International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.40, No.3, SUMMER 2009

FARM MACHINERY INDUSTRIAL RESEARCH CORP.

International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.40, No.3, SUMMER 2009

Edited by

YOSHISUKE KISHIDA

Published quarterly by

Farm Machinery Industrial Research Corp.

in cooperation with

The Shin-Norinsha Co., Ltd.

and

The International Farm Mechanization Research Service

TOKYO

EDITORIAL STAFF
(Tel.+81-(0)3-3291-5718)
Yoshisuke Kishida, Chief Editor
Masako Terauchi, Managing Editor
Zachary A. Henry, Editorial Consultant

ADVERTISING
(Tel.+81-(0)3-3291-3672)
Yoshito Nakajima, Manager (Head Office)
Advertising Rate: 300 thousand yen per page

CIRCULATION
(Tel.+81-(0)3-3291-5718)
(Fax.+81-(0)3-3291-5717)
Editorial, Advertising and Circulation Headquarters
2-7-22, Kanda Nishikicho, Chiyoda-ku, Tokyo 101-0054, Japan
URL: http://www.shin-norin.co.jp
E-Mail: sinnorin@blue.ocn.ne.jp

Printed in Japan

This is the 140th issue since its maiden isue in the Spring of 1971

EDITORIAL

Global recession has finally started to converge due to the persistent effort of developed countries. Despite the depression, China still shows tremendous economic growth. It may not be an exaggeration to say that China is leading the world economy. This year, they have reached the world's top annual production of cars. With respect to agricultural mechanization, the pace of progress in China is outstanding as compared to other countries. The government of China has speculated huge amounts of money for agricultural mechanization to bridge the gap between cities and rural areas. The grant money used has totaled more than three hundred billion Japanese Yen every year. Agricultural mechanization in China is in a highly active situation. Once being a less industrialized country, China is now becoming a very good example of a country growing efficiently for agricultural mechanization. I hope that all the developing countries grow like China; however, there is a wide gap between regions. Agricultural mechanization in Africa is not going well at all. I have in mind that it is the next task for Africa to energize the agricultural mechanization.

Agricultural mechanization has been changing dramatically with the great growth of communication technology such as that provided by the computer and the internet. Also, science and technology, like deciphering the mendelian factor, has grown to make a revolutionary change in agriculture. It is no exaggeration to say that the whole system of agricultural mechanization has come to a point to make such a change. It is anticipated that the new science and technology will make a significant contribution for agriculture at a frantic pace. However, recent events in the world might not permit that. Terror attacks in places such as Afghanistan and Iraq are not likely to stop anytime soon. There are still numbers of battles breaking out in many regions.

Humans today have the ability to utilize enormous powers, unthinkable from the past, like nuclear bombs or the gigantic information handling capability of the computer. It is now important to address the question of how to control these tremendous powers. A mistake related to improper usage would invite catastrophe to the world.

Humans are born within a vital system and must coexist with it in the future. It is in question now how we can be harmonized with the system. Agricultural mechanization is one of the most important ways to achieve the goal. We must have our sights set on a new understanding of what it means to be human while promoting agricultural mechanization. People have been talking about the environment during recent years. However, the whole picture hasn't yet been revealed. We must all match wits with agricultural mechanization as we use our abilities and available power to improve our economy and maintain a safe environment.

Yoshisuke Kishida
Chief Editor

October, 2009

CONTENTS

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

Vol.40, No.3, October 2009

Parasol Sprayer for Efficient Chemical Application in Dwarf and Semi Dwarf Mango Orchards

by

C. Ramana
Associate Professor & Head
Department of Agricultural Engineering
Agricultural College
Angrau-M.C. Farm (post)
Nandyal-518502
INDIA
ramana1963@rediffmail.com

D. Manohar Jesudas
Professor
Department of Farm Machinery
Agril. Engineering College &
Research Institute, Tnau
Coimbatore-641003
INDIA

Abstract

A parasol sprayer for spraying mango orchard was developed based on physiological parameter of the mango tree and characteristics of hydraulic nozzles. Field trials have shown that the maximum deposition on the upper side of the leaf was 1,211.12 ng cm^{-2} on surface layers of the upper segment. Minimum deposition of 489.82 ng cm^{-2} was on the central portion of lower segment. Deposition on the bottom side of the leaf was around 1/3 of deposit on the upper side of leaf. The maximum ground deposit (186 ng cm^{-2}) was observed between the trees along the row. The deposition between rows was minimum (28 ng cm^{-2}). The capacity of the sprayer was also measured and the economics of operation was calculated. The parasol sprayer can cover 0.5 ha h^{-1} and resulted in savings of 90 % in time and 87 % in labour. The cost of operation was Rs. 435 ha^{-1}, which gave a saving of Rs. 381 ha^{-1} compared to conventional spraying.

Introduction

India is the second largest producer of fruits and also leads the world in production of mango, banana, sapouta and acid lime. In commercial horticulture, it is essential to protect the orchard from pest and disease and reduce the number of times with expensive chemicals to maintain the quality and meet the demands of the export market. Much efficient application of machinery for field crops is available, but none are useful for orchard spraying. The majority of the Indian farmers are still dependent on manual sprayers (foot operated and rocking arm sprayer with hand gun sprays) for pesticide application in orchards. These conventional sprayers (hand guns) loose between 25 and 50 % of the product (Derksen *et al.*, 1999) and chemical contamination on operator is very high (Lee and Yang, 1991).

Constraints like shortage of the suitable land, high management cost, restriction of water use, labour problems and need of early returns on investment necessitated the concept of high density orchards and have become extremely significant. The availability of a *dwarf* or *semi-dwarf plants* is the first and foremost pre-requisite for establishing any high density orchard (Goswami *et al.*, 2001). One of the major difficulties in these dwarf tree orchards is the chemical treatment of inner zones, protected by the dense foliage. Keeping the dense foliage in view, air assistance was introduced for better penetration. However, an air assisted sprayer produced the greatest air borne drift and ground deposit. These air borne, highly active chemicals caused adverse effect on the non-target crops and to the ecosystem (McFadden-Smith *et al.*, 1993 and De Jang *et al.*, 1985). In addition, the drift would be further enhanced due to spray sourced from a height in orchards (Fenske, 1990). In this context, to cater the mechanization needs of Indian tropical and subtropical fruit orchards and to suit socio-economic conditions of the farmer, an investigation was undertaken to develop a tractor operated dwarf tree orchard spraying system (Parasol spraying) by incorporating hooded spraying and tunnel spraying concepts.

Concept of Parasol Sprayer and Its Construction

Parasol spraying is a new concept for application of plant protection chemicals on dwarf and semi dwarf trees as illustrated in **Fig. 1**. This technique that aims at encircling the tree canopy with hood and spraying all around tree is highly suitable for the mango plantation (under high density planting) and it can be conveniently adopted for other orchards under high density planting. By providing a parasol around the spray boom it is possible to reduce the side drift from application area and hence reduce pollution of environment and also increases operator safety by reducing operator exposure to the spray chemical.

Functional Aspects of Parasol Sprayer

Geometry of Parasol with Respect to Canopy and Plant Spacing

It is very important to run the sprayer very close to the tree so that spray fully covers the tree and penetrates into the canopy (Cross, 1991), the height and spread of trees obtained from a field survey was used to design height and width of the parasol. The height of the sprayer was 4.6 m, to accommodate the tree up to a height of 3.75 to 4 m. The height of the structure could be adjusted for about 0.25 m with the help of the hydraulic lift of the tractor. The inner width of the parasol structure was 4.5 m so that a tree spread up to 3.5 m could be accommodated with 0.5 m side clearance. In order to evaluate stress on the frame and its safe limits of deflection, the frame structure was analysed using the structural analysis package (ANSYS).

Optimum Width of Hood for Minimum Drift and Operator Safety

The width the hood was optimized at 1.5 m to reduce the drift by considering the diameter of spray hitting the canopy when traveling with desired clearance (0.5 m) between nozzle and canopy. The parasol width fully covered the spraying zone so that re-bounded spray droplets were directed back towards the canopy.

Nozzle Selection

Different types of commercial hydraulic nozzles available for orchard spraying were considered for detailed investigation of nozzle characteristics with specific emphasis on spray angle (patternator studies), droplet size (VMD), penetration (artificial canopy studies) and drift (controlled room studies). The current nozzle that was best among the tested orchard nozzles was selected for use in the prototype parasol sprayer. To cover the entire canopy from all the sides, six nozzles were used with proper tubing.

Size of Sprayer Tank and Pump

The tank was designed to cover 100 trees in one filling. The pump was designed to supply 8 nozzles of 2.2 L min^{-1} discharge at 786 kPa. The HTP (Horizontal Triplex Pump) with free discharge capacity of 36 litres per minute was selected. The mounting and drive arrangement from PTO (Power Take Off) for pump was at the rear of the tractor.

Power Requirement and Drive Arrangement for Pump

Power requirement of the spray pump was calculated by a formula suggested by FAO 112/2 (1995).

Power requirement = [Output volume (lpm) × Pressure (kPa) × 0.746] / [44,800 × Pump efficiency] = [8 × 22 × 784 × 0.746] / [44,800 × 0.5] = 0.45 kW

The power requirement of 0.45 kW was well within the tractor power.

Location of Controls

The control panel was mounted within the hand-reach of the operator for controlling spraying and also for control the filling, agitation of the fluid tank.

Materials and Methods

Sampling Spray Deposition

Technique outlined by Raghupathi & Dhamu (2001) was used to evaluate spray deposition. The evaluation was done by spraying a solution of methelene blue formulated by desolving 0.75 g of methelene blue per litre of water. The spray was absorbed on filter paper targets of 40 × 40 mm size. The target paper was washed in methanol and the wash solution was made up to 10 ml. The optical density of this solution was correlated with Systronics UV-VIS spectrophotometer-108 to the quantify spray deposition.

Field Evaluation of Performance of Prototype Parasol Sprayer

The prototype parasol sprayer was evaluated to test the field performance in terms of area covered and deposition on mango orchard with semi dwarf trees. The trees were of age groups varying from 5 to 20 years. The trees were spaced at 6 ×

Fig. 1 Concept of parasol spraying

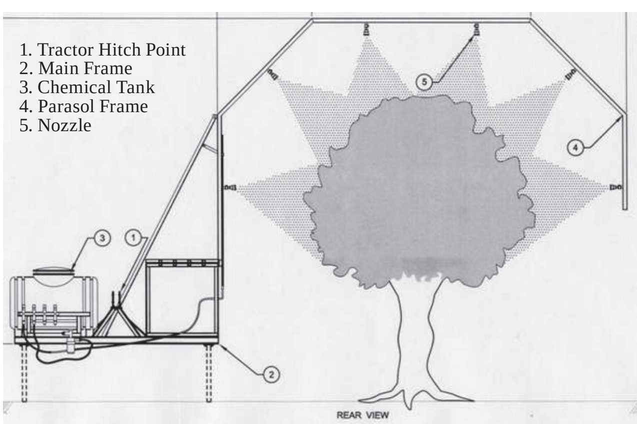
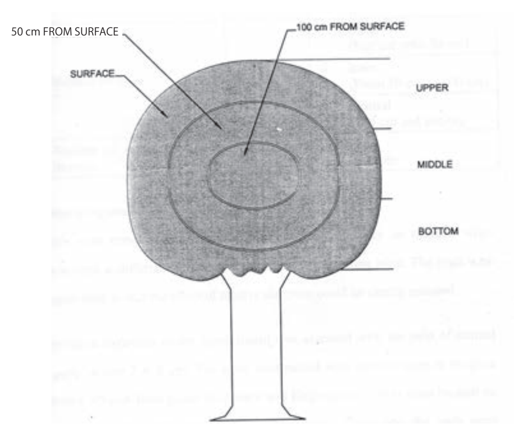


Fig. 2 Different zones selected for spray deposition studies



8 m. The prototype had six current nozzles and operated at 784 kPa.

Measurement of Deposition in Orchard

The prototype parasol sprayer was tested in the mango orchard under still air conditions. The day temperature was 30 °C with clear sky. The forward speed was 1 kmph. To assess the deposition on the canopy sampling locations suggested by various authors, the tree canopy was divided into different zones as illustrated in the **Fig. 2**. Deposition was measured at each zone by stapling 40 × 40 mm filter papers to both upper and lower sides of the leaves. Replicate samples were collected at each location on three trees. The ground deposit was also measured by keeping the filter paper samples below the tree canopy in between trees and rows of plants (Whiteney *et al.*, 1989). The samples were analysed by the following standard procedure.

Results and Discussion

Determination of Field Coverage with Prototype Sprayer

The field coverage was evaluated by spraying water. The forward speed was calculated as 1 kmph for application rate about 4 L tree^{-1} by six nozzles at 784 kPa and discharge rate of 12.6 L min^{-1}. Time taken for the tractor to spray the selected test run was calculated. The theoretical time for covering 50 m was 3 min. However, actual time taken was longer since the tractor was slowed for shut off valve operation and for alignment of parasol with the tree canopy. From the above observations, time taken for spraying on an orchard with trees of similar geometry and 200 m row length was calculated as 18 min. Considering other actual time losses like tank filling, turning losses, the field efficiency was calculated as 50 %. The field coverage under large scale spraying was estimated to be 0.5 ha hr^{-1}.

Field Performance of Prototype Parasol Sprayer

The prototype parasol sprayer (**Fig. 4**) was evaluated for spraying mango in comparison with conventional foot operated stirrup sprayer. RNAM test procedure was used as the standard report format for evaluating the sprayer (**Annex 1**). The field trial results clearly indicated that the cost of operation of the parasol sprayer was less by Rs.381 ha^{-1}, as compared to conventional method of spraying with the foot operated stirrup pump (with hand gun). The parasol sprayer resulted in 87 % saving in labor and 90 % saving in time when compared to the conventional system. Though the field efficiency of the parasol sprayer was 50 %, the above factors were satisfactory and were in conformation with Molto *et al.* (2001).

Spray Deposition Studies on Mango Tree Using Prototype Parasol Spraying

The deposition on different segments of canopy was estimated by using the dye technique (750 µg ml^{-1}). The sampling was done for the upper, middle and lower segments of tree. Three trees along a single row were selected and each tree was divided into upper, middle and lower segment. In order to quantify the penetration into deeper layers the sampling was done at surface (outer), 50 cm from surface (inner), 1 m from surface (central) as shown in **Fig. 2** Results of the field trials obtained by averaging the replicated readings are shown in **Table 2**.

The upper segment deposition values showed that there was no significant difference between outer layers and central layers. The high level of deposition, even at interior areas of trees, was primarily due to the upper regions receiving the spray both from nozzles located at sides and top of the parasol boom. Deposition patterns in middle layers showed that surface cells get 1,021.06 ng cm^{-2} while the deposition reduced to 872.5 ng cm^{-2} and 609.25 ng cm^{-2} as the canopy depth increased. The results coincided with Derksen *et al.* (1999).

The least amount of deposition was in the lower segments and deposition also decreased as the can-

Fig. 3 Ground deposit pattern

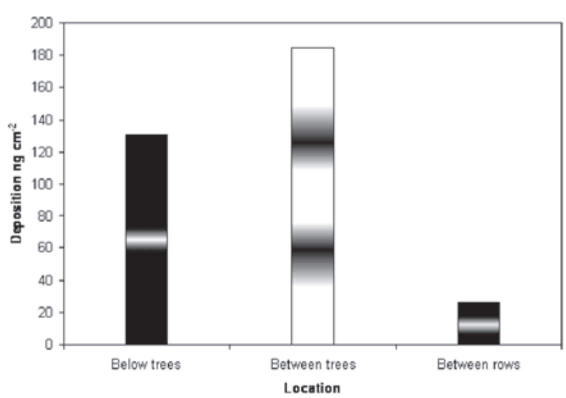


Fig. 4 Prototype parasol sprayer working in dwarf tree mango orchareds

Annex 1 RNAM – field performance evaluation

Particulars			Trial I	Trial II	Trial III
Date of test					
A	Test condition				
	a.	Field condition			
	i.	Location	Horticultural College and Research Institute,TNAU-Coimbatore		
	ii.	Length, m	200	200	200
	iii	Width, m	8	8	8
	iv	Area of field, m^2	1,600	1,600	1,600
	b.	Condition of crop			
	I	Name of crop	Mango		
	ii	Variety	Baneshan		
	iii	Row spacing, m	8	8	8
	iv	On the row spacing, m	5	5	5
	v	State of growth	Before flowering		
	vi	Height of crop	3.25	3.05	3.10
	c.	Source of power			
	i	Type	Tractor		
	ii	Make	Ford		
	iii	Model	3,100	3,100	3,100
	iv	Rated engine horse power, hp	47.5	47.5	47.5
	v	Power transmission	PTO		
	d.	Condition of operator			
	i	Skill of operator	Good		
	ii	Wage of operator, Rs h^{-1}	15	15	15
	e.	Ambient condition			
	i	Temperature, °C	29	29	29
	ii	Wind velocity, kmh^{-1}	1.5	1.5	1.5
	iii	Weather	Cloudy	Clear	
	f.	Sprayer specifications			
	i.	Number of nozzles	6	6	6
	ii	Type of standard nozzle	Current nozzle		
	iii	Nozzle spacing, m	1	1	1
	iv	Tank capacity, 1	200	200	500
	g.	Condition of operation			
	i	Spray fluid discharge rate, ml min^{-1}	2,100	2,100	2,100
		Estimated application rate, lha^{-1}	1,250	1,250	1,250
	ii	Swath width of application, m	3.5 + 4.5	3.5 + 4.5	3.5 + 4.5
	iii	Height of nozzle from the canopy, m	0.5	0.5	0.5
	iv	Orientation of nozzle with vertical, degree	90	90	90
B	Field performance				
	a.	Actual operation time, min	12	12	12
	b.	Time owing to, min			
	i	Refilling of liquid chemical	5	5	5
	ii	Turning head land	2	2	2.5
	iii	Adjustment	1	1	1
	iv	Other	Nil	Nil	Nil

Particulars			Trial I	Trial II	Trial III
Date of test					
B	c.	Area of operation			
	i	Actual area covered, m^2	1,536	1,536	1,536
	ii	Effective field capacity, ha h^{-1}	0.508	0.5108	0.508
	iii	Field efficiency, %	50.8	51.6	49.9
	d.	Effective working width, m	3.0	3.0	3.00
	e.	Forward speed of operation, km h^{-1}	1.00	1.10	0.98
	f.	Wheel slip of power source, %	<10	<10	<10
	i	Number of skilled labour	one	one	one
	ii	At test man-hour	1.5	1.5	1.5
	iii	Number and total man-hour of unskilled labour	Nil	Nil	Nil
	g.	Ease of operation			
	i	Ease of manipulation of flow regulator		Good	
	ii	Ease of manipulation of cut off valve		Good	
	iii	Ease of dismantling and maintenance		Good	
	iv	Ease of refilling		Good	
	v	Ease of operation at straight traveling		Good	
	vi	Ease of turning		Good	
	vii	Safety and others		Good	
	viii	Break down, repair, replacement of parts during test		Nil	
C	Cost of operation (Appendix IV)				
	a.	Prototype parasol sprayer			
	i	Tractor hire charges, Rs ha^{-1}	400	400	400
	ii.	Fixed cost of parasol sprayer, Rs ha^{-1}	35	35	35
	iii	Total cost of operation, Rs ha^{-1}	435	435	435
	b.	Conventional method (stirrup type pump with hand gun)			
	i	Wage of labour, Rs. h^{-1}		15	
	ii	Wage of labour, Rs. ha^{-1}		600	
	iii	Field capacity, trees h^{-1}		6	
	iv	Fixed cost of sprayer, Rs. ha^{-1}		216	
	v.	Total cost of operation, Rs. ha^{-1}		816.50	
D	Comparison of economic efficacy				
	a.	Saving in cost, Rs. ha^{-1}	381	381	381
	b.	Saving in time, %	92	94	90
	c.	Saving in labour, %	87	85	86

opy depth increased. Hence, it was evident that there was considerable deposition in the middle and upper layers and the spray penetrates deep into canopy due to spray from side and top. However, the deposition reduced in lower regions.

Deposition on the bottom of the leaf was less when compared to the upper side of leaf for the different segments of tree. It varied from 28 to 74 % and most of the values were within the range of 30 to 40 %. It could be concluded that the deposition on the bottom was 1/3 of upper side of the leaf. In the upper segment there was no significant difference in the bottom side deposition for the surface and subsurface layer of canopy (Peterson and Hogmire, 1995). In the middle of segment the surface and 50 cm layer had similar deposition on bottom side while this deposition reduced at 100 cm depth. In lower segments the difference between the surface and deeper layers was less significant with reference to deposition on bottom surface of leaf. This conformed to the results of Jubb (1981) and Derksen and Berth (1994).

Estimation of Ground Deposit

The ground deposit was measured during field trials and are presented in **Fig. 3** The values represent the average of 3 replications. This clearly showed that the deposition between rows (along the path of tractor) was minimum and the deposit below the tree was five times greater than the deposit between rows. This may be due to the configuration of the parasol, which reduced the lateral drift (Peterson and Hogmire, 1994). Ade and Pezzi (2001) expressed from their studies that the losses under trees and asymmetry of deposit on outside of the canopy was very common to all tunnel spraying and hardly improvable. The maximum ground deposit was observed between the trees along the row.

Conclusions

The parasol spraying system to spray an entire canopy in a single pass was developed to reduce time for spraying and increase productivity. The prototype parasol sprayer was developed with a height of 4.5 m to accommodate trees up to a height of 3.75 to 4 m. The spread (inner width) of up to 3.5 m could be accommodated with a 0.5 m nozzle distance. The height of the structure could be adjusted by about 25 cm.

The maximum deposition on the upper side of the (on surface layer of top segment) leaf was 1,211.12 ng cm^{-2} Minimum deposit was on the central portion of the lower segment. On the middle layer, the canopy surface got 1,021.06 ng cm^{-2} while the deposition reduced to 872.5 ng cm^{-2} and 609.25 ng cm^{-2} as canopy depth increased. The least amount of deposition (489.82 ng cm^{-2}) was observed in the lower segments and deposition also decreased as the canopy depth increased.

The maximum ground deposit of 186 μg cm^{-2} was observed in between the trees along the row.

Field efficiency for the parasol sprayer was calculated as 50 %. The field coverage under large scale spraying was estimated as 0.5 ha hr^{-1}. The cost of operation of parasol sprayer was Rs. 435 ha^{-1}, which was less by Rs. 381 ha^{-1} when compared with the conventional method of spraying by hand spray gun. The parasol sprayer reduced labour requirement by 87 % and saved 90 % time compared to the conventional system.

Table 1 Details of sampling technique adopted for field trials

Locations	Details
Number of segments	i. Upper ii. Middle iii. Bottom
Number of layer	i. Outer (Surface upto 50 cm) ii. Inner (From 50 cm to 100 cm) iii. Central (100 cm and above)
Number of samples at each location	i. Top ii. Bottom

Table 2 Spray deposition on leaf surface with prototype parasol sprayer

a. Mean table for deposition (ng cm^{-2}) on upper side of leaf

Layers (L)	Segments (S)			
	S_1	S_2	S_3	L-Mean
l_1	1,182.87 a	1,001.49 a	1,077.71 a	1,087.35
l_2	1,022.17 b	872.07 b	609.45 b	834.56
l_3	982.90 b	769.78 c	489.81 c	747.50
S-Mean	1,062.65	881.11	725.66	889.80

b. Mean table for deposition (ng cm^{-2}) on bottom side of leaf

Layers (L)	Segments (S)			
	S_1	S_2	S_3	L-Mean
l_1	390.023 b	342.150 b	302.410 a	344.861
l_2	612.643 a	652.307 a	300.593 a	521.848
l_3	310.977 c	242.890 c	203.527 b	252.464
S-Mean	437.884	412.449	268.843	373.058

In a column, means followed by a common letter are not significantly different at the 5 % level.

REFERENCES

Ade, G. and F. Pezzi. 2001. Results of field tests on recycling air - as-

sisted tunnel sprayer in a peach orchard. J. Agric. Engng. Res., 80(2): 147-152.
Cross, J. V. 1991. Patternation of spray mass flux from axial fan air blast sprayers in orchards. Britch crop protection councile Monograph, 46, 15-21.
De Jange, J. O., G. Ayers, and D. Branson. 1985. Pesticide deposition patterns on garments during air blast field spraying. Home Economics Res. J. 14(2): 262-268.
Derksen, R. C. and D. I. Breth. 1994. Orchard air-Carrier sprayer application accuracy and spray coverage evaluations. Applied Engineering in Agriculture, 10(4): 463-470.
Derksen, R. C., C. V. Coffman, C. Jiang, S. W. Gulyas. 1999. Influence of hooded and air assist vineyard applications on plant and worker protection. Transactions of ASAE, Vol. 42(1): 31-36.
Fenske, R. A. 1990. Non uniform dermal deposition patterns during occupational exposure to pesticides. Archives of Environ. Contamina. and Toxicol., 19: 332-337.
Goswami, A. M., R. P. Sharma, and S. K. Saxena. 2001. High density planting in tropical subtropical fruits crops. Indian J. of Horticulture (Spl. Issue) Vol. 58(1 & 2): 23-27.
Jubb Jr., G. L. 1981. Evaluation of low volume sprayers in vineyards. Eastern Grape Growers and Winery News, 7(4): 27.
Lee, S. A. and Yang, S. C. 1991. Studies on contamination pattern, penetration of pesticides through clothing and spray operator protection. The Planter Vol. 67, No. 778, January.
McFadden-Smith, W., K. Ker, and F. Walker. 1993. Evaluation of vineyard sprayers for coverage and drift. ASAE paper No. 93-1079. St. Joseph, Mich.: ASAE.
Molto, E., B. Martin, and A. Guitierrez. 2000. Design and testing of an automatic machine for spraying at a constant distance from tree canopy. J. Agric. Engng Res, 77(4): 379-384.
Peterson, D. L. and H. W. Hogmire. 1994. Tunnel Sprayer for dwarf fruit trees. Transactions of the ASAE, 37(3) : 709-715.
Regupathy, A. and K. P. Dhamu 2001. Statistics work book for insecticide toxicology. Soft Tech. Computers, Coimbatore pp. 48-49.
Whitney, J. D., M. Salyani, D. B. Churchill, J. L. Knapp, J. O. Whiteside, and R. C. Littlle. 1989. A field investigation to examine the effects of sprayer type, ground speed and volume rate of spray deposition in florida citrus. J. Agric. Engng. Res., 42:

■■

Development of Rice Cleaner for Reduced Impurities and Losses

by
M. N. El-Awady
Professor Emerit.,
Agricultural Engineering,
Ain Shams University,
EGYPT

I. Yehia
Senior Researcher,
Agricultural Engineering,
Research Institute,
EGYPT

M. T. Ebaid
Senior Researcher,
Agricultural Engineering,
Research Institute,,
EGYPT

E. M. Arif
Senior Researcher,
Agricultural Engineering,
Research Institute,
EGYPT

Abstract

The aim of this investigation was to improve a winnowing and cleaning machine for better efficiency and reduced losses. A general theory described the impurities and losses in terms of the other efficiency factors.

Cleaning efficiency and total losses were positively affected by air speed, and sieve tilt angle, but purity was negatively affected by moisture content, and feed rate. The total losses were negatively affected by moisture content and feed rate. Purity increased when using a round-hole sieve compared with slotted sieve.

The optimum performance was at air speed of 4 m/s, moisture content of 18 %, sieve tilt-angle of 2 degree, round-shaped sieve, and feed rate of 1,200 kg/h. Purity of these conditions was 98.98 %, with total losses of 0.21 %.

Relationships describing % impurities (i) and total % losses (L) were derived into the following forms:

$i = [k - (0.2\, a + k_s\, S)]\, c^{0.5}$

$L = (k_L + 2.5\, a)\, S^{2.19} / c^2$

Symbols are as defined in the paper. "k, k; and k" take different values for round and slotted holes, as determined in the paper.

Introduction

Harvesting is a bottleneck since it can be the most labor-intensive field operation. Separation of over and under-sized particles and impurities using an oscillating screen is important. Rice is probably the most important crop in Egypt. Its area is one million feddan (0.42 Ha) and production is 2.4 million ton/year (variety of Giza 176).

An experimental winnowing machine was developed and its performance verified, such as product cleanliness and losses of separation. It was intended to fill the need for a faster and more efficient method of grain cleaning. The main target of the present experimental investigation was to separate rice grains from large amounts of chopped straw produced from threshers. The separation was made by using aeromechanical separation. Thus, it was necessary to determine the parameters affecting the separation effectiveness which led to improve the design of the locally made winnowing machines. A mathematical model was devised to describe factors affecting impurities and loss percentages.

Berlage *et al.* (1984) stated that seed crops contain weed seeds, unwanted crop seeds, broken plant parts, fungal bodies and soil particles. The function of seed conditioning or seed cleaning operations is to remove or reduce these contaminants.

Awady and El Sayed (1994a) concluded that the terminal velocity of different product components of shelled peanut can be predicted according to surface dimensions, mass and drag coefficient. The mean values of terminal velocity were 4.3, 6.5, 6.8 and 7.2 m/s for shells, unshelled, split and intact seeds respectively. The air velocity of 7.5 m/s was recommended to separate 96 % of shells with losses of 3 % of unshelled seeds. Meanwhile, at high air speed of 6 m/s, 100 shells could be separated with losses of 15, and 3 % unshelled and split seeds, respectively. At low speed of 5.3 m/s only 78 % shells could be separated with air.

Awady and El Sayed (1994b) stated that, when an air stream was used for separation of product from its associated foreign materials, a knowledge of terminal velocity of all particles is involved. For these reasons, terminal velocity has been used as an important aerodynamic characteristic of materials to applications of pneumatic conveying and separation from foreign materials.

Ebaid (1995) concluded that the highest purity of 98.8 % and lowest fan losses of 0.13 % were obtained at sieve tilt angle of 5 degrees, feeding rate of 2.2 t/h, air speed 21 m/s and 110 × 30 cm^2 sieve area. Losses behind the sieve increased from 0.11 to 0.128 % with sieve tilt angle increased from 2 to 8 degrees at a feed rate of 2.2 t/h, air speed of 21 m/s and sieve area of 110 x 20 cm^2.

Ebaid (2001) concluded that variables affecting the purity (P), fan losses (S_1) and losses behind sieve (S_2), air speed (v), diameter of sieve hole (sd), grain diameter (gd), sieve tilt-angle (θ) and sieve oscillation (n) are combined into functional relationships:

$$P = 1.37\ (v/ngd)^{0.60}\ (sd/gd)^{-0.04}\ (\theta)^{0.009}$$

$$S_1 = 1.37\ (v/ngd)^{0.26}\ (sd/gd)^{-0.03}\ (\theta)^{-0.20}$$

$$S_2 = 1.37\ (v/ngd)^{0.12}\ (sd/gd)^{-0.04}\ (\theta)^{0.06}$$

Khan *et al.* (1975) reported the development of a small oscillating rice cleaner for farm-level operation. That machine had two major moving components: a dual oscillating screen assembly and centrifugal fan.

The screens are horizontal and grain moves over the screen due to the vibrating action. Grain is fed into the screen from the hopper due to the vibrating motion of the screens. An adjustable gate of the hopper opening permits control of the feed rate. The screen oscillates 250 cycle per minute with a 2.6 cm stroke. The machine could clean one ton of grain per hour at 0.96 % grain purity. This type of machine was taken as a guide for this investigation.

The objectives of this research were to study: (1) relationships between physical and mechanical properties of rice grains on geometric selection of screens, (2) effect of air velocity on the efficiency of grain separation, (3) effect of moisture content, bulk density, and feed rate on the effectiveness of separation, and (4) general mathematical model to describe effects of design factors of shape of screen holes, sieve-lip angle, and sieve oscillation on separation effectiveness.

Materials and Methods

Machine Specifications and Description

In this study, the machine used for rice winnowing was constructed in the Agricultural Engineering Research Institute (AEnRI). The machine followed the design of Khan *et al.*, 1975. The cleaning machine consisted of frame, grain hopper, oscillating dual-screen assembly, a centrifugal blower and electric motor. The frame and grain hopper were made of sheet metal and steel sections used in the frame and legs. The eccentric and support linkages of screen assembly caused it to oscillate, moving the grain over the flat screen as shown in **Fig. 1**. During the operation, grain was loaded onto the hopper and fed into the oscillating screen through the bottom opening and regulated by the slide gate, as shown in **Fig. 1**. The upper screen separated the impurities that were bigger than the grain, and the lower screen separated those that were smaller and dust. As the grain droped from the lower screen on the wind board, the air blast separated materials lighter than the grain. Cleaned grain was then collected at the grain spout. Recycling the impurities was not usually necessary because grain loss with this machine was negligible when operated properly. The cleaner was small, light and could be accommodated in jeeps, vans, or trailers for long

Fig. 1 Cleaner machine

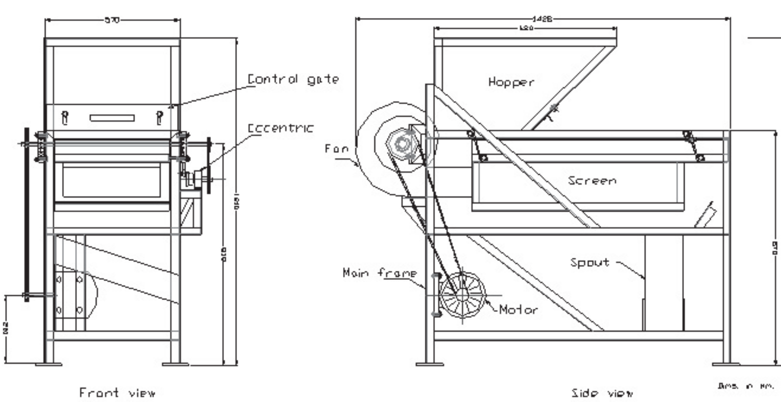


Table 1 General specifications of machine

Item	Specification
Overall length	1,428 mm
Overall width	570 mm
Overall height	1,210 mm
Power	0.3 hp electric motor
Capacity	up to 800 kg/h (rough rice)
Labor requirement	1-2 men
Construction	1 mm sheet metal and 30 × 3 mm angle iron

transport. General specifications of themachine are shown in **Table 1**.

Frame: made of angle steel sections 30 × 30 × 3 mm.

Hopper: made of sheet metal of 1 mm thickness and steel sections 30 × 30 × 3 mm. The hopper had a sliding gate that controled the feeding rate of material. The hopper was located on top of the frame, it was designed in such a way to give a suitable slope for the mixture to slide smoothly inside the machine.

Sieves: made of sheet metal of 1.5 mm thickness. They consised of upper and lower sieves and hang on four links (2 fixed rods in the front and 2 adjustable in the rear to alter the sieve tilt angle). They had two sheets, one solid under the hopper gate and the other perforated nine mm diameter hole and 8 × 25 mm (width × length) slots for separating chaff and straw from grain. The lower sieve was mounted 150 mm below and parallel to the upper screen. The lower screen had 1 mm diameter holes to remove fine impurities and dust. The proper mesh-size of the sieves was determined from physical properties of grain.

Blower fan: made of sheet metal of 1mm thickness. It consisted of six radial blades and was driven by an electric motor with V-belt and pulley. The fan discharges air blast through the sieve perforations. The air flow could be adjusted from the fan inlet openings (fan designed according to Klenin *et al*., 1985).

Electric motor: had power of 0.3 hp (0.225 kW) and speed of 1,500 r.p.m.. The power was transmitted to the moving parts of the machine by means of pulleys and belts.

Crop Properties:

Rice Giza 176 variety, moisture content of 18 %.

All treatments were replicated five times.

Maximum dimensions of rice grains were as follows:

Length (L) = 8.15 mm, Width (W) = 3.85 mm, and Thickness (T) =2.35 mm.

Table 2 shows bulk density, mass of 1000-kernels, volume, geometric diameter, arithmetic diameter, % of sphericity, external friction angle, angle of repose, and moisture content.

Where: Bd: Bulk density, g/cm^3, Km: Mass of 1000-kernels, (g), V : Volume, mm^3, Dg: Geometric diameter, mm, Da: Arithmetic diameter, mm, S : % of sphericity, %, φ,: External friction angle, degree, θ,: Angle of repose, degree, and M.C: Moisture content, %. The following relationships were used

$$V = \pi/6\ (L \times W \times T) \qquad (1)$$

$$Dg = (L \times W \times T)^{1/3} \qquad (2)$$

$$Da = (L + W + T) / 3 \qquad (3)$$

$$S = 100 \times \frac{(L \times W \times T)^{1/3}}{L} \qquad (4)$$

Calculations:

Cleaning efficiency: was calculated according to the following relation:

$$\text{Cleaning efficiency } \% = (W_{cl}/W_t) \times 100 \qquad (5)$$

Where W_{cl} is weight of cleaned grains and W_t is total weight of sample.

Total losses = (Grain lost behind the machine / Grain output) × 100............(6)

Cost analysis: The operation cost of rice-cleaner was calculated according to the following equation given by Awady, 1978 modified for electerical motor drive:

$$C=P/h(1/a+I/2+t+r)+(w.e)+m/144. \qquad (7)$$

Where:

C = hourly cost, P = price of machine, h = yearly working-hour, a = life expected of machine, I = interest rate/year, t = taxes and overhead ratio, w = power of motor in kW, e = hourly cost/kW.h, and m/144 = monthly wage ratio.

Notice that all units have to be consistent to result in "C = L.E./h".

Operating cost (L.E/ton) = Machine cost (L.E/h) / Threshing capacity (t/h)..........................(8)

Innovated method of Analysis

Both purity "P" and losses "T" were expressed as linear variants of the Different Test Conditions (DTC).

Results and Discussion

Purity Vs. Air Speed, Sieve Tilt, Moisture Content, and Shape of Screen Hole

Fig. 2 shows that purity increased by increasing air speed and sieve tilt-angle, and by decreasing moisture content. In addition, the round hole of screen gave higher purity than the slotted hole.

Average purity (P) increased about 2-4 % when air speed increased from 2 to 5 m/s for different sieve tilt-angles, moisture-contents, and shapes of screen hole.

"P" increased about 1-3.5 % when sieve tilt-angle increased from 0 to 3 degree for different air-speeds, moisture-contents, and shapes of screen hole.

"P" increased about 2 % when moisture content decreased from 12 to 24 % for different air-speeds, sieve-tilt angles, and shapes of screen hole.

"P" of round-hole screen was higher (97.11 %) than slotted hole (94.77 %) for different air speeds, sieve-tilt angles, and moisture-contents.

Losses Vs. Air Speed, Sieve Tilt-Angle, Moisture Content, and Shape of Screen Hole

Fig. 3 shows that total losses in-

Table 2 Physical and mechanical properties of rice grains (Giza 176 variety)

Bd	Km	V	Dg	Da	S	φ	θ	M.C
0.8	76.6	28.8	3.8	4.4	50.3	17.5	41	18

Fig. 2 Purity vs. air speed, sieve tilt-angle and shape of screen holes (feed rate of 1,200 kg/h)

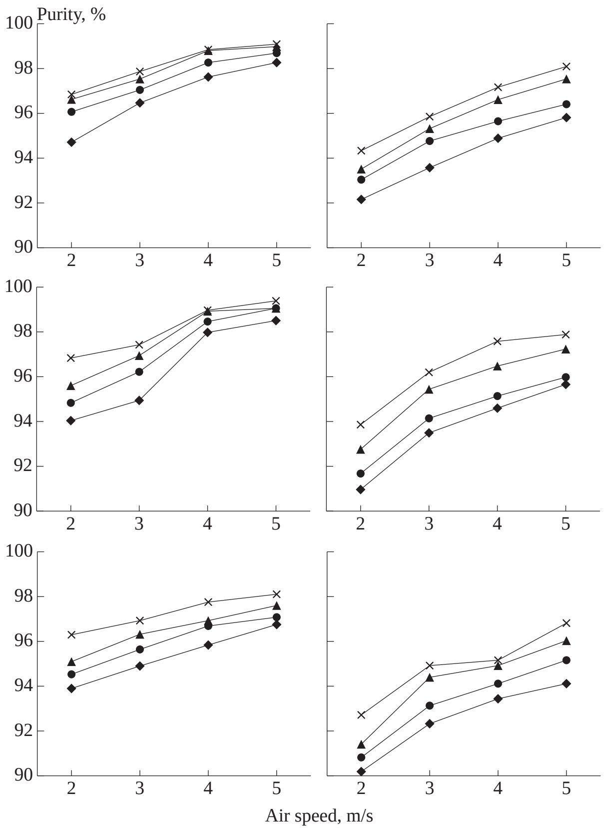


Fig. 3 Total losses vs. air speed, sieve tilt-angle and shape of screen holes (feed rate of 1,200 kg/h)

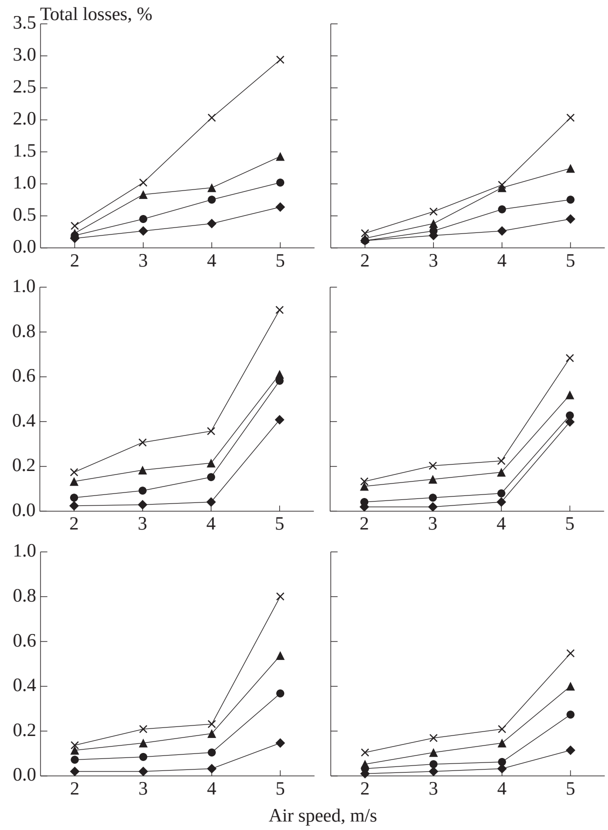


Fig. 4 "I/c$^{0.5}$" vs. "s" for different values of tilt angle "a" for round holes

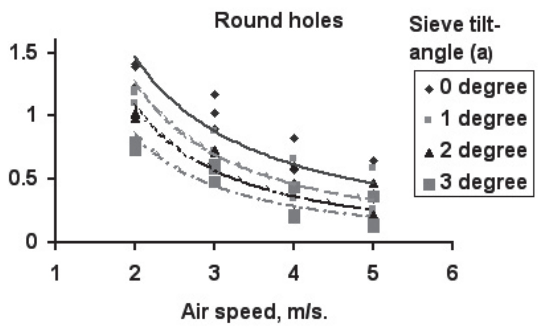


Fig. 5 Means of "I/c$^{0.5}$ + 0.20 a" vs. "s" for round holes

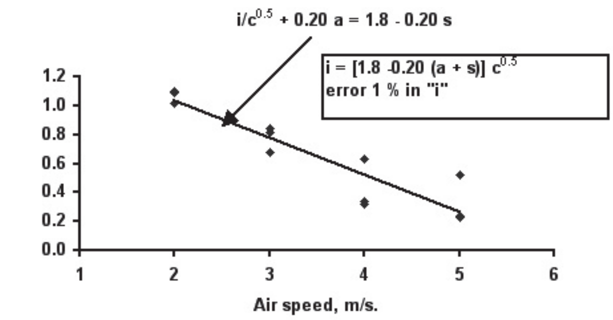


Fig. 6 Means of "I/c$^{0.5}$ + 0.20 a" vs. "s" for slotted holes

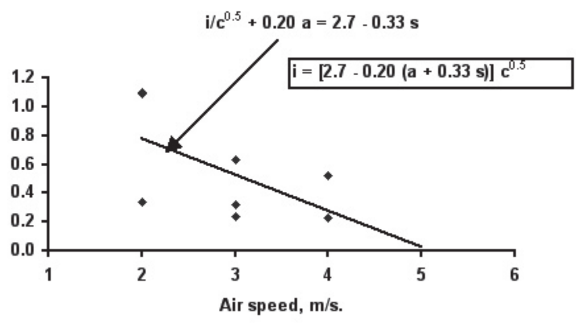


Table 3 Effect of feed rate on purity and total losses at optimum TDC

Feed rate, kg/h	Purity, %	Total losses, %
1,200	98.98	0.21
1,800	97.90	0.35
2,400	65.60	0.65
3,000	93.10	0.81

creased by increasing air speed and sieve tilt-angle, and by decreasing moisture content. In addition, the slotted screen gave higher values of total losses than round holes.

