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This is the 60th issue since the issue, Spring of 1971

EDITORIAL

A Sentimental Journey

This editorial style is a departure from the norm because it is in the first person and that it is a narrative. But that is how it is expected to put the message across as any style of editorials aims to accomplish.

In March of this year, I took time out to attend an international agricultural machinery show in Paris (the Salon International de la Machine Agricole or SIMA) and visited Sudan and Egypt on the return trip. It was indeed a sentimental journey even as the observations relate to agricultural development and agricultural machineries.

The SIMA agricultural machinery show is regarded as the only international exhibition that puts special emphasis on mechanizing farming operations in developing countries – a very laudable posture that should be emulated by other sponsors of international exhibitions on farm machineries. Two outstanding exhibits that drew the attention of the visitors to the show were prototypes of a milking robot and an apple robot harvester. The commercial production of these gadgets is expected to come on stream within the next few years. Already, both robots were hailed by many that they auger well for a more efficient dairy and apple production in the years ahead.

On the other hand, at the booth of Centre d'Etudes et d'Experimentation du Machinisme Agricole Tropical (CEEMAT), I had the good fortune of meeting with an AMA cooperating editor and several engineering researchers from Nigeria. As might be expected, we had a very useful exchange of information and experiences concerning AMA and agricultural mechanization.

The visit to Sudan proved to be a mixture of nostalgia and disappointment: nostalgic because I was there 10 years ago and disappointing because the then famed Gezira District which was a paragon of agricultural development strategy and implementation is now only a picture of neglect and failure. This sad sight is due, in large measure, to civil strife in the country and increasing foreign indebtedness of the government. Most disheartening of all is the neglected state of the irrigated agriculture which needs all the help it can get before the irrigations system becomes unsalvageable or costly, if not impossible to rehabilitate.

In Egypt, the Nile River is threatened by continuous depletion of the water level that is caused by dwindling rainfall and denudation of the surrounding forests. This situation seemed like an irony of history considering that the Nile is biblically known to have produced civilization in ancient times – and it is the same civilization that seems to be causing its demise.

One consolation I had in Cairo, however, was my visit to another exhibition of farm machineries many of which are manufactured indigenously. The brisk manufacture of domestic farm machineries in this country is attributed to the encouragement and support that the industry receives from the Agricultural Machinery Institute – another bright spot that should be pursued by governments of developing countries.

This first-hand report of an equally first-hand observation should lend meaning to the objectives of AMA in disseminating valuable information that must be shared with its readers.

Yoshisuke Kishida
Chief Editor

Tokyo
July, 1988

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Modeling Flow of Irrigation Water Discharge Uniformity in Microtube Emitters

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Abstract

Hagen-Poiseulle friction equations are used to identify the field conditions of a drip irrigations system closest to theory. Six field conditions were tested under low head (82 cm) and high head (182 cm) which consider microtube protrusion depth and orientation with respect to the ground as variables. Discharges measured for each condition were compared with that calculated from the Hagen-Poiseulle equations. A protrusion depth of 1 cm when microtubes are facing up seems to be the best model. Sensitivity analysis shows that the variable which affects discharge most is the microtube diameter. The present study shows that, for the model selected, discharge uniformity can be greatly improved by varying the size of microtube heads.

Objective

Drip irrigation offers important potential to desert or marginal land where water is limited or is of high cost. Consequently, the main object of the present research work is to investigate this special merit of drip irrigation with respect to water saving, water distribution efficiency and cost minimization of systems and facilities used.

