form the initiation of the experimental soil treatments.

In general, the zero tillage system produced higher apparent densities (approximately 1.4 $g\ cm^{-3}$) than the conventional one (0.9 $g\ cm^{-3}$), but the water soil retained in the first case, after the dry period, was larger. It was explained when the soil was being disturbed, such as in the case of the conventional tillage, the loss of water was favored. Conserving the residuals didn't show greater benefits after this period, although it was due to the scarce sensibility of the methods used to measure this parameter. Also, the soil resistance to penetration was higher in the depth 150 to 210 mm, but between 210 and 360 mm the situation was inverted. The addition of residues didn't modify this characteristic.

The previous results show that, besides the agronomic advantages that the zero tillage system presents, the system retains a higher quantity of carbon in the soil than the conventional tillage, independent of the retained residual. This was an additional advantage and it would be necessary to study more deeply to quantify with certainty the quantity of trapped carbon dioxide. This information was of great value from an environmental point of view and it shows the importance of adopting conservation tillage as a way of contributing to the national commitment to diminish the emissions of carbon dioxide and to increase the fixation of carbon to stabilize the current levels and possibly diminish the concentration of this gas.

Conclusions

Conservation tillage in representative soil of the humid sub tropical region, with retention of residuals, turns out to be a good alternative to maintain relatively high yields in sorghum and corn, particularly under conditions of water stress. In one year, production of sorghum and corn did not present good yields in the long term, for the important reduction in the nitrogen supply. The rotations with sorghum and corn behaved better than the one year crop. The incorporation of legumes in the rotations only represented advantages in years with appropriate rain fall.

Conservation tillage, in particular with retention of residuals, presented in general terms better values of some indicators of soil quality than those obtained with the conventional tillage. The microbial biomass was affected positively by the zero tillage and the retention of residuals. The content of organic matter and the soluble carbon also increased that which was judged as an improvement of the quality and health of the soil under evaluation.

Conservation Tillage, for the fact of favoring an increase of the percentage of organic matter in the soil can be recommended as a mechanism for the capture of carbon and, therefore, to reduce the concentration of carbon dioxide in the atmosphere.

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NEWS

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Effect of Manner of Stacking on Changes in Nutritional Value of Treated Baled Paddy Straw by Dripping Technique

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Abstract

The treatment of straw with urea as a source of ammonia offers good potential for upgrading the quality of straw. The various treatment parameters as established in respect of discharge rate Q (1,000 cc/min), specific amount of liquid application (As) 1,125 cc/kg DM and bed depth (3 bales) each of 0.36 m thickness were used for ammonia (urea) treatment of baled paddy straw. Two manners of stacking of treated baled straw during the curing period were chosen and changes in nutritional values of straw after curing were evaluated on the basis of dry matter digestibility (DMD) coefficient, ammonical nitrogen (AN) content and crude protein (CP) content. The average moisture content of the core of a bale in the first and second stack, i.e. 33.5 and 35.0 % was found lower ($P < 0.05$) than that of its sides 39.3 and 38.0 %, respectively, after a curing period of 21 days. There was no significant difference in the nutritional value of straw in first and second stack. However, the change in the nutritional value of treated straw in the second stack was expected to be better because of better equalization of moisture content among the bales.

Introduction

A large number of chemicals such as sodium hydroxide, calcium hydroxide, ammonium hydroxide, anhydrous ammonia and aqueous ammonia (Verma, 1983; Ibrahim *et al*., 1983; Jaiswal *et al*., 1988) have been tried for treatment of agricultural crop residues to improve their feed value. The use of urea as a source of ammonia has been suggested by several workers who found it technically and economically superior to other chemicals. The ammonia (urea) treatment seems to be the only feasible method in developing countries, mainly due to two reasons, firstly, urea is easily available almost every where and the farmers are fully conversant with its use, storage and handling, and secondly, the treatment with urea is very simple which can be easily adopted by farmers. Most of the workers have concluded that ammonia (urea) treated straw is superior to untreated straw in terms of its digestibility (Rashiq, 1980; Saadullah *et al*., 1981); intake of nutrients (Jaiswal *et al*., 1988); and animal performance in terms of growth (Kumarsuntharam *et al*., 1984 and Jaiswal *et al*., 1988)

Most of the work related to ammonia (urea) treatment of paddy and wheat straw has been done in its loose form by packing the material inside pits or some kinds of containers. The basic problem in proper utilization of loose straw is due to the problems associated with its treatment as well as handling and storage of low bulk density straw (40 to 50 kg/m^3). Further there are many practical problems in transporting loose straw to drought flood hit areas from long distances.