Average total losses (L) increased from 0.065 to 0.743 % by increasing air speed from 2 to 5 m/s for different conditions of the test.

"L" increased from 0.263 to 0.734 % by increasing sieve tilt-angle from 0 to 3 degree for Different Test Conditions (TDC).

"L" increased from about 0.7 to 0.2 % when moisture content decreased from 12 to 24 % for Different Test Conditions (TDC).

"L" of slotted screen were higher (0.487 %) than round hole (0.392 %) for TDC.

The optimum conditions: air speed = 4 m/s, sieve tilt-angle = 2 degree, moisture content = 18 % and round sieve-holes.

Effect of Feed Rate on Purity and Total Losses

Table 3 shows that purity decreased and total losses increased by increasing feed rate at optimum air speed, sieve tilt, moisture content and shape of screen holes.

The best feed rate for high purity and least losses was 1,200 kg/h.

Mathematical Models

Impurities % (= 100 – P %)

The data in **Figs. 2** and **3** are reduced by observing the relative values as related to the variable % moisture contents (c).

Impurities % "i" were varied with "$C^{0.5}$". When "$i/C^{0.5}$" was plotted against the air speed "S", all curves converged for different values of "c", as in **Fig. 4** for round holes. The same trend was also observed for slotted holes.

The data were reduced still further by transforming the vertical axes to means of "$i/C^{0.5} + 0.2\ a$" as seen in **Fig. 5** for round holes. They give rise to an almost-linear generalized relation describing impurities % in the form, within 1 % error in values of "i".

$i/C^{0.5} + 0.20\ a = 1.8 - 0.20\ S$

or $i = [1.8 - 0.20\ (a + S)]\ C^{0.5}$

for round holes.

The same argument holds true for slotted holes. **Fig. 6** shows a similar relation for the slotted holes:

$i = [2.7 - (0.20\ a + 0.335\ S)]\ C^{0.5}$

In general, the impurities % can be expressed for the round and slotted-holes in the following forms:

$i = [k - (0.20\ a + k_s)]\ C^{0.5}$,

with the folowing values for "k" and "k_s":

	k	K_s (sec/meter)
Round holes	1.8	0.20
Slotted holes	2.7	0.33

Total Losses % (L)

Losses % "L" were observed to vary inversely with "C^2". When "$L \times C^2$" was plotted against the air

Fig. 7 "I x c^2" vs. "s" for different values of tilt angle "a"

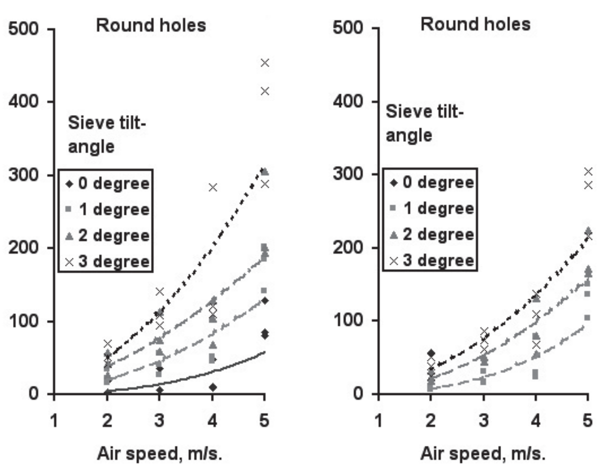


Fig. 8 "I x c^2" vs. "s" on log-log scales for different values of tilt angle "a"

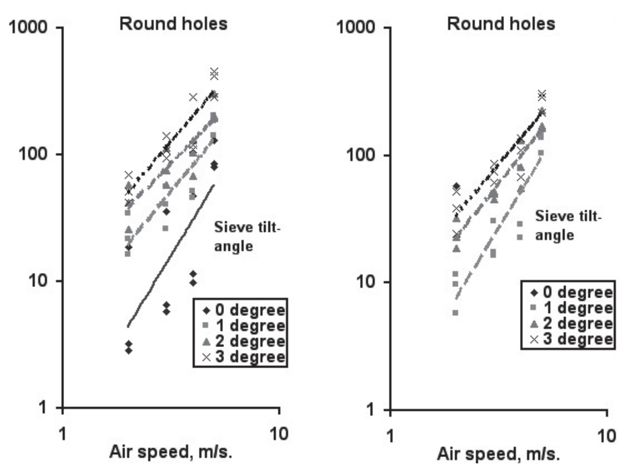
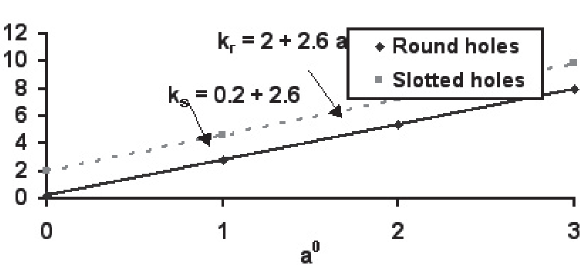


Fig. 9 "k_a" vs. "a"



speed "S", all curves converged for different values of "c", as in **Fig. 7** for round holes. The same trend was also observed for slotted holes.

The means of data were plotted on log-log scales, as shown in **Fig. 8**. They gave rise to power functions in "S" as follows:

$L \times C^2 = (k_L + 2.6\,a)\,S^{2.19}$

or $L = (k_L + 2.6\,a)\,S^{2.19} / C^2$

where k_L = 2.0 and 0.2 for round and slotted holes respectively.

$L \times C^2 = k_a\,S^{2.19}$

"k_a" was found to hold a linear relation with "a" is seen from **Fig. 9**, thus:

$L \times C^2 = (k_L + 2.6\,a)\,S^{2.19}$

or $L = (k_L + 2.6\,a)\,S^{2.19} / C^2$

where k_L = 2.0 and 0.2 for round and slotted holes

Estimating the Cost of Using the Machine

Operation cost of the machine was 2.09 L.E./h (2.6 L.E./ton), against 5 L.E./h. (5 L.E./ton) for large machine. This gave an economical benefit of 2.4 L.E./ton for the designed machine for a small-scale farming.

Conclusion

For high purity and low total losses, the following conditions are recommended for the type of machine under investigation: air speed = 4 m/s (fan speed = 700 rpm), sieve oscillation = 250 rpm), moisture content 18 %, sieve tilt-angle = 2 degree, hole screen-shape, and feed rate = 1,200 kg/h.

With the above-recommended conditions, the following optimum conditions were obtained: Purity = 98.98 % and total losses = 0.21 %.

Variables affecting the impurities (i) % and total losses (L) % were correlated by the following equations:

$i = [2.7 - (0.20\,a + 0.335\,S)]\,C^{0.5}$

$L = (k_L + 2.6\,a)\,S^{2.19} / C^2$

" k, k_s, and k_L " take the different values of the round and slotted holes, given in the paper.

REFERENCES

Awady, M. N. 1978. Engineering of tractors and agricultural machinery, Text Bk., Col. Ag., Ain Shams U., 5th Ed.: 164-167. (In Arabic.) (Updating 1998).

Awady, M. N. 1994. Agricultural machinery engineering, Text. Bk., col. Ag., Ain-shams University, : 165 p. (In Arabic).

Awady, M. N. and A. S. Sayed. 1994, Separation of peanut seeds by air stream, Misr J. of Ag. Eng., 11(1): 137-147.

Berlage, A. G., D. M. Bilsland, N. R. Brandenburg, and T. M. Cooper. 1984. Experimental indent cylinder for separating seed, Trans. of ASAE, 27(2): 358-361.

Ebaid, M. T. 1995. Optimization of air screen cleaning system for threshers, M. Sc. Th., Fac. of Ag., Ain Shams U., Egypt.: 70-75.

Ebaid, M. T. 2001. Air flow and threshing machine parameters affecting the separation process of rice crop. Ph. D. Th., Fac. of Ag., Ain Shams U., Egypt.: 116p.

Khan, A. U., B. Duff, D. O. Kuefther, and J. A. McMennamy. 1975. Small oscillating grain cleaner, Rice Machinery Development and Mechanization Research, Semi An. Prog. Rep. No. 21, IRRI, Manila, Philippines: 14-15.

Klenen, N. I., I. F. Popov, and V. A. Sukun. 1985. Agricultural Machines, Theory of Operation, Coputation of Controlling Parameters and the Conditions of Operation. Amerind Pub. Co. PVT. Ltd., New Delhi.

■■

Evaluation of a Handy Tool for Sugacane De-Trashing

by
G. Kathiresan
Professor (Agronomy),
Sugarcane Research Station,
Tamil Nadu Agricultural University,
Sirugamani-639 115,
Tamil Nadu,
INDIA

Abstract

De-trashing is the removal of dried, yellowish green, bottom leaves in the sugarcane crop. This single operation has several advantages. It reduces the pest menace like internode borer, white flies, mealy bugs, scales and pyrilla and can remove the sprouted buds in the cane stalk. Also, aeration and sanitation of the cane field can be improved and the rodent and reptile problems can be reduced. This can improve the cane yield and quality.

Earlier, labourers, particularly the women, have done de-trashing. The drudgery involved in this operation makes the labourers not come to work. There are several advantages for cane farmers to have a tool to assist with this operation, especially since there is not available labour. Hence, the tool described here (Sugarcane de-trasher - Karumpuk kathi) was designed to improve labour efficiency by decreasing drudgery. This is a tool with two knives fitted in a 'U' shape and made from mild, flat steel that moves side ways with tension. The operation is easy and there is no complex technology involved.

Introduction

Sugarcane produces a leaf along with a node every week in the growth period after tillering. The five month old cane crop has eight to ten nodes. After un-folding of the top most new leaf, it harvests photosynthesis from solar radiation for up to ten weeks. It then starts to by yellowing and drying of the margin and finally drooping down. Thereis no constructive use for the leaf after senescence, but it adheres to the cane stalk and serves as a hiding place for sucking pests.

Removal of old dried, yellowish green, bottom leaves of the sugarcane crop is called de-trashing. It recommended that this be adopted after cultivation due to the several advantages.

Existing Method and the Drawbacks

Women labourers are generally engaged for stripping the dried and old, greenish yellow leaves, which are at the bottom of the cane plant. This is time consuming and laborious without a tool. Moreover, it gives drudgery to the labourers and damages or wounds the hands because of the leaves, which have serrated margins with spines in the leaf sheath. This is another reason labourers are not coming forward for this job.

Description of the Tool

The sugar cane de-trasher has three components. Viz; 1. Two mild steel knives. 2. Mild steel flat for providing tension and 3. Handle attachment. The knives are used to detach the leaves of greenish yellow colour, dried and sprouts and side shoots. The knives are 3″ long with a 6″ stem attachment in which a ring of 6 mm mild steel rod is placed that can be moved to facilitate adjustment. The knife stems are welded with a 5″ long 12 × 5 mm mild steel flat that will give tension and enough stiffness to detach the leaves that are to be de-trashed. At the bottom of the U shaped steel flat, a 3″ long ¾″ galvanized iron pipe is attached. This provides for a convenient wooden handle. By holding the handle of the tool, the knives are placed at the top portion of the cane stalk from where de-trashing is done. Naturally, the cane leaves are arranged alternatively opposite to each other at 180 degrees. The buds are also arranged like leaves. Hence, it is easy to de-trash the older, drier and sprouted shoots at one stroke by pulling down the tool to the bottom of the cane. The cane stalks are similar in diameter, which is genetically a controllable phenomenon. After de-trashing of all leaves in a clump, the fallen leaves are also collected easily by these knives for bundling.

Results and Discussion

The tool was evaluated in sugarcane research stations located in different places of Tamil Nadu. The sugarcane genotypes which have different cane stalks were selected for evaluation of the tool. It was also evaluated in the farmer's field. The mean labour savings by the tool was 42.16 % at the Sugarcane Research Stations (**Table 1**). No noticeable difference could be observed on the quality of juice (**Table 2**). The same tool has saved up to 50.65 % labour in on-farm trails (**Table 4**). The difference in savings of labour was due to the efficiency of the labours engaged for the de-trashing operation.

The maximum cane yield recorded was 133.75 t/ha by using the tool for de-trashing in the variety CoSi 95071. The same variety registered a cane yield of 128.75 t/ha by hand de-trashing. The same trend was also observed in the variety Co 86032. This might be due to fact that the labour that did not have the tool possibly removed the dried leaves alone and did not removed the sprouted buds. Hence, the additional cane yield was attributed and reflected on the economics (**Table 3**).

Table 1 Evaluation of tool at sugarcane research stations (SRS) of tamil nadu

Locations	Variety	Type of leaf sheath attachment	Required labour for detrashing / Acre		Labour saved (%)
			By hand	By tool	
SRS, Sirugamani (Female labour)	Co 86032	Loose	16	5.0	31.40
	CoSi 95071	Clasping	20	8.0	44.44
SRS, Sirugamani (Male labour)	Co 86032	Loose	17	6.5	38.00
	CoSi 95071	Clasping	22	12.2	55.60
SRS, Cuddalore	Co 86032	Loose	16	10.0	37.50
	CoC (SC)22	Semi clasping	24	16.0	33.30
SRS, Melalathur	CoC 90063	Semi clasping	36	20.0	44.40
	CoC 90063	Semi clasping	36	17.0	52.70
				Average	42.16

Table 2 Juice quality of de-trashed cane at harvest

Quality traits (%)	Variety / De-trashed by			
	CoSi 95071		Co 86032	
	Hand	Tool	Hand	Tool
Total Solids	19.14	19.40	21.18	21.28
Sucrose	16.73	17.18	18.80	19.02
Purity	85.09	88.59	88.77	89.36
CCS	11.67	12.22	13.38	13.58

Table 3 The benefit of de-trashing of cane on yield and economics

Particulars	Co 86032 - de-trashing by			CoSi 95071- de-trashing by		
	Hand	Tool	Control	Hand	Tool	Control
Cane yield (t/ha)	125.00	130.00	117.50	128.75	133.75	122.50
Additional yield over control (t/ha)	7.50	12.50	-	6.25	11.25	-
Additional income over control (Rs./ha)	7,680	12,800	-	6,400	11,520	-
Additional expenditure over control (Rs./ha)	3,300	1,150	-	4,200	2,100	-
B:C Ratio	2.32	11.13	-	1.52	5.48	-

Note: (1) Price of cane Rs.1024/ton, (2) Wages for labour Rs.80/day

Table 4 Performance of de-trasher in farmers holdings

Type of leaf sheath	Varieties (No. of locations)	Labour saved by the tool (%)
Loose	Co 86032 (9)	47.50
Semi clasping	CoC (SC) 22 (1)	33.30
	CoC 90063 (2)	48.50
	CoSi (SC) 6 (1)	54.50
Clasping	Co 85061 (1)	50.00
	83R23 (1)	55.50
	CoV 92102 (1)	65.30
	Mean	50.65

Conclusion

It is concluded from the above study that the sugarcane de-trasher is easy to handle with less drudgery, less operation cost and cheaper. There is no complicated technology involved in the operation.

Recommendations

The tool was demonstrated and tested in the presence of Engineers at the Indian Institute of Technology, Chennai. And the tool was selected for award by Rural Innovation Network.

■■

Performance of a Mixed-Mode Type Solar Crop Dryer in Drying Rough Rice Under Natural Convection

by

M. A. Basunia
Department of Soils,
Water & Agricultural Engineering,
Sultan Qaboos University,
P.O. Box 34, Al-Khod 123, Muscat, Sultanate
OMAN

T. Abe
Retired Professor,
Department of Biomechanical Systems,
Ehime University,
Matsuyama, 790-8566,
JAPAN

Abstract

The performance of a three-shelf mixed mode type solar crop dryer was analyzed in drying rough rice. The dryer had a collector area of 1.74 m^2 and the area of each shelf was 0.81 m^2 (900mm × 900 mm). Tests were conducted with alternately loading all the three shelves, two shelves, and a single shelf with varying (33-110 mm) depths of grain beds. The three and two shelves tests were conducted with partial loading of the shelves, keeping approximately 10 % area of each shelf grain free along the width of the dryer and alternating the back and front ends of the adjacent shelves. This procedure helped to create an S-shaped path for easy movement of the drying air. All these tests showed that single/double shelf tests with complete loading the shelf area increased the energy utilization efficiency of the dryer. Keeping the grain free space for easy movement of drying air reduced the energy utilization efficiency of the dryer. The drying capacity of the dryer was 1.75 kg/(h·m^2) of wet rough rice under natural convection although the air temperature rose by some 15 ˚C before passing through the grain bed. This indicated that the dryer needed an air moving device in order to increase the drying performance.

Introduction

Rice is the staple food of over half of the world population. It is also the staple food in Bangladesh where the main crop is paddy. Paddy is usually harvested at moisture levels ranging from 18 to 35 % (w.b.) and must be dried to approximately 13 to 15 % (w.b.) to be suitable for storage. The most common and pressing problem in handling wet grain in most non-industrialized countries like Bangladesh is the delay in open air sun drying caused by unfavorable weather conditions. In Bangladesh open air natural sun drying is one of the most common methods to dry agricultural products. A considerable amount of product produced deteriorates rapidly in quantity and quality after harvest. Field losses are high because the crops are usually left in the field after harvest to dry slowly and partially. After threshing normally the rural farmers spread the grains on open spaces (even earth surfaces), woven mats, roofs and roadsides to dry it to a safe storage level. Thus, the grain is submitted to adverse conditions such as dust, rain, birds, insect and rodent attack, which lower the quality of the dried grains. Considerable losses ranging from 10 % to 25 % can often occur (Exell, 1980). The natural open air sun drying of a high moisture paddy requires little capital cost, but there is a high labor cost in keeping the grain turned regularly and protecting it from wet weather. Even then, kernel checking and breaking is a serious set-back. Because of the difficulties with open air sun drying, particularly in wet weather, an alternative and efficient drying method is needed in tropical countries.

Bangladesh receives abundant solar radiation throughout the year, so a solar heated dryer can be used to solve the drying problem. Most of the farmers in Bangladesh operate on a small scale and can not afford mechanically powered drying systems. An intermediate solution takes advantage of the ready availability of solar energy to utilize it for drying. Bala and Ziauddin (1990) reported that solar dryers can be designed to enhance the effectiveness of solar drying and that there is potential for their adoption and application by small farmers in Bangladesh. This would reduce the grain loss and help to maintain the quality of dried grain.

Mulbauer *et al*. (1993) stated that in developing countries, the use of solar energy technologies in agriculture are most economically viable compared to industrialized countries. The introduction of solar drying system seems to the most promising alternative in reducing post harvest losses and could be a significant contribution to enhance continuous food supply. Jindal and Gunasekaran (1982) reported that extensive field testing and more technical data on the construction and operation aspects of the solar drying systems using natural convection of warm air are needed to harness their full potential and to popularize them.

The amount of solar radiation available on horizontal surfaces during the major rice harvesting season, November to December, in Bangladesh, and September to October, in Matsuyama, Japan (Basunia, 2000) is almost equal to 14 Mj/m^2. A prototype of a three-shelf mixed-mode type natural convection solar dryer was constructed and tested in Matsuyama, Japan with the idea that it could be utilized in Bangladesh. This paper reports the performance of the prototype dyer under natural convection with different loading conditions of the three-shelf.

Materials and Method

Instrumentation and Measurements

A simple sketch of the dryer is shown in **Fig. 1**. Detailed description and design procedures are described in an earlier article (Basunia and Abe, 2001). Prior to the operation of the dryer, thermocouples were installed to record the temperature at 18 locations within the solar drying system. Nine thermocouples were connected within the space between main solar collector and absorber plate, and the remaining were located within the drying chamber. A thermocouple was installed at the bottom of the dryer unit just over the extended surface of the absorber plate. Two thermocouples were connected at the bottom of the first (bottom) shelf to record the dry-bulb and wet-bulb temperatures of the entering air. Two thermocouples, one at each of the bottom of the middle and the bottom of the top shelf, measured the dry-bulb temperatures (**Fig. 2**). Two thermocouples were also connected near the entrance of the chimney to measure the dry and wet-bulb temperatures of the air going out of the grain bed. Two more thermocouples were used to record the dry and wet-bulb temperatures of the ambient air entering the collector. In total, 18 thermocouples were installed.

The thermocouples were connected through an interface of an AD (analog to digital) converter (Green kit 77A model) then to a personal computer for data collection. The temperature readings from the thermocouple probes were recorded every 5 minutes. The thermocouples used for measuring the temperatures had an accuracy of ± 0.5 ˚C. The relative humidity of the drying air, ambient air and exhausted air were calculated from the measured dry-bulb and wet-bulb temperatures of the drying air, ambient air and exhausted air, respectively.

A pyranometer of Moll-Goregynstic type was used to measure the solar radiation incident on a horizontal surface. The sensitivity of the pyranometer was 10.5 mV/(cal.cm^2 min). The pyranometer was also connected through the interface of the AD converter and then to the personal computer to record the radiation data. The BASIC program used in recording temperature was also used for recording radiation data. Data were collected at 5 minute intervals from morning to evening in each test.

Sample Preparation

Medium grain rough rice (Japonica variety), freshly harvested, was obtained at approximately 26.5 % moisture content (wet-basis) from Ehime University Agricultural Farm. Grain was stored in a cooler at 5 ˚C to be used for the subsequent drying tests. The moisture content of each sample was measured before each drying test using JSAM (JSAM, 1984) standards. The required amount of grain was removed from storage one day prior to the drying test and kept overnight in plastic bags at room temperature. This step brought the grain into

Fig. 1 Schematic diagram of the mixed-mode type of natural convection solar grain dryer (Shelves are not visible in diagram)

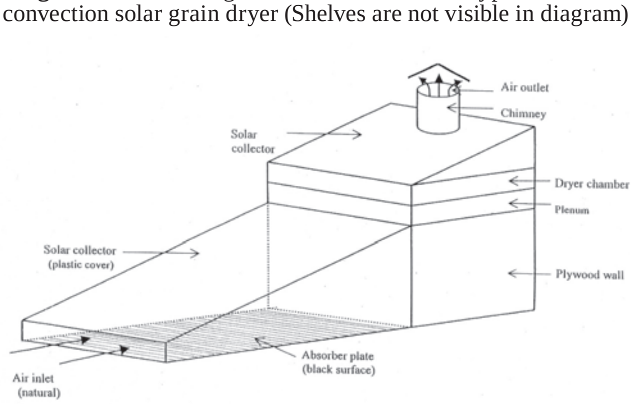
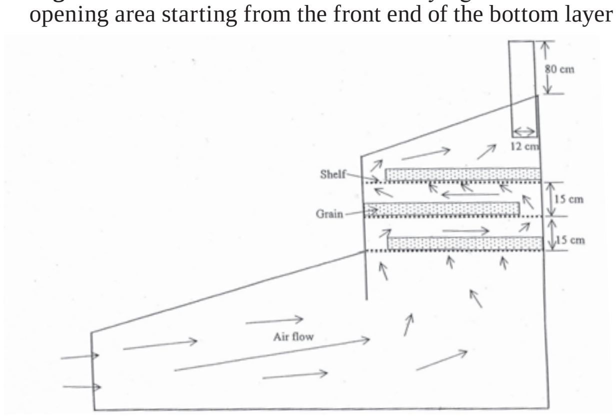


Fig. 2 Direction of air flow inside the drying chamber with opening area starting from the front end of the bottom layer



thermal equilibrium with the room temperature and prevented any condensation on the rough rice when it was placed in the dryer chamber.

Moisture Content of Grain

For the determination of moisture content of the grain bed during the drying periods, grain samples were collected from each shelf in the morning (8 AM) and also in the afternoon (5 PM) while drying 3-11 cm deep grain beds. Samples were collected from three locations: the center, near the wall, and between the wall and the center of the dryer. The moisture content was determined for each shelf individually to determine the moisture gradient in the horizontal direction and then an average was made for each shelf when drying grain in more than one shelf. For drying grain in a single shelf, grains were collected from the bottom, middle and top layers of the grain bed. The moisture contents measured from each shelf were averaged to determine the mean moisture content of the entire grain bed during each day. Thus, the mean moisture content during the drying period was the mean of nine, six and nine replications while drying rough rice in three-shelf, two-shelf and single shelf, respectively. After the drying was terminated, the whole unit was covered by a large polyethylene sheet and the grain was left in the dryer undisturbed for about 12 h. After 12 h the average moisture content of the grain was also measured by collecting grain from different locations of the dryer.

Functional Performance of the Dryer

The thermal performance of the solar crop dryer was obtained by using the following equations (eqns. 1-4).

The energy added to the drying air while passing through the space between the collector and absorber plate was estimated from the following equation.

$$E_a = A_c\, H\, R_b\, \eta_c = Q_a\, \rho_a\, c_a\, (T_i - T_a)\, t_d \quad (1)$$

where E_a is the total useful energy added to the drying air, kj; A_c is the area of the collector, m^2; H is total global radiation on the horizontal surface during the drying period, kj/m^2; t_d is the drying time, h; R_b is the average geometric factor for the harvesting season; η_c is the collector efficiency, 30 to 50 % (Sodha *et a*l.,

Table 1 Performance of the dryer in drying rough rice with 3-shelves loading and keeping approximately 10% area of each shelf grain free for easy movement of the drying air. (Average ambient temperature was 24.8-26.7 ˚C)

Depth of grain bed,cm	Collector temp-erature, ˚C	Tem.at the bottom of bottom shelf, ˚C	Tem. at the top of top shelf, ˚C	Air flow rate of drying air, m^3/min	Energy strike at the collector surface, MJ/h	Energy added to the drying air in the collector, MJ/h	Energy used efficiency, %	Collector efficiency, %
3[a]	36.9	33.3	28.2	0.611	1.58	0.505	42.6	31.9
5[a]	44.0	39.2	33.2	0.780	2.16	0.916	35.0	42.4
3[b]	36.2	32.8	27.6	0.746	1.50	0.601	44.1	40.1
5[b]	37.8	33.7	28.8	0.577	1.61	0.447	43.1	27.8

[a]Keeping grain free space at the back end of the bottom layer, [b]Keeping grain free space at the front end of the bottom layer

Table 2 Performance of the dryer in drying rough rice with two shelves loading, keeping approximately 10% of area of each shelf grain free and also with complete loading the shelves. (Average ambient temperature was 22.3-23.5 ˚C)

Depth of grain bed,cm	Collector temp-erature, ˚C	Tem.at the bottom of the shelf, ˚C	Tem. at the top of upper layer, ˚C	Flow rate of drying air, m^3/min	Energy strike at the collector surface, MJ/h	Energy added to the drying air in the collector, MJ/h	Energy used efficiency, %	Collector efficiency, %
3[a]	38.8	33.3	28.6	0.848	1.94	0.887	30.7	45.7
5[a]	34.6	30.7	26.9	0.882	1.64	0.742	30.9	45.3
3[b]	39.9	35.7	25.0	0.543	1.75	0.610	65.0	34.7

[a]Keeping grain free space at the back end of the bottom shelf, [b]Complete loading the shelves area

Table 3 Performance of the dryer in drying rough rice in 8 and 11 cm deep beds with single-shelf loading. (Average ambient temperature was 18.6-22.9 ˚C)

Depth of grain bed,cm	Collector temp-erature, ˚C	Tem.at the bottom of first stack, ˚C	Tem. at the top of top layer, ˚C	Air flow rate of drying air, m^3/min	Energy strike at the collector surface, MJ/h	Energy added to the drying air in the collector, MJ/h	Energy used efficiency, %	Collector efficiency, %
8	37.0	33.1	25.1	0.509	1.81	0.491	56.4	27.1
11	33.7	31.4	24.4	0.441	1.71	0.455	46.4	26.6

1987); T_a is the ambient temperature ˚C; T_i is the temperature of the drying air in the space between the collector and absorber plate, ˚C.

The energy actually used in drying of wet rough rice is was obtained from the following equation.

$E_u = Q_a\, c_a\, r_a\, (T_b - T_f)\, t_d$...............(2)

where E_u is the energy actually used in drying, kJ; T_b is the temperature of the entering air at the bottom of the first (bottom) shelf, ˚C (< T_i); and T_f is the temperature of the exhaust air leaving the top-shelf grain bed, ˚C.

The energy used efficiency η_c of the dryer was calculated from

$\eta_u = E_u / E_a \times 100$........................(3)

Collector efficiency η_c in % was calculated by re-writing Eqn (1) to the following form:

$\eta_c = E_a / [A_c\, H\, R_b] \times 100$.............(4)

Results and Discussion

Tests with Three-Shelf Loading

Four tests were conducted with three-shelf loading and keeping grain free space along the width of each shelf by alternating the front and back ends of the adjacent shelves starting from the bottom shelf. These procedures created an S-shaped path for easy air movement. The S-shaped path ended at the front end of the top shelf if it is started at front end of the bottom shelf (**Fig. 2**). Alternatively, the S-shaped path ended at the back end of the top shelf if it started from the back end of the bottom shelf. The grain free space was left widthwise of each shelf, and it was approximately 10 % of the area of each shelf. Two tests were conducted with 3 cm deep grain beds in each shelf, keeping the grain free space at the front end and back end of the bottom shelf, respectively. Similarly, two tests were conducted with 5 cm deep grain beds in each shelf. Results are summarized in **Table 1**. Only 35 to 44.1 % of the total energy that was added to the drying air was used in drying while keeping the path for air movement (**Table 1**). A considerable amount of drying air passed through the grain free space of each shelf instead of passing through the grain bed. The time required for dying was considerably high. The final product moisture content remained high (22 % w.b.) even after drying 2 to 3 days. Thus, this type of arrangement for air movement would not increase the drying performance of a solar crop dryer. The condensation of moisture at the inner surface of the top collector was observed if the opening arrangement ended at the back end of the top shelf near the opening of the chimney. This problem was not observed if the opening ended at the front end of the top shelf. Another major problem was that the moisture removal rate from the middle shelf was very low compared to the bottom and top shelves. The highest moisture removal rate was higher in the bottom shelf than the middle and top shelves. The variations of temperature and total (beam and diffuse) solar radiation on a horizontal surface are shown in **Figs. 3** and **4**, respectively, while drying a 3 cm deep grain bed in each shelf. **Fig. 4** indicates that the amount of solar radiation incident on the solar collector surface continuously varied from morning to evening. The temperatures at the different points of the dryer unit and ambient temperatures are directly dependent on the intensity of solar radiation on the surface of the collector. As indicated in **Fig. 4**, the weather was almost bright on the first half of the day, but on the second half was partly bright and partly cloudy. The highest solar irradiance on the horizontal surface was 0.33 kW/m^2 at the solar noon.

Fig. 3 Variations of temperatures from morning to evening (8:00-16:30 h) at different locations of the dryer in drying a 3 cm deep grain bed on each shelf of the three-shelf dryer.

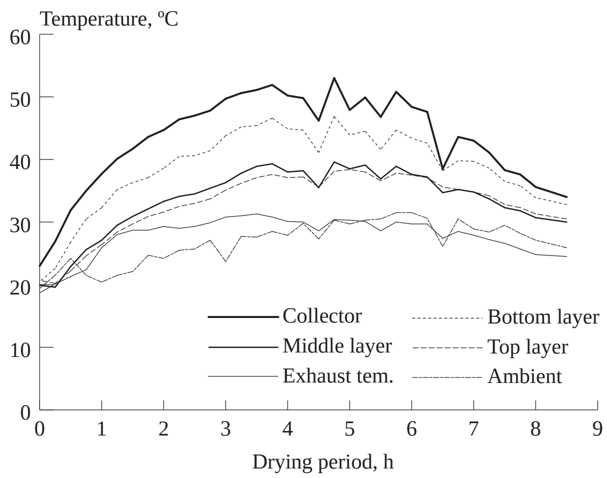
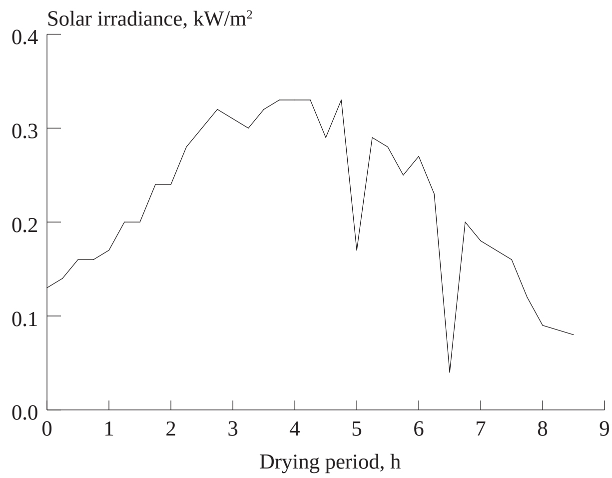


Fig. 4 Variations of solar irradiance incident on a horizontal surface during one day drying with 3 cm deep grain bed on each shelf of the three-shelf dryer.



Tests with Two-shelf Loading

In these tests only the top and bottom shelves were used, and the middle shelf was removed. Three tests were conducted, two with grain free space in both the shelves, alternating the back and front end of the adjacent shelves, and one test with complete loading of the shelves. The results are summarized in **Table 2**. Energy utilization efficiency increased with complete loading of the shelves areas instead of keeping the grain free space in both the shelves. Thus, the moisture removal rate from the wet grain was higher in complete loading the shelf area than in the partial loading. The variations of temperature and total (beam and diffuse) solar radiation on a horizontal surface are shown in **Figs. 5** and **6**, respectively, while drying a 5 cm deep grain bed on each shelf. **Fig. 6** indicates that the amount of solar radiation incident on the solar collector surface continuously varied from morning to evening. The temperatures at the different points of the dryer unit and ambient temperatures are directly dependent on the intensity of solar radiation incident on the surface of the collector. As indicated in **Fig. 6**, the weather was almost bright on the first and third day, but on the second day it was partly bright and partly cloudy. The highest solar irradiance on the horizontal surface was 0.42 kW/m^2 at the solar noon.

Test with Single Shelf and Complete Loading

Two tests were conducted under this condition with 8 and 11 cm deep grain beds. The middle and top shelves were removed from the dryer unit. The results are summarized in **Table 3**. The variations of ambient temperatures, air temperatures between the collector and absorber, and temperatures at the bottom of layer are shown in **Fig. 7** in drying an 8 cm deep grain bed. The shapes of temperature variation curves with drying time are similar with the shapes of radiation curves (**Fig. 8**). This indicates that the intensity of solar radiation incident on the collector surface has direct effect on temperatures at the different locations of the solar dryer. The drying air temperatures easily rose by about 15 ˚C above the ambient temperature, but air flow rate was very low (**Tables 1-3**).

As indicated in **Fig. 8**, the weather was almost bright on the first day, but on the second and third days was partly bright and partly cloudy. The sky was almost bright on the fourth day. The average total (beam and diffuse) solar irradiance on a horizontal surface on 1st, 2nd, 3rd and 4th day of drying were 0.198, 0.170, 0.179 and 0.215 kW/m^2, respectively. The amount of wet grain dried in 4 days was 39.8 kg while the depth of grain bed was 8 cm. The average moisture content was reduced to 15.9 % w.b. from an initial moisture content of 26.5 % w.b. within 4 days. The grain was mixed every day at around 5 PM for the first three days of drying. The average moisture content of the top layer was 16.5 % w.b. while the bottom layer moisture content was 13.7 % w.b. at the end of drying. This small moisture gradient may not cause a problem of deterioration of grain quality.

The amount of wet grain dried in an 11 cm deep bed was 45.8 kg. The moisture was reduced to 15.4 % w.b. from an initial moisture content of 26.9% w.b. within 4 days. Approximately half of the area of the grain bed was mixed every day at 5 PM for the first three days of drying and the remaining area of the bed was left as undisturbed. The average moisture content of the bottom, middle and top layers at the end of drying were 13.5, 18.3 and 16.4 % w.b, respectively, on the mixing side

Fig. 5 Variations of temperatures at different locations of the dryer unit in drying a 5 cm deep grain bed on each shelf of the two-shelf dryer with the shelves areas completely loaded (drying time 8:00-16:00 hr/day).

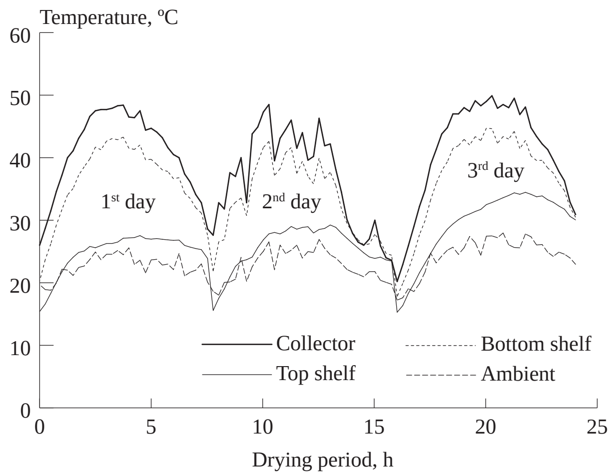
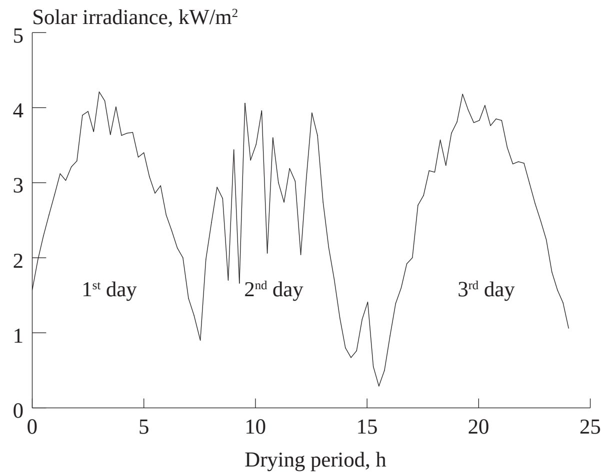


Fig. 6 Variations of total (diffuse and beam) solar irradiance incident on a horizontal surface from morning to evening during three days drying with a 5 cm deep grain bed on each shelf of the two-shelf dryer.



of the dryer. The average moisture content of the bottom, middle and top layers at the end of drying were 11.0, 24.8 and 18.3 % w.b, respectively, on non-mixing side of the shelf. Grain within the bed just below the top surface remained under-dried. Exell (1980) also reported that if the grain bed was left untouched during drying the rice at the bottom is liable to be over-dried while the rice within the bed just below the top is under-dried. This indicated that grains need mixing while drying higher depths of grain bed, otherwise, the bottom layer grain will be slightly over-dried and the middle grain layer remains under-dried even after 4 days drying. The middle layer remained under-dried due to very low air flow rate under natural convection. This indicated that the temperature front was not penetrating well into the grain bed due to low air pressure under the influence of natural convection.

Bala (1993) theoretically showed that the bottom of the rice bed of 5-7.5 cm deep severely over-dried in two days drying period and the moisture reached below 5% w.b. even after considering complete mixing between each day. However, practically, the bottom of the rice bed of 11 cm deep does not go below 11% w.b. even after 4 days drying without mixing the grain, as observed in this study. This indicated that the simulated performance of natural convection solar dryer using a deep-bed simulation model does not agree well with the practical performance. One of the reasons may be due to using the thin-layer drying equation in the simulation model that was developed under isothermal and constant air conditions. These conditions do not exist under natural convection drying. The simulated performance might be closer to the experimental using the thin-layer drying equation that was developed under variable air conditions with natural convection.

The grain at the top layer dried a little faster than the middle layer due to direct absorption of solar heat. The mixing of grain is also a problem while drying higher depth of grain bed. It seems that the depth of grain bed should not be more than 11 cm in solar drying of rough rice under natural convection. The average collector efficiency of theses two tests was 26.9 %, which is very near to 30 % considered normally in designing natural convection solar dryer.

The moisture removal rate and energy utilization efficiency in both these tests increased more than that of the two and three shelves tests with grain free space for air movement (**Table 3**). It was observed that the energy added to the drying air, while passing through the space between the collector and absorber, was not used fully. A part of the energy was lost while drying air moved from the collector to bottom of the grain bed.

It seemed that two-shelf with complete loading of the shelves produced better result than the single shelf loading, but loading and unloading are major set backs in two and three shelves drying. In view of this fact it would be better to use single-layer with 8-11 cm deep grain bed. Drying capacity of the dryer was only 1.75 (kg/h) of wet rough rice in per m^2 area of the dryer. This showed that it was possible to dry approximately only 450 kg rough rice in 4 days using the designed dryer instead of 600 kg as estimated theoretically (Basunia and Abe, 2001).

Harvesting of paddy was late due to rainy days, and the experiment was continued until November 20. The available solar energy in November is less than that of September and October in Mastusuyama, Japan (Basunia, 2000). The low

Fig. 7 Variations of temperatures at different locations of the dryer in drying a 8 cm deep bed of rough rice on a single-shelf in four days with the shelf area completely loaded (drying time: 8:00-6:00 hr/day)

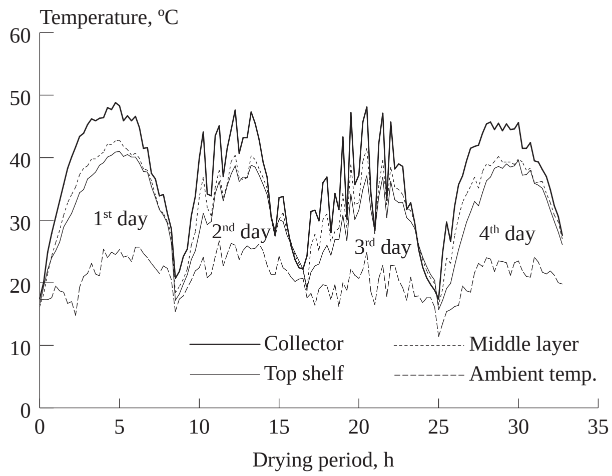
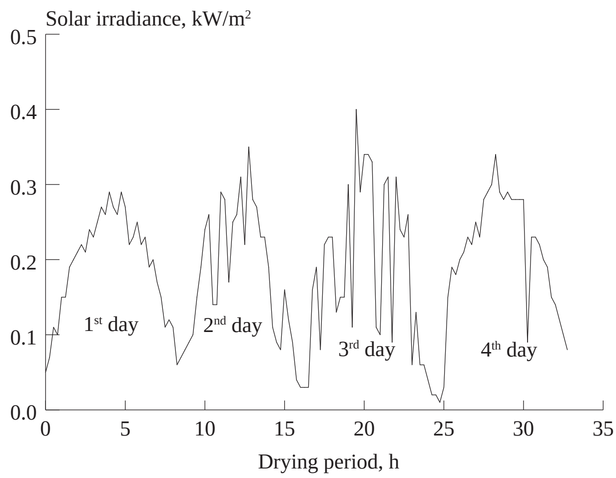


Fig. 8 Variations of solar irradiance on a horizontal surface from morning to evening (drying time: 8:00-16:00 hr/day) during four days drying of a 8 cm deep bed of rough rice bulk on a single shelf.



drying rate was due to very low incident of solar radiation on the collector surface during the tests periods, and very low air flow rate due to natural convection than expected. This experiment showed that these types of dryers may not be acceptable to the farmers of developing countries because of very low drying capacity in unit area of the dryer.

Conclusions

The performance of a prototype three-shelf solar crop dryer was analyzed in drying rough rice under natural convection. The tests were conducted with partial loading and also with complete loading the shelves. In the partial loading, an approximately 10 % area of each shelf was left as grain free widthwise alternating back and front ends of the two adjacent shelves as a S-shaped path for easy air movement. Partial loading did not improve the efficiency of the dryer. A considerable portion of the hot air passed thorough the opening area instead of passing through the grain bed. The drying rate was low in partial loading compared with shelf area completely loaded. A single shelf or two shelves with complete shelf loading increased the drying rate but even then drying capacity of the dryer was very low; 1.75 (kg/h.m^2) of wet rough rice. This experiment showed that these types of dryers under natural convection may not be acceptable to the farmers of developing countries because of very low drying capacity in per unit area of the dryer. The temperature front did not penetrate well deep into the grain bed due to very low air pressure under natural convection. The drying efficiency of the dryer could be increased greatly by using a solar powered or electrical powered fan making it forced convection instead of natural convection.

REFERENCES

Bala, B. K. and A. T. M. Ziauddin. (1990). Simulation of solar drying of rough rice. Proceeding of the 1st World renewable Energy Congress, 938-942, Reading UK.

Basunia, M. A. 2000. Simulation of available solar energy and its utilization in drying rough rice. Research report of the Japan Society for the Promotion of Science (JSPS), JSPS Postdoctoral Fellowship, Department of Biomechanical Systems, Ehime University, Matsuyama 790-8566, Japan.

Basunia M. A. and T. Abe. 2001. Design and construction of a simple three-shelf solar rough rice dryer. Agricultural mechanization in Asia, Africa and Latin America, 3 (32): 54-59, 66.