In this paper, regarding water saving and water distribution efficiency special consideration will be given to the water emission uniformity. The efficiency of drip irrigation depends on the uniform application of water from emitters. Flow variability has been associated with different factors, including friction drop along the drip irrigation line, slope, designed emitters characteristics, clogging and emitter connection losses. Ideally, the application of water throughout a drip irrigation system should be absolutely uniform: this would require that each emitter has the same rate of discharge even though pressure losses are unavoidable. Some authors have developed drip lateral line design procedures which specify that varying the diameter and length of microtubes offer a practical approach to uniform application. Unfortunately, the utilization of different sized emitters in a system requires troublesome and impractical field work. A simple way to achieve a near absolute uniformity pattern of irrigation is through computer simulation. To do so, microtubes discharge rates obtained under different conditions were measured, statistically analyzed and classified under a given flow regime. Friction equations developed by Hagen-Poiseulle were used to simulate theoretical discharges that were compared to the discharges measured in the experiment. These field conditions yielding results closest to the simulation results could be identified. These field conditions were found, and the microtubes head distribution that will allow the same discharge for each single microtube can be computed, for a given inlet pressure head.

Methodology

The drip irrigation system used in the experiment consisted of: 1) a main lateral tube with length 800

cm, internal diameter 1.8 cm; 2) 10 microtubes of identical size (almost identical discharge under same head) with length 100 cm, internal diameter 0.1 cm and distance between microtubes about 80 cm; 3) a tank with depth 28 cm set at different pressure heads (82 cm and 182 cm) supplies water; 4) one manometer to measure, Po, the inlet pressure after the filter and another manometer to measure, Pt, the pressure at the end of the line; and 5) one thermometer to measure the water temperature. Six different field conditions were set as follows:

Condition	Protrusion depth, cm	Position
A0.5	0.5	Ground
B0.5	0.5	Facing up
A1	1	Ground
B1	1	Facing up
A1.5	1.5	Ground
B1.5	1.5	Facing up

The drip irrigation system and the field conditions are shown in **Figs. 1a** and **1b**, respectively. In all the field conditions, the microtubes entrances are facing the flow and the outlets are located at the same head(z) 16 cm above the ground.

Fig. 1 Drip irrigation system and field conditions.

Results

For all conditions the flow is laminar. The Hagen-Poiseulle equation for laminar flow was then used in the simulation. **Fig. 1a** shows a line with n equal sections where the outflow from each section is qi (i = 1, 2, 3, ..., p, ..., n). From the Hagen-Poiseulle equation, the discharge at the p section is such that the expression:

$$Po - F_1 L\,[Q_1 + (Q_1 - q_1) + (Q_1 - q_1 - q_2) + \ldots + (Q_1 - q_1 - q_2 - q_3 - \ldots q_{p-1})] - F_2 q_p - \rho q_p^2 / 2\pi^2 r^4 - \rho gz = 0$$

is satisfied.

where,

Po: inlet pressure [dyne/cm^2]

F_1: friction coefficient of a lateral of radius R ($8\mu/\pi R^4$) with μ = coefficient of dynamic viscosity

F_2: friction coefficient of a micro-

Table 1 Experiment and Statistical Data with Simulation Results (Microtube depth is 0.5 cm)

Head	Condition	H_o	H_t	Water temp.	Average discharge	Coefficient of variation	Slope	Y-axis intercept	r	Reynolds no.		Simulation difference
cm		cm	cm	°C	cm^3/5 min	%				Micro	Lateral	%
82	A.5	79.19	79.17	13	35.9	11	-.015	42.4	-.96	125	76	43
82	B.5	79.30	79.21	13	36.4	10	-.015	42.8	-.97	127	77	41
182	A.5	179.18	179.10	6	91.7	5	-.019	99.9	-.94	258	156	17
182	B.5	179.18	179.16	6	91.6	5	-.018	99.6	-.96	259	157	17

Table 2 Experiment and Statistical Data with Simulation Results (Microtube depth is 1 cm)