Efforts have been made to develop suitable injectors for injecting urea solution into baled paddy and wheat straw for the past several years. The treatment process has been accomplished in two stages; (1) the application of urea solution into baled straw with a hand held injector and (2) the storage of treated material for curing in an air tight container made with polythene sheets by adopting the 'Norwegian Method.' However, due to numerous disadvantages, mainly the economics of treatment, it is doubtful as to whether it could be adopted for the treatment of baled straw on a commercial scale. Thus, keeping the above points in view a new technique named the 'Dripping-Technique' was designed (Bamaga, 1996), developed and evaluated for the treatment of baled paddy straw. The best levels of operating parameters such as discharge rate of liquid applicator, specific amount of liquid application and bed depth of straw bales, were used for ammonia (urea) treatment of baled paddy straw.

The present research work was carried out with the objectives: to establish the optimal operating parameters (the discharge rate and specific amount of liquid application) of the drip applicator for ammonia (urea) treatment of baled paddy straw; to see the effects on liquid retaining efficiency and variations in moisture content along the bed depth of bales; and to establish the manner of stacking of ammonia (urea) treated bales during curing period to see the efficacy in terms of availability of nutrients.

Materials and Methods

An experimental set-up was developed and used for treating that consisted of two different units (**Fig. 1**). The first unit consisted of two tanks for storage of urea solution, Pipes were used to connect the main liquid tank with constant liquid tank and, finally, with the liquid applicator and connections, two control valves and liquid applicator, which consisted of four polythene pipes mounted laterally on a wooden frame. Another polythene pipe of the same diameter

Fig. 1 Experimental set-up used in the investigation

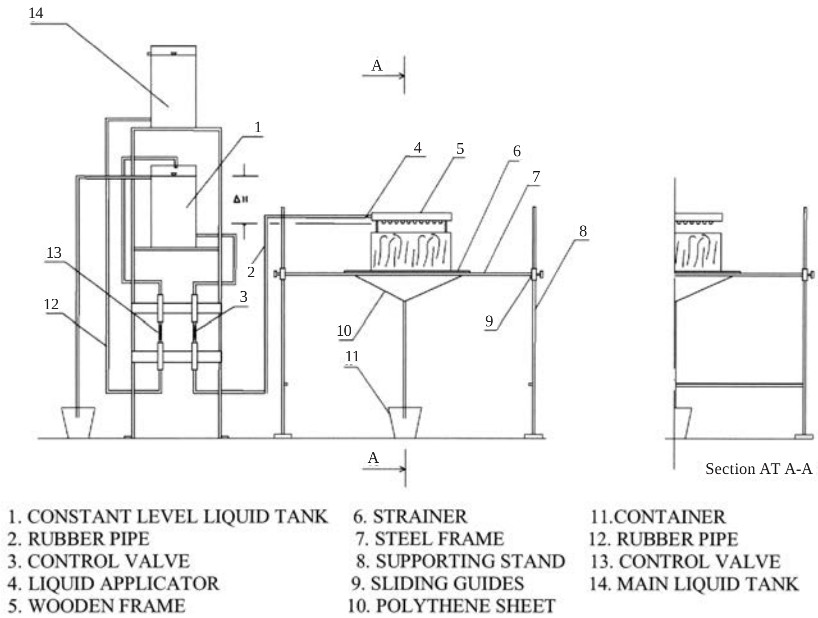
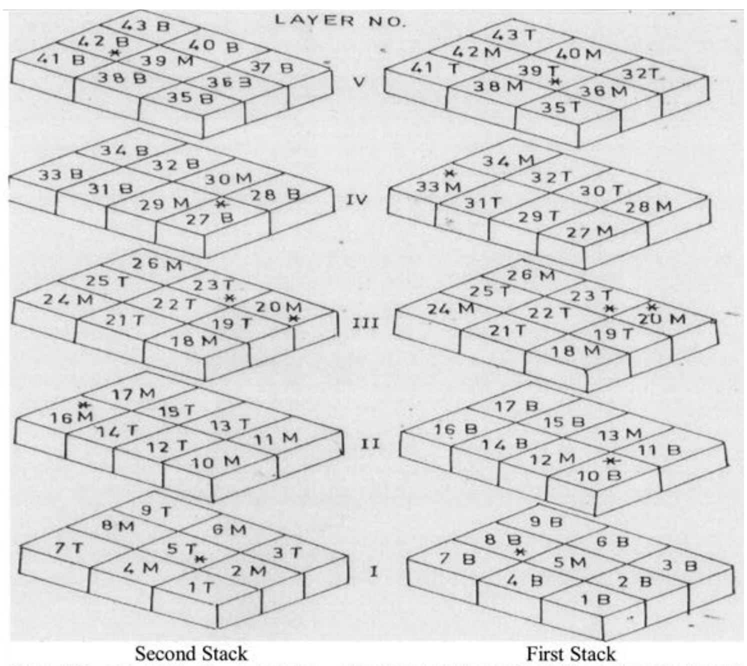