Excell, R. H. B. 1980. Basic Design Theory for a simple Solar Rice Dryer, Renewable Energy Review Journal, 1(2): 1-14.

Jindal, V. K. and S. Gunasekaran. 1982. Estimating air flow and drying rate due to natural convection in solar rice dryers. Renewable Energy Review Journal, 4(2), 1-9.

JSAM. 1984. Hand Book of the Japanese Society of Agricultural machinery, New edition, Korona Publisher, Tokyo, Japan.

Muhlbauer, W., A. Esper, and J. Muller. 1993. Solar energy in agriculture. ISES Solar World Congress, August 23-27, Budapest.

Sodha, M. S., N. K. Bansal, A. Kumar, P. K. Bansal, and M.A.S. Malik. 1987. Solar crop drying Vol. 1 and II CRR Press, Boca Raton, Florida, USA.

Research on Shear Characteristics of Chinese Cabbage Rootstalk

by

Xu Liming
Associate Professor
College of Engineering,
China Agricultural University
Haidian, Beijing, 100083
CHINA
xlmoffice@126.com

Yao Huiling
Masters student
College of Engineering,
China Agricultural University
Haidian, Beijing, 100083
CHINA
homtownyhl814@163.com

Abstract

The Chinese cabbage harvest is very intensive. In order to design a cutter for the Chinese cabbage harvester, taking “Beijing New No. 3” for example, several testing cutters were made. The shear characteristics of the Chinese cabbage rootstalk was tested with the RGT-2 digital electronic universal testing machine using the different conditions in cutting speed, knife edge curve, knife edge thickness and knife edge degree of smoothness. The results showed that the shearing force varied as the cutting speed increased. The shearing forces of the different cutter curves ranged from small to large and followed a convex curve, diagonal curve, concave curve and beeline curve. The knife edge thickness and shearing force were positively correlated. The knife edge smooth degree and the shearing force were negatively correlated. Therefore, the cutter of the Chinese cabbage harvester was chosen as convex curve, 0.5 mm knife edge thickness and smooth knife edge.

Introduction

In recent years, with the improvement of living standards and rich vegetable varieties, Chinese cabbage has a more significant standing in the life of the people. China planted 16,339,000 ha of vegetables in 2001, with 2,646,000 ha devoted to Chinese cabbage (16.2 %). China planted 17,720,700 ha vegetables in 2005, with 2,609,300 ha devoted to Chinese cabbage (14.7 %).

However, the whole production of Chinese cabbage is a manual operation, especially harvesting. During harvesting, the farmers ceaselessly bow, and the greater labor intensity easily leads to lumbar muscle strain and other diseases. In order to reduce the labor intensity and increase the production mechanization level of Chinese cabbage, the Chinese cabbage harvester was designed. For the Chinese cabbage harvester, the cutter was one of the key components. The Chinese cabbage is mainly shear cut. Therefore, this paper conducts the shear characteristics research of Chinese cabbage rootstalk so as to provide the important theoretical basis for the cutter design of the Chinese cabbage harvester.

The abroad research of plant mechanical characteristics focus on wheat straw, rice straw and pasture. Chattopadhyay studied the cutting characteristics of jowar straw and pasture. James G. studied the change of the cutting energy for the potato under different cutting angles and cutting speeds. Having analyzed the effect of the cutting speed, the cutter parameter and the number of roots cut in the cutting process, Odogherty pointed out that there was a critical speed from 15 to 30 m/s during cutting straw. If the actual speed is below the critical speed, the cutting energy consumption will rapidly increase and invalid cutting will result. If the actual speed is above the critical speed, the cutting energy consumption is nearly unchanged. The actual cutting length is nearly equal to the theory. The research on Chinese cabbage focuses on performance tests and improvement after having completed the machine. SUZUKI studied the cutting location on Chinese cabbage. He showed that the cutting process could be smoothly completed and the Chinese cabbage could be smoothly carried behind the belt by adjusting the cutter height and the angle of transmitting equipment. Other Japanese researchers have attained a 400 mm/min cutter speed through experiment.

In domestic research, Gao Mengxiang *et al.* tested the joining force of stalk and leaves, the resistance of the sheath pulling force and the resistant impact of stalk and sheath for corn stalk. Wu Ziyue *et al.* conducted a bench test on the cutting velocity and power requirement of maize stalks supported at two-ends. The results showed that the cutting mode had the maximal influence on cutting velocity, and the number of stalks to be cut, obviously, affected the power of chopping. Zhang Jinguo *et al.* conducted self-made test equipment for the chopping properties of wheat straw under different conditions. The main cutting curves of wheat straw were given under different cutting speeds of the rotary blade with different straw lengths, moisture contents and cutting positions, thickness of knife edge, and with and without shear bar. Sheng Quanjun, Sun Li and Yang Zhongping have studied the physical characteristics and mechanical properties of wheat straw, cotton stalks and other crops. Jiang Jinlin studied the force properties of corn rootstalks and the shear properties of rootstalk-soil composition.

In order to study the influence factor of the rate of broken root of cutting sugarcane, Song Rongrong *et al.* carried out a simulated field experiment to study working parameters of a harvester cutter by using a sugarcane test-bed. They discussed the effects of cutting speed, cutter-disk obliquity, number of knives, cutting angle and harvester walk speed on sugarcane cutting force. The influence order of each factor to cutting sugarcane force and the experimental equation for the calculation of sugarcane cutting force were obtained from variance analysis and regression analysis. Liu Qingting *et al.* found the theoretical equation for the cutting force for sugarcane stalk by using elastic theory and a double beam model. Based on the theoretical equation and taking single direction composite material as the model for sugarcane stalk material, the experimental unit cutting force equation for sugarcane stalk was made through analyzing the influencing factors.

The above research has not related to the study of mechanical characteristics for Chinese cabbage rootstalk. In this paper, taking "Beijing New No. 3" for example, the study on shear characteristics of Chinese cabbage rootstalk was conducted, then the cutter structure was put forward for the Chinese cabbage harvester.

The Physical Characteristics of Chinese Cabbage Rootstalk

The Chinese cabbage rootstalk is composed of the overground part and underground part. The overground root is 2 cm high and 30 cm diameter. The underground root is shallow and straight (**Fig. 1**), including the major root and lateral roots. The major root is developed, and its upper is thicker and its lower is thinner. The two lateral roots are distributed in the major root growth. There are also many small roots on all sides of the major root and lateral roots to form a thick absorbable net. The Chinese cabbage root is strong and mostly growing horizontally. All roots are distributed in 30-35 cm depth and 60 cm width under the ground.

There are various kinds of cabbages. The planting model and parameters are very different among breed and producing area. This paper takes "Beijing New No. 3" Chinese cabbage for example.

Test and Methods

Test Device and Test Material

When harvested, the Chinese cabbage rootstalk is sheared, so the shear characteristic of the cabbage rootstalk is studied first. The shear characteristic of the cabbage rootstalk is related not only to the rootstalk moisture, the cutting speed and the root size, but also to the shape, thickness and cutter edge curve. Therefore, the factors including cutting speed, knife edge curve, knife edge thickness and knife edge shape are key points to be tested, so that the cutter for the Chinese cabbage harvester is confirmed.

Test Device

The RGT-2 desktop digital electronic universal testing device made in Shenzhen (**Fig. 2**) and the self-made Chinese cabbage support trough (**Fig. 3**) were adopted to test the Chinese cabbage rootstalk.

Test Material

The samples were "Beijing New No. 3" Chinese cabbages with the long stubbles. The stubble moisture was 86.95 %, and the diameter was about 30 mm. The samples were collected from fields, watered and cleaned.

Test Methods

The Testing Factors and the Testing Levels: The alterable factors during the test were the cutter structure and the cutting speed. All the

Fig. 1 The chinese cabbage root

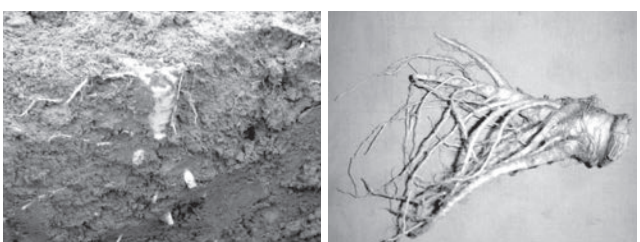


Fig. 2 The shearing test devicet

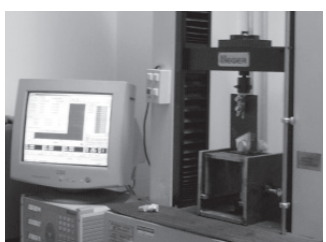


Fig. 3 The chinese cabbage supported trough

test factors and selected levels are shown in **Table 1**.

Test Design: In order to find the effects of the cutter shapes with different knife edge curves on the shearing forces, four kinds of cutters with different cutter curves, such as beeline curve, diagonal curve, concave curve and convex curve, were designed (**Fig. 4** and **Fig. 5**). Otherwise, the four kinds of cutters with denticulate knife edge were especially designed to research the influence of the knife edge smooth degree on the shearing forces. All the four kinds of knife edges were burnished into 0.5 and 1 mm thickness, respectively, to measure the influences of the knife edge thickness on the shearing forces.

Results and Discussion

With the other conditions kept invariable, the cutting speeds were changed and the results are shown in **Fig. 6**. There was a negative correlation between the cutting speed and the shearing force. The shearing force became smaller as the cutting speed increased. The relationship between the cutting speed V and shearing forces F can be expressed as the following equation:

$$F = 2.1575V^2 - 29.457V + 232.96 \quad (N)$$

The correlation is: $R^2 = 0.9953$

With the other conditions kept invariable, the shearing forces of different knife edge curves lined from small to big are convex curve, diagonal curve, concave curve and beeline curve. (**Fig. 7**). The convex and diagonal curve were mainly sliding when cutting, so the shearing force was small. The beeline and concave curve were mainly chop cutting, therefore, the shearing force was reversely large.

With the other conditions kept invariable, the relationship between the knife edge thickness (0.5 and 1 mm) and the shearing force was measured (**Fig. 8**). The smooth knife edge and denticulate knife edge were tested, and the relationships are described as the in **Fig. 8**. The results show that the thickness and the shearing forces have a positive correlation with both knives. For the smooth knife edge, the 0.5 mm thickness knife edge shearing forces were 10.1 % lower than that of the 1 mm knife. For the denticulate knife edge, the shearing force of the 0.5 mm thickness knife edge was 18.7 lower % than that of the 1 mm knife. However, it will abrade faster if the blade thickness is too thin. Therefore, the knife edge thickness should be taken into account synthetically while designing the harvester cutters.

With the other conditions kept invariable, the relationship between the knife edge type, including the smooth one and the denticulate one, the shearing forces were tested (**Fig. 9**). The results show that the shearing forces of the smooth knife edge is smaller (14.4 %) than that of the denticulate one. The knife edge smooth degree and the shearing forces were negatively correlated.

Conclusion

The labor intensity for harvesting Chinese cabbages manually is enormous. In order to design the cutter for the Chinese cabbage harvester, the different cutter forms are designed in this research to conduct the shearing test for the “Beijing new No. 3”. The conclusions are as follows:

The faster the cutting speed for the Chinese cabbages rootstalk, the smaller the shearing force. The relationship between the shearing force F and the cutting speed V can be expressed as:

$F = 2.1575V^2 - 29.457V + 232.96$, $R^2 = 0.9953$;

The four types of knife edge; curve, including beeline curve,

Table 1 Testing factors and levels factors

Cutting speed, mm/min	Knife edge thickness 0.5mm, smooth knife edge	Knife edge thickness 1mm, smooth knife edge	Knife edge thickness 0.5mm, denticulate knife edge	Knife edge thickness 1mm, denticulate knife edge
400			A3 (beeline curve)	
300			B3(diagonal curve)	
200			C3 (concave curve)	
100	D1 (convex curve)	D2 (convex curve)	D3 (convex curve)	D4 (convex curve)

Fig. 4 The self-made cutters

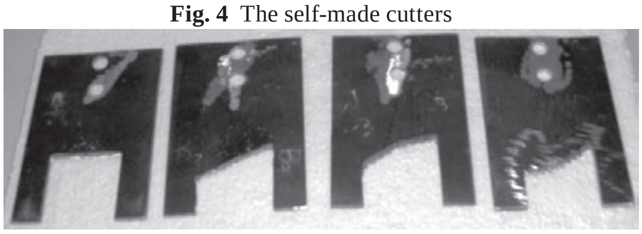
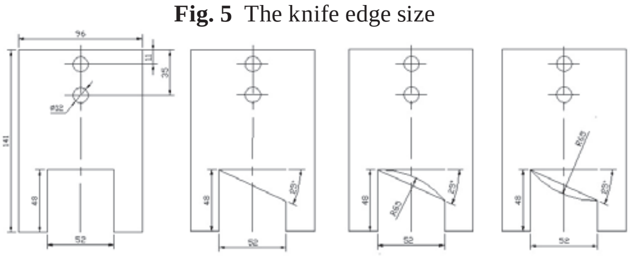


Fig. 5 The knife edge size



a. beeline curve b. diagonal curve c. concave curve d. convex curve diagonal curve, concave curve and convex curve were tested in the shearing force test. The shearing forces lined up from small to large were for: convex curve, diagonal curve, concave curve and beeline curve.

The knife edge thickness and the shearing forces were positively correlated, but the knife edge thickness should be considered synthetically in practice.

The knife edge smooth degree and the shearing forces are negatively correlated. The shearing forces of the smooth knife edge is lower by 14.4 % than that of the denticulate knife edge.

Based on the difference of the knife edge curve, the knife edge thickness and the knife edge smooth degree, the Chinese cabbage harvester should be designed design using the cutter with convex curve, 0.5 mm knife edge thickness and smooth knife edge.

REFERENCES

The People's Republic of China Ministry of Agriculture. China Agricultural Statistics (2005). Beijing: China Agriculture Publishing Press. 2006.

Secretary for the Ministry of Agriculture. National Agricultural Statistical Abstract [M]. Beijing: 2004.

Liu Yisheng. 1998. Chinese Cabbage. Beijing: China Agriculture Publishing Press.

P. S. Chattopadhyay and K. P. Pandey. Effect of knife and operational on energy equipment in forage harvesting. Journal of Agricultural Engineering Research. 1999. (73): 3-12.

P. S. Chattopadhyay and K. P. Pandey. 1999. Mechanical properties of sorghum stalk in relation to quasi-static deformation. Journal of Agricultural Engineering Research. (73): 199-206.

Fig. 6 Relationship between the cutting speed and shearing forces

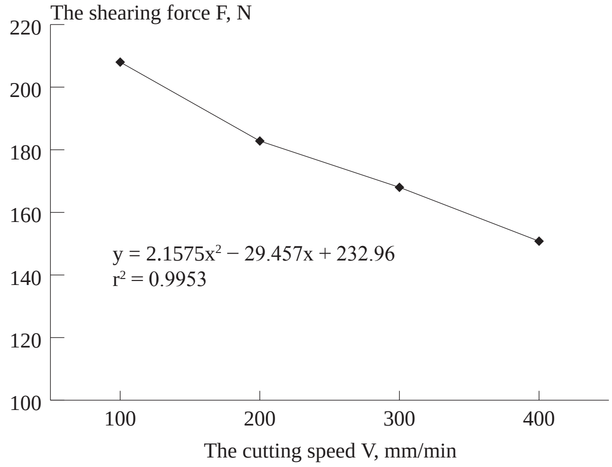


Fig. 7 Relationship between the knife edge curve and shearing force

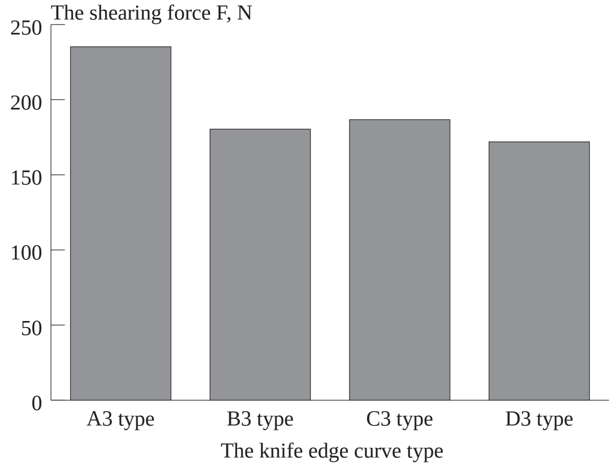


Fig. 8 Relationship between the knife edge thickness and the shearing force

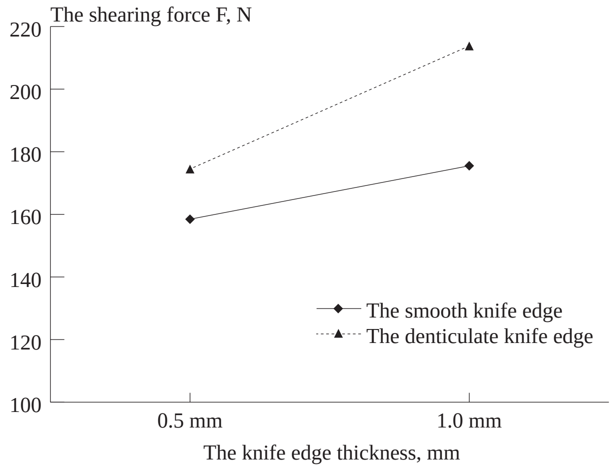
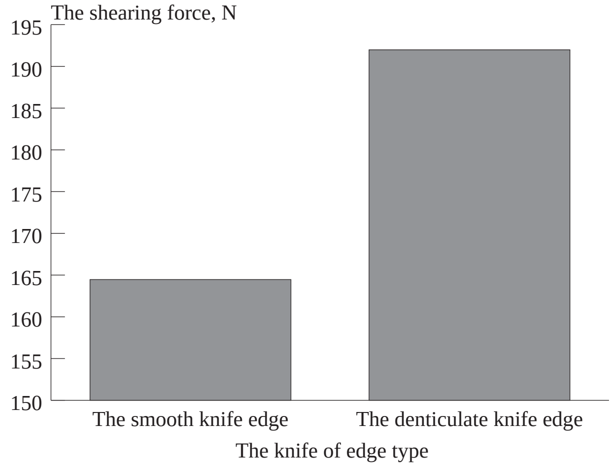


Fig. 9 Relationship between the knife edge type and the shearing force



James G. 1996. Effect of knife angle and velocity on the energy required to cut cassava tubers. Journal of Agricultural Engineering Research. 64(2): 99-106.

Odogherty, M. J. 1995. A study of the physical and mechanical properties of wheat straw. Journal of Agricultural Engineering Research. 62: 133-142.

Hisatoshi Suzuki. 2003. Lettuce Harvester Development (part2)-Improvement of cutting mechanism and development of conveyance device. Journal of Japanese Society of Agricultural Machinery. 65(5): 24-132.

Mikio Kanamitsu, Kenji Yamamoto, and Yasunori Shibano. 1993. Development of a Chinese cabbage harvester (part 1)-Fundamental research and development of harvesting mechanism. Journal of Japanese Society of Agricultural Machinery. 55(5): 133-140.

Mikio Kanamitsu, Kenji Yamamoto, and Yasunori Shibano. 1993. Development of a Chinese cabbage harvester (Part 2)-Tractor attached type experimental harvester. Journal of Japanese Society of Agricultural Machinery. 55(6): 121-128.

Gao Mengxiang, Kuo Kangquan, Yang Zhongping, and Li Xingshu. 2003. Study on mechanical properties of cornstalk. Transactions of the Chinese Society for Agricultural Machinery. 34(4): 47-52.

Wu Ziyue, Gao Huanwen, and Zhang Jinguo. 2001. Study on cutting velocity and power requirement in a maize stalk chopping process. Transactions of the Chinese Society for Agricultural Machinery. 32(2): 38-41.

Zhang Jinguo, Gao Huanwen, and Yang Guang. 2000. Study on the chopping property of wheat straw. Transactions of the Chinese Society of Agricultural Engineering. 16(3): 70-72.

Sheng Quichuan, Ahmed EI-Behery, and Hassan Gom aa. 1999. Experimental studies on chopping cotton stalk and briquetting process. Transactions of the Chinese Society of Agricultural Engineering. 15(4): 221-225.

Sun Li, Zhao Haojie, and Lisuolao. 1998. Compression and shear properties of wheat stalk. Journal of Northwest Sci-tech University of Agriculture and Forestry (Natural Science Edition). 26(4): 106-109.

Yang Zhongping, Yang Linqingand, Guo Kangquan. 1996. Study on the industrialized processing technology of cornstalks. Transactions of the Chinese Society of Agricultural Engineering. 4: 185-188.

Jiang Jinlin. 2004. Study on the corn roots cutting and digging device of no-tillage planter [Paper of Dr.］. Beijing：China Agricultural University.

Song Rongrong, Li Shangping, and Sun Xiuhua. 2006. Experimental research on influence factor of cutting-force of sugarcane harvest machine. Journal of Agricultural Mechanization Research. 7: 128-132.

Liu Qingting, Qu Yinggang, and Qing Shangle. 2006. Cutting force calculation of sugarcane stalk. Transactions of the Chinese Society for Agricultural Machinery. 37(6): 89-92.

■■

Design, Development and Performance Evaluation of Rota Drill

by

Muhammad Yasin
Director,
Agricultural Mechanization
Research Institute
(AMRI), Multan,
PAKISTAN

Muhammad Anjum Ali
Director of Agriculture
(Adaptive Research),
Punjab Lahore,
PAKISTAN

Abstract

The rota drill was been designed to promote line sowing, ensure timely planting of wheat and to save fuel cost and energy because it takes only one pass of a tractor to complete the operation in the field. Agronomic data recorded during field testing with respect to germination count/m^2, number of tillers/m^2 and root development (cm) revealed that the rota drill performed better, produced 3.4 % higher germination, 28.3 % more tillers and 4.12 % higher root growth than the wheat grown through conventional methods. Weed infestation was also targeted significantly through this innovation and 36.72 % less weeds were recorded in rota drill wheat plots. The cost of planting wheat was calculated around US$ 8.17/ha. Thus, this cost of planting was 500 % less than conventional planting. The data pertaining to man-hour/ha also supported significant savings of 512 % less than the conventional planting.

Introduction

Wheat is the staple food in Pakistan and its per capita consumption is around 126 kg/annum. With the burgeoning increase in population, the demand of this grain crop is increasing to feed the increasing mouths. Efforts are underway to enhance the production of this crop through increase in per hectare yield. In the past, Pakistan fell in the list of those countries who fulfilled their food requirement through import of wheat, but now Pakistan has attained a self sufficient level in wheat production. During the year 2004-05, Pakistan increased its wheat production by 8.97 % as compared to previous years, but yield per hectare was still very low as compared to the international level (Agri. Stat., 2005).

The low yield per hectare of wheat was due to late sowing, improper seedbed preparation, inaccurate planting method, excessive weeds, improper use of fertilizer and shortage of irrigation water. The major impediment to enhance its yield was the delay in planting because a significant area of this crop comes after the rice crop on an area around 1.74 million hectares in Punjab (Yasin *et al*., 2005). The major rice variety is basmati (over 65 %), which matures in the last fortnight of October or early November. Therefore, there is only a short period for the timely planting of wheat and follow the proper practices. The common wheat planting method in rice growing areas is broadcasting of seeds, which is not an appropriate method. Line sowing is desirable since it results in more even seed spacing, accurate depth of planting and proper space for weeding. In comparison with broadcasting of seeds, line sowing, i.e. seed drill method, gives higher yield because of the greater uniformity of seed distribution and seeding depth. A higher germination and more uniform crop-stand were found in the seed drill method. (Khan & Salim, 1981)

The sowing of wheat at the proper time has a significant contribution to achieve higher yield. Early sowing of wheat gives proper time and temperature for seed germination, tillering, grain formation and proper maturity. In late sowing, low temperature effects seed germination that gets delayed. Furthermore, there is less time available for proper growth and tillering of plants. Experiments have shown that sowing of wheat after November 15 decreased yield by 37 kg/ha/day, despite better management and use of proper inputs (Khan & Salim, 1981). Weeds rob crop plants of nutrients and water and serve as hosts to insects and pests. Weeds affect yield by 12 to 35 % (Ahmed *et al*., 1998). Sowing of wheat at the proper time gives higher yield per hectare, better seed germination, proper growth of plants and less attack of diseases (Bajwa *et al*., 1987 and Nayyar *et al*., 1999). The delay of sowing wheat normally occurs in the East and South districts of the Punjab where rice and cotton crops are grown, respectively, because the harvesting of rice and cotton delays the availability of fields for the tillage operations required for field planting preparation.

The rice fields are not properly prepared for sowing of wheat at the appropriate time due to either higher moisture contents or dried soil, which requires fresh irrigation for performing tillage operations. The fresh irrigation delays seedbed preparation for at least 20 to 30 days. The preparation of a rice stubbled field with tillage implements to achieve accurate soil tilth is a time and energy demanding process (Yasin *et al*., 2005). Tillage operations are generally performed to break up and pulverize the soil to allow the free movement of air and water in order to promote plant growth. Excessive pulverization by means of heavy equipment is, however, detrimental to soil structure and produces soil compaction (Kepner *et al*., 1982).

In recent years there has been increased interest in minimum tillage systems as a means of reducing crop production costs and improving soil conditions. Therefore, the performance evaluation of tillage implements is important in order to achieve required soil pulverization with reduced input cost (Yasin *et al*., 1997). A zero tillage technology was introduced in the field to solve the problems of heavy cost for tillage operation and delayed planting of wheat in rice areas (Yasin *et al*., 2005). Some negative impacts of zero tillage technology like increase in soil density, reduce infiltration rate and pore space, and increase incidence of weeds and insect propagation were noticed in the field (Sidhu & Byerlee, 1992; Ashraf *et al*., 2006).

The optimum solution to overcome the problems discussed above is the minimum tillage equipment along with planting units that enable the sowing of wheat immediately after harvesting of rice. In order to achieve this objective and adapt resource conservation technology the Agricultural Mechanization Research Institute, Multan, has designed and developed a Rota Drill to achieve the following objectives.

i. To replace conventional broadcasting wheat sowing with drill sowing.
ii. To ensure timely sowing of wheat just after rice harvest by utilizing the residual moisture.
iii. To uproot and shred the stubbles to avoid spread of stem borer and incorporate organic matter into the soil.
iv. To perform two operations in a single pass of the tractor in order to save time, fuel and energy.

Development of Rota Drill

The rota drill is a combination of modified rotavator and seed drill, which can be easily attached and detached (**Figs. 1** & **2**). It is 1,200 mm long, 2,640 mm wide and 1,300 mm high. The rotavator can be used independently without seed drill, when required.

Rotavator

Two rotavators of 1,524 and 2,388 mm width with 36 and 54 blades, respectively, are commonly used in the field. The 1,524 mm rotavator was modified and used in the rota drill. The modification was done to increase its working width while maintaining the appropriate number of blades to decrease its draft force. The width of the rotavator was increased from 1,524 mm to 2,388 mm, the rotor shaft plates were increased from 7 to 10 and blades per plate was decreased from 6 to 4. The shaft rpm was enhanced by 24.5 % by changing the location of gears. The rotor shaft was a seamless steel pipe having an outer diameter of 88 mm and wall thickness of 9 mm with a forged axle of 60 mm diameter. Ten M.S. circular

Fig 1. Rota drill - A combination of rotavator and seed drill

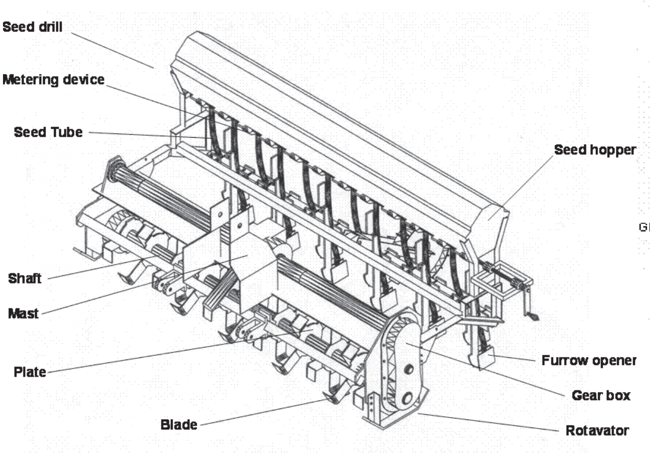
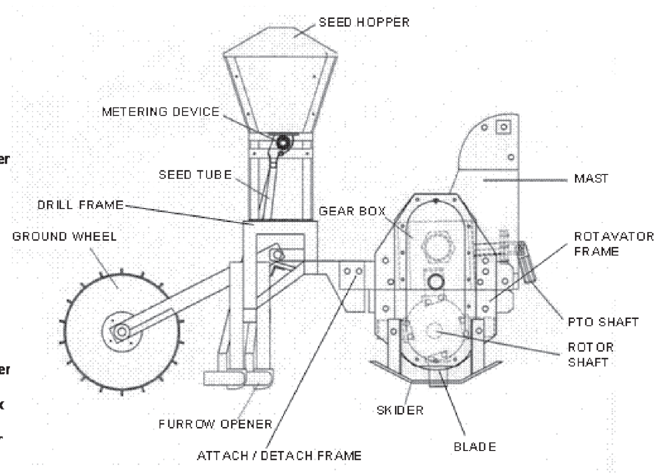


Fig 2. Side view of rota drill showing detail of parts



plates of 12 mm diameter each were fitted on the rotor shaft at a space of 250 mm for mounting of 4 blades on each plate. Thirty six L- shaped alloy carbon steel blades were used. The power transmission system consisted of three steel gears of 25, 28 and 30 teeth.

Seed Drill

The common wheat seed drill with improved furrow opener of inverted T-type with cover plates was mounted on the modified rotavator. The width of seed drill was matched with the width of rotavator and the seed hopper was also improved. The weight of the wheat drill was reduced from 300 to 200 kg. The seed hopper with a capacity of 125 kg was made of M.S. sheet 38 × 38 × 5 mm. The seed metering devices were fluted type fitted underneath the seed hopper. There were 12 furrow openers at 228 mm spacing. The power transmission system consisted of 15 and 30 teeth gears and a ground wheel of 450 mm diameter.

Materials and Methods

The rota drill was designed and developed at AMRI workshop in 2004. The design was based upon the combination of modified rotavator and seed drill. The prototype was fabricated at the same workshop using available materials, techniques and facilities. The rota drill was tested in the field and necessary modifications were incorporated to improve its performance. The final version of the rota drill was tested in the field during 2005 (**Figs. 3a** & **b**). The testing was jointly conducted by the engineers and scientists of AMRI and Adaptive Research of the Government of the Punjab. The drill was tested in the rice stubbled field of Gujranwala along with the conventional method of wheat sowing. The experiment was conducted at a farmer's field in Songowal village and the Agriculture Adaptive Research Farm, Gujranwala. The conventional method of wheat planting was land preparation with tillage implements plus planting with a common seed drill. The data for seedbed preparation, seed germination, tillering, root development, weeds, man-hr and operational cost were collected. The machinery used for seed bed preparation were a Massey Ferguson MF 375 Tractor of 75 hp, disc harrow with 18 discs, cultivator with 13 tines, sohaga and seed drill with 13 tines.

Results and Discussion

The operation of the rota drill in the rice stubbled field gave 82.0 % and 3.37 % completely chopped and partially chopped stubbles, respectively. The stubbles uprooted but no chopped and partially uprooted were 10.11 % and 4.49 %, respectively. The data are presented in the **Table 1**. There was no intact stubbles left in the field and the soil was completely tilled and pulverized. The depth of tilled soil was 51 mm to 76 mm as compared to that of a field prepared with conventional tillage implements with a tilled depth of 76 mm to 101 mm. The shallow tilled depth did not effect the seed germination and root development. The significant effect of this shallow depth cultivation was found on implement draft, time of cultivation and fuel consumption.

The seed germination, tillering and weed data collected in the field are presented in the **Table 2**. The average germination count for two sites for three replications was 163 and 158 per m^2 for rota drill and conventional planting plots, respectively. The conventional planting method was land preparation with tillage implements plus planting with a common seed drill. The numbers of tiller per m^2 of two sites for the rota drill and conventional planting plots were 526 and 408, respectively. The number of tiller per m^2 for the rota drill was 28.3 % higher than that of conventional planting

Fig. 3a Testing of rota drill in rice stubbles field

Fig. 3b Condition of rice stubbles field after the operation of rota drill

and this may be due to the contribution of non destruction of lower pore spaces already established in the field due to the roots of the previous crop. The pore spaces caused better water movement and aeration of crop roots. The root development was almost equal for the rota drill and conventional planting plots. The number of weeds per m^2 of the two sites was 53 and 83 for rota drill and conventional planting plots, respectively. The weeds were 36.7 % higher in conventional planted plots.

The results for tillers and weeds per hectare of both the sites showed significant effect of the rota drill treatment as compared to conventional planting. The germination count and root development of both sites showed a non significant effect for the rota drill treatment.

The operational costs of the machines/implements used in the experiment are given in the **Table 3**. The cost and man-hr spent for seedbed preparation and planting of one hectare of wheat with the conventional method and with the rota drill are given in the **Table 4**. The cost incurred for tillage operations was US$ 43.48 per hectare and planting cost with the seed drill was US$ 5.61 per hectare. The man-hr required was 5.42 per hectare for seedbed preparation and with the seed drill operation it was 0.70 per hectare.

The cost for cultivation of one hectare of wheat with the rota drill method was US$ 8.17 per hectare which was 500 % less than the conventional. The man-hr for the rota drill operation was 512 % less as compared to the conventional method. There was a direct saving of US$ 43.48 per hectare for eliminating the tillage operations.

The use of the rota drill facilitated early planting of wheat in a rice stubbled field in addition to time, fuel and cost saving. The early planting helped increase yield per hectare. The rota drill easily and quickly off-sets the existing energy consuming practices of planting wheat in a rice stubbled field and substitutes those with resource conservation technology of minimum tillage plus accurate line sowing.

Summary

The rota drill is a combination of modified rotavator and seed drill. The rota drill was tested and demonstrated in the rice stubbled field in

Table 1 Field condition of rice stubbles per m^2 after the operation of rota drill

Observation	stubbles (nos.)	Completely chopped stubbles (Nos.)	Partially chopped stubbles (Nos.)	Uprooted & not chopped stubbles (Nos.)	Partially uprooted stubbles (Nos.)
I	19	16	1	1	1
ii	18	13	0	3	2
iii	18	15	0	3	0
iv	15	13	1	1	0
v	19	16	1	1	1
Average	17.8	14.6	0.6	1.8	0.8
Percentage		82	3.37	10.11	4.49

Table 2 Wheat Seed germination, tillers, root development and weeds for rota drill and conventional planting

Replications	Treatments			
	Site No.1		Site No.2	
	Rota Drill	Conventional planting	Rota Drill	Conventional planting
A. Germination Count/m^2				
R1	174	166	147	142
R2	164	181	170	156
R3	186	156	143	149
Average	174	167	153	149
Percentage (+3.43)	4.19	-	2.68	-
B. Number of Tillers/m^2				
R1	590	400	502	424
R2	599	432	453	355
R3	597	526	418	313
Average	595	452	457	364
Percentage (+28.3)	31.6	-	25.0	-
C. Numbers. of weeds/m^2				
R1	55	84	69	85
R2	56	84	47	79
R3	66	95	25	74
Average	59	88	47	79
Percentage (-36.72)	−32.95	-	−40.50	-
D. Root Development, cm				
R1	12.83	11.28	14.49	14.05
R2	12.47	12.71	15.6	15.14
R3	15.36	12.57	13.23	15.50
Average	13.55	12.18	14.44	14.89
Percentage (+4.12)	11.24	-	−3	-

Site 1: Farmer field songowal, gujranwala. Site 2: A.R. farm gujranwala rota drill without land preparation. Seed drill with land preparation

district Gujranwala of Punjab Province. The operation of the rota drill in the rice stubbled field gave 82 % completely chopped stubbles, 3.37 % partially chopped stubbles and 10.11 % uprooted but not chopped stubbles.

The cost for planting of one hectare of wheat with the conventional planting method was US$ 49.08 which was 500 % higher than that of the plot planted with the rota drill. The cost for planting one hectare wheat with the rota drill was US$8.17. The man-hr required for the rota drill planting method for one hectare was 512 % less than that of required for the conventional planting method.

The operation of the rota drill for wheat planting did not effect seed germination and root development, but significantly reduced the draft force, time of operation and fuel used. The tillers per m^2 for rota drill plots were 28.3 % higher as compared to that of the conventional planting plots. The weeds per m^2 were 36.7 % less in the rota drill plots than in the conventional planting plots.

The rota drill helped in advancing the sowing of wheat, and saved time and energy required for the tillage operation to prepare a seed bed. The rota drill encouraged timely sowing of wheat, promoted use of drill sowing and adapted resource conservation technology in a rice stubbled field for sowing of wheat crop. There was a direct saving of US$ 43.48 for planting one hectare of wheat with the rota drill due to eliminating the tillage operations.

Table 4 Cost and man-hr for planting one hectare wheat in rice stubble field

Machines/ Implements	Field Capacity ha/hr	No. of passes of implement	Man-hr/ha	Operational cost	
				($/hr)	($/ha)*
A. Seed drill with land preparation					
Tractor MF-375, (75hp)	-	-	-	7.89	-
Disc Harrow (18 discs)	1.21	2	1.66	0.33	13.59
Cultivator (13 tines)	1.21	2	1.66	0.10	13.20
Sohaga (3,050mm)	1.42	3	2.10	0.01	16.69
Sub Total	-		5.42		43.48
Wheat drill (13 tines)	1.42	1	0.70	0.08	5.61
Total			6.12		49.08
B. Rota drill without land preparation					
Tractor MF 375 75hp	-	-	-	7.89	-
Rota Drill	1.00	1	1.00	0.28	8.17

* Implement operational cost including tractor operational cost

Table 3 Operational cost of the machines/implements used in the experiment

Description	Tractor MF 375 (75 hp)	Cultivator (13 tines)	Disc harrow (18 discs)	Sogha (3,050mm)	Wheat drill (13 tines)	Rota drill (10 tines)
Purchase cost, P ($)	8,672.13	426.23	1,393.44	32.79	327.87	1,147.54
Useful life, L (Year)	10	5	8	5	4	4
Useful life (hr)	10,000	5,000	4,000	2,000	4,000	4,000
Annual use, AU (hr)	1,000	1,000	500	400	1,000	1,000
Salvage value @ 10 % of purchase cost, S ($)	867.21	42.62	139.34	3.28	32.79	114.75
Depreciation ($/hr)	0.78	0.077	0.314	0.015	0.074	0.258
Interest @ 10 % ($/hr)	0.48	0.023	0.153	0.005	0.018	0.063
Tax, Insur., Housing @ 2% ($/hr)	0.17	0.009	0.056	0.002	0.007	0.023
Total fixed cost ($/hr)	1.43	0.109	0.523	0.021	0.098	0.344
Repair cost ($/hr)	1.04	0.051	0.167	0.004	0.039	0.138
Fuel consumption (Lit/hr)	8.50	-	-	-	-	-
Fuel cost @ US$ 0.65/lit., ($/hr)	5.57	-	-	-	-	-
Labour charges ($/hr)	0.24	-	-	-	-	-
Total operating cost ($/hr), R10 + R12 + R13	6.85	0.051	0.167	0.004	0.039	0.138
Total cost, R10 + R14 ($/hr)	7.89	0.1	0.33	0.01	0.08	0.28

Depreciation = [(P-S)/L] / AU, Interest Taxes, Insur & Housing = [{(P+S)/2}*i%] / AU, Repair cost = [(P × CF / 100) × AU],
Where: i = interest rate, insurance, taxes & housing rates. P = Purchase cost ($), S = Salvage value ($),
AU = Annual Use (Yr), CF = Repair & Maintenace cost factor ($), Pak. Rs 1 = US$ 61

REFERENCES

Agriculture Statistics of Pakistan. 2004-05. Federal Bureau of Statistics, Ministry of Food, Agriculture and Livestock, Govt. of Pakistan, Islamabad.

Ahmed, M. Y., S. Hussain, N. Ahmed, and M. R. Ahmed. 1998. Grain yield and nutrient losses by weed infestation in wheat. Agric. Res. 36(2): 159-64.

Ashraf, M., M. Yasin, R. Rehman, and M. Hassan. 2006. Performance evaluation of spade cultivator. International conference on Agricultural Engineering; issues and strategies, Feb. 16-18, 2006, Faisalabad Pakistan.

Bajwa, M. A., N. I. Khan, S. H. Khan, and F.A. Khan. 1987. Effect of date of planting on the grain yield and size of wheat cultivators. J. Agric. Res.25(1): 35-43.

Hunt, D. 1977. Farm power and machinery management 6th Ed. National Book Store, Inc, Cor. Soler St. Marula.

Khan, A and M. Salim. 1981. Grain yield as influenced by seeding dates in wheat in NWFP. Pak. J. Agri. Res. (7): 14-9.

Kepner, R. A., R. Bainer, and E. L. Barger. 1982. Principles of farm machinery 3rd Ed. Avi publishing company, Inc., West Port, CT.

Nayyar, M. M., G. Habib, and M. Naseem. 1999. Report on minimum/no-till technology for successful cultivation of wheat after rice and cotton in Punjab (Pakistan). Directorate of Agronomy, Ayub Agricultural Research Institute, Faisalabad.

Sidhu, D. S., and D. Byerlee. 1992. Technical Change and Wheat Productivity in the Indian Punjab in the Post-Green Revolution. CIMMYT Economics Working Paper 92-02 Mexoco, D.F: CIMMYT.

Wahid, M. A., M. A. Cheema, M. A. Malik, and H. Z. Khan. 2006. Wheat Cultivation-in the light of Modern Recommendation. Zari Digest. Sep-Nov. 2006. University of Agriculture, Faisalabad.

Yasin, M, M. A. Ali, and M. Hassan. 1997. Comparative performance of Mould Board, Chiesel and Para plows. J. Agric; Res; 35(3): 189-195.

Yasin. M, M. Faqeer, M. F. Sher, B. A. Bajwa, and T. Hussain. 2005. Mechanized Farming of Wheat Crop to Enhance per acre Yield. Syndicate Report 12th In-Service Training Course (2005). Government Engineering Academy Punjab, Lahore.

■■

Effect of Seedlings Age on Performance of Rice Transplanter

by
Aswini K. Goel
Associate Professor
College of Agricultural Engineering & Technology,
Orissa University of Agricultural & Technology,
Bhubaneswar-751003
INDIA
aswinigoel@yahoo.com

S. Swain
Professor
College of Agricultural Engineering & Technology,
Orissa University of Agricultural & Technology,
Bhubaneswar-751003
INDIA

Debaraj Behera
Associate Professor
College of Agricultural Engineering & Technology,
Orissa University of Agricultural & Technology,
Bhubaneswar-751003
INDIA

Abstract

Three rice transplanters, namely OUAT, CRRI and Yanji, were evaluated in sandy loam soil conditions in the Central Farm, OUAT, Bhubaneswar, with four levels of seedlings 15, 20, 25 and 30 days old. Transplanters were evaluated with respect to number of seedlings per hill, missing hills, floating hills, mechanical damaged hills and hill mortality and the data were analyzed in accordance with a split-plot experimental design. It was found that 20 day old seedlings were most suitable for all the transplanters under study.

Introduction

Rice (*Oryza sativa*) is one of the major cereal crops cultivated in more than 110 countries in the world with a total production of 527 million tones, out of which 78 % is contributed by major rice growing countries of Asia. India is the largest grower of rice in the world in terms of area with 44.97 million hectare and an annual production of 89.4 million tonnes at an average yield of 1,990 kg/ha (Anon, 1999). However, it ranks second to China in terms of production.

Rice is grown either by direct seeding, i.e. broadcasting, drilling, sowing or transplanting. Many comparative studies have been conducted to compare transplanting and direct seeding. In India, higher and more stable yield was obtained from transplanted rice than direct seeded rice. In most provinces of India, transplanted rice had 10 to 20 % higher yield than broadcasted rice (Garg *et al.*, 1997). Besides, transplanting has some added advantages as compared to direct seeding, i.e. better water and weed control, uniform ripening and less lodging. Also the transplanted rice occupies the field less time than the direct seeded rice and facilitates control of weeds effectively. In Orissa, the yield increased by 22.2 % over the direct seeding methods. In Orissa 2,241,000 ha is under broadcasting and 1,639,000 ha is under transplanting. This may be due to varying socio-economic conditions of the people, non-availability of labour at peak transplanting seasons and non-availability of suitable transplanting machines. Timeliness of transplanting is essential for optimizing the yield and this can only be achieved through mechanical transplanting. A delay in transplanting by one month reduces the yield by 25 % and a delay of two months reduces the yield by 70 % (Rao and Pradhan, 1973). Manual transplanting of paddy requires about 300-350 man-hours per ha. In spite of the huge labour requirement, plant to plant and row to row spacing are not achieved and hence mechanical weeding is not possible. So, it is high time for mechanizing the transplanting operation. Mechanical transplanting needs a suitable transplanter and performance of the transplanter depends on nursery mats with a particularly density of seedlings, thickness of mats and seedlings age. The aim of this present study is to optimize the age of seedlings for proper functioning of the transplanters.