Head	Condition	H_o	H_t	Water temp.	Average discharge	Coefficient of variation	Slope	Y-axis intercept	r	Reynolds no.		Simulation difference
cm		cm	cm	°C	cm^3/5 min	%				Micro	Lateral	%
82	A1	79.24	79.17	10	37.4	8	-.011	42.2	-.95	121	73	28
82	B1	79.37	79.31	6	37.2	5	-.007	40.1	-.92	102	62	12
182	A1	178.69	178.50	8	99.2	4	-.015	105.8	-.92	321	195	15
182	B1	178.59	178.41	8	103.1	3	-.012	108.6	-.88	334	203	10

Table 3 Experiment and Statistical Data with Simulation Results (Microtube depth is 1.5 cm)

Head	Condition	H_o	H_t	Water temp.	Average discharge	Coefficient of variation	Slope	Y-axis intercept	r	Reynolds no.		Simulation difference
										Micro	Lateral	
cm		cm	cm	°C	$cm^3/5$ min	%						%
82	A1.5	79.30	78.45	13	34.8	11	-.014	41.1	-.94	121	74	48
82	B1.5	79.30	78.66	13	34.7	9	-.013	40.4	-.97	121	73	48
182	A1.5	179.27	178.72	7	92.0	4	-.016	98.9	-.95	269	163	21
182	B1.5	178.94	178.40	7	93.1	4	-.015	99.9	-.95	273	165	18

Fig. 2 Comparing A0.5 and B0.5 (high head).

Fig. 3 Comparing A1 and B1 (high head).

Fig. 4 Comparing A1.5 and B1.5 (high head).

Fig. 5 Comparing A0.5 and B0.5 (low head).

Fig. 6 Comparing A1 and B1 (low head).

Fig. 7 Comparing A1.5 and B1.5 (low head).

tube of radius $r(8\mu/\pi r^4)$

ρ: water density [g/cm^3]

Q: total discharge supplied from the head end: Σqi [cm^3/s]

qi: outflow from microtube at section i [cm^3/s]

l: microtube length [cm]

L: distance between microtubes [cm]

g: acceleration of gravity [cm/s^2]

z: microtube potential head [cm]

Tables 1, 2 and 3 show the experiment and statistical data with the simulation results. Figs. 2 to 7 show the regression curves.

Comparison among Different Field Conditions

a) High operating head (182 cm) – A frequently used criterion in drip irrigation for good flow variability is a mean discharge deviation of less or equal to 5%. The microtube emitters were within the 5% discharge criterion for all conditions. The regression lines exhibit a close pattern suggesting that there is no significant difference between these conditions; orientation and protrusion depth of the microtubes do not have much effect on the flow uniformity. However, it is worthy to note that the flow coefficient of variation recorded is smaller when the microtubes are facing up (B0.5, B1 and B1.5), suggesting that these conditions seem to improve flow variability. A comparison of the experimental data with the simulation results showed that the errors ranged from 10 to 15%, respectively, for B1 and A1, 18 to 21% for conditions B1.5 and A1.5 and were 17% for conditions A0.5 and B0.5.

b) Low operating head (82 cm) – The microtube emitters, except for condition B1, exceeded all the 5% discharge criterion and ranged around 8% for condition A1 and 10% or more for the other conditions (A0.5, B0.5, A1.5, B1.5). The regression lines for these latter conditions also exhibit a close pattern suggesting that these conditions are the same and negatively affect the flow uniformity the same way. In these conditions, the protrusion depth is located near the walls of the lateral tube where friction is maximal. Along these walls where the flow is retarded, the microtubes interference and additional flow retardance is greatest. This justifies the higher coefficient of variation recorded at 0.5 and 1.5 cm protrusion depths. The regression lines of conditions A1 and B1 exhibit a different pattern as they intercept and show a wide gap. This suggests that condition B1 with coefficient of variation 5% seems to be the best. A comparison of the experimental data with the simulation results confirms this observation. In fact, the differences recorded ranged from 12 to 28% for B1 and A1, 41 to 43% for B0.5 and A0.5 and were 48% for conditions B1.5 and A1.5, respectively.