Fig. 2 Manner of stacking of treated bales during the curing period of 21 days



NOTATIONS: T= TOP, M = MIDLE, B = BOTTOM BALES AS PLACED IN BED OF THREE BALES DURING REATMENT

*SAMPLE BALES SELECTED FOR EVALUATION OF CHANGEG IN THEIR NUTRITIONAL VALUE AFTER CURING was used as a main liquid supply line and provided with elbows and T-joints for mounting of the lateral pipes equipped with a number of emitters. The second unit consisted of a bale holder with three detachable components; a steel frame, supporting stand and strainer. A total of 45 bales were treated for each stack (**Fig. 2**). The first layer of each stack consisted of three rows of bales placed side by side with their lengths in the direction of the stack length. Each row had three bales. Nine bales were used in the first, third and fifth layers, while eight bales were used in second and fourth layers for obtaining the best possible binding of the stack. In the first stack, the bales with low MC were kept at the bottom layer according to assumption that the free water would run off from the upper layer of the stack due to squeezing action caused by the weight of bales. This water would be absorbed by the straw bales in the bottom layers and would increase its moisture content. Similarly, the bales with high MC were kept at the core of the stack according to assumption that a part of moisture would migrate from the core of the stack towards its periphery under the effect of thermal gradients that would developed due to daily variation in ambient temperature. Moreover, the moisture would also accumulate at the bottom sheet, which would be absorbed by the straw bales located at the periphery of the stack.

In the second stack, the stacking of the bales was done according to suggestions made by Bamaga (1996), in which the migration of water vapour occurred from the core and bottom portions of the stack towards the periphery through the hollow space between bales. This process resulted in accumulation of moisture near to the stack walls resulting an increase in MC of bales located at the periphery. Therefore, in this method the stacking was done by placing the bales with high moisture content at the bottom and in the core of stack. The bales with medium moisture content were placed at the periphery of the stack, whereas bales with lowest MC were kept at the top layers. At the end of the curing period of 21 days, the stack was opened for examination and further analysis of nutritional aspects of paddy straw. Bales were removed one by one and weighed to determine the variation in MC during the curing period.

From each stack, six bales, two each representing top middle and bottom levels were selected for evaluation of changes in nutritional values of straw. The moisture migration inside the first and second stacks during the curing period took place towards the outer and top surfaces of the stack. Moisture content was determined by adopting ASAE Standard S352.1 for forages (ASAE Standards, 1995). The dry matter digestibility was determined by the technique proposed by Mehrez and Orskov (1977). The CP content, total nitrogen was determined first by the method described by AOAC (1975). The ammonical nitrogen in a sample was determined according to the micro-diffusion technique of Conway (1957).