Materials and Methods

The specifications of the transplanters used in the experiment are presented in **Table 1**.

Nursery Raising

A mat type nursery was raised on a field adjacent to the experimental plot in order to minimize the transportation time. The field preparation

Table 1 Specification of transplanters

Specification.	OUAT transplanter	CRRI transplanter	Yanji transplanter
Type of machine	Manual	Manual	Power operated 2.4 kW air cooled diesel engine
Manufacturers address	Kalinga Engineers, Bhubaneswar	CRRI, Cuttack	Yanji Rice transplanter plant, peoples Republic of China
Model	Ajit	-	2ZT-238-8
Overall dimensions, cm			
Length	130.0	127.0	241.0
Width	94.5	117.0	213.1
Height	62.5	62.0	130.0
Weight, kg	28.0	22.5	320.0
Type of float	Modulated plastic	GI sheet	Fiber glass
No. of rows	4	4	8
Row spacing, cm	20.0	24.0	23.8
Finger			
Type	Fixed fork	Fixed fork	Fixed fork
Length, mm	140	120	130
Width, mm	11	17	10
Gap, mm	5	11	5
Width of seed-ling gate, mm	20	14	17

Table 2 Performance of different transplanters with four levels of seedlings age

Treatments	Seedlings age, days	No. of seedlings/ hill	Missing hills, %	Floating hills, %	Mechanical damaged hills, %	Hills mortality rate, %
OUAT transplanter (T_1)	15	3.23	4.85	2.71	6.82	12.57
	20	3.97	4.78	1.02	0.63	2.92
	25	4.57	6.94	1.24	1.51	4.09
	30	5.37	7.11	2.35	2.56	6.35
CRRI transplanter (T_2)	15	5.57	7.06	4.50	7.78	16.24
	20	6.67	6.38	3.23	4.69	15.65
	25	7.07	8.82	5.11	7.56	16.69
	30	7.53	10.51	5.16	5.32	16.88
Yanji transplanter (T_3)	15	3.13	4.99	2.08	6.2	11.11
	20	3.53	4.97	1.04	4.92	7.54
	25	4.3	5.69	1.64	5.54	9.33
	30	5.33	7.92	1.98	5.75	11.76

Table 3 ANOVA of the dependent parameters studied

Sources of variation	Degrees of freedom	F_{cal}				
		No of seedlings/ hill	Missing hills	Floating hills	Mecha-nical damaged hills	Hills mortality
Replication	2	0.380	1.630	0.155	2.819	0.975
Mainplot	2	208.107^{**}	39.636^{**}	847.489^{**}	71.945^{**}	42.164^{**}
Subplot	3	71.958^{**}	38.188^{**}	59.097^{**}	36.994^{**}	4.448^{*}
Interaction	6	1.258	1.922	10.920^{**}	12.726^{**}	1.945

F_{cal}: Calculated F value

was similar to that of conventional nursery raising and was ploughed thrice by a bose plough and leveled by planking. The field was left as such for one day and water was drained out from the field. Polythene sheet of 50-60 gauge of 1.0 m × 10.0 m was spread over the leveled field. Polythene sheets 75 sq. m/ha were used for preparation of nursery, keeping a 50 cm gap between beds. Small perforations were made randomly on the sheets to bring out entrapped air and water under the sheets. A prefabricated wooden frame 1.0 m × 2.0 m × 2.0 cm was placed over the sheet. Puddled soil was filled inside the frame from two sides of the bed in such a way that the soil became free from any stone, stubble and grass. The soil in the frame was then leveled with the help of a wooden bar. Thereafter, the frame was removed and similar procedure adopted to complete the beds (**Fig. 1**). Sprouted seeds of swarna variety, at 45 kg/ha, were spread uniformly over the bed. To protect from birds and rain, the beds were covered with paddy straw. Water was sprinkled twice a day till complete emergence of seedlings. After four days the straw was removed from the beds and standing water was maintained in the bed. Nursery beds were prepared at an interval of 5 days so that, at the time of transplanting, seedlings of different age groups were available. The seedling mats were cut as per the respective tray size of the transplanters (**Fig. 2**).

Transplanting was conducted in a prepared field after 36 hours of puddling with each age group of seedlings (**Fig. 3** to **5**). The Yanji transplanter was set at 12 cm row to row spacing and 3.0 cm depth of planting. The number of seedlings per hill, missing hills, floating hills, mechanical damaged hills and hill mortality were recorded for each transplanter.

The experiments were conducted using split-plot experimental design. The main plots were three different transplanters, namely OUAT transplanter (T_1), CRRI transplanter (T_2) and Yanji transplanter (T_3), while the sub-plots were the age of seedlings such as 15, 20, 25 and 30 days. Each treatment was replicated thrice.

Fig. 1 Nursery bed preparation

Fig. 2 Seedlings ready for transplanting

Fig. 3 OUAT transplanter in operation

Fig. 4 CRRI transplanter in operation

Fig. 5 Yanji transplanter in operation

Fig. 6 Effect of seedlings age on number of seedlings/hill

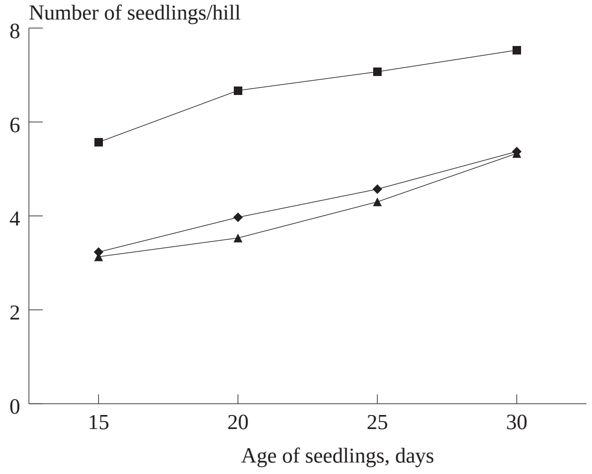


Fig. 7 Effect of seedlings age on missing hills

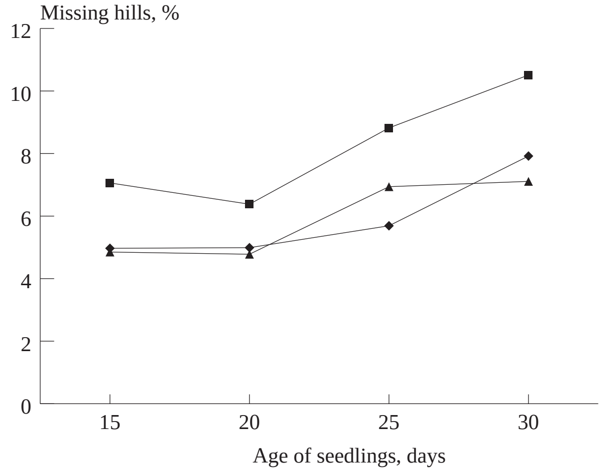


Fig. 8 Effect of seedlings age on floating hills

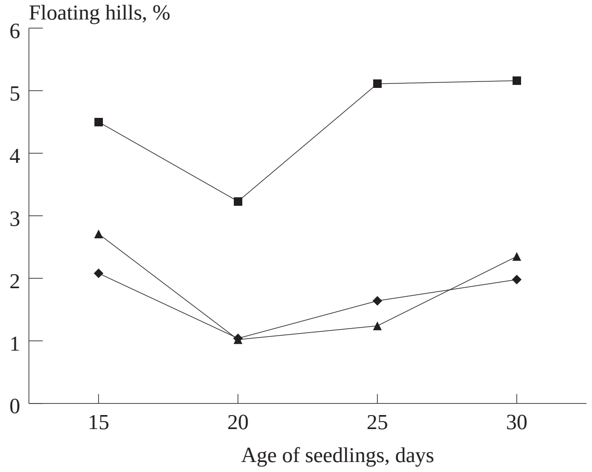


Fig. 9 Effect of seedlings age on mechanical damaged hills

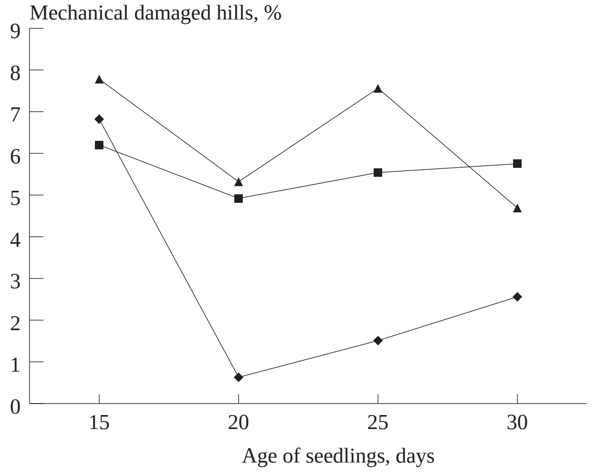
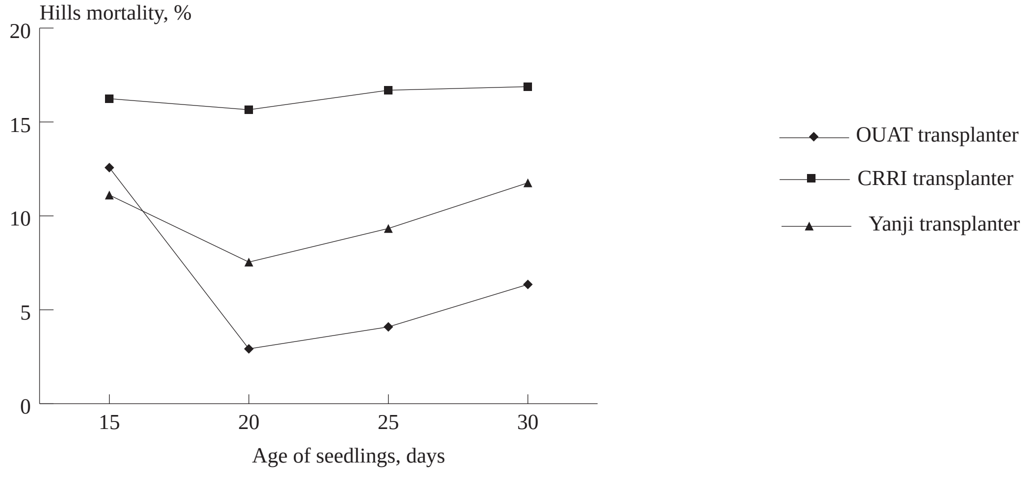


Fig. 10 Effect of seedlings age on mortality of hills



Results and Discussion

The performance of OUAT, CRRI and Yanji rice transplanters with respect to the dependent parameters like number of seedlings per hill, missing hills, floating hills, mechanical damaged hills and hills mortality rate were studied and the data were analysed in accordance with split plot design of experiments. The results obtained are presented in **Table 2**. The analysis of variance (ANOVA) of the above parameters is presented in **Table 3**.

Number of Seedlings Per Hill

The mean number of seedlings per hill varied from 3.23 to 5.37 for the T_1 (OUAT transplanter), 5.57 to 7.53 for the T_2 (CRRI transplanter) and 3.13 to 5.33 for the T_3 (Yanji transplanter) when seedling age varied from 15 to 30 days. The numbers of seedlings per hill increased with the increase in seedling age from 15 to 30 days for all transplanters (**Fig. 6**). This might have been due to the fact that the entanglement of roots of seedlings increased with the increase in seedlings age and more seedlings were pulled along with the detached seedlings. The results are in accordance with the studies conducted at various institutes (Garg *et al*., 1982; Swain and Maity, 1989 and Behera, 2000). The desired number of 3 to 4 seedlings per hill were obtained for T_1 and T_3 for 15 as well as 20 day old seedlings. For T_2, the number of seedlings was in the range of 5.57 to 7.53 for the same range of seedling age. This was due to the fact that, the wider finger gap (11 mm) of T_2 picked more seedlings in each stroke. The effect of transplanters (main-plot) and age of seedlings (sub-plot) on the number of seedlings per hill were found to be highly significant. However, the interaction of transplanters and seedling age on number of seedlings per hill was insignificant.

Missing Hills

The average percentage of missing hills were in the range of 4.78 to 7.11, 6.38 to 10.51 and 4.97 to 7.92 for treatments T_1, T_2 and T_3, respectively, at various seedling age under study. The minimum missing hills was with 20 day old seedlings but it then increased for 25 and 30 day old seedlings in all the treatments (**Fig. 7**). The reason may have been due to development of thicker stem and more roots in older seedlings that stuck firmly in finger gaps and did not release in soil. Similar results have been reported in the study conducted at Bangkok (Singh *et al*., 1985). The missing hills were found to be at par with 15 and 20 day old seedlings for all the transplanters. Studies on modification and testing of a manual rice transplanter in Bangkok indicated the similar results (Singh and Hussain, 1983). The effect of transplanters as well as seedling age on missing hills were highly significant while their interaction was insignificant.

Floating Hills

The average percentage of floating hills was in the range of 1.02 to 2.71, 3.23 to 5.16 and 1.04 to 2.08 for T_1, T_2 and T_3 respectively, at various seedling age varying from 15 to 30 days. The maximum floating hills was 15 day old seedlings for T_1 and T_3 while the same was observed for T_2 with 30 day old seedlings. The minimum floating hills was 20 day old seedlings for all the transplanters. But the percentage of floating hills increased with increase in seedling age from 20 to 30 days in all the transplanters (**Fig. 8**). The reason may have been due to the fact that, the older seedlings are picked at the root and they tend to fall before entering into the soil due to their higher weight resulting a higher floating hills. This result was in accordance with the studies conducted by Singh *et al*. (1985). Also, highest floating hills for T_1 and T_2 at 15 day old seedlings may be due to improper anchorage of seedlings in both fingers and soil for the lower root growth while higher floating hills with T_2 was observed at all seedling age due to absence of releaser. The effect of transplanters as well as seedling age on floating hills was highly significant. The interaction of transplanters and seedling age on floating hills was also found to be highly significant.

Mechanical Damaged Hills

The mean percentage of mechanical damageded hills was observed to be in the range of 0.63 to 6.82, 4.69 to 7.78 and 4.92 to 6.20 % for treatments T_1, T_2 and T_3, respectively, at various seedling age of 15 to 30 days. The highest mechanical damage was observed with the lowest seedling age of 15 days for all the transplanters (**Fig. 9**). This might have been due to the tenderness of the stems and roots at this age. The mechanical damage was minimum for 20 day old seedlings for all the transplanters. This might have been due to the optimum stem and root thickness that can sustain the impact force of fingers. The percentage of damaged hills increased from 1.51 to 2.56 in T_1 and 5.54 to 5.75 in T_3 for 25 and 30 day old seedlings, respectively. But, the same was reduced from 7.56 to 5.32 % for T_2 and this might have been due to its wider finger gap. But, in case of T_1 and T_3, the higher percentage of damaged hills at higher seedling age was because of thicker stems and more roots of the older seedlings, which sometimes stuck in the finger gap firmly and did not release in soil and, in subsequent strokes, got damaged. Studies conducted at Bangkok also indicated similar results (Singh and Hussain, 1983). The effect of both transplanters and seedlingage on mechanical damage of hills was highly significant. The interaction of transplanters and seedling age on mechanical damaged hills was highly significant.

Mortality of Hills

The mean mortality of hills varied from 2.92 to 12.57, 15.65 to 16.88 and 7.54 to 11.76 % in treatments T_1, T_2, and T_3, respectively, with different age of seedlings (**Fig. 10**). The minimum percentage of hill mortality was observed for 20 day old seedlings in all the transplanters. This may be due to the minimum percentage of unproductive hills (damaged hills + floating hills) with 20 day old seedlings for all transplanters. The highest percentage of mortality was achieved with smaller seedlings of 15 days under T_1, while the same was at par with 15 and 30 day old seedlings under T_2 and T_3. Mortality of hills in all transplanters decreased as seedling age increased from 15 to 20 days and then increased as seedling age increased from 20 to 30 days. This might have been due to the fact that, at lower and higher age of seedlings, mechanical damage was maximum. Studies conducted in Pakistan during evaluation of a rice transplanter with different age of seedlings also indicated similar results (Mufti and Khan, 1995). The percentage of hill mortality was found to be within 10 % for T_1 and T_3 for 20 day old seedlings but was higher than 15 % for T_2 at all four levels of seedling age and this might have been due to higher percentage of unproductive hills obtained with this transplanter. The effect of transplanters on mortality of hills was highly significant while the effect of seedlings age on hill mortality was significant at the 5 % level. The interaction of transplanters and seedling age on hill mortality was insignificant.

Conclusion

i. The desired number of 3 to 4 seedlings per hill was achieved with T_1 and T_3 for 15 and 20 day old seedlings. Higher number of seedlings per hill (5 to 8) was observed with T_2 at different levels of seedlings age.

ii. Minimum missing hills was recorded with 20 day old seedlings in all treatments. Missing hills of T_1 and T_3 with 15 and 20 day old seedlings was found to be with in the allowable limit of 5 %. But, in case of T_2, a higher percentage of missing hills (6 to 11 %) was observed at various levels of seedling age

iii. Minimum floating hills and damaged hills were observed with 20 day old seedlings in all the transplanters.

iv. Minimum mortality of hills was observed with 20 day old seedlings in all the treatments. Mortality of hills under T_1 and T_3 were below 8 % with 20 day old seedlings while a higher mortality of hills (more than 15 %) was observed with T_2 at all four levels of seedlings age.

It was concluded that 20 day old seedlings were most suitable for all the transplanters. Therefore, it was recommended that 20 day old seedlings may be used by the farmers of this region.

REFERENCES

Anonymous. 1999. FAO Production Year Book, Vol 53

Behera, B. K. 2000. Investigation on puddle soil characteristics in relation to performance of self propelled rice transplanter. Unpublished Ph. D Thesis. GBPUAT, Pantnagar.

Garg,I. K., C. P. Singh, and V. K. Sharma. 1982. Influence of selected seedling mat parameters and planting speed on performance of rice transplanter. AMA. 13(2): 27-33.

Garg, I. K., V. K. Sharma, and J. S. Mahal. 1997. Development and field evaluation of manually operated six-row paddy transplanter. AMA. 28(4): 21-28.

Goel, A. K. 2003. Evaluation of rice transplanters for adoption in Orissa, Unpublished Ph. D thesis, Utkal University, Bhubaneswar

Mufti, A. I. and A. S. Khan. 1995. Performance evaluation of Yanmar paddy transplanter in Pakistan. AMA. 26(1): 31-36 & 40.

Rao, M. V. and S. N. Pradhan. 1973. Cultivation Practices. Rice Production Manual, ICAR, 71-95.

Swain, S. and S. P. Maity. 1981. Field evaluation of Annapurna transplanter. AMA. 12(4): 16-18.

Singh, G. and U. K. Hussain. 1983. Modification and testing of a manual rice transplanter. AMA. 14(2): 25-30.

Singh, G., T. R. Sharma, and C. W. Bockhop. 1985. Field performance evaluation of a manual rice transplanter. J. Agric Engg. Res. 32: 259-268.

Development of a Motorized Stationary Sorghum Thresher

by
K. J. Simonyan
Agricultural Engineering Technology Programme,
College of Agriculture;
Ahmadu Bello University,
P M B 1058, Samaru-Zaria
NIGERIA
dr_simonyan@hotmail.com

Abstract

A motorized stationary sorghum thresher was developed and tested. The sorghum thresher had the following components: frame, hopper, threshing unit, sieve, reciprocating mechanism, blower and the collecting trays. The performance variables investigated were: threshing efficiency, cleaning efficiency and cleaning loss at six threshing speeds (2.64, 3.64, 4.4, 5.03, 5.78 and 6.28 m/s), six air speeds (3.67, 4.67, 5.17, 5.47, 7.33 and 8.33 m/s), five sieve oscillation speed (0.59, 0.88, 1.47, 2.05 and 2.64 m/s) and five feed rates (492.86, 521.43, 640, 720 and 740 kg/hr). A 3^4 factorial experiment in a completely randomized block design was used to study the effects and interactions of variables on the threshing efficiency, cleaning efficiency and cleaning loss. The threshing efficiency varied between 99.94 and 99.96 %, cleaning efficiency ranged between 94.35 % and 96.14 % and the cleaning loss varied between 6.5 % and 9.91 % at the average sorghum moisture content of 8 % wb. All the main factors and their interactions were not statistically significant for the threshing efficiency, cleaning efficiency and cleaning loss.

Introduction

Sorghum has a great potential both on the domestic and international markets due to its increasing demand for the production of food and feed products, alcoholic and non alcoholic beverages (Rohrbach, 2004). Sorghum, also, has a great potential as a source of starch used as raw material in different industries. However, it has been reported that the major constraints in producing excellent food products from sorghum is the lack of consistent supply of good quality grain for processing (Rooney, 2003). Mazvimavi (1997) classified threshing and winnowing of sorghum which accounts for 50 % of total labour used in the production as an arduous task.

Threshing, which is one of the most important post harvest operations involving the detachment of grain kernels from their panicle, is accomplished by impact of a fast moving element, rubbing, squeezing or a combination of these methods on the heads (Pickett and West, 1988). Traditionally, threshing of sorghum is manual involving beating the heads strenuously with sticks at the different spots in or near the farm. The threshing points may be bare ground, on tarpaulin in the field, stony or rocky areas and abandoned roads near the farm. Threshing is also accomplished by treading the heads under human feet or hooves of animals, or by rubbing between stones or wooden rollers (Simonyan, 2006). Ali (1986) classified manual threshing of sorghum as labour - intensive drudgery in terms of energy expenditure (41.87 KJ/min and heart beat rates/min of 150). Losses occur during threshing due to spillage, incomplete removal of grains from heads, damage to grain and contamination with sands and stones.

Mechanical threshers are designed using the same striking, squeezing and rubbing principles. ICRISAT (1978) conducted trials on various types of existing threshers and found that certain varieties of sorghum and millet are very difficult to thresh at moisture contents higher than 15 %. However, the genotypes used in the experiments were not specified. There are different types of threshing cylinders. Spike and loop threshers operate mainly on striking action while rasp bar threshes mainly by friction or rubbing. Singh and Kumar (1976) studied the effect of swinging hammer, spike-toothed and rasp bar cylinders on the threshing effectiveness and damage of wheat. The cylinder speed was found to be an important variable in the percentage of unthreshed and damaged grain. Increasing cylinder speed and decreasing concave clearance decreased the quantities of unthreshed grain, but increased grain damage and power requirement. They also published that the swinging hammer cylinder type consumed more power than the rasp bar and spike-tooth cylinder. Singhal and Thierstein (1987) published that the spike tooth and rasp bar cylinders are safe for use among the village farmers using manually fed stationary threshers. Spike-tooth and rasp bar cylinders have high threshing efficiency and low power consumption (Sarwar and Khan 1987). Dodds (1968) published that spike tooth cylinders have more positive feeding action and consume less power than the rasp bar. However, the rasp bar requires less maintenance (Singh *et al*., 1998 and Singh *et al*., 2001).

The threshing efficiency is related to the peripheral speed of cylinder. Threshing efficiency increases with increase in cylinder speed (Ige, 1978; Sharma and Devnani, 1980). Increasing cylinder speed means more impact between grain ear and revolving cylinder per unit time leading to grain damage (Harrison, 1975). Lamp and Buchele (1960) mathematically modeled the relationship between threshing forces, cylinder speed and concave clearance and found that threshing force was proportional to the square of peripheral cylinder speed and inversely proportional to concave clearance. This shows that peripheral cylinder speed has more effect on the threshing effectiveness than concave clearance.

$F = KV_c^2 / X$..................................(1)

Where

F = average threshing force, N

V_c = Peripheral cylinder speed, m/s

X = average concave clearance which is proportional to the distance through which impulsive accelerations caused by the impact occur, cm

K= constant

Adjustment of concave clearance is a crucial factor for the quality of threshing. From Lamp and Buchele (1960)'s model, threshing force is inversely proportional to concave clearance. This implies that there will be greater grain damage for closer concave clearance and less unthreshed grain. Crop feed rate is an important factor, affecting threshing efficiency (Simonyan and Oni, 2001). There is an optimum feed rate, excess of which causes blockage of threshing and separation system and a possible breakdown. A low feed rate would lead to a waste of time and money. Also, a higher than optimal feed rate increases the total grain loss. Feed rate increases with cylinder speed and spike length (Joshi and Singh, 1980). Power requirement for threshing has been found to increase with cylinder speed, feed rate and concave length. Large diameter and open grate concave reduces power requirement (Ghaly, 1985). Grain damage increases with increase in cylinder speed and decreases with increase in concave clearance, feed rate and moisture content (Joshi and Singh, 1980 and Ghaly, 1985). Grain loss increases with cylinder and blower speed (Kashyap and Pathak, 1976). The aim of this paper is to report on the development of a motorized conventional sorghum thresher.

Materials and Methods

Preliminary Investigation

Test Material

Samaru Sorghum 17 (SAMSORG 17) was used for the experiment. The seed was obtained from the Seed Multiplication Unit of the Plant Science Department, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

Sorghum used for the test was manually windrowed using a cutlass when the sorghum head was physiologically matured, when the black layer formation was complete and when it had reached its maximum dry weight (Nath and Johnson, 1983). Sorghum heads were manually detached from the stem with knives when the moisture content was about 20 % and sun dried until the moisture was convenient for threshing. **Fig. 1** gives an array of sorghum samples.

Equipment and Procedures

Moisture content of sorghum grain was determined using the procedure detailed by Henderson *et al*. (1997). The grain samples were dried at 130 ˚C for 18 hours (ASAE, 2003). The weight loss of the samples was recorded and the moisture determined in percentage. This was replicated three times. The moisture content was calculated as:

$MC_{wb} = [(W_i - W_d) / W_i] \times 100$.....(2)

Where

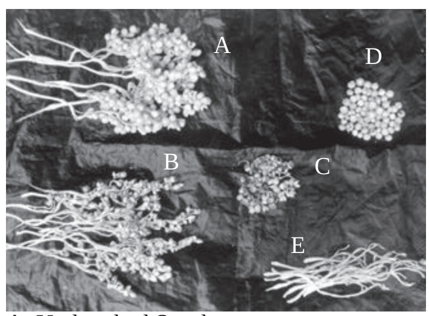
MC_{wb} = Moisture content, wet basis, %.

W_i = Initial weight of sample, kg.

W_d = Dried weight of sample, kg

Sorghum grain was conditioned to obtain different moisture contents in the range 8.89 and 16.50 % wb. This was obtained by rewetting the samples to a higher moisture content using the method given by Aviara *et al.* (2004). This method involved soaking 1 kg of sorghum grain in clean water for a given number of hours depending on the final moisture content desired. At the end of soaking, the sorghum grain were spread out in thin layer to dry in natural air in the room to enable

Fig. 1 An array of sorghum samples



A: Unthreshed Sorghum ear
B: Threshed Sorghum ear C: Chaff
D: Sorghum grain E: Stalk

stable and uniform moisture content to be obtained. The moisture content was determined for each day of the experiment. The moisture levels used for the experiment were 8.89, 10.87, 12.33, 14.56, and 16.50 % wb.

Micrometer screw gauge (Sheffied S 139 Br) with least resolution of 0.01 mm was used to determine the diameter of the sorghum grains. Three groups of 50 sorghum grains samples were drawn randomly from each moisture content level. From each group, 20 grains were picked randomly and were thoroughly mixed together from which 30 sorghum grains were randomly selected. The diameter of each individual sorghum grain was measured triaxially along the principal axis, major (L_1), intermediate (L_2) and minor (L_3). Its equivalent diameter D_e was calculated using the using equation 2 given by Ciro, 1997 (reported by Aseogwu *et al.*, 2006).

$D_e = (F_1 + F_2 + F_3) / 3$.................(3)

Where

F_1 = Arithmetic mean diameter = $(L_1 + L_2 + L_3) / 3$., mm.

F_2 = Geometric mean diameter = $(L_1 L_2 L_3)^{1/3.}$, mm.

F_3 = Square mean diameter = $[(L_1 L_2 + L_2 L_3 + L_3 L_1) / 3]^{1/2}$, mm.

The projected area of the samples was determined by tracing method as described by Oje and Ugbor (1991). The projected area was determined by tracing out the boundary on a linear graph paper and counting the number of square boxes the traced boundary covered.

The mass of sorghum samples were measured using an electronic mettler balance (Sarturlus 2,355, max 160 g, d = 0.001 g). Thirty replications were taken.

The volume of sorghum samples were determined by water displacement method as described by Oje (1993). The samples were put in a polyethylene bag attached to a thread and immersed in water inside a measuring cylinder (100 ml). The volume of the empty polyethylene bag was obtained with the aid of a sinker. Samples were placed in the polyethylene bag and immersed in the water. The volume of water displaced was measured. The volume of the sorghum samples was the difference in water level minus the volume of the polyethylene. The representative value of the volume of sorghum samples were taken as the average of thirty replications. The particle density of samples was determined by dividing the sample mass by the sample volume.

The Experimental Machine

Principle of Operation

The principle of operation of the sorghum thresher was as follows:

i. Sorghum head samples were fed manually into the hopper
ii. Crop samples flowed under gravity to threshing chamber where the impact of the revolving threshing cylinder threshed the grain.
iii. Threshed, unthreshed, partially threshed heads and some grains fell on the upper sieve.
iv. The reciprocation of the sieves created horizontal and vertical displacement, which moved straw to the front of the thresher to be discharged.
v. Air stream from the blower helped to disperse grain and straw which allowed grain to pass through upper sieve hole to lower sieve.
vi. As grain and chaff passed across air stream, the lighter materials were blown off, while clean grain was collected in collector compartments.

Operational Features

In view of the morphology-related machine performance constraints of sorghum, the following were considered in developing the sorghum thresher-testing rig:

(i) Develop a machine to thresh sorghum efficiently
(ii) Develop a machine that will be able to clean sorghum, utilizing the differences in the aerodynamic characteristics of the sorghum grain and the constituents.
(iii) Minimize the loss as a result of threshing and cleaning.
(iv) Minimize the drudgery in-

Fig. 2 Sorghum thresher testing-rig

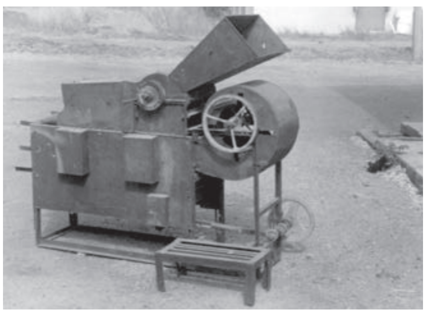


Fig. 3 Threshing cylinder (A) and concave (B)

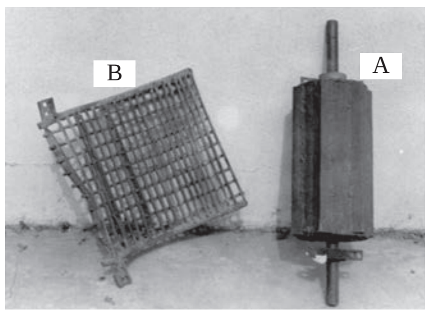
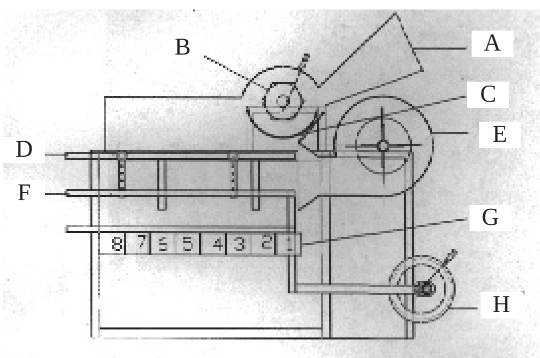


Fig. 4 Sectional view of the sorghum thresher testing rig



LEGEND

A: Hopper
B: Threshing cylinder
C: Concave
D: Brower housing
E: Upper sieve
F: Lower sieve
G: Collector boxes
H: Pulley

volved in the processes.

A horizontal air stream was used. Hassebrauch (1964) and Phillipson (1970) reported that horizontal airflow separation was more efficient than vertical airflow method, for cleaning.

The sorghum thresher-testing rig had the following component units: frame, hopper, threshing unit, sieve, reciprocating mechanism, blower and collecting trays. **Figs. 2** and **3** shows the side view and the threshing cylinder-concave of the sorghum thresher-testing rig, respectively.

Frame: The frame and other structural members were constructed using a 40 mm by 40 mm angle iron for stability and rigidity.

Hopper: The hopper was constructed from 16-gauge (1.6 mm) sheet metal and formed a frustum that tapered at the threshing cylinder. It was 270 by 520 mm at the inlet and 130 by 370 mm at the threshing cylinder side and 460 mm high.

Threshing Unit: The threshing unit removed the grains from sorghum heads. It was comprised of the threshing cylinder and concave. (i) The threshing cylinder (**Fig. 3A**) consisted of a cylinder 140 mm diameter and 320 mm long. Six 20 mm by 20 mm pieces of angle iron were inverted and welded equidistant on the outside diameter of the cylinder to give an overall cylinder diameter of 175 mm. A 600 mm long shaft with a diameter of 25 mm passed through the center of the cylinder. (ii) A concave was formed into a basket (**Fig. 3B**) using flat bars 4 mm thick and 10 mm diameter iron rods. The concave has a semicircular diameter of 310 mm. The threshing cylinder concave was the same and fixed throughout the test at 15 mm at the inlet, 3 mm at the middle and 7 mm at the outlet.

Sieve: The sieve scalped, removing larger material particles and trash. There were two sieves, arranged horizontally and carried in separate racks, one above the other, reciprocating as a unit. The sieve racks had adjustable inclinations. The distance between the sieves was 150 mm. The sieves were constructed from 16 gauge (1.6 mm) metal sheet and were 935 mm long and 300 mm wide. Sieve hole diameters were 6.5 mm and were readily removable whenever necessary.

Reciprocating Mechanism: The reciprocating mechanism exerted force on the particle in the horizontal and vertical directions.

The stroke of reciprocation was 100 mm. The length of the connecting rod was 575 mm.

Blower: The centrifugal blower blew an air stream between the two sieves with air current aiding in lifting up straw and stalk on the upper sieve. The inner diameter for the air inlet was 220 mm with provision for regulation of the air opening through gates. The throat of the blower housing was 150 mm. There were 4 straight paddle blades 160 mm by 120 mm bolted to a 25 mm diameter shaft. This type of blade was capable of operating satisfactorily in a dusty environment because of the self-cleaning characteristics (Ige, 1978).

Grain Collector: The cleaned grain that passed the sieves was collected for analysis. The grain collector was 1,000 mm long divided into eight compartments of equal distances of 110 mm each as done for alfalfa by Mkomwa (1988). Grains in each compartment were collected separately for analysis.

Test Procedure

One kilogram of Sorghum (SAMSORG 17) was taken randomly from a heap of harvested crop heads and fed into the hopper manually. Feeding time, cylinder speed, blower speed and sieve reciprocation speed and frequency were recorded. The feed rate was calculated in kg/hr. Grain output was expressed in kg/hr by recording the time taken in the threshing operation and weight of grain recovered. Unthreshed tailings were separated from the straw by manually threshing them and collected grains were weighed after cleaning manually to determine the threshing efficiency (TE).

The threshed product became the input in the cleaning process. Cleaned grains in each collector compartment were collected in a transparent polyethylene bag and labeled to be analyzed. Samples collected in each compartment were weighed with an electronic weighing balance and cleaned manually to quantify the grain and material other than grain. The weight of cleaned grain was recorded for each compartment. The difference gave the weight of impurities. This was used to calculate the cleaning efficiency (CE). Chaff blown out of the machine was collected in a black polyethylene bag and labeled accordingly. The waste collected was weighed using the electronic balance and cleaned manually to separate the grains. The cleaned grain separated from the waste was used to calculate the cleaning loss (CL).

Threshing Efficiency

$$E_T = 100 - (D / A) \quad (4)$$

Where

E_T = Threshing efficiency, %

D = weight of unthreshed grain at the outlet per unit time, kg.

A = Total grain input per unit time ($A = B + C + D$), kg

B = weight of threshed grains at the main outlet per unit time, kg.

C = weight of threshed grain at all other outlet per unit time, kg.

Cleaning Efficiency

$$\eta = [G_o / (G_o + C_{cg})] \times 100 \quad (5)$$

Where

η = cleaning efficiency, %

G_o = weight of pure grain at the outlet, kg.

C_{cg} = Weight of contaminant in cleaned grain, kg.

Cleaning Loss

$$C_L = (G_w / G_i) \times 100 \quad (6)$$

Where

G_o = weight of grain at the waste outlets, kg.

G_i = weight of grain at input, kg.

Statistical Analysis

Data collected were analysed using analysis of variance (ANOVA) technique given by Gomez and Gomez (1984). The General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 1989) was used to analyze the data. The standard error (SE) of each mean was calculated.

A 3^4 factorial experiment in a completely randomized block design was used to study the effect and interactions of variables on the threshing efficiency, cleaning efficiency and cleaning loss. **Table 2** gives the values of variable chosen as treatment. Three replications were made for each treatment level combination.

Results and Discussion

Size and Shape

Table 3 presents the mean values and standard errors of the axial dimensions of the sorghum grain at different moisture contents. The average values obtained for the arithmetic mean, geometric mean and equivalent diameters were 3.32 mm, 3.31 mm and 3.31 mm, respectively, at a moisture content of 8.89 % w.b.. At a moisture content of 16.50 % wb, the values were 4.20 mm, 4.16 mm and 4.18 mm, respectively. The average diameter of the sorghum grains calculated by the arithmetic mean, geometric mean and equivalent diameter methods in the moisture range of 8.89-16.50 % w.b. are similar (**Table 3**).The result obtained from this study are in agreement with those of Picket and West (1988) who obtained arithmetic the mean and geometric mean diameters of 3.73 and 3.66 mm, respectively, while Gorial and O'Callaghan (1990) obtained equivalent and geometric diameters of 3.5 and 3.61 mm, respectively, for sorghum, though the variety and moisture content was not specified. However, the values obtained were higher than the 2.72 mm obtained by Waziri and Mittal (1983) for LS187 variety of sorghum. The arithmetic mean and geometric mean can, therefore, be used to determine the average diameter of sorghum grain. This was useful in determining the diameter of sieve hole.

The summary of results of mass, projected area and particle density of individual samples is given in **Table 4**. The threshing and cleaning experiment was conducted at average sorghum head moisture content of 8 % w.b. with three replications each.

Threshing Efficiency

The effects of threshing speed and feed rate on the threshing efficiency of the sorghum thresher are as shown in **Figs. 4** and **5**. The highest threshing efficiency of 99.96 % was obtained at cylinder threshing speed of 5.78 m/s. It has been reported that increase in the threshing speed leads to increase in threshing efficiency. This was attributed to greater impact between the ear and the revolving cylinder per unit time

Table 2 Variables and treatment levels*

Variables	Treatment levels					
Threshing speed, m/s	**2.64****	3.64	**4.40**	5.03	**5.78**	6.28
Air speed, m/s	**3.67**	4.67	**5.17**	5.47	**7.33**	8.33
Sieve oscillation speed, m/s	**0.59**	0.88	**1.47**	2.05	**2.64**	
Feed rate, kg/hr	**492.86**	521.43	**640.00**	720.00	**740.00**	

*Average of 3 values, **Bold treatment levels were used for the statistical analysis.

Table 3 Dimensions of sorghum grains

MC, %wb	Major axis, L_1, mm	Medium axis, L_2, mm	Minor axis, L_3, mm	Arithmetic Mean, mm $(L_1 + L_2 + L_3) / 3$	Geometric mean, mm $(L_1 L_2 L_3)^{1/3}$	Equivalent diameter, D_e mm
8.89	3.70(0.29)*	3.18(0.30)	3.08(0.22)	3.32	3.31	3.31
10.87	3.81(0.22)	3.29(0.18)	3.09(0.24)	3.40	3.38	3.41
12.33	4.04(0.04)	3.50(0.03)	3.61(0.05)	3.72	3.71	3.71
14.56	4.45(0.07)	4.39(0.12)	3.40(0.38)	4.08	4.05	4.06
16.50	4.62(0.06)	4.53(0.01)	3.44(0.07)	4.20	4.16	4.18

* Standard error (SE)

Table 4 Some physical properties of sorghum grain and straw materials

Sample	Mass, g	Projected area, mm^2	Particle density, g/cm^3
Unthreshed	1.47 ± 0.35*	101.28 ± 40.68	0.78 ± 0.14
Threshed	0.37 ± 0.50	64.98 ± 16.66	0.31 ± 0.06
Grain	0.044 ± 0.007	4.66 ± 0.85	1.02 ± 0.20
Stalk	0.067 ± 0.02	26.14 ± 5.90	0.09 ± 0.02
Chaff	0.032 ± 0.008	7.34 ± 1.53	0.05 ± 0.01

* Standard error (SE)

Fig. 4 Effect of the threshing speed on the threshing efficiency

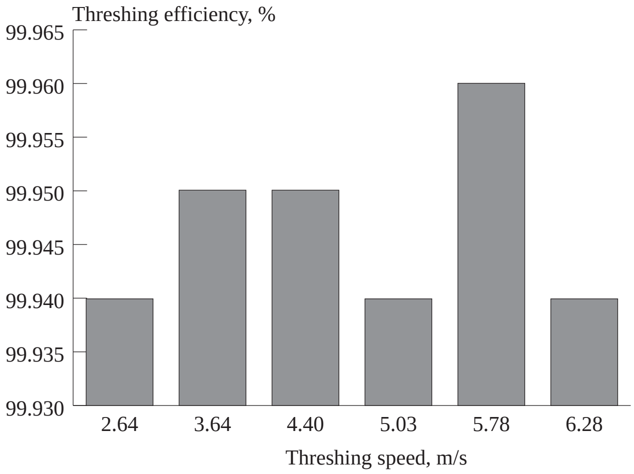


Fig. 5 Effect of feed rate on the threshing efficiency

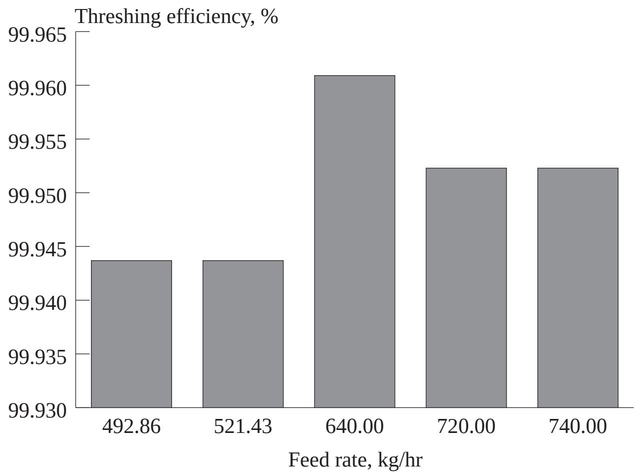


Fig. 6 Effect of threshing speed on the cleaning efficiency

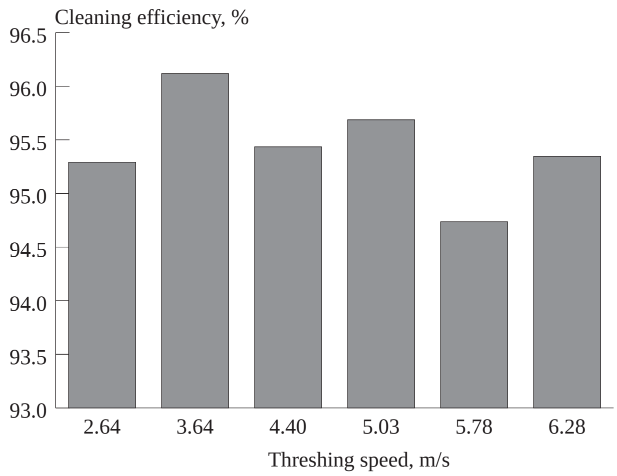


Fig. 7 Effect of air speed on the cleaning efficiency

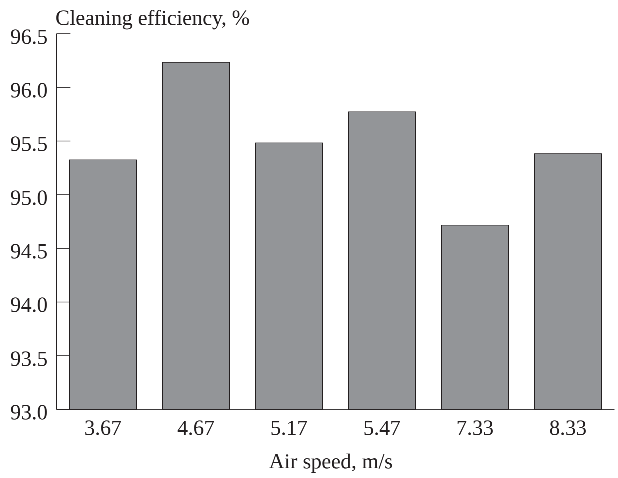


Fig. 8 Effect of sieve oscillation speed on the cleaning efficiency

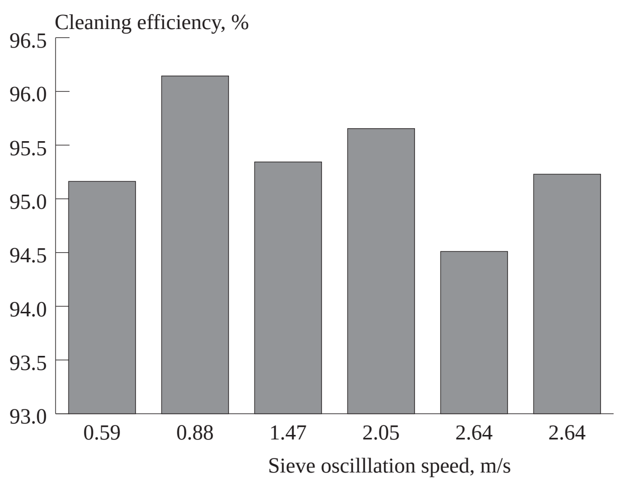
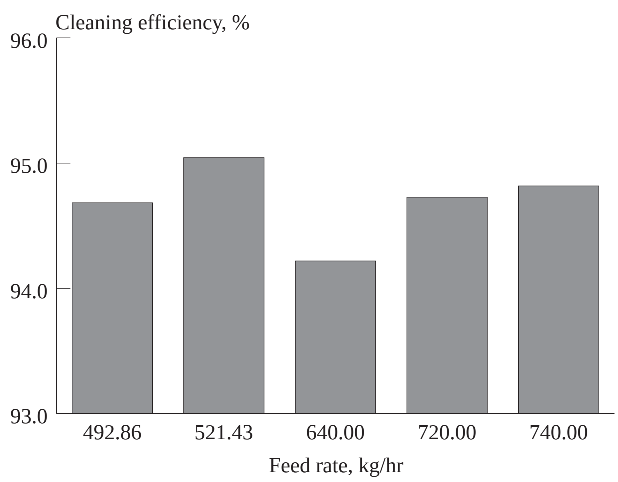


Fig. 9 Effect of feed rate on the cleaning efficiency



(Ige, 1978; Sharma and Devnani, 1980 and Harrison, 1975). The feed rate influenced the threshing efficiency (Joshi and Singh, 1980). Increasing the feed rate beyond the optimum may lead to blockage. The highest threshing efficiency of 99.96 % was obtained at a feed rate of 640 kg/hr.