Sensitivity Analysis

Tables 4 and 5 summarize the percentage changes in discharge rates given a 5% change in each parameter involved in the discharge rate computation. The tables show the mean or initial value of all the variables; the sensitivity analysis was carried out by changing one parameter at a time and holding the others at their respective mean values. The tables show that the parameter which influences water discharge rate the most is the microtube diameter. Pressure, microtube length and water temperature had a lesser effect. Lateral diameter and distance between microtubes showed no effect. When it is assumed that the accuracy of the instruments used to measure the different parameters was better than 5% instrumental errors will account for less than 30% of the differences recorded between simulation results and experimental results. This indicates that at high operating head (182 cm) there is no difference between simulation results and experiment for all conditions; each condition could be a good model but B1 was the best

Table 4 Changes in Discharge per Unit Change in Variable (Low Head and 5% Variation)

Variable	Initial value	ΔVariable (%)	ΔQ/ΔVariable	ΔQ/Q(%)
D (lateral diam.)	1.6cm	±5	0	0
d (microtube diam.)	0.1cm	±5	±6.03cm^3/scm^{-1}	±20
l (microtube length)	100cm	±5	0.01cm^3/scm^{-1}	5
L (microtube dist.)	80cm	±5	0	0
T (water temp.)	10°C	±5	±0.004cm^3/scm^{-1}	±2
H (inlet pressure)	82cm	±5	±0.002cm^3/scm^{-1}	±5

Table 5 Changes in Discharge per Unit Change in Variable (High Head and 5% Variation)

Variable	Initial value	ΔVariable (%)	ΔQ/ΔVariable	ΔQ/Q(%)
D (lateral diam.)	1.6cm	±5	0	0
d (microtube diam.)	0.1cm	±5	±13.39cm^3/scm^{-1}	±20
l (microtube length)	100cm	±5	0.004cm^3/scm^{-1}	5
L (microtube dist.)	80cm	±5	0	0
T (water temp.)	10°C	±5	±0.008cm^3/scm^{-1}	±2
H (inlet pressure)	82cm	±5	±0.002cm^3/scm^{-1}	±5

model nearest to theory. At low operating head (82 cm), conditions A1 and B1 were good models with B1 yielding the best results.

Simulation of an Equal Discharge System

In this analysis, only an example of low operating head will be presented because high operating heads are rarely reached in greenhouses. Condition B1 was taken as our model. Figs. 8 and 9 show the microtubes head distribution for a 8 lateral pipe with 79 microtubes spaced 10 cm and for a 4 m lateral pipe with 40 microtubes spaced 10 cm, respectively. The figures show that z barely changes along the pipe when absolute uniformity is reached. This is explained by the small friction loss recorded in short pipes; consequently, the emitter head variation along the pipe necessary to compensate for that loss is small, z is almost constant. In the field, water discharges from the same microtube (to minimize errors from difference in diameter) placed at 9 different locations spaced 1 m apart on a 8 m lateral with 79 microtubes subjected to the same conditions as in the simulation give a coefficient of variation of 1%, a near absolute uniformity, at z = 16 cm. For long pipes, however, because of the larger friction drop recorded, z will change significantly along the pipe to compensate for that loss when absolute uniformity is reached. Figs. 10 and 11 which show a 50 m lateral pipe with 50 and 500 microtubes respectively, clearly illustrate that point.

Fig. 8 Microtubes head distribution given a similar discharge.

Fig. 9 Microtubes head distribution given a similar discharge.

Fig. 10 Microtubes head distribution given a similar discharge.

Summary and Conclusion

This study shows that the Hagen-Poiseulle equations model best field conditions when microtubes are introduced 1 cm into the lateral and are facing up under low (82 cm) or high (182 cm) operating head. Error analysis indicated most of the model errors could have been caused by errors in the parameters used, specially the microtube diameter which greatly affects discharge. It is shown that application uniformity from low pressure trickle irrigation system can be greatly improved by varying the microtube heads to compensate for friction induced pressure changes in long lateral pipes.