A total of 90 bales with a weight about 0.8 tonne were used for making two stacks, and all the bales were weighed and assigned a number for identification before the treatment. The whole treatment was carried out in two stages. In the first stage, bale was treated with urea solution with the best level of operating parameters (Q = 1,000 cc/min, As = 1,125 cc/kg DM and bed depth = 1.08 m) and stacked and sealed (with polythene sheets) by adopting the "Norwegian Method". DMD coefficient parameter was analysed in two factor randomized block design by taking the location of samples in a bale. However, the results of CP content and AN content were analysed by applying ANOVA technique in a two way classification design by taking individual bales as a variable. The CD value for each significant factor was determined to compare the means of each factor at 5 % level of significance. The C.V. of each parameter was also determined to observe the extent of variability among the observations.

Results and Discussions

The moisture content of samples taken from the side of the bale compared to the core of the bale should significantly increase (P = 0.05). The average of moisture content of the core and side samples varied between 33.5 to 35.0 % and 39.3 to 38.0 % in the first and second stack. It is the important to note that arrangement of the emitter on applicator is such that it would apply more water in the core of bale than its sides. Therefore, the higher moisture content could be expected in the core of the bale immediately after treatment. However, the moisture migration within the bale during curing period clearly shows a reduction in the moisture content in the core of the bale in comparison to its sides. It could, therefore, be postulated that for equalization of moisture content during curing period the bales with high moisture content should be placed in the centre of the stack while the bales of lower moisture content could be kept at the periphery of the stack.

The CP content of the stacks was comparable (P = 0.05) among bales as well as within a bale, i.e. side and core of a bale in the both stacks (Table 1). The average crude protein content of straw varied between 14.2 to 14.5 %, and CP content increased by 9.9 to 10.2 percentage units in comparison to untreated straw (4.24 %).

The ammonical nitrogen between stacks varied non-significantly (0.89 and 0.85 %). The AN content of sides samples of first and second stacks were 0.925 % and 0.997 %, which was higher than that of core samples obtained as 0.800 and 0.782 %, respectively. The AN content of the core and sides of a bale of first stack differed non-significantly (P 0.05). The AN content of treated over untreated straw (0.049 %) was around 0.849 and 0.803 percent units in first and second stacks, respectively.

The DMD of sides was higher than that of core in both the stacks (**Table 1**). The average DMD of treated straw in both the stacks was comparable. The DMD showed an average increase of about 12.5 % units and 12.8 % units in DMD coefficient over the control (41.07 %) in first and second stacks, respectively.

Conclusions

The best arrangement of stacking would be the one in which the bales with maximum moisture content, minimum moisture content and bales with moisture content within two limits are placed at the core and bottom, top layers(s) and periphery of the stack, respectively. There is no significant difference in the nutritional values of straw in first and second manner of stacking based on the analysis of 6 sample bales.

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Table 1 Variation of different parameters (% DWB) in the First and Second stack after 21 days

Parameters	Between Stack	Between bales						Mean	Location		SEM
		1	2	3	4	5	6		Side	Core	
Moisture content	1	47.7	39.3	39.3	33.6	29.8	28.9	36.4	39.3	33.5	2.9
	2	40.6	39.6	38.1	37.6	32.0	31.2	35.5	38.0	35.0	1.6
CP content	1	17.5	14.9	14.5	13.5	13.0	13.5	14.5	15.1	13.9	-
	2	14.8	14.9	14.2	14.1	14.1	13.2	14.2	14.5	13.9	-
AN content	1	1.5	1.0	1.0	0.8	0.6	0.5	0.9	1.0	0.8	0.1
	2	1.0	1.0	0.9	0.9	0.6	0.5	0.9	0.9	0.8	0.1
DMD coefficient	1	54.5	59.1	53.0	51.7	48.5	52.5	53.5	55.8	51.3	1.5
	2	58.1	55.4	56.8	56.2	48.9	47.3	53.8	56.1	51.5	0.8

Note: CP content (control) = 4.24 %, AN content (control) = 0.049 % and DMD coefficient (control) = 41.02 %

Pneumatic Wheeled Multipurpose Tool Frame for Efficient Utilization of Draught Animal Power