Cleaning Efficiency

The effects of the threshing cylinder speed, air speed, sieve oscillation speed and feed rate on the cleaning efficiency of the output of the sorghum thresher are shown in **Figs. 6, 7, 8** and **9**. The blower speed was transmitted by the pulley and belt from the threshing cylinder. Increasing or decreasing the threshing cylinder speed increased or decreased the blower speed, respectively, and, by implication, the airspeed available for cleaning. The highest cleaning efficiency of 96.14 % was obtained threshing speed of 3.64 m/s, air speed of 4.67 m/s, sieve oscillation speed of 0.88 m/s and feed rate of 521.43 kg/hr, respectively.

Cleaning Loss

Figs. 10-13 give the effects of the threshing speed, airspeed, sieve speed and feed rate, respectively, on the cleaning loss. A desirable index of performance was loss minimization .The least cleaning loss of 6.05 % was obtained at a threshing speed 4.4 m/s, air speed of 5.17 m/s, sieve speed of 1.47 m/s and feed rate of 640 kg/hr, respectively. The cleaning loss was 9.91 % at the threshing speed of 6.28 m/s. The corresponding air speed was 8.33 m/s, which may result in the sorghum seed being blown away with the waste.

Statistical Analysis

Table 5 gives the summary of the analysis of variance. It was interest-

Fig. 10 Effect of threshing speed on the cleaning loss

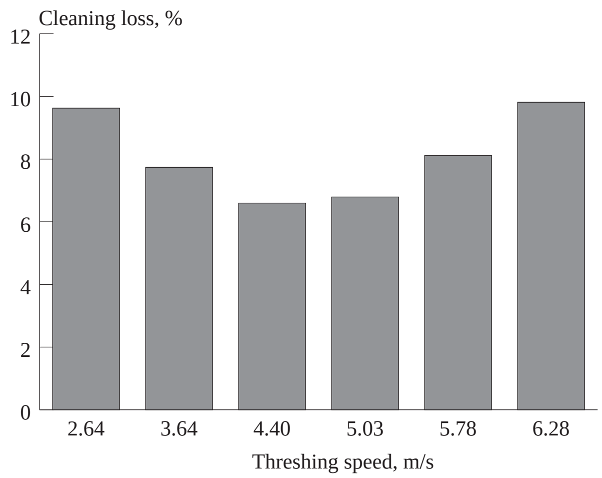


Fig. 11 Effect of air speed on the cleaning loss

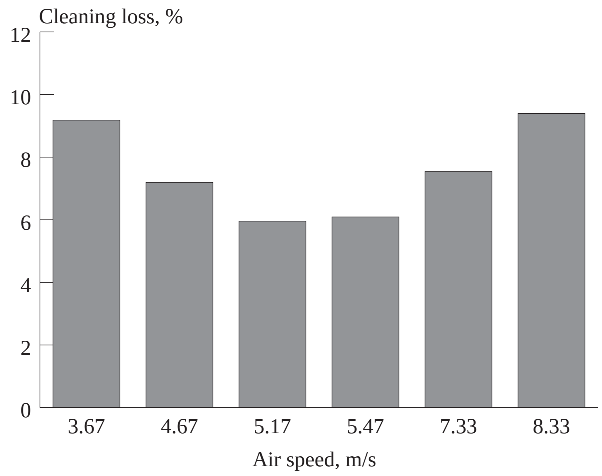


Fig. 12 Effect of sieve oscilation speed on the cleaning loss

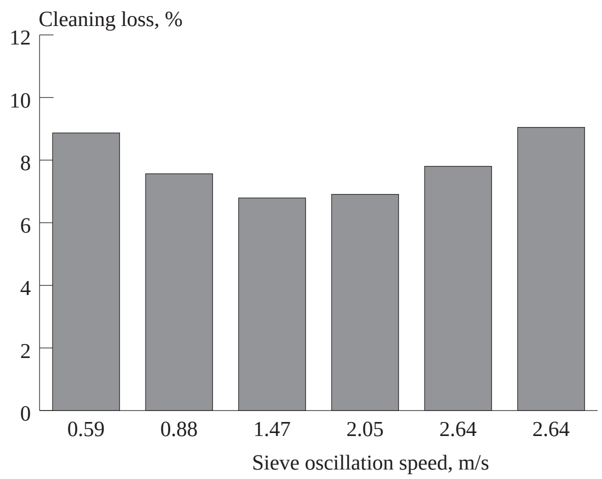
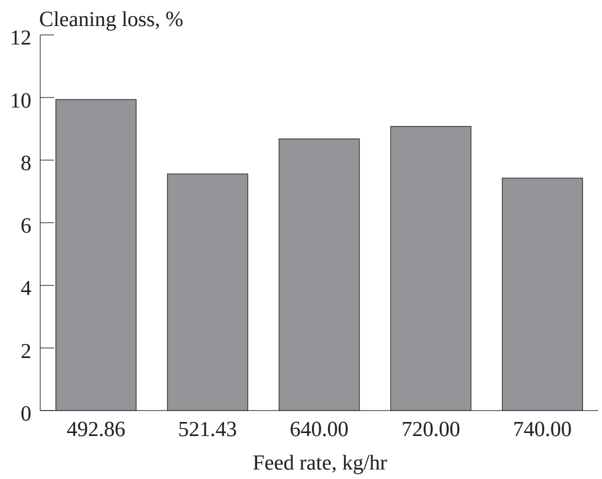


Fig. 13 Effect of feed rate on the cleaning loss



ing to note that all the main factors and their interactions were not statistically significant for the threshing efficiency, cleaning efficiency and cleaning loss, respectively. This might be due to the closeness of the levels of treatment used for the experiment.

Conclusions

A motorized sorghum thresher was developed and tested. The following performance test results were obtained:

- The highest threshing efficiency of 99.96 % was obtained at a cylinder threshing speed of 5.78 m/s, and feed rate of 640 kg/hr.
- The highest cleaning efficiency of 96.14 % was obtained at a threshing speed of 3.64 %, air speed of 4.67 m/s, sieve oscillation speed of 0.88 m/s and feed rate of 720 kg/hr.
- The least cleaning loss of 6.05 % was obtained at a threshing speed of 4.4 m/s, air speed of 5.17 m/s, sieve speed of 1.47 m/s and feed rate of 740 kg/hr.
- All the main factors and their interactions were not statistically significant for the threshing efficiency, cleaning efficiency and cleaning loss.

REFERENCES

Ali, M. A. 1986. Comparative ergonomic studies of male and female operators on selected farm tasks. Unpublished MSc Thesis Ahmadu Bello University, Zaria, Nigeria.

ASAE Standards.2003. S352.2 FEB03.Moisture measurement-unground grain and seeds. St Joseph, Michigan. pp 606

Asoegwu, S. N., S. O. Ohanyere., O. P. Kanu, and C. N. Iwueke. 2006. Physical properties of African oil bean seed (Pentaclethra macrophylla) *Agricultural Engineering International*: the CIGR Ejournal Manuscript FP 05 006 Vol VIII, August 2006.

Aviara, N. A., Ajibola, O. O., and S. A. Oni. 2004. Sorption equilibrium and thermodynamic characteristics of soyabean. *Biosystems Engineering* 87(2): 179-190. doi: 101016/j.biosystemseng.2003.11.006.

Dodds, M. E. 1968. Power requirements of a self propelled combine. *Canadian Agricultural Engineering* 10(2)74-76, 90.

Ghaly, A. E. 1985. A stationary threshing machine: design, construction and performance evaluation. *Agricultural Mechanization in Asia, Africa and Latin America* 16(3): 19-30.

Gomez, K. A. and A. A. Gomez. 1984. *Statistical procedures for Agricultural Research*. 2nd Edition. John Wiley and Sons New York. pp 357-423

Gorial, B. Y. and J. R. O'Callaghan. 1990. Aerodynamic Properties of grain/straw materials. *Journal of Agricultural Engineering Research* 46: 275-290.

Harrison, H. P. 1975. Effects of moisture content of wheat on threshing. *Canadian Agricultural Engineering* 17(1): 55.

Hassebrauch, B. 1964. The sorting of grain - chaff mixtures in separators with vertical rising airflow. *Landtech forsch* (1) 14.

Henderson, S. M., R. L. Perry, and J. H Young, 1997. *Principles of Process Engineering.* 4th Edition ASAE Michigan USA Pp280-283.

ICRISAT. 1978. Annual report.India ICRISAT Patancheru. Pp 324,502.

Ige, M. T. 1978 Threshing and separation performance of a locally built cowpea thresher. *Journal of Agricultural Engineering Research* 23: 45-51.

Joshi, H. C. and K. N. Singh. 1980. Development of Pantnagar- IRRI multicrop thresher. *Agricultural Mechanization in Asia, Africa and Latin America* XI(4): 53-63.

Kashayap, M. M. and B. S. Pathak. 1976. Effect of air stream depth on air velocity requirement for winnowing operation. *Journal*

Table 5 Summary of Anova Results

Source	DF	Threshing Efficiency	Cleaning Efficiency	Cleaning Loss
R	2	441.64**	1.18 NS	1.07 NS
T	2	0.04 NS	0.02 NS	0.02 NS
A	2	0.04 NS	0.02 NS	0.02 NS
O	2	0.04 NS	0.02 NS	0.02 NS
F	2	0.04 NS	0.02 NS	0.02 NS
T*A	4	0.16 NS	0.08 NS	0.02 NS
T*O	4	0.16 NS	0.08 NS	0.02 NS
A*O	4	0.16 NS	0.08 NS	0.02 NS
A*F	4	0.16 NS	0.08 NS	0.02 NS
O*F	4	0.16 NS	0.08 NS	0.02 NS
T*A*O	8	0.64 NS	0.34 NS	0.03 NS
T*A*O*F	40	1.41 NS	0.76 NS	0.04 NS
Error	160			
	242			

*T: Threshing speed, m/s, *A: Air speed, m/s, *O: Sieve oscillation speed, m/s, *F: Feed rate, kg/hr

of Agricultural Engineering Research 13(4): 1-35.

Lamp, B. J. and W. F. Buchele. 1960. Centrifugal Threshing of small grains. *Transactions of the ASAE* 3(2): 24-28.

Mazvimavi, K. 1997. *An overview of sorghum and millet production and utilization in Zimbabwe semi and smallholder sector.* 18pp Http://www.cphp.uk.com

Mkomwa, S. S. 1988. Aerodynamic separation of Alfalfa haylage into high and low protein fractions. An unpublished MSc thesis. The University of Guelph, Canada.

Nath, S. and Johnson, H. 1983. A model of field grain sorghum moisture contents. *Agricultural Mechanization in Asia, Africa and Latin America* 14(2): 21-24.

Oje, K. and E. C. Ugbor. 1991. Some physical properties of oilbean seed. *Journal of Agricultural Engineering Research* 50: 305-313

Oje, K. 1993. Some engineering properties of Thevetia nut. *Journal of Agricultural Engineering and Technology* 1: 38-45.

Phillipson, A .1970. *Development test of hand operated winnower.* Overseas Department NIAE Silsoe. pp11.

Picket, L. K. and N. L. West. 1988. Agricultural Machinery - Functional elements - Threshing, Separating and Cleaning. In CRC *handbook of Engineering in Agriculture* Vol. 1 Eds Brown RH CRC press Florida USA. Pp 65-84.

Rohrbach, D. D. 2004. Improving the commercialization of sorghum and pearl millet in Africa. Http://www.afripo.org.uk/papers/paper22.rohrbach.pdf.30/12/14

Rooney, L. W. 2003. Overview: sorghum and millet food research failures and successes. Food Science Faculty, Cereal Quality Laboratory, Soil and Crop Science Department. Texas A&M University USA. Http://www.afripo.org.uk/papers/paper09.rooney.pdf15/10/03

Sarwar, J. G and A. U. Khan .1987. Comparative performance of rasp bar and wire loop cylinders for threshing rice crop. *Agricultural Mechanization in Asia, Africa and Latin America*. 18(2): 37-42.

SAS, 1989 SAS *Users guide*: Statistics. SAS Institute Inc. Box 8000 Cary North Carolina 27511.

Sharma, K. D. and R .S. Devnami. 1980. Threshing studies on soybean and cowpea. *Agricultural Mechanization in Asia, Africa and Latin America* 11(1): 65-68.

Simonyan, K. J. and K. C. O. ni. 2001. Performance evaluation of a motorized locust bean decorticator. *Journal of Agricultural Technology* 9 (1): 55-65.

Simonyan, K. J. 2006. Mathematical modeling of the grain cleaning process in a stationary sorghum thresher. Ph.D Dissertation. Samaru, Nigeria. Ahmadu Bello University. Department of Agricultural Engineering.

Singh, B. and A. Kumar. 1976. Effect of cylinder type on threshing effectiveness and damage of wheat. *Journal of Agricultural Engineering Research* 13 (3): 124-129.

Singh, M, S. S. Ahuja, and V. K. Sharma. 2001. Relative performance of spike-tooth and serrated-tooth type bruising mechanisms used in wheat straw combine. *Agricultural Mechanization in Asia, Africa and Latin America* 32(4): 28-34.

Singh, M., S. S. Ahuja, and V. K. Sharma. 1998. Selected design and operational parameters of serrated tooth type bruising mechanisms of a straw combine. *Agricultural Mechanization in Asia, Africa and Latin America* 29(3): 33-38.

Singhal, O. P. and G. E. Thierstein. 1987. Development of an axial flow thresher with multi-crop potential. *Agricultural Mechanization in Asia, Africa and Latin America* 18(3): 57-65.

Waziri, A. N. and J. P. Mittal. 1983. Design related physical properties of selected agricultural products. *Agricultural Mechanization in Asia, Africa and Latin America* 14(1): 59-62.

■■

Performance Enhancement of Traditional Unpeeled Longan Dryers with Design Modification

by

Nakorn Tippayawong
Department of Mechanical Engineering,
Faculty of Engineering,
Chiang Mai University
Chiang Mai 50200,
THAILAND

Chutchawan Tantakitti
Department of Mechanical Engineering,
Faculty of Engineering,
Chiang Mai University
Chiang Mai 50200,
THAILAND

Satis Thavornun
Department of Mechanical Engineering,
Faculty of Engineering,
Chiang Mai University
Chiang Mai 50200,
THAILAND

Abstract

Several techniques to increase energy efficiency and reduce energy cost in traditional unpeeled longan drying were investigated. Existing dryers were modified into a new dryer arrangement. Performance analysis in terms of energy utilization index, thermal efficiency and energy cost for both traditional and new designs was carried out. The results indicated that the new dryer consumed less energy and had lower fuel cost than the existing traditional dryer. This was largely due to fuel switching from liquefied petroleum gas to firewood and energy recovery via hot air recirculation inside the dryer. The new dryer with improved design and better energy efficiency was demonstrated.

Introduction

Longan (*Dimocarpus longan Lour.*) is one of the main cash crops commonly grown in Northern Thailand. Chiang Mai and Lampoon are major producers, accounting for over 85 % of the total production volume. Around 300,000-500,000 tons of longan are produced each year, earning over US$ 100 million in export value annually (Office of Agricultural Economics, 2005). The products are either sold domestically or exported. Trade is important and expanding in China and Taiwan. Further expansion is occurring in Thailand to meet demand generated by the increasing regional affluence. Flowering and main fruit development takes place during the dry season. The fruit ripens only on the tree and is normally harvested between July and August. Fresh longan has a very short self life without refrigeration. Early longan may fetch a high selling price, but as supplies increase, the price drops. Several preservation methods have to be implemented to lengthen self life or add value to the product. These methods include gas treating, canning, freezing, and drying. High efficiency methods can play an important role in increasing productivity to meet the demand for processing the harvested crop.

Hot air drying is the most common method for the industry to dry longan. Whole unpeeled longan is traditionally dried by individual farmers or local entrepreneurs. The traditional drying method is based on a batch dryer cabinet where fresh longan is laid on top each other to form a stationary thick bed on one large tray. Heat is provided to the fruit layer by a diesel or liquefied petroleum gas (LPG) burner, in the form of a mixture of hot flue gas and induced air as it passes through the bed. Induced air is forced by means of a motor-driven fan. Hot and dry gas will absorb moisture from longan and relatively cooler and humid gas exhausts to the ambient environment. Drying of longan is an energy intensive process with controlled conditions of temperature and humidity. Typically, heat applied to the longan produces chemical and enzymatic changes which condition and fix the color. The process employs around 55-80 ˚C with diminishing humidity and ends when the product is dried. The final moisture content is about 22 % dry basis. One drying cycle lasts approximately 48-52 hours. Thailand's typical unpeeled longan dryer is small. Commonly used dimensions have floor areas of 2.35 m × 2.35 m with a loading capacity of about 2,000 kg of fresh longan per batch. The dryer usually has walls of galvanized iron sheets with a perforated metal tray that separates the plenum chamber from the bed of longan, as shown in **Fig. 1**.

Its overall efficiency is reported to be low, being less than 30 %. This highly energy-intensive process consumes enormous quantities of fossil fuels. In the past, energy conservation and ecological consideration in longan drying practice have not been emphasized sufficiently or, in some cases, neglected. There is an urgent necessity to improve efficiency of the drying process by improvements in the dryer structure, the heat source and the flow distribution system design (Phaphuangwittayakul *et al*., 2004). A research effort in the Department of Mechanical Engineering, Chiang Mai University has been made over past several years to introduce a number of energy conservation measures to the agro-industrial processes in Northern Thailand (Tantakitti and Thavornun, 2000; Tippayawong *et al*., 2004; 2006) that can be applied to longan drying. In this paper, a modified longan dryer is introduced, based on a modern tobacco bulk curing practice. Experimental data obtained from the modified dryer are presented and analysis of its thermal performance and energy efficiency are conducted and compared with those from a traditional dryer.

Fig. 1 Structure of a traditional longan dryer

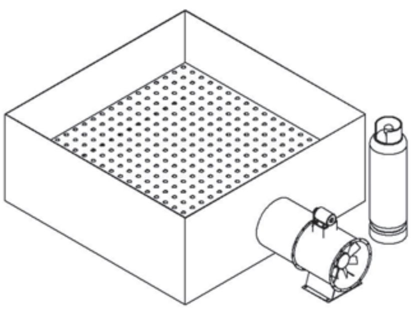
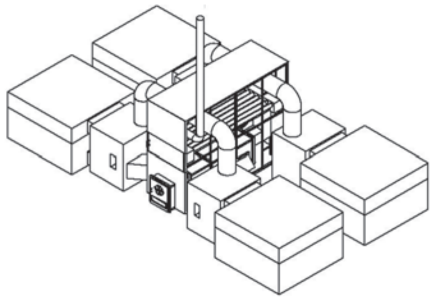


Fig. 2 Structure of a modified longan dryer



Methodology

A modified dryer was constructed as shown in **Fig. 2**. It consists of 4 trays, each piped to a plenum. All trays are connected to a centrally located hot air chamber where a grate furnace and a staggered tube-type heat exchanger were accommodated, similar to that used in a modern curing barn. The trays and the motor-driven fans were taken from existing dryers. This furnace-flue gas system was a novel feature for this dryer that would allow farmers to switch from LPG to wood. The furnace, made of firebrick, was built inside the heat exchanger section to reduce heat loss to the surrounding air outside. A primary air vent was located at the front door of the furnace via an adjustable aperture. A grate was provided to collect ash with an access through the front at the bottom. Hot exhaust gas transferd heat to circulated air in the hot air chamber, which was tightly insulated with 50 mm-thick wool insulator. Drying air was circulated between the hot air chamber and longan beds by means of individual motor-driven axial fan. The hot air used for drying was recirculated and mixed with fresh air in the hot air chamber. A fresh air intake was located near the bottom of the chamber while there was an opening at the side of each plenum to allow moist air out. The connecting plenum for each tray was designed in such a way that air flow could be directed either from top to bottom of the bed or in reverse by a simple valve mechanism. Therefore, the longan bed need not be turned over during drying cycle.

The dryer was modified to improve its performance according to the following concepts;

i. Fuel switching: LPG burners were switched to a wood furnace with similar thermal output
ii. Hot air recirculation: heat was recovered by air recirculation and fresh make-up air replaced some of moist return air.
iii. In bed flow direction control: flow through the bed of longan can be forward and reverse, and it was evenly distributed.

In all, five batches of actual longan drying were conducted between July-September 2006. Over 30,000 kg of fresh longan were dried. Type k thermocouples were used to measure temperature of the flue gas, the dryer wall temperatures and furnace door and wall temperatures, as well as ambient temperature. Dry and wet bulb thermometers were used to measure temperature and humidity inside the dryer. Circulated hot air was measured, using a sensitive anemometer. Pressure drop across the fan, the heat exchanger and in the curing section were monitored, using manometers. All measurements were taken at intervals of about 1-3 hours throughout the drying cycle. Wood logs with average weight of 2-5 kg were used. The amount of wood used was noted. Previously obtained data from a number of traditional dryer experiments were used to compare with this study.

Results

Experimental longan drying trials carried out in the instrumented research dryer showed that drying time was comparable, in comparison with a traditional dryer. Samples of longan from across each tray appeared to be dried to similar levels. According to the farmers, quality of dried longan from both existing and modified dryers was not different. Table 1 shows the summary of findings. From the flue gas temperatures and barn space temperatures, heat lost to the surroundings through the walls and the front side of the furnace, and heat lost to the atmosphere in the form of hot flue gas escaping through the chimney during the running period of the dryer were calculated. Flue gas loss and wall loss were small as a result of effective heat exchange between the circulated air and the hot flue gas and a tight insulation. Similar thermal input was required for drying the same amount of longan.

However, with an average fresh longan to dried longan ratio of 3.2, energy utilization index was found to be 14.5 MJ per kg dried longan for the modified dryer, compared to 17.3 MJ per kg dried longan for existing dryers. Fuel as well as electricity were included. Thermal efficiency was improved from 29 % for the traditional dryer to about 35 % for the modified dryer. Since wood was a lot cheaper than LPG, the fuel cost per kilogram of dried longan was markedly lower than that from the traditional fossil powered dryer.

Discussions and Conclusion

Longan drying is one of the biggest consumers of LPG among the agro-industrial processes in Northern Thailand. Experimental results from previous studies underline the urgent need to improve traditional longan dryer design. This can be done via fuel switching, hot air recirculation, and flow direction control. Substitution of LPG by wood is obvious due to its cheaper price and availability, and can be realized with a grate furnace. Adoption of a forced draft system, better insulation installation, modification of furnace – flue system, and air recirculation design in the modified dryer proved to yield six-times lower fuel cost per kg dried longan. With a control of air flow direction through the bed of longan, there is no need to turn over the bed. Less labor is used and damage to dried longan is minimized. The modified dryer proved to have advantages over the traditional dryer in energy saving and reduced labor requirement. With a well insulated system, a much narrower temperature spreads inside the dryer, and the day-night cyclic variations, as well as inversion of temperatures can be greatly reduced. More stable temperature profiles contribute to fuel economy and also to the quality of the dried product. Data reported here reflect general overall results well but further investigation is still required to obtain statistically significant and reliable results derived from greater amount of data collection and refinement of experimentation.

On the basis of experimental results from this study in comparison with those from existing traditional dryers, it has been established that an increase in energy efficiency and a reduction in energy cost were achieved. It should be pointed out that drying was undertaken by an experienced farmer who was familiar with the traditional system but not with the modified one. With more training and supervision, he will be able to operate the modified dryer satisfactorily well in a relatively short period of time. Adoption of this new system in place of old traditional dryers should be encouraged. From a preliminary cost estimate, it is financially viable for potential individual farmers to invest in the system. Governmental incentives in terms of partial subsidy or low-interest loans may be made available to interested farmers to help speed up this development.

Table 1 Performance comparison between the traditional and modified dryers

	modified	traditional
Longan loading capacity, kg	7,500	2,000
Operation time, hour	75	60
Fuel cost, $/kg$^{dried\ longan}$	0.03	0.18
Electricity cost, $/kg$^{dried\ longan}$	0.01	0.01
Labor cost, $/kg$^{dried\ longan}$	0.04	0.03
Energy utilization, MJ/kg$^{dried\ longan}$	14.5	17.3
Thermal efficiency, %	35	29

Note: fresh longan to dried longan ratio = 3.2, LPG price = $0.52/kg, Wood price = $0.03/kg, Thai baht / US dollar = 34.5

REFERENCES

Office of Agricultural Economics. 2005. Import-export statistics. http://www.oae.go.th.

Phaphuangwittayakul, W., S. Limpiti, and Z. Alikhani. 2004. A batch dryer for unpeeled longan drying. AMA 35(1): 41-44.

Tantakitti, C. and S. Thavornun. 2000. Energy conservation in tobacco curing. Asian Journal of Energy & Environment 1(3): 213-222.

Tippayawong, N., C. Tantakitti, and S. Thavornun. 2004. Energy- and emission-based performance of an experimental tobacco bulk-curing barn. Chiang Mai University Journal 3(1): 43-52.

Tippayawong, N., C. Tantakitti, and S. Thavornun. 2006. Investigation of lignite and firewood co-combustion in a furnace for tobacco curing application. American Journal of Applied Sciences 3(3): 1775-1780.

Conversion of Large Diesel Engine to Run on Biogas for High Efficiency Electrical Power Generation

by

S. Siripornakarachai
Department of Mechanical Engineering,
Faculty of Engineering,
Chiang Mai University,
Chiang Mai, 50200
THAILAND
siripornakarachai@yahoo.com

T. Sucharitakul
Associate Professor,
Department of Mechanical Engineering,
Faculty of Engineering,
Chiang Mai University,
Chiang Mai, 50200
THAILAND
thawan@dome.eng.cmu.ac.th

Abstract

This study was to convert and tune a bus diesel engine for electricity production on a farm using biogas as fuel. The engine under study was a Hino K-13CTI 13,000 cc 24 valve turbocharged engine coupled to a 3 phase 4 pole induction motor to produce electricity at 50 Hz. Modifications included an addition of biogas carburetor for air-fuel mixing, replacing the fuel injection system with spark ignition system, reduction of compression ratio from the original 16:1 to 8:1 using a cylinder head spacer, and modification of the turbocharger waste gate so the boost pressure could be adjusted. When the induction motor was synchronized to the power grid, the running speed of the engine was 1,500 rpm. Optimal engine efficiency was achieved at 28.6 % by setting the lambda factor at 1.097, ignition timing at 54˚ before top dead center, and the turbocharger boost at 56 kPa. With this setting, the generator power output was 134.20 kilowatt with emission of CO and NO_X being 1,154 and 896 ppm, respectively. The generator specific output for biogas containing 62 % methane was 1.71 kilowatt-hours per cubic meter of biogas consumed.

Introduction

Biogas is a byproduct from waste treatment in an animal farm and can be used to replace fossil fuel to produce electrical energy. Biogas is formed by digestion of animal waste by anaerobic bacteria and the approximate composition is 60-80 % methane (CH_4), 20-40 % carbon dioxide and about 1 % of hydrogen sulfide (H_2S) and other trace gases. Biogas has liquefying pressure of 200-300 bar and heating value of about 23,400 kJ/m^3 (Werner *et al*, 1989 and Mitzlaff, 1988). The gas density is 1.2 kg/m^3 and has research octane number (RON) of about 130 (Mitzlaff, 1988). From the above property, it can be seen that it is difficult to liquefy biogas for storage or transport and it is quite suitable to be used as fuel in internal combustion engines (King James and Minlner Timothy, 1996). Statistics as of 2006 show that there are pig farms in Thailand that have biogas waste treatment systems that can produce biogas totaling 35,000,000 cubic meter per year. If all are used to produce electricity, the total energy of 35,000,000 kilowatt-hours can be produced per year (Potikanond, 1995).

With the increase in biogas production towards larger quantities, the technical utilization like the transformation into mechanical energy became an issue to be researched. While larger engines specifically designed for biogas were on the market, smaller engines modified from standard Otto or diesel engines were seen to fill the gap for small to medium and decentralized applications. Indian (Kulkarni publ, 1980), Chinese (Cao Zexi, 1982), and French (Bilican *et al*, 2003) publications have mainly dealt with the modification of small stationary diesel engines for dual fuel operation. Others went on to modify medium-sized diesel engines including their governors (Ortiz Canavate, 1981), or researched the performance parameters of dual fuel biogas engines in more detail (Mitzlaff and Mkumbwa, 1985). To generate electrical power by adapting diesel engine for biogas fuel, three major parameters have to be adjusted for best running efficiency. The three parameters are:

1. Spark ignition system must be added to the engine and the ignition timing adjusted to yield maximum efficiency.
2. Compression ratio must be reduced so biogas can be used as the fuel.
3. A biogas carburetor should be used for easy adjustment as well as lower pollution.

This study aims to adapt a large

diesel engine to run on biogas only. The adaptation involves an addition of a biogas carburetor for air-fuel mixing, replacing the fuel injection system with spark ignition system, reduce the compression ratio to suit biogas fuel using a cylinder head spacer, and modification of the turbocharger waste gate so the boost pressure can be adjusted. The test rig uses Hino K-13CTI 13,000 cc 24 valve turbocharged engine coupled to a 3 phase 4 pole induction motor to produce electricity at 50 Hz. The engine is then tuned by changing air/fuel ratio, ignition timing, and turbocharger boost pressure to obtain the optimal running condition.

Materials and Methods

The Hino K-13CTI engine being studied is a turbocharged bus diesel engine that came with fuel injection system as well as the high compression ratio of 16:1 and fixed waste gate boost control. For biogas fuel adaptation, a biogas carburetor was designed, manufactured, and installed. The fuel injection system was replaced with spark ignition system, the compression ratio was reduced to 8:1, and the waste gate was modified so the boost pressure can be adjusted. Each of these modifications are discussed, in turn, in the following section of the paper:

The biogas carburetor designed and installed in this study is shown in **Fig. 1**. Literature survey shows that a suitable carburetor for a biogas engine should be a venturi with an accelerator cone being tapered as a curve of 40 mm radius and the diffuser cone angle of 10˚. The biogas is fed into the venturi through multiple circular ports around the throat area and the throat air velocity should be between 100 to 150 meters per second (Mitzalff, 1988). With this information, a carburetor is designed for the 13,000 cc engine operating at 1,500 rpm should have the throat diameter of 7.5 mm. The metering needle for the gas inlet is fabricated with a square root profile to provide some linearity between needle position and the gas flow rate. The venturi is machined from aluminum stock and the carburetor body is fabricated from PVC pipe parts.

The distributor and ignition coil is adapted from the one used in the 6 cylinder Toyota 5-ME engine. The vacuum and centrifugal advance was disabled because the engine will run at constant speed and full load when being used to drive the generator. The distributor is driven by the original fuel injection distributor mechanism.

The fuel injection nozzle in the cylinder head is removed and replaced with spark plug and appropriate guide tube. The spark plug modification detail is shown in **Fig. 2**.

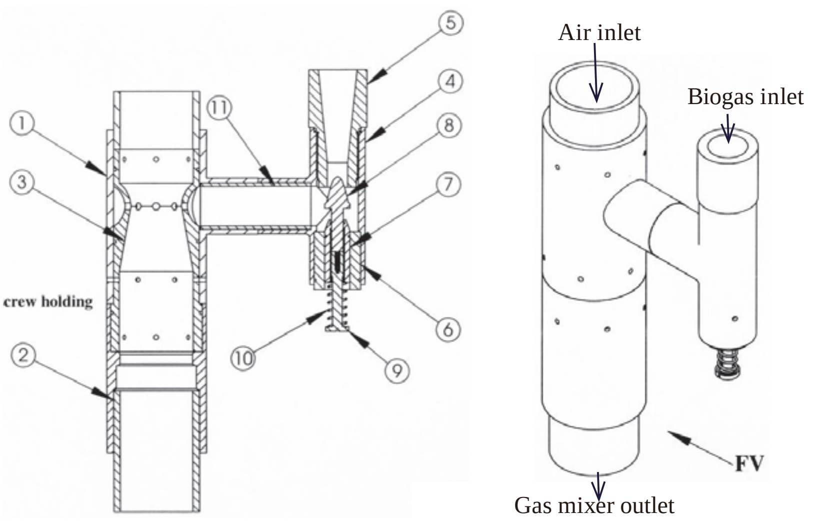
For proper biogas operation, the compression ratio needs to be brought down from the original 16:1 to some value lower to avoid engine knock. Literature suggests that the compression ratio should be between 10:1 and 12:1 for biogas operation (Mitzalff, 1988). Since a turbocharger will be used, the compression ratio is further lowered to 8:1. To achieve this, a steel spacer 10 mm thick was fabricated for this purpose. The turbocharger pressure is another parameter to be optimized. Too low pressure will cause loss of efficiency while too much boost will cause knocking which can damage the engine in the long run. The boost pressure in the experimental engine is varied by modifying the waste gate spring housing so it can be adjusted to vary the turbocharger pressure. After the modification, the turbocharger boost can be adjusted between 40 kPa and 80 kPa. Details of the modification are in **Fig. 3**.

Tuning Procedure

Initial Tuning, Generator Synchronization with the Power Grid, and Engine Start Up Procedure

The modified diesel engine can be started with a wide range of air/fuel ratio but once the engine is started for the first time using biogas as the fuel, some initial tuning should be done. This can be accomplished by inserting an exhaust gas analyzer sampling tube in to the exhaust pipe and adjust the gas metering screw until the amount of oxygen in the exhaust gas is about 6.2 % (Siripornakarachai and Sucharitakul, 2007). With a smaller engine, the engine can be permanently coupled to the

Fig. 1 Biogas carburetor design



1. Venturi housing, 2. Venturi base, 3. Venturi mixer, 4. Metering housing, 5. Main jet, 6. Metering adjusting nut spacer, 7. Metering adjusting nut, 8. Metering needle, 9. Metering adjusting screw, 10. Return spring, and 11. Pipe junction

induction motor. To start the engine, the user simply supplies the motor with the grid power. In the beginning, the motor will turn the engine to get it started. Once the engine is started, the motor will start to function as a generator (Siripornakarachai and Sucharitakul, 2006). With a larger engine and motor, starting the engine this way will cause excessive current consumption and can damage the grid's transformer so more care must be taken. The proper procedure is to decouple the engine from the generator using a clutch mechanism. The engine is then started and warmed up to the operating temperature and turning at about 1500 rpm. After that, the motor is started using the star start system to minimize the current consumption. When the motor speed reaches about 70 % of the rated operating speed, the delta start system will take over automatically until the motor speed reaches the operating speed of 1500 rpm. Once the synchronization speed is reached, the clutch mechanism is used to couple the engine to the generator and then the engine can be allowed to operate at full power. Engine speed control during the warm up and cool down is done using a ball valve connected between the gas line and the carburetor as shown in **Fig. 4**. After the engine has been running at full power for many hours, shutting down the engine will require a cool down period to avoid undue thermal stress to the engine parts. To do this, first, the ball valve is used to reduce the amount of biogas fed to the engine until the generator output is near zero. After that, the clutch is disengaged and the gas valve is closed further until the engine speed is between 800 and 1200 rpm. The engine is allowed to run at this speed with no load for about five minutes and then the engine can then be shut down (Siripornakarachai and Sucharitakul, 2007).

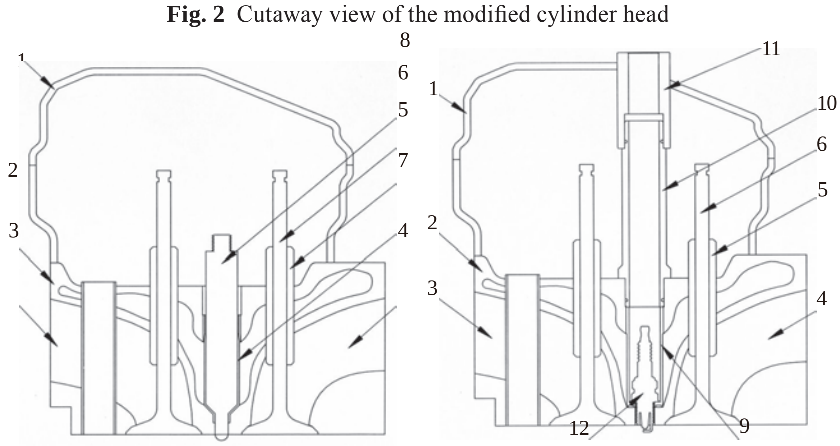
Specific Tuning Steps

The test engine was a Hino 13,000 cc diesel engine with 4 valves per cylinder modified for biogas fuel as described above. The engine model was K-13CTI and was normally installed in buses in Thailand. This engine was chosen because of used engine availability and commonly available spare parts. It was overhauled to new engine specification before testing and is currently undergoing an endurance test at 4T farm, Chiang Mai, Thailand as shown in **Fig. 5**. The experiment was carried out using the following steps to collect data for analysis.

Turbocharger Pressure Adjustment

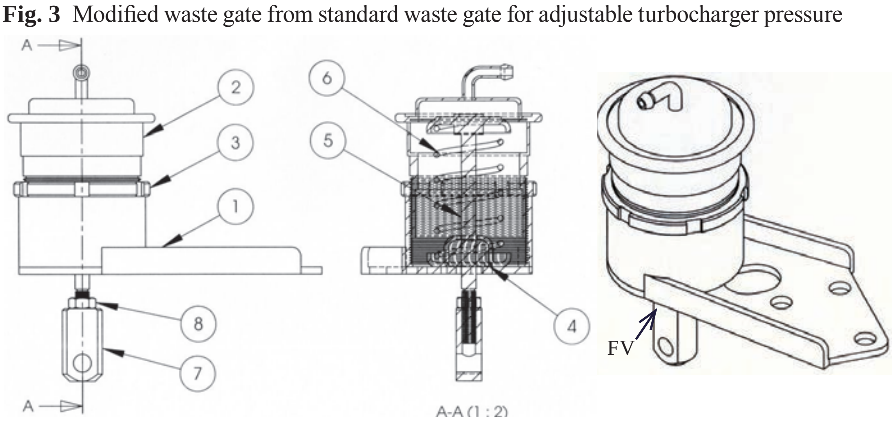
The Engine will be running on

Fig. 2 Cutaway view of the modified cylinder head



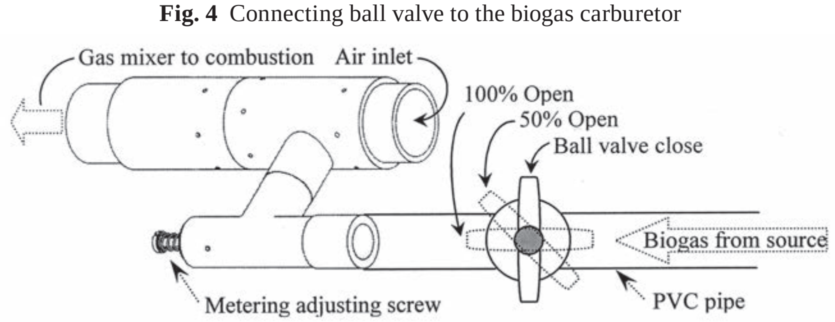
1. Valve cover, 2. Cylinder head, 3. Intake port, 4. Exhaust port, 5. Valve guide, 6. Exhaust valve, 7. Diesel injection nozzle guide, 8. Diesel injection nozzle, 9. Sparkplug guide, 10. Middle sparkplug rod guide, 11. Upper sparkplug rod guide, and 12. Sparkplug

Fig. 3 Modified waste gate from standard waste gate for adjustable turbocharger pressure



1. Waste gate base, 2. Waste gate spring housing, 3. Waste gate adjustment lock nut, 4. Push rod bushing, 5. Waste gate push rod, 6. Return spring, 7. Push rod junction adjustable, and 8. Lock nut

Fig. 4 Connecting ball valve to the biogas carburetor



biogas that has a research octane number of about 130. To get the most benefit from the higher RON, higher compression ratio should be used for higher thermal efficiency (HinoMotors, 2005; Jingdang Huang and Crookes, 1998 and Heywood, 1988). The proper compression ratio for the spark ignition engine to be run on biogas fuel is between 10 to 12:1 (Mitzalff, 1988). While a naturally aspirated spark ignition engine may have sufficient margin of safety relative to knock to allow modest inlet-air boost, any substantial air compression prior to cylinder entry will require charges in engine design and/or operating variables to offset the negative impact on knock. The variables that are adjusted to control knock in turbocharged SI engines are: compression ratio, spark retard from optimum, charge air temperature, and air/fuel equivalence ratio (Heywood, 1988). Therefore, a spacer is used with the cylinder head to increase the combustion chamber volume and produce lower compression ratio. The experiment is designed start at the compression ratio of 8:1 and the turbocharger pressure adjusted by the waste gate at 40 kPa and increase at an increment of 4 kPa until engine efficiency begins to decrease.

Initial Air/Fuel Mixture Adjustment

Start the engine and set the ignition timing at about mid range (55˚ BTDC) and adjust the air/fuel mixture screw (metering adjustment screw in the carburetor) to the position that the engine is just running smoothly (lean mixture).

Initial Ignition Timing Adjustment

Set the ignition timing at 50˚ BTDC at the beginning of a data set collection.

Data Collection

Recording was made of air temperature, biogas temperature before and after boost by turbocharger and after cooling by intercooler, engine coolant temperature, lubricating oil temperature, exhaust gas temperature, air and biogas consumption rate, ignition timing, generator power output, oxygen to remain from combustion, carbon monoxide and oxide of nitrogen emission in the exhaust gas.

Ignition Timing Increment

The ignition timing was advanced 2˚ and again collected as described above. The process was repeated until the ignition timing reached 60˚ BTDC or excessive pre-ignition was observed.