Fig. 11 Microtubes head distribution given a similar discharge.

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Power Requirements of Different Cropping Systems in Bangladesh

by
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Abstract

Farm power is one of the important determinants for successful crop production. In Bangladesh where the farming systems are still traditional, human and animals are the main sources of power. Mechanical power is increasing at a slow rate but only for irrigation purposes in the dry season. Under rainfed situation, the total power consumption does not vary significantly between *Aus* and *T.aman* seasons in growing modern and local varieties of rice. But it varies significantly among the different environments. The power consumption per unit of output is less in growing both rainfed and deep water crops than the irrigated condition.

In terms of net income from different cropping patterns, the deep water cropping pattern produced the highest value of TK. 29 861/ha followed by TK. 23 252/ha for irrigated and TK. 19 111/ha for rainfed crops. On average, the small farmers in Bangladesh are not financially capable of adopting mechanical power (power tiller) in crop production. If the Government provides loan or subsidy to them through the Department of Agricultural Extension, it might have some positive effect on farm production and income and increases the national production.

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Introduction

The introduction of high yielding varieties of rice by the Bangladesh Rice Research Institute (BRRI) has created a significant contribution to the nation for increasing total production. But deficit in food grains still exists because of the rapid growth of population. The Government has to import 1.2-1.5 million t of clean rice every year and expending huge amounts of foreign currency. In order to be self-sufficient in food, production needs to be raised at a minimum 3% per annum and this could be made possible by intensifying land use.

Multiple cropping approach makes possible a fuller use of time and increases the yield per unit area of land. Farm power is one of the most important determinants for the successful execution of multiple cropping. In a developing country like Bangladesh, human and animals are the main sources of energy in farming activities. Mechanical power is increasing at a very slow rate and mostly for irrigation purposes in dry season. The level of power or energy consumption and its composition varies with farm sizes, crops grown, technique of production and physical environments.

Most of the Bangladesh farms are small and fragmented. Generally, livelihood depends mainly on crop production. The consumption of power for different crops is important for efficient utilization. A macro-study of the entire farming system rather than fragmented investigations should help determine the desirability of animal vs mechanical source of power on farms.

Objective and Method

The objective of this study was to analyse the alternative cropping systems for small farmers for power utilization intensively and efficiently. More specifically, the study sought:

1. To estimate the availability, use and composition of farm powers in producing different crops;
2. To measure the total power consumption, costs, and returns of cropping systems in different environments; and
3. To find out the capability of using mechanical power for growing crops.

Table 1 Comparative Power Requirements in Rice Production for Modern and Local Varieties Among Different Seasons under Rainfed Situation (hp h/ha)

Operation	*Aus* season				*T.aman* season			
	Modern variety		Local variety		Modern variety		Local variety	
	Human power	Animal power	Human power	Animal power	Human power	Animal power	Human power	Animal power
Land preparation	19.10	176.00	16.10	161.00	21.20	197.00	17.90	170.00
Transplanting	18.40	–	16.40	–	18.90	–	17.00	–
Weeding	11.10	–	7.60	–	10.80	– –	6.80	-- –
Fertilizer application	1.3	–	.30	–	1.70	–	.45	–
Insecticide application	.30	–	–	–	.40	–	–	–
Harvesting hauling	16.50	–	13.80	–	17.20	–	15.30	–
Threshing	6.00	36.69	4.2	20.00	6.3	40.00	4.9	32.01
Total	71.40	212.69	58.40	181.00	76.50	237.00	62.35	202.01
Yield kg/ha	4142		2002		4688		2049	
Power consumption /Output (kg)	0.069		0.12		0.067		0.13	

The data were taken from the Cropping Systems Division of the Bangladesh Rice Research Institute (BRRI). This division has a joint programme with the Department of Agricultural Extension (DAE) at 17 locations of different environments for experimental trials of cropping systems in the farmers' fields. Some of these results have been used for this study. Secondary data were also used. Actual hours of work were converted into energy on the assumption that one adult man, on an average, develops 0.10 hp and one pair of animal develops 1 hp. In the case of mechanical power, its rated horse power is taken into account.