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Abstract

Despite increasing trends towards mechanization in India, the contribution of draught animals in agricultural development cannot be ignored. In general all aspects of wheeled tool carrier design have to be based on compromises between the need for high versatility and the need for low cost and simplicity. To make best use of draught animal power and to increase the working efficiency, an animal drawn pneumatic wheeled multipurpose tool frame (MPT) was developed. The tool frame consisted of a rectangular shaped frame, pneumatic wheels with screw jacks, and an operator's seat, handle and beam. Different implements could be attached to the tool frame with quick fixing type U clamps. The present multipurpose tool frame permitted farmers to carryout their basic operations of tillage, seeding, fertilization and weeding in a timely and precise manner to increase productivity and, as bonus, ccould be used as a cart to provide transportation. Performance of the MPT was compared with the traditional practices followed by the farmers for tillage and sowing. The draught requirement of the MPT was well within the draught capacity of animals as it varied in the range of 500-550 N in tillage and 440-480 N in sowing. About 240 to 325 percent increase in command area was observed in tillage and sowing operation by MPT over the traditional implement.

Introduction

Agriculture in India is one of the most prominent sectors in its economy. Agriculture and allied sectors like forestry, logging and fishing account for 16.6 % of the GDP in 2007 and employ 60 % of the country's population. It accounts for 8.56 % of India's exports. About 43 % of India's geographical area is used for agricultural activity. Despite a steady decline of its share in the GDP, agriculture is still the largest economic sector and plays a significant role in the overall socio-economic development of India. The monsoons play a critical role in the Indian subcontinent's agriculture in determining whether the harvest will be bountiful, average, or poor in any given year. The entire rainfall in the sub-continent is concentrated in the few monsoon months (Anonymous, 2009).

The contribution of the agriculture sector has gone down in India GDP in the last few years but, in spite of this, the sector remains the largest economic sector in India. Continued land fragmentation has left Indian agriculture with a large number of small farmers (79 % of the total number of farmers in India). It is not feasible to mechanize small land holdings, hence, small farmers continue to depend on traditional methods of operations (Anonymous, 2003).

Draught Animal Power (DAP), by and large, continues to be a major power source for farm operations. Most farmers in Rajasthan use very simple animal drawn traditional im-

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plements, e.g. Wooden (indigenous) plough, blade harrow and a two or three row seed drill with hand metering of the seeds. These implements are either pulled by a pair of bullocks or a single camel. The size and shape of these implements often vary from region to region depending upon such things as soil type, cultural practices and breed of the animal. But there is no substantial difference among implements meant for similar operations.

Most of the indigenous animal drawn implements used do not make the best use of available energy because of their low draught utilization (Goe and McDowell, 1980 and Singh *et al.*, 1987). At the same time the work is inefficient and involves considerable strain and drudgery for the operator and animals (Bansal and Thierstem, 1982). Another major drawback is that each implement has its own frame and beam in addition to its soil engaging part, incurring additional cost. This cost could be reduced and problems associated with traditional implements could be solved to some extent by introducing a machine/frame to which different soil working tools could be attached as per the requirement. The animal drawn tool carriers/frames are designed to provide the advantage of improved implements to animal power based farming.

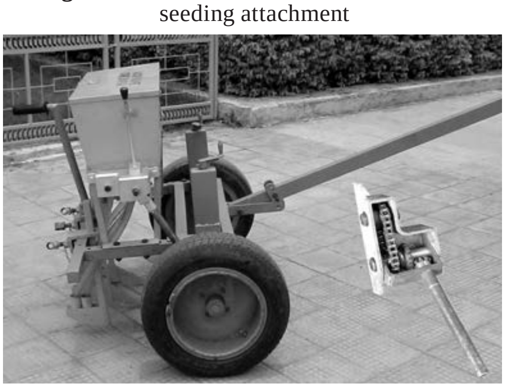
This type of machine popularly known as multipurpose tool frame (MPT) has been defined by various authors (ICRISAT, 1983; Bansal and Thierstein, 1982; Lal and Nunes, 1982 and Garg and Devnani, 1992) as a machine designed to perform various agricultural operations and transportation consisting of a rigid frame supported by two wheels with a processes of attaching implements behind the chassis and mechanism to raise and lower them, and a beam connecting the frame to the yoke of the animals.