Air/Fuel Mixture Increment

After a set of data was collected, the air/fuel mixture screw was turned half a revolution in the rich direction. Another set of data was collected and the process repeated until the mixture was too rich for the engine to run smoothly.

Data Processing

Collected data were processed into air/fuel ratio, engine efficiency and then the system efficiency, power output, exhaust gas temperature, specific biogas consumption, oxygen to remain from combustion, carbon monoxide and oxide of nitrogen emission were plotted against the ignition timing, excess air ratio, and turbocharger pressure. The resulting graphs are shown in **Fig. 6**.

Test Results

Three categories of tuning optimizations were done. The categories were lowest CO emission, highest engine efficiency, and highest power output. The tuning parameters and collected data for the three categories are presented in **Table 1**.

Conclusion

In this study, engine performance and pollution figures were recorded for a range of engine tuning parameters such as turbocharger boost, ignition timing and air/fuel ratio. The compression ratio was set at 8:1 and the turbocharger boost varied by adjusting the waste gate. When the system was operating at 1,500 rpm, the range of engine settings was air/fuel ratio between 0.9 to 1.2, ignition timing between 50˚ to 60˚ before top dead center, and turbocharger pressure setting between 40 to 68 kPa. Under those operating conditions, the engine efficiency in-

Fig. 5 Hino 13,000 cc diesel engine converted to biogas engine with test engine

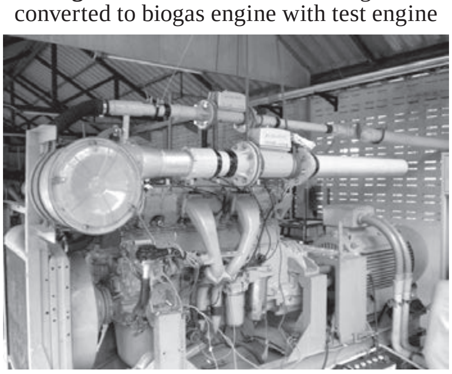
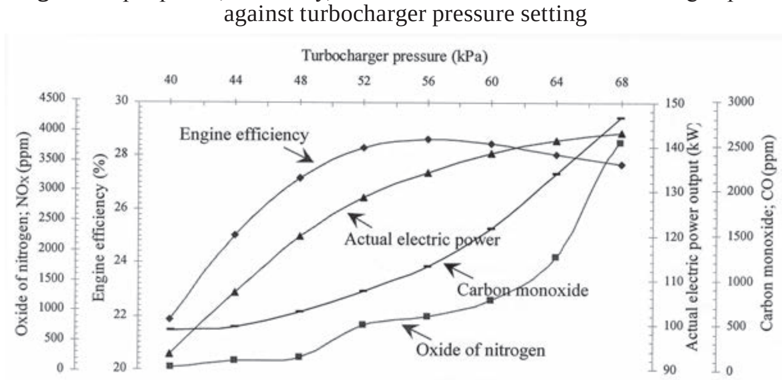


Fig. 6 Output power, efficiency, carbon monoxide and oxide of nitrogen plotted against turbocharger pressure setting



creased as the boost increased from 40 to 56 kPa and there was a slight increase of NO_X and CO as the boost went up. As the boost was increased from 56 kPa to 68 kPa, the engine efficiency began to decrease and the amount of pollution increased. Increase in engine vibration was also noted in this turbocharger boost range. Oxides of nitrogen (NO_X) were high when high pressure and temperature occured in the combustion. The system produced electrical power of 93.40 to 143.20 kW. Tests showed that more power could be generated if the engine was operated with rich air/fuel ratio and high turbocharger boost. Higher engine output yielded shorter payback period for the investment but increase of the boost pressure beyond 56 kPa caused excessive pollution emission and engine vibration, which will probably shorten the engine life. It can be concluded that boost pressure of 56 kPa yielded highest efficiency with acceptable pollution level for this engine.

Acknowledgement

The authors would like to express their sincere appreciation to the Faculty of Mechanical Engineering, Chiang Mai University, Thailand and Biogas Technology Center (BTC), Thailand, for help in tangible ways and material, and the 4T farm Chiang Mai, Thailand, for the location and biogas support. Last and most importantly, the Energy Policy and Planning Office (EPPO), Thailand, for the financial support.

Table 1 Summary of fine tuning of biogas engine for optimum conditions with compression ratio at 8:1 and turbocharger booster at 56 kPa

Item	Lowest CO emission	Highest engine efficiency	Highest power output
Optimum ignition timing, ºBTDC	57	54	52
Excess air ratio; λ	1.215	1.097	0.989
Fuel consumption; fC, m^3/hr	71.8	78.6	86.1
Specific fuel consumption; sfc, m^3/kWh	0.64	0.59	0.61
Actual electric power output; P_{EL}, kW	111.4	134.2	140.7
Engine efficiency; η_{eng}, %	26.01	28.63	27.40
Overall efficiency; η_{tot}, %	23.41	25.76	24.66
Oxide of nitrogen emission; NO_X, ppm	511	896	843
Carbon monoxide emission; CO, ppm	854	1,154	2,576
Oxygen to remain from combustion; O_2, %	10.0	6.2	5.9
Engine coolant temperature; T_{eng}, ˚C	88.2	88.7	89.0
Lubricating oil temperature; T_{oil}, ˚C	87.8	87.2	87.6
Exhaust gas temperature; T_{fg}, ˚C	536.0	521.5	533.8
Payback period, year	0.63	0.42	0.40

REFERENCES

Werner, U., U. Stoehr, and N. Hees. 1989. Biogas plants in animals husbandry, A Practical Guid in Deutsche gesellschaft fuer Technische Zusammenarbeit (GTZ), Germany.

Mitzlaff, Klaus von. 1988. Engine for biogas; Theory, modification, econum, operation, federal, Republic of Germany.

King James L., and Minlner Timothy, J. 1996. Biogas-driven generator set, Bio Technology, Patent No. US5501185, U.S.A.

Potikanond, N. 1995. “Use of animals dung from biogas reactor as fertilizer.”, Project for promotion biogas production in animals farm, Biogas Advisory Unit (BAU).

Kulkarni publ, M. K. 1980. Kirloskar Dual Fuel Biogas Engines, Commonwealth Regional (Asia/Pacific) Rural Technology Programme, Bombay, India.

Cao Zexi. 1982. Application of Biogas on Farm Internal Combustion Engine, Provincial Agricultural Mechinery Research Institute of Sichuan, P.R. of China, Nov.

Bilican, A., O. Le Corre, and A. Delebarre. 2003. Thermal efficiency and environmental performances of a biogas-diesel stationary engine, Journal of Environment Technology, 24, 1165-1173.

Ortiz Canavate, J. 1981. Diesel Engine Modification to operate on Biogas, Transactions of the ASAE.

Mitzlaff and Mkumbwa, K. Y. 1985. Use of Biogas as an Alternative Fuel in Stationary Diesel Engines, Res. Rep. University of Dar-es-Salaam, Tanzania.

Siripornakarachai, S. and T. Sucharitakul. 2007. Modification of diesel engine for electricity production fueled by biogas, International Conference on 6th Asia Pacific Conference on Sustainable Energy and Environmental Technologies (APCSEET 2007), 7-11 May 2007, Bangkok, Thailand.

Siripornakarachai, S. and T. Sucharitakul 2006. Tuning of multi-valve automotive engine for electricity production fueled by biogas, International Conference on Green and Sustainable Innovation (ICGSI 2006), 29 November - 1 December 2006, Chiang Mai, Thailand.

HinoMotors, Ltd. 2005. Industrial Engines, Hinodai 3-chome, Hino-shi, Tokyo 191-8660, Printed in Japan.

Jingdang Huang, and Crookes, R. J. 1998. Assessment of simulated biogas as a fuel for the spark ignition engine, Journal of Science, 77, 1793-1801.

Heywood, J. B. 1988. Pollutant formation and control, Engine Operating characteristics. In: Internal combustion engine fundamentals, McGraw-Hill Book Company, New York, USA.

■■

Empirical Equations to Predict the Tractor Center of Gravity

by

S. M. Abd El Aal
ASABE Member, B.Sc.(Agric.),
Agricultural Engineering Department,
Faculty of Agriculture, Alexandria University,
#201 Internal Bldg, #5 Dawood Aamoon St., Loran,
Alexandria 21411, EGYPT.
shereefmetwally@hotmail.com

Abstract

Nebraska Tractor test data, as published by Al Ashry, 2005, were used to obtain some empirical equations to acceptably predict, with accuracy, the location of the center of gravity of any tractor for the farmer or the driver who may not have the proper utilities in the field for identification or calculation.

Finding an easy way to calculate the approximate values which describe the center of gravity might be helpful in calculating the critical speeds and draw bar pull to be considered while operating the tractor in order to secure certain stability by preventing sideways overturns or tipping over backward.

Introduction

Knowing the center of gravity of the tractor is usually not easy to determine for the driver or the farmer because manufacturers are do not usually mention it in the tractor's catalog or specification sheet. At the same time, not all the users have the proper access to the standard European or American tractor tests, or they might just not know that it is there. Also, it is not easy for the farmer to get himself the equipment needed to identify the center of gravity by hanging the tractor to the ceiling or weighing it while it is hanging.

We should take into consideration, also, the studies and reports which have shown that tractors can roll over if the driver makes a fast or sudden turn. Also half of all injury-related fatalities in the agricultural industry are associated with farm tractors according to a report of investigations conducted by New York State Department of Health Occupational Health Nurses in Agricultural Communities (OHNAC) program and published by the US Government Printing Office in 1996 then by Gale Group in 2004.

This study investigated the 27 incidents with 15 fatalities in the period from 1991 to 1995 of sudden rear rollover of farm tractors in which the tractor flipped backward and rotated around its rear axle. One of the major causes of 11 incidents, representing about 40 % of the total, was the imbalance resulting from pulling an excessively heavy load.

Rollovers can also occur in flat fields when the tractor gets too close to a ditch and the tire slips down the side. Sometimes rollovers happen when trailing equipment is not hooked up correctly, causing the tractor to become unbalanced and flip over backwards causing accidents like those mentioned above.

Because all of that, it was considered that it might be helpful to identify a simple mathematical solution that could be used in predicting, with accuracy, the location of the center of gravity of any tractor that might be acceptable to the farmer or the driver.

Methodology

Data were used from Nebraska Tractor tests, as published by Al Ashry, 2005, that included tractor characteristics as shown in **Table 1**. Tractor characteristic data for 83 known commercial brand and model tractors were used that should be easily obtained from the specification sheet or the catalog of the tractor, or by using any length measuring tool. The data were entered into a spreadsheet according to the tractor ascending weight. Data for the five light weight tractors and the five heavy weight tractors are given in **Table 1**.

Trial and error experiments were made between these characteristics and the center of gravity identifiers to find a possible relationship between one of them and one of the identifiers.

Relationships between characteristics and the identifiers (by themselves or divided by or multiplied by each other) were plotted in different types of charts. These included various functional trend lines such as linear, logarithmic, polynomial, power, and exponential to identify possible relationships that might be used graphically for the most accepted accuracy in predicting the center of gravity identifiers (X_{cg}, Y_{cg}, and Z_{cg}).

Accuracy was identified by comparing center of gravity identifiers specified in tractor test reports that had been used to reach the equation or other tests and the identifiers calculated by the assumed empirical final equations.

To increase accuracy of identifying equations that bind factors together while no direct relationship could be reached between them, primary curves were used and the equations of these curves were calculated by spreadsheet software. These primary curves related the value of each factor to the unit (x) axis. These figures were related to the x values calculated from the primary equations presented by the software. Then, final equations could be identified by merging these primary equations according to the needed information.

Results and Discussions

The trial and error experiments led to the following conclusion. If the wheel base and the tractor weight were multiplied, it would give a value that had a clear relationship with both X_{cg} and Y_{cg} as compared with any value represented by dividing or multiplying any of these characteristics into or by another one. This was identified this value as WL.

Regarding Z_{cg}, the easiest way to calculate it with an acceptable accuracy was to relate it directly to the tractor wheel tread, as discussed in the following explanation.

Finding X_{cg}

Data for tractors weighing more than 4 tons could not be represented by the same equation as data of the tractors of weights less than 4 tons. So, the latter best trend line was logarithmic and the trend line that represented WL was linear (**Fig. 1**). The former best trend line was a polynomial and the trend line that represented WL was exponential (**Fig. 2**).

Equation presenting tractors less than 4 tons in weight:

$WL = 113.43x + 1470.2$..............(1)

Table 1 Sample of tractors nebraska tests as published by al ashry 2005

S.N.	Tractor type and brand	Outside diameter tire, m	Rear tractor width, m	Tractor weight, N	Tractor weight, Kg	Wheel base, m	X_{cg}, m	Y_{cg}, m	$(Wt/2) + Z_{cg}$, m
1	John Deere 750	1.05	0.92	8877.2	905.8	1.55	0.62	0.67	0.46
2	Massey Ferguson 1020	0.99	1.02	9922.8	1012.5	1.77	0.66	0.64	0.51
3	Ford 1510 (12x4) M	1.05	1.05	9922.8	1012.5	1.6	0.57	0.75	0.52
4	Ford 1510 (12x4) S	1.05	1.05	10167.6	1037.5	1.6	0.57	0.76	0.52
5	Ford 1710 (12x4) M	1.1	1.13	10990.8	1121.5	1.6	0.6	0.78	0.57
79	John Deere 2955	1.76	1.61	49035.7	5003.6	2.58	0.9	0.99	0.81
80	John Deere 3150	1.76	1.78	53151.7	5423.6	2.58	0.92	0.98	0.89
81	Massey Ferguson 2640	1.76	1.63	55332	5646.1	2.73	0.99	1.16	0.81
82	White 2 - 88	1.83	1.7	60582.7	6181.9	2.19	0.89	1.07	0.85
83	White 2-110	1.83	1.79	62095.6	6336.3	2.19	0.86	1.10	0.85

Fig. 1 Relation between the WL value and X_{cg} for tractors less than 4 tons in weight

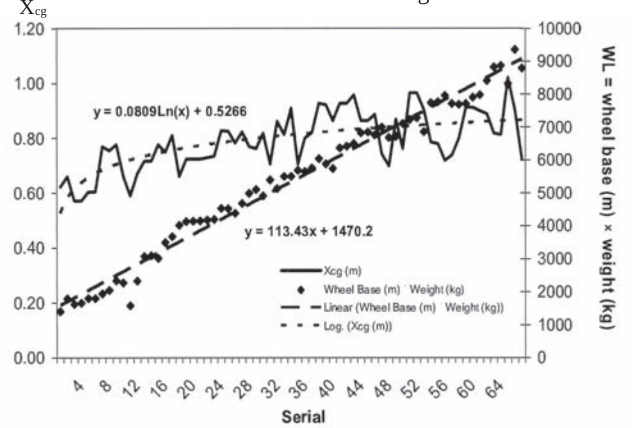
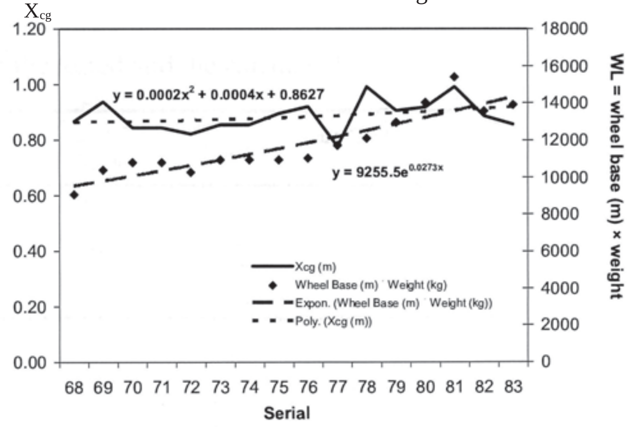


Fig. 2 Relation between the WL value and X_{cg} for tractors more than 4 tons in weight



where

WL = wheel base (m) × weight (kg)

Equation presenting X_{cg}:

$X_{cg} = 0.0809 \ln(x) + 0.5266$.....(2)

From Equations (1) & (2):

$x = (WL - 1{,}470.2) / 113.43$

$\therefore X_{cg} = 0.0809 \ln(WL - 1{,}470.2) + 0.143$

$(WL - 1470.2 > 0)$......................(3)

Tractors more than 4 tons in weight:

Equation presenting WL:

$WL = 9{,}255.5e^{0.0273x}$.....................(4)

Equation presenting X_{cg}:

$X_{cg} = 0.0002\,x^2 + 0.0004x + 0.8627$ ....(5)

From Equations (4) & (5):

$x = [\ln(WL / 9{,}255.5)] / 0.0273$

$\therefore X_{cg} = 0.268\,[\ln(WL / 9255.5)]^2 + 14.65 \times 10^{-3}\,[\ln(WL / 9255.5)] + 0.8627$

$\therefore X_{cg} = 0.268\,(\ln WL)^2 - 4.87 \ln WL + 23$....................................(6)

Finding Y_{cg}:

The best trend line was linear and the trend line represented WL was linear also (**Fig. 3**). Equations are as follows:

Equation presenting WL:

$WL = 135.38x + 739.98$..............(7)

Equation presenting Y_{cg}:

$Y_{cg} = 0.0038\,x + 0.6978$...............(8)

From Equations (7) and (8):

$x = (WL - 739.98) / 135.38$

$\therefore Y_{cg} = 28 \times 10^{-6}\,WL + 677.8 \times 10^{-3}$ ....(9)

Finding Z_{cg}:

The easiest way to calculate Z_{cg} with an acceptable accuracy was to relate it directly to the tractor's wheel tread as in the following equation:

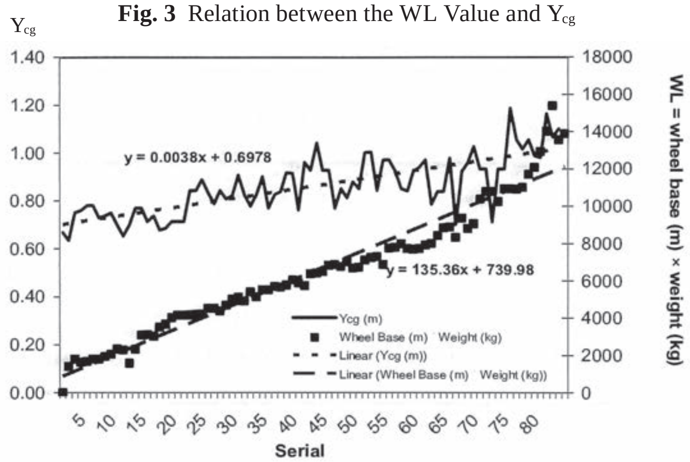
From the tractor tests; we found that

$W_t / [(W_t / 2) + Z_{cg}] = S \Rightarrow W_t = S\,(W_t / 2) + S \times Z_{cg}$

$\therefore Z_{cg} = W_t\,[\,1 - (S / 2)] / S$.......(10)

From the tests, we found that (S average = 2), this meant that (Z_{cg} average = 0).

Fig. 3 Relation between the WL Value and Y_{cg}



Statistical Calculations:

Some statistical calculations were applied to understand the deviation between the actual and the calculated values of X_{cg}, Y_{cg} and Z_{cg}. Using equations (3), (6) and (9), X_{cg} and Y_{cg} were calculated then compared with the actual values measured through the tests except the value related to the John Deere 750 because $WL - 1{,}470.2 < 0$. The results of a sample of four light weight tractors and four heavy weight tractors are shown in **Table 2**.

Statistical Calculations Showed the Following:

For tractors less than 4 tons, the average difference or the deviation between the calculated and the measured X_{cg} values was 7.66 %, representing 6 cm with a standard deviation of 4 cm, which meant that the total deviation value was around 10 cm as per the values shown in **Table 3**.

For tractors more than 4 tons, the average difference or the deviation between the calculated and the measured X_{cg} values was about 5 %, representing 4 cm with a standard deviation of 3 cm, which meant that the total deviation value was around 7 cm as per the values shown in **Table 4**.

For all tested tractors, the difference or the deviation between the calculated and the measured Ycg values was 6.96 % representing 6 cm with a standard deviation value of 5cm, which meant that the total

Table 2 Sample of center of gravity comparison between the tested and the calculated

S.N.	Tractor Type and Brand	Rear Tractor Width, m	Tractor Weight, Kg	Wheel Base, m	X_{cg}, m	Calculated X_{cg}, m	Y_{cg}, m	Calculated Y_{cg}, m
1	Massey Ferguson 1020	1.02	1012.5	1.77	0.66	0.61	0.64	0.73
2	Ford 1510 (12x4) M	1.05	1012.5	1.60	0.57	0.55	0.75	0.72
3	Ford 1510 (12x4) S	1.05	1037.5	1.60	0.57	0.57	0.76	0.72
4	Ford 1710 (12x4) M	1.13	1121.5	1.60	0.60	0.61	0.78	0.73
79	John Deere 3150	1.78	5423.6	2.58	0.92	0.93	0.98	1.07
80	Massey Ferguson 2640	1.63	5646.1	2.73	0.99	0.96	1.16	1.11
81	White 2 - 88	1.70	6181.9	2.19	0.89	0.93	1.07	1.06
82	White 2-110	1.79	6336.3	2.19	0.86	0.93	1.10	1.07

deviation value was around 11cm as per the values shown in **Table 5**.

Finding the Critical Turning Speed (V_c):

When the driver of the tractor makes a sudden turn, the tractor might fall (turn over) on the side opposite its turning direction. This is because the moment caused by the centrifugal force around the point of contact (C) between the ground and the tiers at the opposite side of tractor at the current tractor speed became higher than the moment caused by weight of the tractor and the centripetal force around the same point (**Fig. 4**).

Critical Turning Speed (V_c) can be identified as the speed the turning vehicle reaches that makes the centrifugal force equal centripetal force. It is speed the turning vehicle reaches before it turns over from the driving track. At this speed, the two moments become equal.

At the critical speed, friction provided by the centripetal force was insufficient; centripetal force could not hold the vehicle. That was similar to cutting the string in **Fig. 5**.

Forces Affecting any Turning Body, In General, Include the Following:

Centripetal force can be identified as the force which must be applied by an external agent to force an object to move in a curved path

$F_{centripetal} = m\,(v^2 / r)$ ....(11)

where

r = turning radius (m)

m = weight of the tractor (kg)

v = turning speed (m sec^{-1})

Centrifugal force is represented by the following equation:

$F_{Centrifugal} = m\,(v^2 / r)$ ....(12)

From **Figs. 4** and **5**, it can be seen that the only force acting on the vehicle will be the centrifugal force.

$M_c = F_c \times Y_{cg}$

(M_c) is the moment caused by the centrifugal force.

From Equations (11) and (12):

$\therefore M_c = m\,(v^2 / r) \times Y_{cg}$...............(13)

$M_w = m \times g \times [(w_t / 2) + Z_{cg}]$

(M_w) is the moment caused by the weight of the tractor and (g) is the constant of gravity.

When $M_c = M_w$, the turning speed has reached the critical speed (V_c).

$m\,(v_c^2 / r) \times Y_{cg} = m \times g \times [(w_t / 2) + Z_{cg}]$

$$\therefore V_c = \sqrt{\frac{g \times (\frac{W_t}{2} + Z_{cg}) \times r}{Y_{cg}}} \quad ....(14)$$

Equation (14) calculates the approximate critical speed which should not be reached by the driver when he turning the tractor at the turning radius (r). And, it is approximate as long as the values of both Z_{cg} and Y_{cg} are approximate.

This means that (V_c) can be calculated as follows:

$$V_c = \sqrt{\frac{W_t \times g \times r}{S \times (28 \times 10^{-6} WL + 677.8 \times 10^{-3})}}$$

....(15)

Considering $Z_{cg} = 0$

$$\therefore V_c = \sqrt{\frac{g \times W_t \times r}{56 \times 10^{-6} WL + 1.35}} \quad ....(16)$$

Finding the Critical Pull Force (F_{db}):

Pulling performance of a tractor is limited by one of three factors. First, the engine may not be able to deliver enough rear axle torque for the tractor to pull the load. This torque

Table 3 Statistical analysis for tractors less than 4 tons

	Absolute (X_{cg} - Calculated X_{cg}) m	X_{cg} Deference Percent
Average:	0.06	7.66%
Median:	0.05	6.41%
Standard Dev.:	0.04	5.17%
Mean:	0.01	4.34%

Table 4 Statistical analysis for tractors more than 4 tons

	Absolute (X_{cg} - Calculated X_{cg}) m	X_{cg} Deference Percent
Average:	0.04	4.99%
Median:	0.04	4.22%
Standard Dev.:	0.03	3.91%
Mean:	0.04	5.14%

Table 5 Statistical analysis for all the tractors to calculate Y_{cg} tons

	Absolute (Y_{cg} - Calculated Y_{cg}) m	Y_{cg} Deference Percent
Average:	0.06	6.96%
Median:	0.05	6.17%
Standard Dev.:	0.05	6.16%
Mean:	0.05	5.08%

Fig. 4 Major Forces Affecting a Turning Tractor

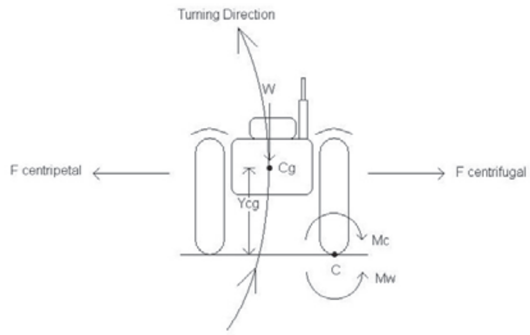
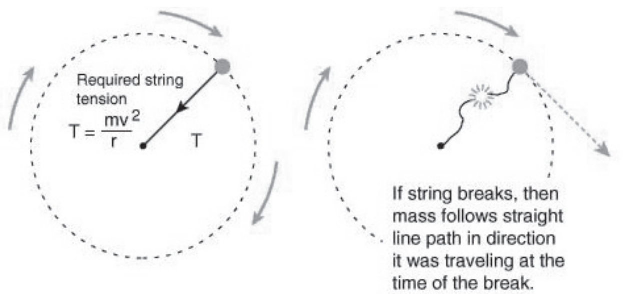


Fig. 5 After Hyper Physics Web Project. Department of Physics and Astronomy, Georgia State University



limit can nearly always be overcome by shifting the transmission to a lower gear. Second, traction may be insufficient to pull the load, and the drive wheels will spin. If traction is not limiting, stability may become the limiting factor. Stability is lost when the weight transfer becomes so large that the front wheels lift off the ground. Equation (17), shown below, can be used to calculate the critical drawbar pull at which stability is lost - that is, when $R_f = 0$. The critical pull is:

$R_f = (WX_{cg} - F_{db} Z_r) / WB$ ......(17)

where

R_f = dynamic front wheel reaction (kg m sec^{-2})

F_{db} = force on drawbar (kg m sec^{-2})

Z_r = distance from drawbar force to point A (m)

$F_{db} = (WX_{cg}) / Z_r$ ....(18)

Considering equations (3) and (6) the critical pull force could be reached directly as follows:

Tractors less than 4 tons in weight:

$F_{db} = (W / Z_r) \times [0.0809 \ln (WL - 1470.2) + 0.143]$.....................(19)

Tractors more than 4 tons in weight:

$F_{db} = (W / Z_r) \times [0.268 (\ln WL)^2 - 4.87 \ln WL + 23]$...................(20)

Conclusion

- An approximate X_{cg} for tractors weighing less than 4 tons could be calculated from the following equation:
  $X_{cg} = 0.0809 \ln (WL - 1470.2) + 0.143$
- An approximate X_{cg} for tractors weighing more than 4 tons could be calculated from the following equation:
  $X_{cg} = 0.268 (\ln WL)^2 - 4.87 \ln WL + 23$
- An approximate Y_{cg} for most of the tractors could be calculated from the following equation:
  $Y_{cg} = 28 \times 10^{-6} WL + 677.8 \times 10^{-3}$
- An approximate critical speed V_c for most of the tractors could be calculated from the following equation:
  $$V_c = \sqrt{\frac{g \times W_t \times r}{56 \times 10^{-6} WL + 1.35}}$$
- An approximate critical pull force F_{db} for tractors less than 4 tons:
  $F_{db} = W / Z_r \times [0.0809 \ln (WL - 1470.2) + 0.143]$
- Approximate critical pull force F_{db} for tractors more than 4 tons:
  $F_{db} = W / Z_r \times [0.268 (\ln WL)^2 - 4.87 \ln WL + 23]$
- The average deviations between the calculated and the measured values of Xcg and Ycg were from 7 cm to 11 cm. These deviations might be acceptable for the tractor owner or users who most probably do not have this information in the field when needed to secure most of their field operations by adjusting the farm machinery positions behind the tractor.
- Tractor owners or users can have an idea about the suitable speed for use of their tractors on the go in order to avoid accidents that might happen due to the tractor being unbalanced while performing a turning action or a certain farm operation.
- Analyzing more data might lead to more accurate equations.

REFERENCES

Al Ashry. 2005. Experimental Methods of Tractor Engineering. Bostan El Maarefa Library publishing house.

Goering, Carroll E., Hansen. 2004. Engine and Tractor Power Chapter 16 Weight, Transfer, Traction, and Safety. American Society of Agricultural and Biological Engineers.

Burley, Carrington, Kobes, and Kunstatter. 1996. Center of Gravity. Introductory Physics Notes. IUN/FYDE distance education program of the University of Winnipeg. http://theory.uwinnipeg.ca/physics/rot/node4.html

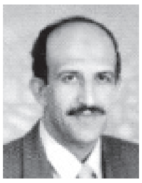
Nave. 2005. Centripetal Force. Hyper Physics. Department of Physics and Astronomy, Georgia State University. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

New York State Department of Health Occupational Health Nurses in Agricultural Communities (OHNAC) program. 1995. Fatalities associated with improper hitching to farm tractors York (1991-1995). US Government Printing Office and Gale Group. http://www.findarticles.com/p/articles/mi_m0906/is_n15_v45/ai_18269373/pg_6

Jepsen, Todd, Handrosh and Bean. Extension Fact Sheet (Agricultural Engineering 43210) Tractor Tips. OHIO State University. http://ohioline.osu.edu/aex-fact/pdf/0993.pdf

■■

The Utilization of a Drilling Planter for Rice Band Sowing



by
Ismail, Z. E.
Professor.
Agricultural Engineering.
Faculty of Agriculture, .
Mansoura University,
EGYPT

Abstract

During the last decade, the Agricultural Minster of Egypt gave a great deal of attention to planting rice by drilling machine. Further increase in rice production by increasing the yield per unit area is required to increase the drilling intensity, which may be realized by band sowing rice. The objective of this study was to evaluate two sowing methods and the interaction between the primary and secondary tillage treatments.

Using the band sowing as a new method of rice planting had no significant effect on the yield as compared with the common mechanical sowing, although the first recorded the better percentage distribution of seeding per area. The effect of secondary tillage system (disc harrow two strips followed with rotary-"d_2r") at the moldboard "m" or dick plow "dp" during band sowing "S_2" recorded a slight increase, in general, compared with the common mechanical method "S_1". On the other hand the good yield may be due to good soil surface roughness, good pulverization, suitable reduction conditions, good establishments and distributions of roots and also, good weed control, which was affected by good pulverization and plowing depth.

Introduction

Rice is the main food crop for a majority of people in the whole world; it is considered as a staple food in Asia, Africa, and South America. In Egypt, rice production plays a significant rule in the strategy to overcome food shortage and improvement of self-sufficiency. The yearly average planted area has been about one million feddan during the past ten years with an approximate production of 3 million metric tons per year. Increase in rice production from increased yield per unit area is needed to face the increasing in the population. It is evident that the increase of rice production in quality and quantity, not only depends on the improvement and conservation of soil fertility, new promising varieties and control of plant insects and diseases but also depends on improved methods and technology to develop suitable methods of planting.

Planting or seeding is an important operation in crop farming. The choice of seed, time and a suitable method of seeding are essential for the future crop. At seeding, seeds are placed on a seedbed at the desired depth and at an interval to provide each plant with an area of nutrition (Konokhova, 1982). Good results can be obtained only when a crop is seeded or planted on a good seedbed by a suitable method, at a proper date, optimum rate and covered at an adequate depth.

Sowing requires that an area around the roots called the plant area is sufficiently large to make efficient use of essential soil nutrients (Grist, 1975). The provision of an optimum plant area for each individual plant is extremely important for a high level of production. Kanetani and Mansor (1991) reported that the rice-farming system in the Muda area in the Malaysia Peninsula made great changes in sowing rice, which were represented by a rapid shift from transplanting to direct seeding. In their study about mechanized direct seeding of rice, the paddy yields of the drilled plots were slightly higher in general as compared to those of the broadcasted plots. Moreover, the drill seeding method would be effective in reducing harvesting losses. They also reported that the most appropriate space of rows would be in the range of 20 to 25 cm for direct seeding in that area.

In Egypt, the manual transplanting is the common method for cultivating rice. Hamad *et al.* (1983) studied the ability of transplanting in dry condition with manual feeding rice transplanting designed by Ismail (1981) to overcome some of transplanting problems in wet conditions. Many of our farmers nowadays distribute the plants to permanent fields in dry condition but this is not enough to overcome the disadvantage of transplanting. On the other face, the direct-seeded rice area is increasing year after year in Egypt as one of the last labor consuming practices (Mahrous and Badawi, 1990). Thus, there is a need to look for another method for rice cultural practices, including new land preparation methods, and planting. Therefore, the aim of this work is to determine the utilization ability of a drilling planter for rice band sowing as one of the methods to overcome the disadvantages of rice transplanting method.

Materials and Methods

The Tye Oriental drill machine was used to drill the seeds by two methods. The first was drilling the seeds under the soil surface 1-2 cm (common method, "S_1") and the second was drilling the seeds above the soil surface with 20 cm to achieve the proper band sowing rice "S_2". The operating width of the drilling machine was 2.88 m, which had 16 rows with a distance between rows of 18 cm. It had two hoppers; one for seeding and the other for fertilizing.

The calibration was conformed under the field conditions to give a seeding rate of 40 kg/fed. The average drilling speed was adjusted to be about 6 km/h and the space between rows was 18 cm. The experiment was carried out in Sakha research farm (Kafer El-Sheikh Governorate) at the summer season. Clover was the previous crop. The land preparation for clover was done by chisel plow twice in the two directions and then disked and dry leveling. The soil mechanical analysis and chemical characteristics were carried out at Sakha Research Station Laboratory at Soil Department as shown in **Table 1**.

Giza-175 was selected as one of the new rice varieties grown in Egypt. Its properties are a medium grain, harvest index (46-69), total duration 137, and good grain quality for feeding people.

The experimental field was carried out under the interaction between the primary and secondary tillage of soil bed preparation, and the two methods of sowing rice. The primary tillage operations were divided into five systems (Non-tillage - "no", the moldboard plow - "m" of 20 cm in depth, chisel plow - "c" of 20 cm in depth, disk plow - "dp" of 20 cm in depth and disk harrow - "dh" of 10 cm depth. The secondary tillage operation was done in the perpendicular direction as sub plot treatments. The disk plow - "d1", the disk plow twice - "d2", disk harrow - "d_2h" and the offset disk harrow - two strips followed with rotary - "d_2r" were performed as the second tillage treatments.

The latitudinal distribution and number of seedlings per unit area (seedling intensity) were measured 26 days after sowing by using a wooden frame (100 × 36 cm) which divided into plots (10 × 1 cm) by robs. The latitudinal distribution of seedling was found by collecting the number of seedlings per each plot around the centerline of row. A wooden frame (18 × 50 cm) was used to calculate the numbers of panicles per square meter for each plot at harvesting time, which was replicated four times (four samples from each sub-sub plot). The grain yield was taken form an area (1.8 × 3 m) for each treatment and then calculated related to the area of a feddan.

All data collected for all parameters of different treatments were statistically analyzed. The split-split plot and strip-split plot designs (Gomez and Arture, 1984) were adopted in these studies for statistical analysis of the data. In order to ascertain whether the observed treatment effects were real and discernible from chance effects the "Null Hypothesis" was tested by "F" test at 5 % level of probability as well as LSD at 1 % level of probability (in case of highly significant differences) according to Sendecor and Cockran, 1967. The data of this paper was provided from the M. Sc. of "Mechanization of seedbed preparation and planting of rice crop". Whose supervisor was Prof. Dr. Ismail, (1994).

Results and Discussion

The experiments were carried out to evaluate the new methods of rice sowing (band sowing as one of the methods) to overcome the disadvantage of transplanting and at the same time evaluate different seedbed preparation methods on rice yield.

The Latitudinal Distribution of Seeding

The percentage of rice seedlings per meter that scattered in "3 cm" for each side around the center line of the row were calculated to evaluate the seedling distribution for the independent variable under study (**Fig. 1**). Generally, the tillage systems "d_2r" and "d_2h" recorded the lowest variation of seeds distribution in percentage. On the other hand, the band sowing (S_2) recorded better percentage distribution compared with drilling under the soil surface 1-2 cm (common mechanical method, S_1). As an example, the percentages of rice seedling that scattered in "3 cm" for each

Table 1 Soil mechanical analysis and chemical characteristics

Clay, %	Silt, %	Sand, %	Residual, %	Soil texture	pH	E.C, m.mohs/cm	OM, %	M, %	P, ppm	Zn, ppm
57.3	36.1	4.2	2.4	Clay soil	8.5	1.5	2.4	0.21	9.2	1.7

side around the center line as the interaction between tillage systems "m-d_2r", "dp-d_2r" and "dp-d_2h" and sowing method S_1 recorded 54.9 %; 63.2 % and 60.83 %, respectively. While the percentages under the same methods of sowing, were 90.29 % and 75.1 % for tillage systems "m-non" and "dp-non", respectively. The tillage system "m-non" recorded the highest percentage of seedlings scattered in "3 cm" for each side around the centerline for sowing method "S_1".

The Seedling Intensity

The second indicator to evaluate the interaction between the tillage systems and sowing method is considered the number of seedlings per unit area (seedling intensity). The seedling intensity is illustrated in **Fig. 2** Generally, the highest numbers were recorded with "d_2r" and "d_2h" as secondary tillage systems with "dp", "dh" and "m" as primary tillage on the band sowing method "S_2". The "S_2" recorded a slight increase compared with the sowing method "S_1".

As an example, the tillage system "m-d_2r-S_2" recorded the highest number of seedlings (415 seedlings/m^2). Nevertheless, the minimum value was 182 seedlings/m^2 for the "m-non-S_2" treatment. It may be recommended that the highest number of seedlingss/m^2 can be obtained for tillage system "m-d_2r-S_2" which gave the MWD 48.12 mm and 36.64 % of soil roughness.

The Panicle Intensity

The average number of panicles per unit area (panicle intensity) as influenced by primary tillage, secondary tillage and sowing methods are shown in **Figs. 3** and **4**. The data demonstrated that the interaction between tillage treatments "m-d_2r-S_2" gave the maximum intensity of 518 panicles/m^2, while the tillage treatment "Non-non" with sowing method, "S_2" gave the lowest number of panicles (371 panicles/ m^2). On the other hand, as shown in **Fig. 3**, the maximum were recorded 474 and

Fig. 1 The sowing methods via the latitudinal distribution of seeding

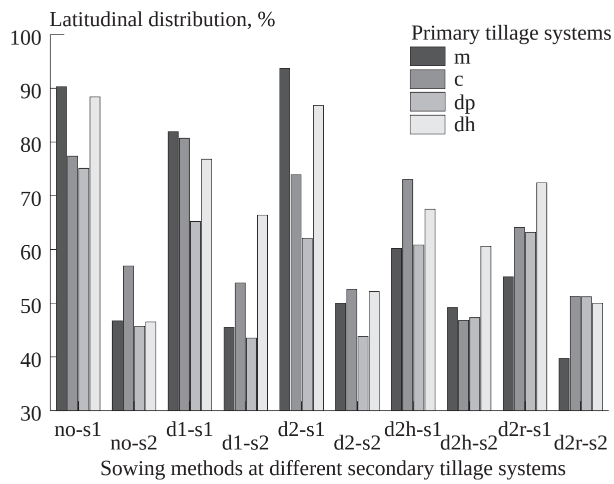


Fig. 2 The sowing methods via the seedling intensity

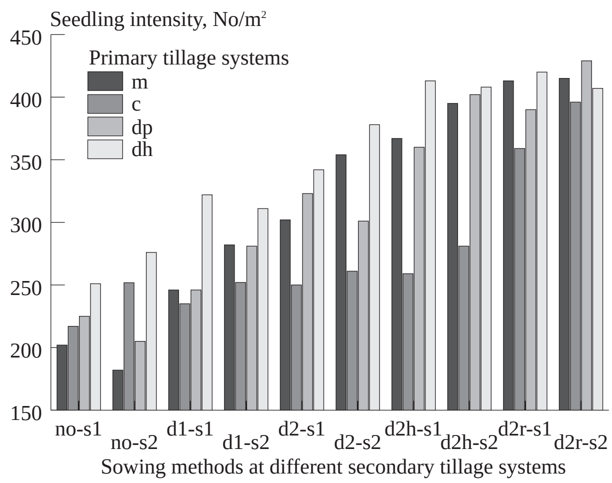


Fig. 3 The tillage systems versus the panicles intensity at S_1

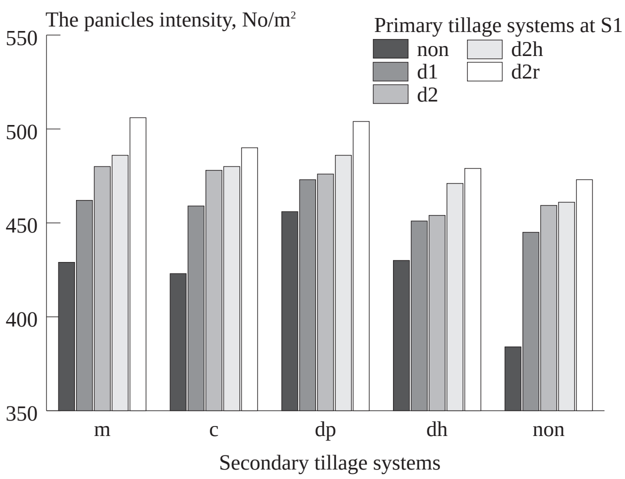
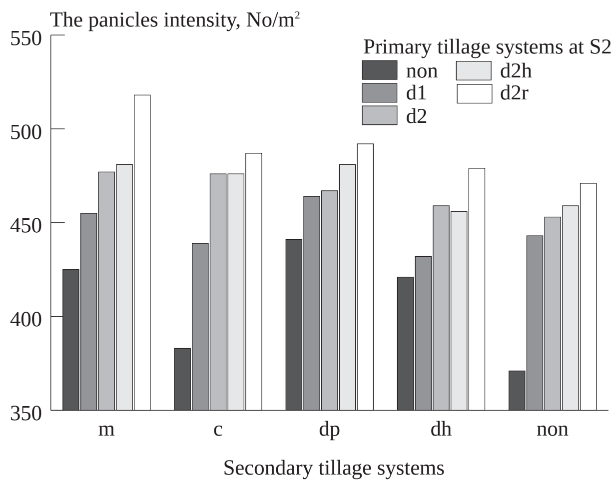


Fig. 4 The tillage systems versus the panicles intensity at band sowing (S_2)



471.9 panicles/m^2 with “dp” and “m” as primary tillage, respectively, while the minimum was 441.9 panicles/m^2 recorded with non primary tillage.

The tillage system “d_2r” as secondary tillage recorded the maximum 489.9 panicles/m^2 at “dp” and “S_2” compared with the other secondary tillage systems in that experiment **Fig. 4** Primary tillage, secondary tillage, and sowing method had highly significant effect on the number of panicles/m^2 (pr > 0.0001).

Grain Yield

Rice grain yield (ton/fed) as influenced by primary tillage, secondary tillage and sowing methods is graphically drawn in **Fig. 5**. The highest average of grain yield as shown in **Fig. 5** was 3.78 ton/fed for tillage systems “m-d_2r-S_2” and 3.63 ton/fed for the dp-d_2r tillage system and the lowest value of 2.635 ton/fed was recorded for “Non-non” tillage system at “S_2”. There was a highly significant effect on the average rice grain yield due to the effect of primary and secondary tillage. The average of yield for primary tillage “dp” and “m” for the sowing methods S_1 and S_2 were 3.29, 3.08, 3.16 and 3.02 t/feddan, respectively. While the primary tillage treatments “no”; “dh” and “c” were 2.68, 3.09, and 3.08 t/feddan, respectively, at “S_1”.

Table 2 shows the analysis of variance for yield as affected by experimental parameters. These data indicated that the effect of primary, secondary tillage and sowing methods on the average yield were highly significant with LSD. The interaction effect between the primary tillage and sowing methods indicated non-significant effect with “F” test at 0.1 % level [$F_{c\ at\ 0.1}$ (1.237) < $F_{t\ at\ 0.1}$ (2.06)]. In addition, the same result was found at the interaction between the secondary tillage systems and rice sowing methods [$F_{c\ at\ 0.1}$ (1.52) < $F_{t\ at\ 0.1}$ (2.06)].

For all above treatments, it is easy to recommended that:

- The common and band sowing methods have no effect on the yield of rice.
- The secondary tillage system “d_2r” at “m” or “dp” and the method S_2 recorded slight increase, in general, compared with the other sowing method S_2. On the other hand, the good yield may be due to good soil surface roughness, good pulverization, suitable reduction conditions (Konokhova, 1982), good establishments and distributions of roots and, also, good weed control, which was affected by good pulverization and plowing depth.

REFERENCES

Gomez, K. A. and A. A. Arture. 1984. Statistical procedures for Agric. Research. Second Edition. John Wiley & Sons. Inc.

Grist, D. H. 1975. Rice book 5th edition printed in Greeting Britain by whitstable Litho Ltd, whitstable, kent.

Hamad, S. A., M. A. Khalifa, and A. M. Ismail. 1983. A manual feeding rice transplanted. J. Agric. Sci. (Agric.), Mansoura Univ. 8(1): 72-80.

Ismail, Z. E. 1981. Mechanization of rice planting. M.Sc thesis (Agric.), Mansoura Univ.

Ismail, Z. E. 1994. The supervisor on the M. Sc. of El-Bandrawi, M. M. Mechanization of seedbed preparation and planting of rice crop. M.Sc. Thesis, Fac. of Ag. Mansoura Univ., Egypt.

Kanetani, Y. and M. F. B. Hj. Mansor. 1991. Mechanized direct seeding of rice in Muda, Malaysis. JARQ 5(3): 209-213. TARC. Report (Tohoku Agric. experiment research station).

Konokhova, V. P. 1982. Rice growing book. Translated from the Russian by V. Kolykhmatove. Mir publishers. Moscow.

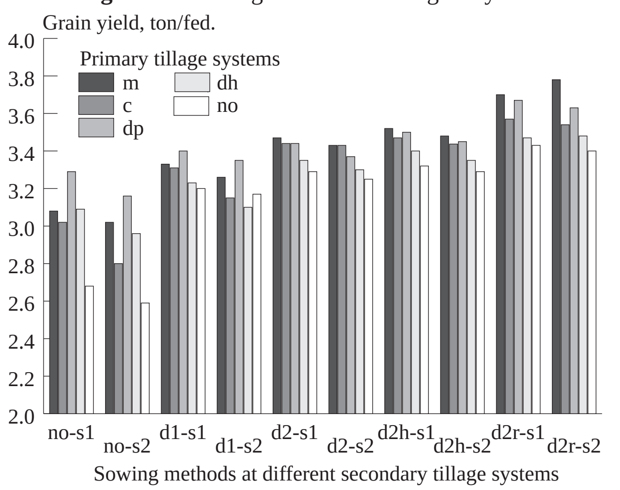
Mahrous, F. N. and A. T. Badawi. 1990. Studies on direct seeded rice in Egypt rice research. Conference Sakha-Kafer El-Sheikh Egypt.

Sendecor, G. W. and G. W. Cockran. 1967. Statistical methods. Iowa USA the Iowa state Univ., press.

Table 2 Analysis of variance for rice grain yield

Source of variance	Df	SS	MS	F value	Prob
Replication	2	0.001	0.001	0.0714	
Primary tillage	4	1.378	0.345	46.9137	0.0001**
Error (A)	8	0.059	0.007		
Secondary tillage	4	6.079	1.520	234.5585	0.0000**
Error (B)	8	0.052	0.006		
AB	16	0.648	0.040	7.6867	0.0000**
Error (C)	32	0.169	0.005		
Sowing method	1	0.134	0.134	35.0943	0.0001**
AC	4	0.019	0.005	1.2374	0.3071^{NS}
BC	4	0.068	0.017	1.5251	0.0034^{NS}
ABC	16	0.039	0.002	0.6423	
Error (D)	50	0.191	0.004		
Total	149	8.837			

Fig. 5 The sowing methods versus grain yield



Optimum Tilt Angle and Orientation for a Flat Plate Solar Water Heater under Egyptian Conditions

by

Salah, M. Abdellatif
Professor & Head
Agricultural Engineering Department,
Mansoura University
EGYPT

Nasser, M. Elashmay
Researcher,
Agricultural Engineering Research Institute,
Agricultural Research Center, Giza
EGYPT

Ahmed, M. Kassem
Senior Researcher
Agricultural Engineering Research Institute,
Agricultural Research Center, Giza,
EGYPT
kassem1956@yahoo.com

Abstract

The solar water heater (SWH) is a most widely used for different Agricultural and Industrial applications in Egypt. But, there are many parameters that affect solar water heater thermal performance. Tilt angle and orientation are considered as an important factors influencing, not only the thermal performance, but also the heat energy acquired by the solar system. Four identical solar water heaters were situated on the roof of Agricultural Engineering Department to investigate, under clear sky conditions, the effect of tilt angle and orientation on solar water heater thermal performance. They were mounted individually on movable frames which could be adjusted so that at any time the angle of incidence of the surface of the solar heater and the sun's rays could be set at zero. Water could be continually cycled through the SWH. After passing through the SWH, the heater water was stored in an insulated storage tank. The obtained result clarified that the solar heater which tracked the sun's rays once each half an hour from sunrise to sunset was more efficient than the other solar heaters. Overall thermal efficiencies for SWH1, SWH2, SWH3, and SWH4 were on average 72.83 %, 65.85 %, 61.60 %, and 55.98 %, respectively.

Introduction

A solar water heater will not operate at its peak potential unless it is orientated to track the sun's rays from sunrise to sunset and tilted from the horizontal plane in such a way that it will minimize the angle of incidence and maximize the transmittance of the glass cover and absorptance of the absorber plate. Consequently, it will absorb the maximum amount of solar radiation. The transmittance of the solar collector cover varies with the incident angle. Transmittance of most cover materials varies little when the incident angle is less than 30°, but it decreases very rapidly with increases beyond 30° (Chau, 1982; Abdellatif, 1985; Duffie and Beckman, 1991; Kalogirou, 1997; and Sayigh, 2001). The annual solar fraction of the system (the fraction of energy that is supplied by solar energy) was used by Shariah *et al.* (2002). It functioned as an indicator to find the optimum inclination angles for a thermosyphone solar water heater installed in northern and southern provinces of Jordan. The obtained results revealed that, the optimum tilt angle for the maximum solar fraction was about $\Phi + (0 \rightarrow 10°)$ for the northern province (represented by Amman city) and about $\Phi + (0 \rightarrow 20°)$ for the southern province (represented by Aqaba town). They concluded that (1) the optimum tilt angle for maximum solar fraction is larger than any of those for the maximum solar radiation at the top of the solar collector by about 5 to 8°, (2) the optimum tilt angle of the solar collector depends on the operating strategy, and (3) the useful energy collected by the system is perceived higher than the load energy during summer, especially for a collector with an area of 3 m^2 or larger. They also recommended that, further work should be carried out to analyze the effect of the latitude angle (Φ) and different climates on the optimum tilt angle. An energy efficient solar collector absorbs incident solar radiation, converts it to thermal energy and delivers the thermal energy to a heat transfer medium with minimum heat losses at each step. It is possible to achieve that, if the solar collector is continuously orientated and tilted with an optimum direction and tilt angle (Kalogirou, 2004).

The objective of the present research work was to determine under clear sky conditions the optimum tilt angle and orientation, and their effect on thermal performance of solar water heater.

Materials and Methods

Four similar solar water heaters were designed and constructed in the work shop of the Agricultural Engineering Department and situated on the roof of the department as demonstrated in **Fig. 1**. Each solar heater had a net surface area of 2.0 m^2. It consisted of seven components (absorber plate, copper pipes, casing, insulation material, glass cover, storage tank, and water pump) The absorber plate was formed of an aluminum slab (2 m long, 1 m wide, and 2 mm thick) and painted with matt black paint in order to absorb the maximum amount of solar energy available. Copper pipes (10 pipes) 12.5 mm diameter were arranged at an equidistance of 10 cm and attached well to the upper surface of the absorber plate using 10 cm long slab ties throughout the length of each pipe. They were also painted matt black paint. The solar heater casing was rectangular in shape (2.1 m long, 1.1 m wide, and 0.1 m deep) made of aluminum bar 25 mm thick. Insulation material 50 mm thick (fiberglass wool) was placed in the bottom and around the sides of the casing to reduce the heat losses from the sides and back of the solar heater. To reduce the heat losses by convection and radiation from the absorber plate, a clear glass cover 5 mm thick was placed to cover the solar heater casing. The solar water heaters were mounted individually on movable frames which were adjusted manually to change the orientation and the tilt angle using a quadrant and clamp. Each movable frame was carried on five small wheels (10 cm in diameter). A screwed pin (as an axial point) was used for orientation of solar heater, where the small wheels were moved around the axial pin. The operating fluid (water) was forced, using a 400 watt water pump to pass the water through the solar heater. After the water passed through the solar heater, it was stored in a 300 liter insulated storage tank. The storage tank was connected to the solar heater by two junctions of insulated rubber hose. One junction was between the bottom of the storage tank (usually cold water) and the bottom of the solar heater (water inlet point). The other junction was between the top of the storage tank and the top of the solar heater (water outlet point). The water pumps were manually switched ON and OFF on sunny days from March 5th until 20th, 2007 (10 days were recorded). The mass flow rate of operating fluid (15 l/min as recommended by Abdellatif, *et al.*, 2006) was tested, adjusted and controlled every day using a control valve and measuring cylinder with stop watch. Four different orientations and tilt angles were used during this research work. The first solar heater (SWH1) was continuously orientated and inclined with an optimum direction and tilt angle in order to track the sun's rays once each half an hour from sunrise to sunset. The second heater (SWH2) was continuously orientated and inclined with one tilt angle (optimum at noon). The third solar heater (SWH3) was continuously orientated and inclined with one tilt angle equal the latitude angle of the place (31.045°N). The last heater (SWH4) was fixed with an optimum tilt angle at noon (stationary non-tracking). For solar heater (SWH1), the optimum tilt angle (β_o) at each hour from sunrise to sunset as a function of solar altitude angle (ψ) was determined using the following equation (Abdellatif, 1985):

$$\beta_o = 90 - \psi \quad (1)$$

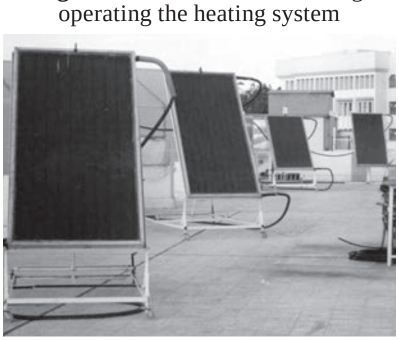
For the stationary non-tracking solar heater (S4), the optimum tilt angle at noon could be calculated as a function of latitude angle(Φ) and solar declination angle (δ) using the following formula:-

$$\beta = \Phi - \delta \quad (2)$$

$$\delta = 23.45 \sin [0.9863(n+284)] \quad (3)$$

The weather data from a meteorological station (Watch Dog model 550) located above the solar heaters were used. Two thermocouples were employed to measure the inlet and outlet water temperatures of each solar heater. The water temperature in each storage tank was measured using one thermocouple installed at the center of the storage tank. Four solarimeters were fixed and installed on the top frame of each solar heater in order to measure the solar radiation flux incident. These sensors were connected to a data logger system to display and record the obtained data throughout the

Fig. 1 Solar water heaters during operating the heating system



experimental work. The parameters of the thermal performance test and the relationship between them were examined and tested by Duffie and Beckman (1991). The solar energy available (Q) could be calculated as a function of solar radiation flux incident (R) and solar heater surface area (Ac) as follows:

$Q = R\, Ac$, W..................................(4)

The absorbed solar radiation (Q_a) could be computed in terms of the transmittance of glass cover (τ) and the absorptance of the absorber plate (α) as follows:

$Q_a = \tau\, \alpha\, Q$ W................................(5)

The absorption efficiency (η_a) could be determined as follows:

$\eta_a = (Q_a / Q) \times 100$, %.................(6)

The useful heat gain to storage (Q_c) could be estimated as a function of the mass flow rate of water (m), specific heat of water (C_p), and temperature difference between outlet (T_{fo}) and inlet (T_{fi}) water temperatures as follows:

$Q_C = m\, C_P\, (T_{fo} - T_{fi})$ W...............(7)

The heat transfer efficiency (η_h) could be calculated as follows:

$\eta_h = (Q_c / Q_a) \times 100$, %...............(8)

The total heat losses from the solar water heater could be computed as follows:

$Q_L = Q_a - Q_C$ W...........................(9)

The overall thermal efficiency (η_o) could be found as follows:

$\eta_o = (Q_c / RA_c) \times 100$, %..........(10)

The "temperature rise" (D_T) could be estimated in terms of the temperature difference between the inlet water (T_{fi}) and the ambient air (T_a) as follows:

$D_T = (T_{fi} - T_a / R)$, °C.m²/W......(11)

The solar energy stored in the storage tank (Q_s) could be computed as a function of mass of water in the storage tank per unit time (m_s), specific heat of water (C_p), and the temperature difference between mean tank at the end (T_{k2}) and beginning (T_{k1}) of each hour as follows:

$Q_s = m_s\, C_P\, (T_{k2} - T_{k1})$ W ....(12)

The storage system efficiency (η_s) can be found as follows:

$\eta_S = (Q_s / Q_c) \times 100$, %............(13)

Results and Discussion

For the ten days duration of this experiment, the four solar water heaters were operated satisfactorily without any malfunctions. Tilt angle and orientation are probably the most important parameters affecting thermal performance of the solar water heater. The daily average solar energy available for SWH1, SWH2, SWH3, and SWH4 was 19.649, 14.012, 13.009, and 12.449 kWh/day, respectively. These obvious differences in solar energy available could be attributed to the difference in tilt angle and orientation between the four solar heaters. The solar water heater (SWH1), which tracked the sun's rays from sunrise to sunset increased the solar energy available by 40.23 %, 51.04 %, and 57.84 % as compared with SWH2, SWH3, and SWH4, respectively. The daily average absorbed solar energy for the four solar heaters was 16.800, 10.744, 9.620, and 8.573 kWh/day, which gave average absorption efficiencies of 85.5 %, 76.68 %, 73.95 %, and 68.87 %, respectively. The differences in absorption efficiencies were due to the differences in the effective absorptance of the absorber black plate and the effective transmittance of the glass cover between the four systems, which were highly dependent upon the solar incident angle. Once each half an hour from sunrise to sunset the rays of the sun were perpendicular to the surface of SWH1 which tracked the sun's rays. Consequently, the solar angle of incidence equaled zero and the absorptance of the absorber plate and the transmittance of glass cover were at their highest values of 0.95 and 0.9, respectively. Meanwhile, the solar incident angles for SWH2 and SWH4 equaled zero only at solar noon, and they were greater than zero particularly in the early morning and later afternoon. The solar incident angles during this experiment ranged from 78° at 7 am to 0° at solar noon. The daily average absorbed solar energy that was converted into useful heat gain to storage during this experiment for the four solar water heaters was 14.310, 9.227, 8.014, and 6.968 kWh/day. This gave average heat transfer efficiencies of 85.18 %, 85.88 %, 83.31 % and 81.28 %, respectively. There was no significant difference in heat transfer efficiency between SWH1 and SWH2 due to the water inlet temperature. The solar heater which tracked the sun rays (SWH1) converted more energy into useful heat gain to storage particularly from sunrise to solar noon due to more energy absorption. After solar noon, the absorbed solar energy converted into useful heat acquired to storage was reduced due to high water inlet temperature, while the maximum amount of useful heat gain to storage for SWH2, SWH3, and SWH4 occurred at and around solar noon. At that time the water temperatures in the storage tanks were lower than that in SWH1, so the heat transfer efficiencies for SWH2, SWH3, and SWH4 were greater than SWH1 around solar noon. Because the overall thermal efficiency of the solar water heater is a combination of absorption and heat transfer efficiencies, the SWH1 was more efficient than the SWH2, SWH3, and SWH4. For the duration of this experiment the daily average overall thermal efficiencies for the four different systems were 72.83 %, 65.85 %, 61.60 %, and 55.98 %, consequently 27.17 %, 34.15 %, 38.40 %, and 44.02 % of the solar energy available were lost, respectively. If the water inlet temperature for the four different systems had been kept the same from sunrise to sunset, the solar water heater which tracked the sun's rays (SWH1) could be increased to an overall thermal efficiency greater than 72.83 %. The overall thermal efficiencies (η_o) for the four different orientations and tilt angles were plotted against "temperature rise" (DT) as shown in **Fig. 2**. Regression analysis revealed a highly significant linear relationship ($R^2 = 0.998$; $P \leq 0.001$) between these parameters. The regression analysis also clarified that, the overall thermal efficiency of the solar water heaters could be represented as:-

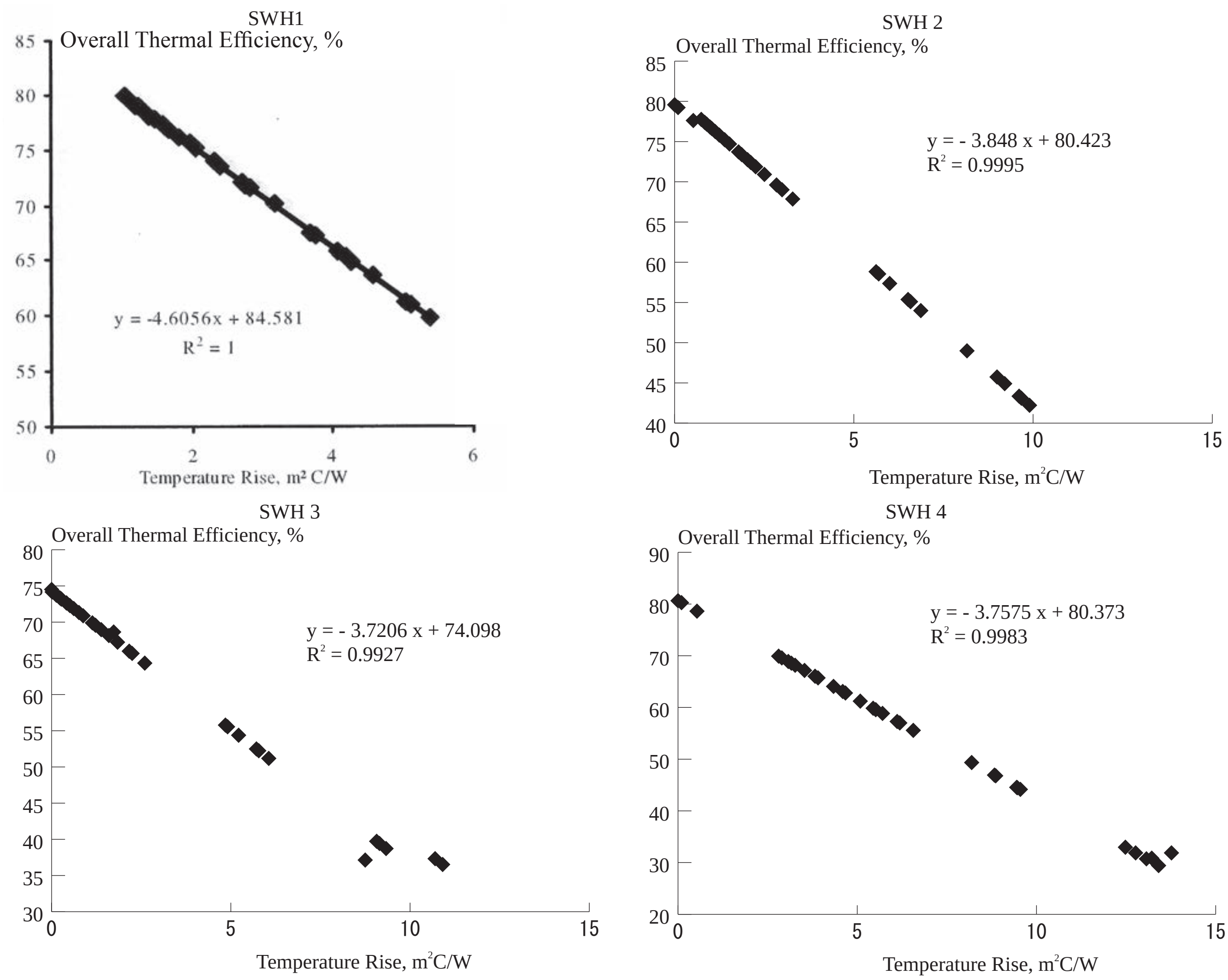
$\eta_o = F_R\,(\tau\alpha) - U_o\,F_R\,(D_T)$

$\eta_o = a - U_o\,F_R\,(D_T)$

Regression equations are definitely the numerical expression of the above two equations. The y-intercept (a) is equal to the product of heat removal factor (F_R) and the optical efficiency ($\tau\alpha$). While, the slope is equal to the product of heat removal factor (F_R) and overall heat transfer coefficient (U_o). The plots of overall thermal efficiency (η_o) versus "temperature rise" (D_T) were straight lines with intercept F_R ($\tau\alpha$) and slope ($- F_R\,U_o$). It is evident that Uo is a function of temperature (difference between mean absorber plate temperature and ambient air temperature) and wind speed. Some variations of the relative proportions of beam, diffuse, and surrounding substances-reflected components of solar radiation occurred during the experimental work due to variations in angle of solar incidence. Thus, scatter in the data of (SWH2, SWH3, and SWH4) were expected, because of water inlet temperature dependence, wind speed effects and solar incident angle variations. In spite of these difficulties, for purposes of estimating long-term thermal performance of many solar heating systems, solar panels couuld be characterized by the intercept and slope (i.e., by F_R ($\tau\alpha$) and $- F_R\,U_o$). According to the previous expression of the regression equations, the daily average heat removal factors (F_R) for the four different solar heating systems were, respectively, 0.9893, 0.9412, 0.8979, and 0.9400.

They also revealed that, the daily average overall heat transfer coefficients were 4.656, 4.089, 4.144, and 3.997 W/m^2.°C, respectively. The daily averages of solar energy stored in the storage tank for SWH1, SWH2, SWH3, and SWH4 during this research work were 11.777, 9.227, 8.014, and 6.968 kWh/day, which gave average storage system efficiencies of 82.30 %, 80.67 %, 77.5 %, and 67.16 %, respectively. During the early morning hours just after sunrise and prior to sunset,

Fig. 2 Overall thermal efficiency against "Temperature rise" for the four systems



very little amounts of useful heat were acquired by the working fluid (water) of SWH4 because of little amounts of solar energy available on the surface of that heater at those times. Thus a large amount of solar energy was required to increase the absorber plate temperature above the average water temperature passing through the heater. The solar water heater (SWH1) which tracked the sun's rays from sunrise to sunset increased the solar energy stored in the storage tank by 27.64 %, 46.96 %, and 69.02 % as compared with SWH2, SWH3, and SWH4, respectively. The heat energy stored in the storage tank for the four solar heating systems were found to be directly proportional to useful heat gain to storage and ambient air temperature, and inversely proportional to working fluid (water) temperature in the storage tank. Therefore, at and around noon the storage system efficiency for the stationary non-tracking solar heating system (SWH4) was greater than that for tracking solar heater (SWH1) at those times because of lower water temperature in the storage tank.

Conclusion

The obtained data of this experimental work can be summarized and concluded as follows:-

1. The solar water heater that was continuously orientated and tilted to maintain an incident angle of zero from sunrise to sunset attained maximum values of the absorptance of the absorber plate and transmittance of the glass cove as compared with the other solar heaters.
2. The solar heater that tracked the sun's rays once each half an hour from sunrise to sunset was more efficient than the other solar heaters. Overall thermal efficiencies for SWH1, SWH2, SWH3, and SWH4 were on average 72.83 %, 65.85 %, 61.60 %, and 55.98 %, respectively.
3. The differences in thermal performance between the four systems varied with solar time from sunrise to sunset according to the day length and water inlet temperature.
4. As the day length was increased, the variation in effective absorptance and transmittance for the stationary solar heating system (SWH4) increased due to the changes in angle of solar incidence throughout the day. Therefore, the differences in thermal performance between the four systems during summer months would be greater than in winter months.
5. Also, these differences depend strongly upon the water inlet temperature. As the tracking solar heating system absorbed more energy than the other solar heating systems, the water inlet temperature became greater than that in the other systems particularly at and after noon.

REFERENCES

Abdellatif, S. M. 1985. Solar energy collection, storage and utilization in protected cropping. Ph. D Thesis, Wye College. University of London.

Abdellatif, S. M., A. M. Matouk, and R. E. Matouk. 2006. Effect of mass flow rate of operating fluid on solar panel thermal performance. J. Agric. Sci. Mansoura University, 31(7) : 479-496.

Chau, K. V. 1982. Optimum tilt angle for solar collector in clear sky conditions. J. Agric. Engng. Res. 27: 321-328.

Duffie, J. and W. Beckman. 1991. Solar engineering of thermal processes. John Wiley and Sons, New York, ed. 762pp.

Kalogirou, S. 1997. Survey of Solar desalination systems and system selection. Energy: Int. J., 22: 69-81.

Kalogirou, S. 2004. Solar thermal collectors and applications. Energy and Combustion Science 30: 231-295.

Sayigh, A. A. W. 2001. Renewable energy : global progress and examples. Renewable Energy WREN, 15-17.

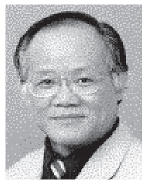
Shariah, A., M. A. Al-Akhras; and I. A. Al-Omari. 2002. Optimizing the tilt angle of solar collectors. Renewable Energy, 26: 587-598.

■■

Performance Evaluation of Locally Fabricated Electric Dryer

by

Pema Dakpa
Dy. Chief Postproduction Officer,
National Post-Harvest Centre,
Department of Agriculture
BHUTAN



Hai Sakurai
JICA Expert
Agriculture Machinery Centre,
Department of Agriculture,
BHUTAN

Ugyen Penjore
Chief Postproduction Officer
National Post Harvest Centre
Department of Agriculture
BHUTAN

Abstract

The performance of a locally fabricated electric dryer with a design based on both an extraction and pressure aeration system was evaluated by drying 10 kilograms of 2 mm thick sliced locally grown pumpkin. The average dryer efficiency was 70 % and the average specific heat consumption was 1,726 KJ/Kg H_20, which was equivalent to 0.48K Whr/kg H_2O. The assumed 50 % recirculation of outlet air increased the inlet humidity ratio by 46.1 % and the enthalpy by 50.5 %. The increased enthalpy and humidity ratio of the inlet air minimized the energy consumption by heat recuperation and avoided case hardening of the product, respectively. The drying time for 10 kilograms of product was concluded to be 15 hours. The quality of the dried products was good in terms of color and shape. Minimal heat loss was observed from the dryer.

Introduction

Fruits and vegetables are grown in all parts of Bhutan. However, the harvesting of many fruits and vegetables occur during summer and autumn; during which plenty of rainfall occurs. Nonetheless, Bhutanese farmers preserve surplus fresh produce by natural sun drying since commercial dryers are not available in the local market. Dried products from fruits and vegetables such as eggplant, pumpkin, chili, turnip, persimmon, mushroom along with cheese and meat are important part of the Bhutanese cuisine.

The main problem for natural sun drying is dust, rain and cloudy weather as mentioned by Dauthy (1995). The rate of quality deterioration during sun drying and subsequent storage is high due to molds, enzymatic action and insects. This deterioration can be negligible only when the moisture from the product is removed to 12-14 % wet basis (Henderson & Perry, 1979). Further, Beuchat (1981) states that there is no microbial proliferation of food products within a water activity range of 0.20-0.50. However, the proliferation of osmophilic yeast and a few molds attack are visible in water activity range of 0.60-0.65, which are normally dried fruits containing 15-20 % moisture.

Conventional air-drying is one of the most frequently used methods for food dehydration. The drying parameters that are usually examined for food quality are air temperature (50-90˚C), air relative humidity (10-40 %) and air velocity 1-4 m/s (Mujumdar, 2000). This conventional air drying is classified for small scale batch operations (20-50 kg/hr) according to Nonhebel and Moss (1971). The efficiency of commercial dryers ranges from 30-80 % (Earle, 1983). However, dryers with air recycling is characterized by higher thermal yield and higher absolute humidity of inlet air, which favors faster and uniform drying (Hendrick, 2004).

Irrespective of the drying types, in early stages of drying, the properties of the material surface layers do not differ much from the centre. As drying proceeds, the surface deforms due to its visco-elastic nature (Lewicki *et al.*, 1997) and shrinkage and curling is a common phenomenon. Furthermore, in fruits and vegetables, chemical changes to carotenoid and chlorophyll pigments are caused by heat and oxidation during drying and residual polyphenoloxidase enzyme activity that causes browning during storage (Fellows, 2005).

The temperature of the drying needs to be governed by the types of products dried to minimize drying losses. Foods that have high economic value due to their characteristic flavors, for example herbs and spices, are dried at low temperatures (Mazza and LeMaguer, 1980). It is generally accepted that rapid drying and high temperature cause greater changes to the texture of foods than do moderate rates of drying and lower temperature. High air temperature, particularly with fruits fish and meats, causes complex chemical and physical changes to solutes at the surface, and the formation of a hard impermeable skin, termed as case hardening (Fellows, 2005)

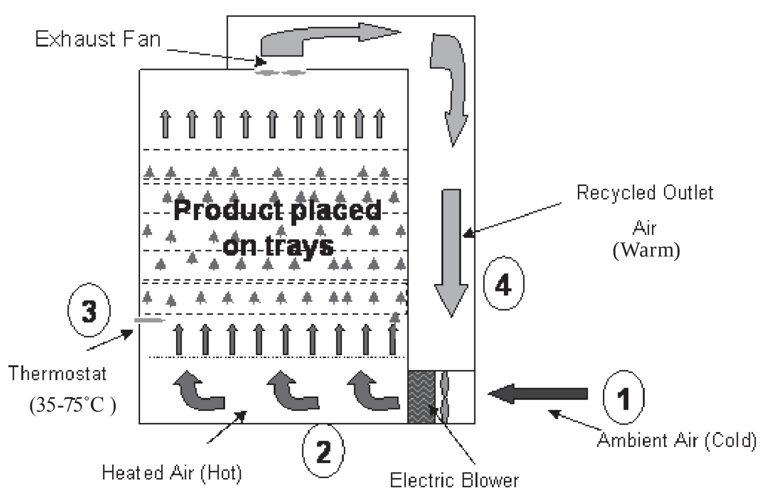
There is a need for a conventional air dryer so that good quality dried products are obtained, and can be safely stored for longer duration and moved from the home to local and regional markets safely. In addition, the unit cost of electrici energy is cheap in Bhutan as compared to other countries because of several large hydro-electric projects.

Thus, to curb the drying problems and to improve food safety, an electric dryer was designed, locally fabricated and its performance evaluation studied. Experimental results on the performance evaluation are presented in this paper.

Materials and methods

The drier cabinet with a holding capacity of 12-15 kg fresh weight was fabricated using locally available raw materials such as wood and bamboo. The dryer consisted of the plenum chamber, dryer cabinet and recycling duct as shown in **Fig. 1**. The dryer aeration system design was based on both the extraction and pressure system where the exhaust fan removed the moisture from the dryer and moved the heated air to the dryer. The temperature of the heated air into the dryer was controlled by a thermostat set within a temperature range of 35-75 ˚C. The outlet air from the exhaust was recycled and allowed to mix with ambient air freely.

Fig. 1 Aeration system of electric dryer



Ten kilograms of 2 mm thick pumpkin slices were used to evaluate the performance of the drier. Two HBO data loggers were installed; one at the recycling duct to measure the exhaust temperature and relative humidity; and one outside the drier to measure the ambient temperature and relative humidity condition. The position of the trays inside the dryer was interchanged after every 6 hours and the products were turned upside down after every 4 hours. The drying of the product was judged to be fully complete by feeling the hardness of the slices with hand. The data loggers were set to record at 15 minute intervals. The recorded data were analyzed using the MATLAB programme.

The following formulae were used for the calculation.

Humidity Ratio

$PS = 6 \times 10^{25} / (T + 273.15)^5 \times exp\,[-6{,}800 / (T + 273.15)]$ (Hunter, 1987)

$X = (0.622 \times Rh \times PS) / (Patm - Rh \times PS)$

Enthalpy

$h = 1.005 \times T + X \times (2{,}501.3 + 1.82 \times T)$ (Cengel & Boles, 2002)

Thermal Yield

$TY = (T_i - T_o) / [(T_i - T_o) + (1 - r) \times (T_o - T_a)]$ ((Hendrickx, 2004)

Specific Heat Consumption

$h_i = r \times (h_o - h_a) + h_a$ (Hendrickx, 2004)

$SHC = (h_i - h_a) / (X_o - X_a)$ (Hendrickx, 2004)

Where

T = Dry bulb temperature of air [˚C]

PS = Saturation Pressure at T [Pa]

Rh = Relative humidity of air [%]

Patm = 75,670, atmospheric pressure at Paro,Bhutan [Pa]

X = Humidity ratio of air [kg H_2O/kg dry air]

h = Enthalpy [kj/kg]

TY = Thermal Yield (%)

SHC = Specific Heat Consumption [kj/kg H_2O]

r = 50%, assumed recycled part of outlet air

The suffix

i = inlet

o = outlet

a = ambient

Results and Discussion

Temperature and Relative Humidity Condition of the Dryer

Fig 2 indicates that the outlet air temperature increased sharply in the first few hours and steadily increased afterwards. This sharp increase was due to rising inlet temperature until the set temperature, 56 ˚C was reached. Similarly, the outlet air relative humidity increased sharply for first few hours but steadily decreased afterwards. The sharp increase was due to removal of surface moisture from the product. The outlet air temperature was lower than the inlet or set point temperature, which confirmed the existence of temperature driving force for heat flow.

Humidity Ratio Condition of the Dryer

As is indicated from **Fig. 3**, the humidity ratio of outlet air increased sharply for a few hours of drying and steadily decreased afterwards. The sharp increase was due to faster removal of surface moisture of the products. Toward the end of drying, the outlet moisture tended to be at equilibrium with the inlet ambient air, confirming completion of drying. Thus, it was concluded that the time taken to dry 10 kgs of sliced pumpkin was 15 hrs. The increase in the humidity ratio profile at seven hours of drying was due to disturbance while the trays were interchanged. The mean humidity ratio of the inlet air for pumpkin was increased to 46.1 % due to assumed 50 % recirculation of the outlet. Despite additional humidity ratio to the inlet air, the inlet humidity was more than 50 % less than outlet air and hence the driving force for moisture removable was not disturbed and avoided casehardening of the dried products.

Enthalpy Condition of the Dryer

The enthalpy condition of the dryer was similar to the humidity ratio (**Fig. 4**). However, the increase of enthalpy content of inlet air was slightly higher than humidity ratio increase. Thus, the recirculation of outlet air contributed to raise the inlet temperature by almost 50 %.

Dryer Efficiency and its Specific Heat Consumption

From **Fig. 5**, it is evident that the dryer efficiency decreased with drying time but specific heat consumption was otherwise. This reverse trend of thermal yield, which expressed dryer efficiency and specific heat consumption, was due to constant addition of heat while moisture removal from the product matrix was difficult with time. The mean dryer efficiency was 70 % and the specific heat consumption was between 1,726 KJ/Kg H_2O.

Fig. 2 Temperature and relative humidity profile of dryer during the drying period

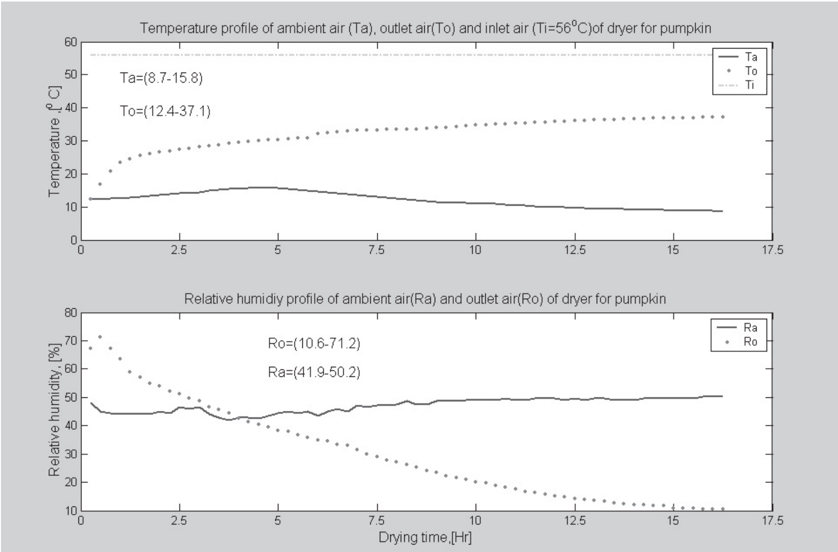


Fig. 3 Humidity ratio profile of exhaust and ambient air of dryer during drying period

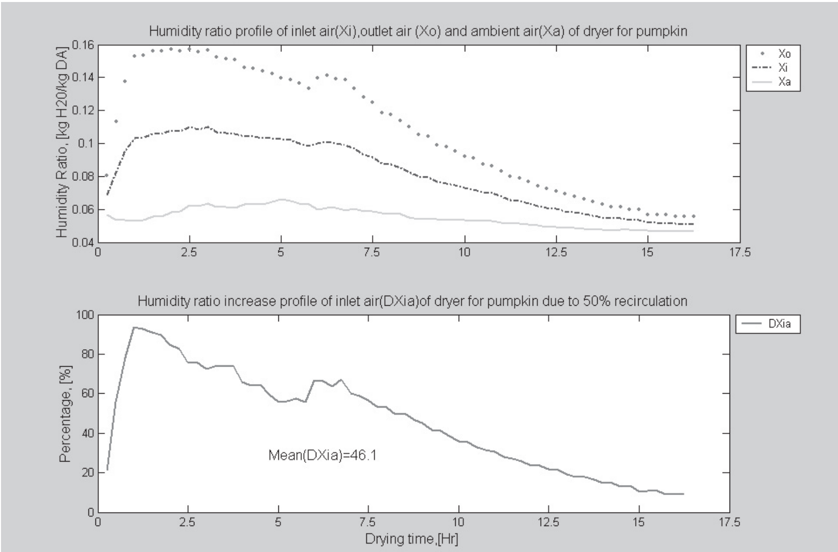


Fig. 4 Enthalpy profile of exhaust and ambient air of dryer during drying period

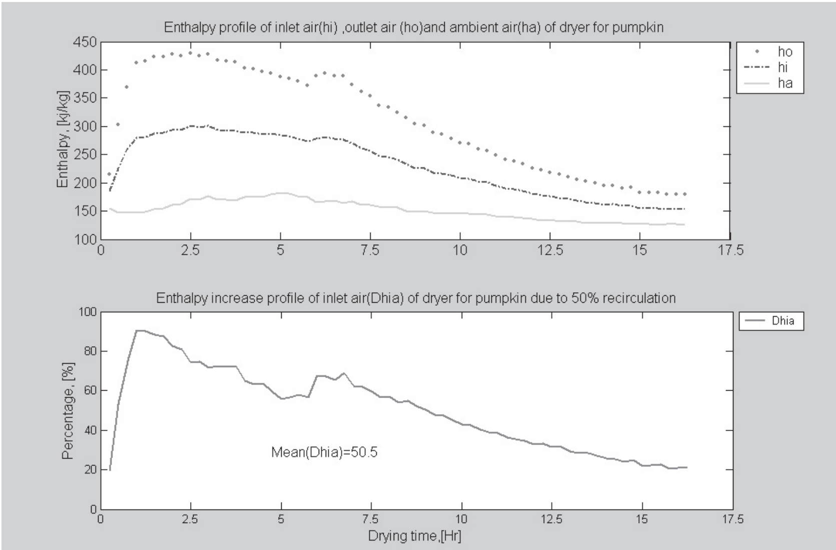


Fig. 5 Thermal yield and specific heat consumption profile of dryer during the drying period

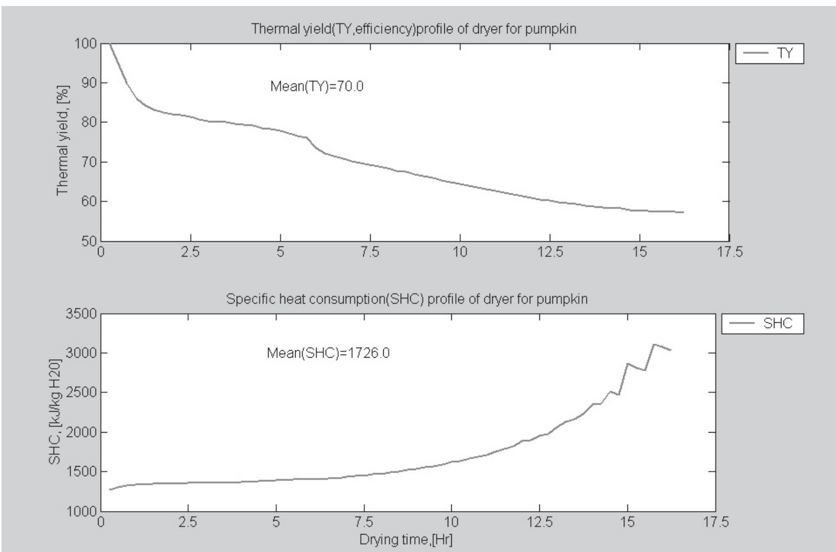
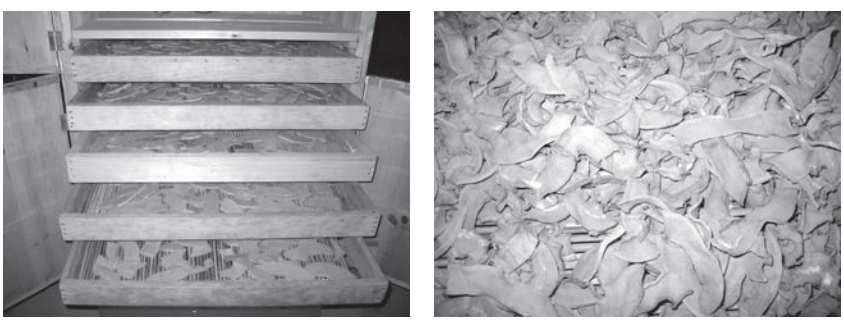


Fig. 6 Pumpkin quality before (left) and after drying (right)



The performance of the dryer with respect to efficiency was as per the literature. The energy consumption corresponded to 0.48 KWhr to remove one kilogram of water from the products, which was small.

The specific heat consumption showed irregularities after 15 hrs of drying time and, hence, confirmed that the effective drying time for 10 kilogram of this product was 15 hrs. The irregularities occurred because the removed moisture in the product was insignificant as compared to the constant energy applied.

Preservation of Color

The natural reddish yellow color of the pumpkin was preserved without discoloration but few curls at the surface of the sliced pumpkin were visible as shown in **Fig. 6**.

Conclusions

The average dryer efficiency of a locally fabricated electric dryer was designed, based on both extraction and pressure aeration system, was 70 %, and the average specific heat consumption was 1,726 KJ/Kg H_2O, which was equivalent to 0.48 KWhr/kg H_2O. The assumed 50 % recirculation increased the inlet humidity ratio by 46.1 % and enthalpy by 50.5 %.

These increased enthalpy and humidity ratios of the inlet air minimized the energy consumption by heat recuperation and avoided case hardening of products, respectively.

The original color retention was very good and minimal shape distortion or curling was observed. Minimal heat loss was observed from the drying cabinet. The initial data indicated that the locally designed electric dryer could be an alternative to natural sun drying for Bhutanese farmers.

There was, however, a need to improve the efficiency and flexibility of the dryer further by carrying out the following:

- The dryer efficiency and optimum drying time needed to be validated by drying other products.
- The quality of the dried products needed to be tested for water activity and texture using a water activity meter and food texture meter, respectively.
- The exact recycled part of outlet air needed to be determined by measuring relative humidity condition at inlet temperature.
- Improvement of the wooden dryer cabinet was necessary by using an alternative lighter and more airtight material.

REFERENCES

Beuchat, L. R. 1981. Microbial stability as affected by water activity. Cereal Foods World 26: 345-349.

Cengel, Y. A and M. A. Boles. 2002. Thermodynamics, an engineering approach, McGraw Hill Inc.

Dauthy, E. M. 1995. Fruits and vegetable processing. FAO Agricultural Service Bulletin No. 119. Rome.

Earle, L. R. 1983. Unit Operation in Food processing. NZIFST (Inc.).