The specific advantage of MPT over traditional implements are time saving, the efficient use of animal power, avoiding the necessity to buy many implements and comfort of the seat for the operator (Sims, 1985). The present multipurpose machine permits farmers to carry-out their basic operations of tillage, planting, fertilization and weeding in a timely and precise manner to increase productivity and, as bonus, can be used as a cart to provide transportation (ICRISAT, 1981).

On the basis of performance of various multipurpose tool frames, a frame with steel wheels was developed by CIAE, Bhopal (Garg and Devnani, 1992). The CIAE tool frame was tested in the field conditions and it was found that steel wheels were more prone to sinkage in sandy and sandy loam soils thereby increasing the draught requirement (Anonymous, 2004). To make best use of available draught animal power and to increase the working efficiency, a pneumatic wheeled animal drawn multipurpose tool frame (MPT) was developed and performance was evaluated at a farmer's field in sandy and sandy loam soils.

Fig. 1 Pneumatic wheeled MPT frame with tillage attachment

Fig. 2 Pneumatic wheeled MPT frame with seeding attachment



Materials and Methods

The developed tool frame consisted of a rectangular shaped main frame made out of MS square section, screw jacks, two pneumatic wheels and a hitch beam (**Fig. 1**). The main frame was mounted on screw jacks to vary the height of the frame from the ground. Two automobile discarded tyres of 5.65-12 size with specially designed and developed rims were mounted on the axels of the screw jack mechanism. The developed rims were cheaper and light in weight as compared to traditional automobile rims. Different implements can be attached to the tool frame with quick fixing type 'U' clamps. At the front side of the frame a bracket was provided for hitching the tool frame to the yoke of animals through a beam. An arrangement was provided to vary the hitch angle. The hitch angle could also be varied by adjusting the height of tool frame with respect to ground with screw jacks. An operator seat was provided which could be fixed on the frame while performing tillage operations. The drudgery to the operator was reduced as he rode on the frame during tillage operations.

The seat was replaced with a seed cum fertilizer box with a metering mechanism for sowing. Fluted rollers were provided for metering of seeds and fertilizer. The drive to the seed and fertilizer metering mechanism was through a pneumatic transport wheel by a set of bevel gears and a telescopic shaft (**Fig. 2**). As the tool frame was lowered or raised with respect to ground surface to increase or decrease the depth of operation, the length of the shaft was automatically adjusted due to telescopic arrangement. To supply or cut off the rotational power of the ground wheel to metering mechanism a small gear box consisting of a fixed and a sliding bevel gear was provided at the side of the seed box. A lever was provided for engaging and disengaging the bevel gears. A handle was provided to guide the MPT frame. A platform could be fitted to make the tool frame into a cart.

The multipurpose tool frame with pneumatic wheels with the two attachments, namely cultivator tynes and seed cum fertilizer drill, was evaluated for its performance in sandy and sandy loam soils at a farmer's field (**Figs. 3** and **4**). The field performance of the pneumatic wheeled tool frame was evaluated on the basis of area covered per unit time and draught requirement. Performance of the pneumatic wheeled multipurpose tool frame with different attachments was compared with the indigenous plough used by the farmers for tillage and sowing.

Results and Discussion

The pneumatic wheeled MPT frame was operated with different attachments and its field performance was evaluated and compared with the indigenous plough. The implements were tested in different soil conditions and crops and the range of effective field capacity and draught requirement have been discussed in the results. Draught requirements and effective field capacity of different implements are presented in **Table 1**. The maximum draught was observed in tillage operation as compared to sowing with the tested implements. This may be due to the high soil resistance in tillage operation. The draught requirement of the pneumatic wheel MPT frame and indigenous plough was almost in the same range of 440-480 N in sowing operation while, in tillage operation, it was 18-20 percent less with MPT frame as compared to the indigenous plough.

Table 1 Comparative performance of implements in tillage and sowing

Performance Parameters	Tillage		Sowing	
	Indigenous Plough	Pneumatic wheeled MPT frame	Indigenous Plough	Pneumatic wheeled MPT frame
Effective field capacity, ha h^{-1}	0.04-0.05	0.16-0.20	0.06-0.07	0.21-0.25
Draught, N	600-650	500-550	450-480	440-480
Area commanded in 8 hrs of effective Working, ha	0.32-0.40	1.28-1.60	0.48-0.56	1.68-2.00
Man days required per ha	2.5-3.0	0.6-0.8	1.8-2.0	0.5-0.6

It is evident from the Table that the field capacity of the pneumatic wheeled MPT frame with tillage attachment increased substantially (0.16-0.20 ha h^{-1}) as compared to the traditional method of tillage (0.04 to 0.05 ha h^{-1}). Similar findings were reported by Bansal and Srivastava (1981), Singh *et al.* (1987) and Anonymous (2002, 2006 and 2009).

The increased efficiency with the MPT frame may be due to the increased working width. The other factor contributing to this is that, when operations are done using the MPT frame the implement is held rigidly, thus, there is no change in the lateral position of the implement with respect to the direction of travel.

The field capacity of pneumatic wheeled MPT with sowing attachment was also very high (0.21-0.25 ha h^{-1}) as compared to the traditional method of sowing, i.e. pora method (0.06-0.07 ha h^{-1}). This confirms the findings of Singh *et al.* (1987). Further, the use of the sowing attachment with the MPT frame was found to meter the seeds and fertilizer very precisely as compared to indigenous method of sowing, which, in turn, reduces the cost of cultivation. Further, the seed and fertilizer were placed at the desired depth separately with the MPT, whereas, in case of the traditional method, farmers usually mixed the seed and fertilizer. It was also observed that the implement could be adjusted accurately to achieve the desired soil working depth and row spacing with the MPT frame. A considerable savings in labour was observed with the use of the pneumatic wheel MPT both in tillage and sowing operations.

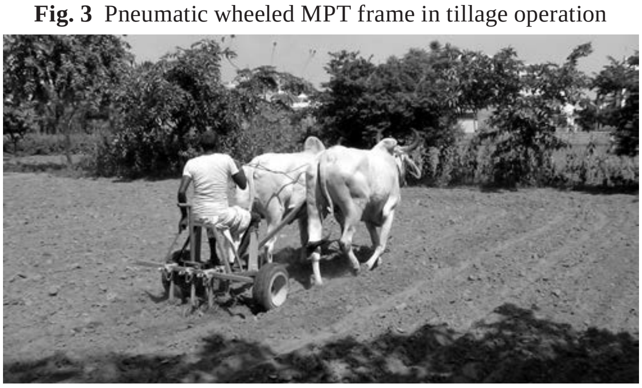


Fig. 3 Pneumatic wheeled MPT frame in tillage operation

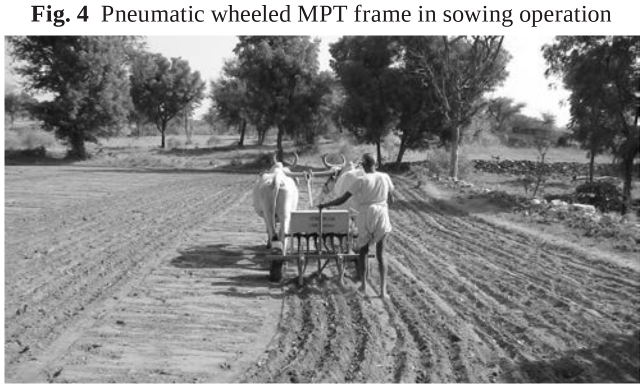


Fig. 4 Pneumatic wheeled MPT frame in sowing operation

Conclusions

1. The field performance of the pneumatic wheel MPT with different attachments was very encouraging in terms of labour saving, timeliness and precision of the operation as compared to the indigenous plough.
2. Animal power can be utilised efficiently with the use of the multipurpose tool frame for different farm operations as compared to the indigenous plough.

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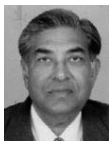
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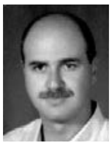
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