Fellows, J. P. 2005. Food Processing technology, Principles and practice. Woodhead Publishing Limited. Cambrridge, England.

Henderson, M. S. and Perry, L. R. 1979. Agricultural Process Engineering. The AVI Publishing Company, Inc. Westport, Connecticut.

Hendrick, M. 2004. Drying of Perishable Crops. Lecture Notes, Master of Science in Food Technology, Interuniversity Programme, K.U Leuven, Belgium.

Hunter, A. J. 1987. A isostere equation for some common seeds, J. Agric. Eng. Res. 37: 93-107.

Lewicki, P. P., D. Witrowa-Rachert, and J. Mariak,1997. Changes of structure during dehydration of dried apples. Journal of food engineering. 32: 347-350.

Mazza, G. and LeMaguer, M. 1980. Flavour retention during dehydration of onion. In: P.

Linko, Y. Malkki, J. Olkku, and J. Larinkari (eds) Food Process Engineering, Vol. 1, Food

Processing Systems. Applied Science, London, pp399-406.

Mujumdar, S. A. 2000. Drying technology in Agriculture and Food Science, Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi.

Nonhebel, G. and A. A. H. Moss, 1971. Drying of solids in chemical industry. Butterworths, London.

■■

ERRATA

	ERROR	CORRECT
AMA Vol. 39, No. 4 Autumn, 2008 CONTENTS page and Page 51 author's name	A. Addo, A. Bart-Plange	Shiv Kumar Lohan
AMA Vol. 40, No. 1 Winter, 2009 CONTENTS Page and Page 25 author's name	Gbabo Agidl	Gbabo Agidi

Liquid Wastes from Methyl Ester Oil Production and Thermal-Emission Properties

by

Gürkan A. K. Gürdil
Faculty of Agriculture,
Department of Agricultural Machinery,
Ondokuz Mayıs University,
55139 Samsun,
TURKEY
e-mail: ggurdil@omu.edu.tr

Jan Malaťák
Technical Faculty,
Czech University of Life Sciences Prague,
CZECH REPUBLIC

K. Çağatay Selvi
Faculty of Agriculture,
Department of Agricultural Machinery,
Ondokuz Mayıs University,
55139 Samsun,
TURKEY

Yunus Pinar
Faculty of Agriculture,
Department of Agricultural Machinery,
Ondokuz Mayıs University,
55139 Samsun,
TURKEY

Abstract

The growth in the use of biodiesel has opened other areas of utilizing liquid wastes from the manufacture of rape seed oil methyl ester (FARME) as an energy source.

The aim of this study is to assess the feasibility of utilizing liquid material wastes from the production of FARME. This study is focused on the evaluation of thermal properties of FARME and distillation residuals from FARME production plants.

Elemental analysis was done for selected liquid wastes in order to set basic parameters of fuels. The stoichiometric analysis of results showed very satisfactory thermal?emission parameters of tested liquid materials sourced from FARME. The only exception was pure rape seed oil which had a higher amount of ash in the tested sample.

Tested liquid samples sourced at methyl ester rape seed oil production line had good emission parameters and effectiveness. These samples could be used for the same kind of liquid combustion equipment if certification requirements are completely met.

Introduction

Within the next 50 years, the share of energy generated from renewable sources should reach 30 % of the total energy consumed. In the European Union (EU) countries, this average share should double in 2010 by an increase of up to 12 % from the current 6 %. Of the total renewable sources, biomass should account for 60 %, with anticipated increase up to 80 %. According to EU plans, by 2020 one fifth of the fuels consumed should be substituted with alternative fuels. This should reduce the dependency on fossil fuels and improve the quality of air. Five to eight percent out of 20 % should be represented by the so called bio-fuels or rape seed oil methyl ester (FARME). For example, Czech Republic, one of the EU member countries, enacted a law stipulating that from May 2004 liquid bio-fuels must being added to all liquid fuels (Jevič *et al.*, 2006, Malat'ák *et al.*, 2006).

Bio-fuels offer one method for decreasing CO_2 emissions from fossil fuels, thus, helping to meet the Turkish and EU targets for mitigating climate change. They also provided a rational option for land use within the EU that could be economically viable provided that an appropriate financial and policy environment was developed. According to results of a research, if 80 % of current set-aside land in England were used for production of biomass crops for electricity generation, about 3 % of current electricity demand could be met (Powlson *et al.*, 2005).

Bio-energy is now accepted as having the potential to provide the major part of the projected renewable energy provisions of the future as biofuels in the form of gas, liquid or solid. There are three main routes for providing these biofuels; thermal conversion, biological conversion and physical conversion (Bridgewater, 2006).

The term modern biomass is generally used to describe the traditional biomass use by efficient and clean combustion technologies. Modern biomass can be used for the generation of electricity and heat. It is possible that wood, straw and even household wastes may be economically converted to bio-ethanol. Bioethanol is derived from alcoholic fermentation of sucrose or simple sugars, which are produced from biomass by hydrolysis. Currently, crops generating starch, sugar or oil are the basis for bio-fuel production. There has been renewed interest in the use of vegetable oils for making biodiesel due to its less polluting and renewable nature against the conventional petroleum diesel fuel. Biodiesel is a renewable replacement to petroleum-based diesel. Biomass energy conversion facilities are important for obtaining bio-oil.

Bio-fuels are important because they replace petroleum fuels. There are many benefits for the environment, economy and consumers in using bio-fuels. Bio-oil can be used as a substitute for fossil fuels to generate heat and power. Upgrading of bio-oil to a transportation fuel is technically feasible, but needs further development. Biochemical conversion of biomass is completed through alcoholic fermentation to produce liquid fuels and anaerobic digestion or fermentation, resulting in biogas (Demirbaş *et al*., 2006, Jevič *et al*., 2006).

With depleting oil resources and negative environmental impact associated with the use of petrol fuels, there is a renewed interest in biomass based fuels, which can still form the base for sustainable development. As it is a locally available resource, energy equity can also be achieved at global levels. However, to exploit the potential of biomass, more work is needed for converting it efficiently into modern energy. Currently, bioethanol and biodiesel have already reached commercial markets, especially as blends with petrol fuels (Vasudevan *et al*., 2005, Jevič *et al*., 2006). This study is done to analyze the utility of liquid wastes from FARME production as biofuel resources.

Material and Methods

Bio-fuel samples were provided from methyl ester oil production line. These samples were:

- diesel fuel, as a reference fuel
- light fuel oil-LTO, as a reference fuel
- pure rape seed oil
- rape seed oil methylesther
- distillation residues from FARME (water free and combustible samples)

All the kinds of liquid fuels, occurring in natural (raw) sort are composed from the three main components: total water content, ash matter and combustibles. This composition can be expressed by following formula:

$$W + C + H + O + S + N + A = 100\ \% \quad (1)$$

Where:

W, C, H, O, S, N, A are weight parts of total water, oxygen, carbon, hydrogen, sulphur, nitrogen and ash amount in the original sample.

Water and ash matter are a non flammable part of the fuel, described as ballast or deadwood. Both of them have a negative effect to the fuel heating power. Their presence directly influences the combustion equipment construction and they are often sources of frequent problems during operations.

The flammable part of the fuel is composed of carbon, hydrogen, sulphur and nitrogen. Carbon, hydrogen and sulphur are involved in exothermic reaction with air oxygen-autogenously burning.

This study is composed of three domains; defining thermal emission properties of selected samples, defining elemental and stoichiometric analyses of tested samples and the last step of the whole procedure is carrying out experimental combusting at laboratory scale.

An elemental analysis was done for selected samples in order to set basic parameters of fuels. It mostly focused on: water content (weight %), ash matter (weight %), carbon (weight %), hydrogen H (weight %), nitrogen N (weight %), sulphur S (weight %), oxygen O (weight %) and chlorine Cl (weight %). Elemental analysis was an important part of the measurements for defining basic stoichiometric and heat properties of the samples. The elemental analysis of the liquid samples were converted to values under normal conditions (temperature t = 0 ˚C and pressure p = 101.325 kPa).

Next, an important task of the research project was to set a stoichiometric of tested samples. Stoichiometric calculations of combustion processes are supplementing fuel's characteristics and were also foundation for any heat calculation. These were very important for heat system design problems solving as well as during the heat equipment control. The following parameters were determined by calculations:

- Fuel heating power
- Oxygen amount (air) necessary for ideal combustion
- Flue gases amount and composition
- Flue gases specific weight

Sample heating power was determined by calculation based on measured combustion heat and elemental analyses. Samples stoichiometric calculations were assessed for a mass combusting as well as for a voluminous combusting.

It was necessary to adjust combustion equipment to higher fuel input and also reset other operational parameters of the device in order to enable possible thermal usage of rape seed oil. The other possibility of rape seed oil was to form a mixture with a fuel with higher value of heating power.

Emissions generated by the combustion of these liquid fuels were determined. Carbon dioxide was determined from the measured concentration of oxygen and the fuel characteristic. Emission concentrations in combustion gases and technical thermal combustion efficiency were determined using a gas analyzer.

The main characteristic was undoubtedly thermal loss caused by physical heat of combustion gases (stack loss q_a). This loss was calculated by following formula:

$q_a = (t_s - t_o)\ [(A_2 / 20.95 - O_{2M}) + B]$ ....(2)

where:

q_a is a stack loss

t_s combustion gas temperature (˚C)

t_o surroundings temperature (˚C)

A_2 fuel constant

B fuel constant

O_{2M} measured oxygen amount.

Efficiency was calculated then by the formula:

$eta = 100 - q_a$................................(3)

Such calculated values of efficiency presumed that only decrease was caused by stack loss. Other kinds of losses such as imperfect combustion and radiations were negligible. This simplifying was possible only when stack loss was much higher than the total sum of other losses. To get more accurate results it was necessary to achieve other calculations, including chemical imperfect combusting loss or just loss of imperfect combustion (%), assigned by formula:

$q_{co} = a\ CO\ /\ CO + CO_2,\ (\%)$.....(4)

where:

CO, CO_2 are measured or calculated contents of components of gas, a fuel parameter.

Calculation of this loss provided a correlation (higher accuracy) of previously calculated efficiency by the formula:

$eta_{kor} = eta - q_{co},\ (\%)$...................(5)

This efficiency was called thermal-technical efficiency of combustion.

Results

First, an elemental analysis was made for the liquid samples. The results of elemental analyses are given in **Table 1**.

As seen from the elemental analysis, there was a tiny amount of chlorine in tested samples because chlorine proceeds to the gas phases during combustion. It is important because of HCl emissions. Sulphur is also mostly changed to the gas phase during combustion in the form of SO_2 or SO_3. Normally, sulphur emissions do not mean a real problem in the case of thermal devices using liquid fuels originated from renewable sources. The limiting factor is the corrosive qualitiy of sulphur and its compounds. Other parameters of elemental analyses meet requirements for usage of these samples in combustion equipment.

The most determining factor of thermal usage of fuels was water and ash content. The range of water content was relatively low in tested samples, which had a positive impact on fuel heating power.

The other nonflammable component was the ash. The amount of ash was low, as is obvious from a **Table 1**. The highest amount of ash was found in pressed rape seed oil. The amount of ash significantly influenced thermal properties of the tested sample. These properties then affected the selection and adjustment of combustion equipment.

The results of the stoichiometric calculations are presented in **Table 2**. The concentration of individual combustion products were subsequently converted to a reference level of oxygen in the combustion gas (O_r). The value for these liquid fuels has been defined in accordance with applicable standards as O_r = 3 %.

Final stoichiometric analyses indicated very good heating value parameters of tested samples of liquid materials sourced from FARME with the exception of rape seed oil itself. Lower heating power of rape seed oil, caused by ash content, was proven in the stoichiometric analyses.

Emission parameters of the samples are given in **Table 3**. The highest technical thermal efficiency (90.9 %) was achieved from the sample metylester from FARME (100 %). The highest CO_2 emission (9.96 %) was achieved from distillation residues from FARME (100 %) and the lowest (8.23 %) was in rape seed oil from FARME (100 %). Sulphur dioxide emission of the sample distillation residues from FARME (10 %) and LTO (90 %) was much higher (522.29 mg m^{-3}) than other samples. HCL emission was also higher in this sample (65.9 mg m^{-3}).

The results of measurements indicated that thermal use of methyl ester production wastes was an asset. An addition of distillation residue to light fuel oil improved its emission parameters, especially sulphur dioxide emissions. Carbon dioxide emissions were increased, especially by imperfect burning of material. The loss was originated by imperfect burning of fuel, which was required by lack of air or imperfect mixing of combusting air with a fuel or flammable surroundings in the grate.

Discussion and Conclusion

The ash content influenced the choice of the appropriate combustion technology and influenced deposit formation (Obernberger *et al.*, 2006). The choice and design of combustion equipment were influenced by the fuel stoichiometry and other fuel parameters, such as heating power, water content, and energy density. Analyses of selected samples confirmed a wide range of

Table 1 Elemental analysis of selected liquid samples

Samples	Diesel fuel	Light fuel oil	Rape seed oil	Methylester	Distillation residues from FARME (water-free sample)	Distillation residues from FARME (combustible)
Carbon C (weight %)	86.50	85.60	77.70	76.90	78.66	78.7
Hydrogen H (weight %)	13.00	12.30	11.60	12.20	11.86	11.87
Oxygen O (weight %)	0.00	0.10	10.60	0.01	9.38	9.38
Sulphur S (weight %)	0.11	1.40	0.00	0.11	0.01	0.01
Nitrogen N (weight %)	0.00	0.05	0.00	0.00	0.04	0.04
Chlorine Cl (weight %)	0.00	0.08	0.06	0.06	0.04	0.04
Water content (weight %)	0.01	0.01	0.00	0.00	0.00	0.00
Ash (weight %)	0.01	0.05	0.10	0.00	0.05	0.00

Table 2 Final stoichiometric calculations of liquid samples

Stoichiometric calculations		Diesel fuel	Light fuel oil	Rape seed oil	Methylester	Distillation residues from FARME (water-free sample)	Distillation residues from FARME (combustible)
Q_n	Heating value - ČSN 44 1352 ($MJ.kg^{-1}$)	42.49	40.01	31.17	37.03	37.64	37.66
Q_v	Calorific value ($MJ.kg^{-1}$)	45.33	42.70	33.70	39.70	40.23	40.25
O_{min}	Theoretical quantity of oxygen for ideal combustion process ($kg.kg^{-1}$)	3.35	3.28	2.89	3.027	2.95	2.95
L_{min}	Theoretical air quantity for ideal combustion process ($kg.kg^{-1}$)	14.43	14.13	12.47	13.05	12.72	12.73
n	Overflow of the air (O_2 = 3 %)	1.20	1.20	1.20	1.20	1.20	1.20
m^s_{spmin}	Theoretical mass quantity of dry combustion gas ($kg.kg^{-1}$)	16.06	15.82	14.26	14.67	14.49	14.49
CO_{2max}	Theoretic mass concentration of oxide carbonic in dry combustion gas (% mass.)	19.74	19.83	19.97	19.22	19.90	19.90
CO_2	Carbon dioxide (weight %)	16.91	17.06	17.42	16.63	17.30	17.30
SO_2	Sulfur dioxide (weight %)	0.01	8.15	0.00	0.013	0.002	0.001
H_2O	Water (weight %)	9.9	9.68	1.02	10.14	10.04	10.05
N_2	Nitrogen (weight %)	69.49	69.43	68.91	69.53	68.99	68.99
O_2	Oxygen (weight %)	3.56	3.56	3.53	3.56	3.53	3.53
		Setting of cubical combustion (values of real molecular gas mass)					
O_{min}	Theoretical quantity of oxygen for ideal combustion process ($m^3.kg^{-1}$)	2.33	2.29	1.29	2.11	2.06	2.06
L_{min}	Theoretical air quantity for ideal combustion process ($m^3.kg^{-1}$)	11.12	10.89	6.18	10.05	9.81	9.81
n	Overflow of the air (O_2 = 3 %)	1.20	1.20	1.20	1.20	1.20	1.20
v^s_{spmin}	Theoretical cubical quantity of dry combustion gas ($m^3.kg^{-1}$)	10.28	10.1	3.72	9.27	9.11	9.12
CO_{2max}	Theoretic cubical concentration of oxide carbonic in dry combustion gas (% vol.)	15.60	15.71	16.11	15.37	16.0	16.0
CO_2	Carbon dioxide (% vol.)	11.02	11.15	8.58	10.81	11.28	11.28
SO_2	Sulfur dioxide (% vol.)	0.01	0.07	0.01	0.01	0.0005	0.0005
H_2O	Water (% vol.)	13.56	13.24	11.30	13.91	13.81	13.81
N_2	Nitrogen (% vol.)	71.37	71.49	69.47	71.23	70.89	70.89
O_2	Oxygen (% vol.)	3.20	3.21	9.83	3.19	3.17	3.18

nitrogen, sulphur, and chlorine concentrations in the wastes. Oxygen was a problematic part of the fuel, because of hydrogen and partly carbon binding, creating hydroxides, water, and other oxides. Oxides are mainly connected with nitrogen (in a form of amines and proteins contained in fuels) and chlorine. There is an interaction of chlorine oxides with conversion equipment, especially with combusting equipment (Malat'ák *et al*., 2005).

All water present in the fuels and the excess air coefficient are primary factors which may significantly affect the combustion equipment's thermal work. By the content of CO_2 the combustion quality (efficiency) can be judged. When the maximum possible concentration of CO_2 was achieved with a small excess of air (perfect combustion), the losses caused by combustion products (at the same temperature of combustion products) were minimal. For any liquid and solid fuel, a maximum achievable proportion of CO_2 existed (the so called CO_{2max}) in the combustion gases, given by the element composition of the fuel's flammable components. Of course, this value was unachievable in real combustion equipment.

Since hydrocarbons and other products of imperfect combustion behave identically as carbon monoxide, this emission component was an important indicator of the combustion process quality. The tested liquid fuels showed good emission parameters and efficiencies.

Support of this agricultural non-food production as a renewable source of energy was regarded as perspective not only from ecological aspects. Without this support, biofuel's could not compete with classic sources of energy. The current agricultural policy of the EU and thus also of the Turkey puts an emphasis on such utilization of agricultural production as the most important alternative to restrictions on agricultural production. Government support was essential for renewable source to penetrate the market on a larger scale.

In order to be able to use FARME and distillation residuals (but other fuels as well) in combustion equipment burning liquid fuels, it is necessary that the combustion process takes place under ideal conditions. Without meeting these assumptions, burning distillation residuals is no benefit. Therefore it is important to burn in a particular equipment, always, only fuel which is by its type, texture, quality, etc., suitable for that equipment. These aspects require permanent attention.

Results of measurements indicate the following conclusions:

- The most limiting factor for the heating value of the tested samples was water and ash matter content. This statement was proven by measurements.
- Highest amount of ash was found in a sample of pressed rape seed oil. Such amount of ash matter will considerably influence thermal qualities of sample. These qualities affected a choice of combustion equipment as well as its adjustment.
- Stoichiometric analyses values indicated very good thermal emission parameters of tested

Table 3 Results of the measurements

Samples	Units	Distillation residues from production FARME (10%) + LTO (90%)	Distillation residues from FARME (100%)	Methylester from FARME (100%)	Rape seed oil from FARME (100%)
Temp. of gas	°C	277.95	274.70	256.82	250.17
O_2	%	12.86	12.87	13.66	14.07
Carbon dioxide CO_2	%	9.07	9.96	8.46	8.23
Carbon monoxide CO	ppm	48.78	28.58	0.67	52.67
Carbon monoxide CO	$mg.m^{-3}$	61.00	35.79	0.83	65.90
Carbon monoxide CO (O_r = 3 %)	$mg.m^{-3}$	131.63	93.49	2.01	170.11
Oxides of sulphur SO_2	ppm	176.85	25.25	2.95	0.00
Oxides of sulphur SO_2	$mg.m^{-3}$	522.29	74.57	8.71	0.00
Oxides of sulphur SO_2 (O_r = 3 %)	$mg.m^{-3}$	1,153.29	172.98	21.44	0.00
Hydrogen chloride HCl	ppm	39.68	23.77	28.85	25.67
Hydrogen chloride HCl	$mg.m^{-3}$	65.90	39.47	47.91	42.63
Hydrogen chloride HCl (O_r = 3 %)	$mg.m^{-3}$	145.95	86.76	117.40	112.21
Nitrogen oxides NOx	ppm	39.68	23.77	28.85	25.67
Nitrogen oxides NOx	$mg.m^{-3}$	81.47	48.80	59.23	52.70
Nitrogen oxides NOx (O_r = 3 %)	$mg.m^{-3}$	180.43	107.26	145.14	138.72
Technical-thermal efficiency of combustion	%	84.30	84.30	90.90	78.50

liquid samples. These were sourced from methyl ester production line. The only one exception was rape seed oil, which showed higher ash matter content, as is displayed on its inferior thermal properties.

- The other problematical parts were sulphur dioxide emissions as well as hydrogen chloride emissions. Sulphur emissions were not a problem as to the trace amounts. These emissions were caused mainly because of sulphur contained in the light fuel oil.
- Hydrogen chloride emissions reached average common values.
- Results of the measurements indicated that usage of wastes sourced from methyl ester production was an asset.
- An addition of distilling residues (10 %) to light fuel oil improved emission properties, mainly sulphur dioxide emissions.
- The tested liquid samples from methyl ester rape seed oil production showed good emission and efficiency values.
- The solution led to emission reduction and in this way also to reduction of environmental pollution.
- Definition of typical physical-chemical properties of selected samples from methyl ester rape seed oil production can be used as the initial data for material and thermal-chemical use.
- Fuel wastes classification and specification will simplify the acceptability on the fuel market and the increase in public trust.
- The definite determination of typical physical-chemical properties was necessary for designing, building and checking of combusting equipments and for the thermal use of liquid samples burning of wastes from methyl ester rape seed oil production was useless without meeting these premises.

REFERENCES

Bridgewater, T. 2006. Biomass for energy. Journal of the Science of Food and Agriculture 86 (12), John Wiley & Sons LTD, Sussex England, ISSN: 0022-5142, 1755-1768.

Demirbaş, M. F. and M. Balat. 2006. Recent advances on the production and utilization trends of biofuels: A global perspective. Energy Conversion and Management 47 (15-16), Pergamon − Elsevier Science LTD, Oxford England, ISSN: 0196-8904, 2371 − 2381.

Jevič, P., J. Malat'ák, M. Přikryl, and Z. Šedivá. 2006. Motor biofuels and environmental. Motor biofuels and blended fuels the present state and future. VZÚT Praha, VÚZT – SVB – MZČR – ČZU v Praze, ISBN 80-86884-13-9, 134-140.

Malat'ák, J., P. Jevič, M. Dvořák, P. Vaculík and J. Karanský. 2006. Utilization of distillation residues from FARME production plants. Recent Advances in Agriculture, Food Processing and Waste Policy, Slovak University of Agriculture in Nitra, SPU Nitra, ISBN 80-8069-711-6, 55-60.

Malat'ák, J., P. Jevič, J. Karanský, M. Přikryl, and D. Plíštil. 2005. Energetical use of liquid products from the rape seed oil methyl ester production. Engineering in management's integrated systems, MUAF in Brno, Boršice, ISBN 80-7157-864-9, 47 – 50.

Malat'ák, J., P. Jevič, J. Karanský, M. Přikryl, and R. Gálik. 2005. Emission characteristics of biomass-based briquets. Acta technologica agriculturae – The Scientific Journal for agricultural engineering, SPU Nitra, ISSN 1335-2555, 48-52.

Obernberger, I., T. Brunner, and G. Barnthaler. 2006. Chemical properties of solid biofuels − significance and impact. Biomass & Bioenergy 30 (11), Pergamon-Elsevier Science LTD, England, ISSN: 0961-9534, 973-982.

Powlson, D. S., A. B. Riche and I. Shield. 2005. Biofuels and other approaches for decreasing fossil fuel emissions from agriculture. Annals of Applied Biology 146 (2), Assoc Applied Biologits, Wellsbourne England, ISSN: 0003-4746, 193-201.

Vasudevan, P., S. Sharma and A. Kumar, 2005. Liquid fuel from biomass: An overview. Journal of Scientific & Industrial Research 64 (11), Nat. Inst. Science Communication, India, ISSN: 0022-4456, 822-831.

■■

Co-operating Editors

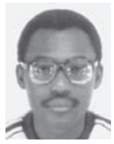

B Kayombo


M F Fonteh


A A K El Behery


A M El Hossary


B S Pathak


R J Bani


I K Djokoto


D K Some


K Houmy


J C Igbeka


E U-Odigboh


K C Oni


L U Opara


N G Kuyembeh


A H Abdoun


A B Saeed


A I Khatibu


E A Baryeh


S Tembo


H A Cetrangolo

-AFRICA-

Benedict Kayombo
Associate Professor of Soil and Water Engineering, Dept. of Agric. Engineering and Land Planning, Botswana College of Agriculture, University of Botswana, Private Bag 0027, Gaborone, BOTSWANA. TEL(+267)-3650125, FAX(+267)-328753
E-mail: bkayombo@bca.bw

Mathias Fru Fonteh
Asst. Professor and Head, Dept. of Agric. Engineering, Faculty of Agriculture, University of Dschang, P.O. Box 447, Dschang, West Province, CAMEROON
TEL+237-45-1701/1994, FAX+237-45-2173/1932
E-mail: m.f.fonteh@camnet.cm

Ahmed Abdel Khalek El Behery
Agric Engineering Research Institute, Agricultural Reserch Center, Nadi El-Said St. P.O. Box 256, Dokki 12311, Giza, EGYPT

Ali Mahmoud El Hossary
Senior Advisor to the Ministry of Agriculture and Chairman of (AGES)-Agengineering Consulting Group, Ministry of Agriculture - P.O.Box 195 Zamalek 11211 Cairo, EGYPT
TEL00-202-335-9304, FAX00-202-3494-132

B. S. Pathak
Project Manager, Agric. Implements Research and Improvement Centre, Melkassa, ETHIOPIA

Richard Jinks Bani
Lecturer & Co-ordinator, Agric. Engineering Div., Faculty of Agriculture, University of Ghana, Legon, GHANA

Israel Kofi Djokoto
Senior Lecturer, University of Science and Technology, Kumasi, GHANA

David Kimutaiarap Some
Professor, Deputy Vice-chancellor. Moi University, P.O. Box: 2405, Eldoret, KENYA

Karim Houmy
Professor and head of the Farm Mechanization Dept., Institute of Agronomy and Velerinary Medicine II, Secteur 13 Immeuble 2 Hay Riad, Rabat, MOROCCO, Tel+212-7-68-05-12, Fax+212-7-775801
E-mail: houmy@maghrebnet.net.ma

Joseph Chukwugotium Igbeka
Professor, Dept. of Agricultural Engineering, Univ. of Ibadan,, Ibadan, NIGERIA
TEL+234-2-8101100-4, FAX+234-281030118
E-mail: Library@Ibadan.ac.ng

E. U. Odigboh
Professor, Agricultural Engg Dept., Faculty of Engineering, University of Nigeria, Nsukka, Enugu state, NIGERIA, TEL+234-042-771676, FAX042-770644/771550, E-mail: MISUNN@aol.com

Kayode C. Oni
Director/Chief Executive, National Centre for Agric. Mechanization (NCAM), P.M.B.1525, Ilorin, Kwara State, NIGERIA
TEL+234-031-224831, FAX+234-031-226257
E-mail: ncam@skannet..com

Linus U. Opara
Research Professor, S. Africa Chair in Postharvest Technology, Faculty of AgriSciences, Stellenbosch University, Private Bag X1, Stellenbosch 7602, SOUTH AFRICA
TEL+27-21-808-4604, FAX+27-21-808-2121, E-mail: opara@sun.ac.za

N. G. Kuyembeh
Associate Professor, Njala University Colle, University of Sierra Leone, Private Mail Bag, Free Town, SIERRA LEONE
TEL+249-778620-780045, FAX+249-11-771779

Abdien Hassan Abdoun
Member of Board, Amin Enterprises Ltd., P.O. Box 1333, Khartoum, SUDAN

Amir Bakheit Saeed
Assoc. Professor, Dept. of Agric. Engineering, Faculty of Agriculture, University of Khartoum, 310131 Shambat, SUDAN, TEL+249-11-310131

Abdisalam I. Khatibu
National Prolect Coordinafor and Direcror, FAO Irrigated Rice Production, Zanzibar, TANZANIA

Edward A. Baryeh
Professor, Africa University, P.O.Box 1320, Mutare, ZIMBABWE

Solomon Tembo
52 Goodrington Drive, PO Mabelreign,Sunridge, Harare, ZIMBABWE

-AMERICAS-

Hugo Alfredo Cetrangolo
Full Professor and Director of Food and Agribusiness Program Agronomy College Buenos Aires University, Av. San Martin4453, (1417) Capital Federal, ARGENTINA
TEL+54-11-4524-8041/93, FAX+54-11-4514-8737/39
E-mail: cetrango@agro.uba.ar

Irenilza de Alencar Nääs
Professor, Agricultural Engineering College, UNICAMP, Agricultural Construction Dept.,P.O. Box 6011, 13081 -Campinas- S.P.,BRAZIL
TEL+55-19-7881039, FAX+55-19-7881010
E-mail: irenilza@agr.unicamp.br

A. E. Ghaly
Professor, Biological Engineering Deparment Dalhousie University, P.O. Box 1000, Halifax, Nova Scotia, B3J2X4, CANADA
TEL+1-902-494-6014, FAX+1-902-423-2423
E-mail: abdel.gahaly@dal.ca

Edmundo J. Hetz
Professor, Dept. of Agric. Eng. Univ. of Concepcion, Av. V.Mendez 595, P.O. Box 537, Chillan, CHILE
TEL+56-42-216333, FAX+56-42-275303
E-mail: ehetz@udec.cl

A. A. Valenzuela
Emeritus Professor, Ag. Eng. Fac., University of Concepcion,Casilla537Chillan, CHILE
TEL+56-42-223613, FAX+56-42-221167

Roberto Aguirre
Associate Professor, National University of Colombia, A.A. 237, Palmira, COLOMBIA
TEL+57-572-2717000, FAX+57-572-2714235
E-mail: ra@palmira.unal.edu.co

Omar Ulloa-Torres
Professor, Escuela de Agricultura de la Region, Tropical Humeda(EARTH), Apdo. 4442- 1000, San Jose, COSTA RICA, TEL+506-255-2000, FAX +506-255-2726, E-mail: o-ulloa@ns.earth.ac.cr

S. G. Campos Magana
Leader of Agric. Engineering Dept. of the Gulf of Mexico Region of the National Institute of Forestry and Agricultural Research, Apdo. Postal 429. Veracruz, Ver. MEXICO


I de A Nääs


A E Ghaly


E J Hetz


A A Valenzuela


R Aguirre


O Ulloa-Torres


S G C Magana


H Ortiz-Laurel


W J Chancellor


M R Goyal


A K Mahapatra


G R Quick


S M Farouk


Daoulat Hussain


M A Mazed


Chetem Wangchen


Wang Wanjun


S Illangantileke


S M Ilyas


A M Michael


G Singh


T P Ojha


S R Verma


Soedjatmiko


M Behroozi-Lar


Saeid Minaei


J Sakai


B A Snorbar


C J Chung


C C Lee

Hipolito Ortiz-Laurel
Head of Agric. Engineering and Mechanization Dept./ Postgraduate College, Iturbide 73, Salinas de Hgo, S.L.P., C.P. 78600, MEXICO
TEL+52-496-30448, FAX+52-496-30240

William J. Chancellor
Professor Emeritus, Bio. and Agr. Eng. Dept., Univ. of California, Davis, CA, 95616, U.S.A.
TEL+1-530-753-4292, FAX+1-530-752-2640
E-mail: wjchancellor@ucdavis.edu

Megh R. Goyal
Professor in Agric. & Biomedical Engineering, University of Puerto Rico, P.O.Box 0086, RINCON, Puerto Rico, 00677-0086, U.S.A.,
TEL+1-787-265-4702
E-mail: m_goyal@ece.uprm.edu

Ajit K. Mahapatra
Present add: Agric. & Biosystems Eng. Dept., South Dakota State Univ., P.O. Box2120 Brookings, SD 57007-1496, U.S.A., TEL605-6885291, FAX 605-6886764, E-mail: mahapata@sdstate.edu

-ASIA and OCEANIA-

Graeme R. Quick
Consulting Enginner, 83 Morrisons Road, Peachester, Queensland, 4519, AUSTRALIA

Shah M. Farouk
Professor (Retd.),Farm Power & Machinery Dept., Bangladesh Agricultural University, Mymensingh 2200, BANGLADESH, TEL+880-91-5695ext.2596, FAX91-55810, E-mail: smf@bdcom.com

Daulat Hussain
Dean, Faculty of Agric. Engineering and Technology, Bangladesh Agricultural University, Mymensingh-2202, BANGLADESH, TEL+880-91-52245, FAX91-55810, E-mail: dhussain@royalten.net

Mohammed A. Mazed
Member-Director, Bangladesh Agri. Res. Council, Farmgate, Dhaka, BANGLADESH
E-mail: mamazed@barcbgd.org

Chetem Wangchen
Programme Director Agricultural Machinery Centre Ministry of Agriculture Royal Government of Bhutan, Bondey Paro Bhutan 1228, BHUTAN, E-mail: krtamc@druknet.bt

Wang Wanjun
Past Vice Director and Chief Engineer/Chinese Academy of Agricultural Mechanization Sciences, 1 Beishatan, Beijing, 100083, CHINA
TEL+86-(0)83-001-6488-2710, FAX001-6488-2710
E-mail: wwj@isp.caams.org.cn

Sarath Illangantileke
Regional Representative for South and West Asia, International Potato Center (CIP), Regional Office for CIP-South & West Asia, IARI (Indian Agric. Res. Institute) Campus, Pusa, New Delhe-12, 110002, INDIA, TEL+91-11-5719601/5731481, FAX./5731481, E-mail: cip-delhi@cgiar.org

S. M. Ilyas
Director, National Academy of Agricultural Research Management (NAARM), Rajendranagar, Hyderabad-500030, INDIA, Tel+91-40-24015070, Fax:+91-41-24015912, E-mail: smiyas@sity.com

A. M. Michael
1/64, Vattekunnam, Methanam Road, Edappally North P.O., Cochin, 682024, Kerala State, S. INDIA

Gajendra Singh
Professor, Gajendra Singh, Former Vice Chancellor, Doon University 260, SFS Flats, Ashok Vihar Phase IV, Delhi-110052 INDIA, TEL+91-11-2730 7664, Email: gajendrashinghb@gmail.com

T. P. Ojha
Director General(Engg.) Retd., ICAR, 110, Vineet Kung Akbarpur, Kolar Road, Bhopal, 462 023, INDIA
TEL+91-755-290045

S. R. Verma
Prof. of Agr. Eng, & Dean Eng.(Retd), 14, Good Friends Colony, Barewal Road , Via Ayoli Kalan, Ludhiana 142027 Punjab, INDIA, TEL+91-(0)161-463096
E-mail: srverma@hotmail.com

Soedjatmiko
President, MMAI(Indonesian Soc. of Agric. Eng. & Agroindustry), Menara Kadin Indonesia Lt.29 Jl. HR. Rasuna Said X-5/2-3 Jakarta, 12940, INDONESIA
TEL+62-(0)21-9168137/7560544, FAX(0)21-527448 5/5274486/7561109

Mansoor Behroozi-Lar
Professor, Agr. Machinery, Ph.D, Tehran University Faculty of Agriculture, Karaj, IRAN
TEL+98-21-8259240, E-mail: mblar@chmran.ut.ac.ir

Saeid Minaei
Assistant Professor, Dept. of Agr. Machinery Eng., Tarbiat Modarres Univ., P.O.Box 14115-111, Tehran, IRAN
TEL+9821-6026522-3(office ext.2060, lab ext.2168)
FAX+9821-6026524, E-mail: minaee7@hotmail.com

Jun Sakai
Professor Emeritus, Kyushu University, 2-31-1 Chihaya, Higashi-ku, Fukuoka city, 813, JAPAN
TEL+81-92-672-2929, FAX+81-92-672-2929
E-mail: junsakai@mtj.biglobe.ne.jp

Bassam A. Snobar
Professor and Vice President, Jordan University of Science and Technology, P.O.Box 3030 Irbid, 22110, JORDAN, TEL+962-2-295111, FAX+962-2-295123
E-mail: snobar@just.edu.jo

Chang Joo Chung
Emeritus Professor, Seoul National University, Agricutural Engineering Department, College of Agriculture and Life Sciences, Suwon, 441-744, KOREA
TEL+82-(0)331-291-8131, FAX+82-(0)331-297-7478
E-mail: chchung@hanmail.net

Chul Choo Lee
Mailing Address: Rm. 514 Hyundate Goldentel Bld. 76-3 Kwang Jin Ku,Seoul, KOREA
TEL+82-(0)2-446-3473, FAX+82-(0)2-446-3473
E-mail: ccsslee@chollian.net

Muhamad Zohadie Bardaie
Professor, Department of Agricultural and Biosystems Engineering, University Putra Malaysia, 43400 upm, Serdang, Serdangor, MALAYSIA
TEL+60-3-89466410
Email: zohadie@eng.upm.edu.my

Madan P. Pariyar
Consultant, Rural Development through Selfhelp Promotion Lamjung Project, German Technical Cooperation. P.O. Box 1457, Kathmandu, NEPAL

David Boakye Ampratwum
Associate Professor, Dept.of Bioresource and Agricultural Engineering, College of Agriculture, Sultan Qaboos University, P.O. Box 34, Post Code 123, Muscat, Sultanate of Oman, OMAN
TEL+968-513866, FAX513866
E-mail: davidamp@squ.edu.om

EITag Seif Eldin
Mailling Address: Dept. of Agric. Mechanization, College of Agriculture, P.O. Box 32484, Al-Khod, Sultan Qaboos University, Muscat, Sultanate of Oman, OMAN

Allah Ditta Chaudhry
Professor and Dean Faculty of Agric. Engineering and Technology, University of Agriculture, Faisala-


M Z Bardaie


M P Pariyar


D B Ampratwum


E S Eldin


A D Chaudhry


A Q Mughal


R ur Rehmen


B T Devrajani


N A Abu-Khalaf


Surya Nath


R M Lantin


R P Venturina


S A Al-Suhaibani


A M S Al-Amri


S F Chang


T S Peng


S Krishnasreni


S Phong-supasamit


C Rojanasaroj


V M Salokhe


Y Pinar


I Haffar


N Hay


P V Lang


A A Hazza'a


A P Kaloyanov


P Kic


J Müller


G Pellizzi


W B Hoogmoed


Jan Pawlak


O S Marchenko


J Kilgour


M Martinov

Back Issues

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

(Vol.38, No.4, Autumn, 2007-)

Vol.38, No.4, Autumn, 2007

◇ ◇ ◇

Vol.39, No.1, Winter, 2008

◇ ◇ ◇

Vol.39, No.2, Spring, 2008

◇ ◇ ◇

Vol.39, No.3, Summer, 2008

◇ ◇ ◇

Vol.39, No.4, Autumn, 2008

◇ ◇ ◇

Vol.40, No.1, Winter, 2009

◇ ◇ ◇

Vol.40, No.2, Spring, 2009

■■

INSTRUCTIONS TO AMA CONTRIBUTORS

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

Criteria for Article Selection

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

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

Rejected/Accepted Articles

a. As a rule, articles that are not chosen for AMA publication are not returned unless the writer(s) asks for their return and are covered with adequate postage stamps. At the earliest time possible, the writer(s) is advised whether the article is rejected or accepted.
b. When an article is accepted but requires revision/modification, the details will be indicated in the return reply from the AMA Chief Editor in which case such revision/modification must be completed and returned to AMA within three months from the date of receipt from the Editorial Staff.
c. "The AMA does not pay for articles published. However, the writers are given collectively 5 free copies (one copy air-mailed and 4 copies sent by surface/sea mail) of the AMA issue wherein their articles are published. In addition, a single writer is given 25 off-prints of the article and plural writers are given 35 off-prints (also sent by surface/sea mail)"
d. Complimentary copies: Following the publishing, three successive issue are sent to the author(s).

Procedure

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

Format/Style Guidance

a. Article must be sent on 3.5 inch floppy disk or CD-R with MS DOS format (e.g. Word Perfect, Word for DOS, Word for Windows... **Absolutely necessary TEXT FORMAT**) along with two printed copy (A4).
b. The data for graphs and the black & white photographs must be enclosed with the article.
c. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features:
(i) brief and appropriate title;
(ii) the writer(s) name, designation/title, office/organization; and mailing address;
(iii) an abstract following ii) above;
(iv) body proper (text/discussion);
(v) conclusion/recommendation; and a
(vi) bibliography
d. The printed copy must be numbered (Arabic numeral) successively at the top center whereas the disc copy pages should not be number. Tables, graphs and diagrams must likewise be numbered. Table numbers must precede table titles, e.g., "Table 1. Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Figure 1. View of the Farm Buildings".
e. **The data for the graph must also be included. (e.g. EXCEL for Windows)**
f. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
g. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
h. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
i. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
j. Convert national currencies in US dollars and use the later consistently.
k. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
l. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers..., or Five tractors..."instead of 45 workers..., or, 5 tractors.

INQUIRY and REQUEST to AMA

Please let us know your need. We shall promptly reply them. Inquire on any catalog listed in the advertisement in this issue. We shall try our best to serve you. We welcome articles of interest to agricultural mechanization. FIll in the reverse side of this card and send us by sealed letter.

FARM MACHINERY INDUSTRIAL RESEARCH CORP.

2-7-22 Kanda nishikicho, Chiyoda-ku, Tokyo 101-0054, Japan

ADVERTISED PRODUCYS INQUIRY

Product	Advertiser	Vol., No., Page

EDITORIAL REQUEST TO AMA

Your Name :

Address :

Occupation :

SUBSCRIPTION/ORDER FORM

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA (AMA)

Issued Quarterly

Subscription Rate (includes surface mail postage)

Annual (4 issues)...........................¥6,000
Single copy....................................¥1,700

Back Issues (1971-75, ¥2,000 per copy)
(1976-77, ¥1,200 per copy)
(1978-80, ¥1,500 per copy)

- ■ Spring, 1971
- ■ Vol. 2 Autumn, 1971
- □ Vol. 3 No. 1, Spring, 1972
- □ Vol. 3 No. 2, Summer, 1972
- ■ Vol. 4 No. 1, Spring, 1973
- □ Vol. 4 No. 2, Autumn, 1973
- ■ Vol. 5 No. 1, Summer, 1974
- □ Vol. 6 No. 1, Spring, 1975
- ■ Vol. 6 No. 2, Autumn, 1975
- □ Vol. 7 No. 1, Winter, 1976
- □ Vol. 7 No. 2, Spring, 1976
- □ Vol. 7 No. 3, Summer, 1976
- □ Vol. 7 No. 4, Autumn, 1976
- □ Vol. 8 No. 1, Winter, 1977
- □ Vol. 8 No. 2, Spring, 1977
- □ Vol. 8 No. 3, Summer, 1977
- □ Vol. 8 No. 4, Autumn, 1977
- □ Vol. 9 No. 1, Winter, 1978
- □ Vol. 9 No. 2, Spring, 1978
- ■ Vol. 9 No. 3, Summer, 1978
- ■ Vol. 9 No. 4, Autumn, 1978
- □ Vol.10 No. 1, Winter, 1979
- □ Vol.10 No. 2, Spring, 1979
- □ Vol.10 No. 3, Summer, 1979
- □ Vol.10 No. 4, Autumn, 1979
- ■ Vol.11 No. 1, Winter, 1980
- ■ Vol.11 No. 2, Spring, 1980
- □ Vol.11 No. 3, Summer, 1980
- □ Vol.11 No. 4, Autumn, 1980

■ : Indicates issues out of stock.

□ **Abstract and Index, 1971-80(Special Issue, 1983)**

(Check issues and number of copies you wish to order)

Back Issues from 1981, ¥1,700 per copy (Vol. 12 No.1 and No.4 are out of stock)
Abstract and Index, Special Issue, 1983, ¥2,000 per copy.

Vol.______No. _____, ____________ ,________copy / copies

(Check one)
□ Please invoice me/us
□ I/We enclose remittance for ¥_________

****

Name: ____

Firm: ____

Position: ____

Address: ____
(block letters)

FARM MACHINERY INDUSTRIAL RESEARCH CORP.
2-7-22 Kanda-Nishikicho, Chiyoda-ku, Tokyo 101-0054, Japan
Tel. (03)-3291-3674

STAMP

FARM MACHINERY INDUSTRIAL RESEARCH CORP.
2-7-22 Kanda Nishikicho, Chiyoda-ku,
Tokyo 101-0054, Japan

1st FOLD HERE

2nd FOLD HERE