Results and Discussions

Table 1 shows the consumption of power per hectare from human and animal sources for growing *Aus* rice (transplanting) and *T. aman* crops in rainfed condition. Modern and local varieties and power were supplied by 25% and 75% from human and animal sources, respectively. But in different operational activities: land preparation, transplanting, harvesting, consumption of human power represented 27, 26, 23% of the total requirements, respectively.

In irrigated areas where mechanization is practiced partly for only water supply by deep tubewell in dry season to grow *Boro* (Winter) rice crop, the total power requirement was 3051 hp h/ha. This is higher than in rainfed areas because of deep tubewell operation. But for the local variety, power consumption was 241 hp h/ha. In the winter season mechanical power provides 89% of the total followed by 9% animal and 2% human sources.

Power consumption in deep water areas differs from rainfed and irrigated areas because of different cropping patterns. Deep water rice (DWR) is usually sown in April-May and harvested in October-November. This utilizes 35% and 65% human and animal power, respectively, of the total 244 hp h. Weeding operation is more labourious which requires 52% of the total human power followed by 25% for harvesting and hauling. But among the *rabi* crops, potato uses greater human power (1 165 hp h/ha) than other crops. For wheat and sesame, energy uses are more or less similar but differ for animal power by 36%. Only 46 hp-h/ha human and 115 hp /ha animal sources are required for growing

Table 2 Comparative Power Requirements in Rice Production for Modern and Local Varieties under Irrigated Situation, Bangladesh (hp h/ha)

Operation	*Boro* season				
	Modern variety			Local variety	
	Human power	Animal power	Mechanical power	Human power	Animal power
Land preparation	29.6	220	–	13.6	136
Transplanting	19.2	–	–	16.2	–
Weeding	18.8	–	–	6.9	–
Fertilizer application	3.0	–	–	6.2	–
Irrigation	6.2	–	*2700	** 2.6	–
Insecticide application	1.2	–	–	–	–
Harvesting hauling	12.5	–	–	20.5	–
Threshing	8.2	40.66	–	5.9	36.77
Total	90.50	260.66	2700	67.80	172.77
Yield kg / ha	5872			2265	
Power consumption / Output (kg)	0.52			0.11	

* Deep tubewell (15 hp), ** Tradional method of irrigation

mustard. After recession of flood water in the months of October-November, the land has enough soil moisture and land preparation can be completed earlier and thus require less energy or farm power.

Power consumption per unit of output is lowest (0.067 hp h/kg) in producing modern varieties under rainfed situation. For local varieties in both seasons, the consumption of power are 0.12 and 0.13 hp h/kg, respectively. The low yield of local varieties in comparison to modern varieties is attributed to higher power consumption per unit of output (Table 1). The consumption of energy per unit of output in both varieties and seasons are significantly different but not the total requirements of power in different varieties and seasons. In irrigated situation the used power per kg is highest (0.52 hp h/kg) because of the application of mechanical energy in the dry season to supply water in the farmers' field (Table 2).

In deep water environment, potato cultivation requires more energy than other rabi crops – wheat, mustard, sesame. But per unit of output power consumption used is lowest because of high production (Table 3). The requirements of energy or power per unit of output of different crops under three environments vary greatly.

The total consumption of power for various cropping systems as well as cost and returns in different environments are presented in Table 4. Greater energy is used for growing modern variety in the winter season followed by modern variety in *T.aman* season (3 365 hp h/ha). This pattern produced TK.23 262/ha net return following the total cost of TK. 21 882/ha. The rainfed, double, modern rice cropping patterns used 589 hp h/ha followed by 553 hp h/ha in local modern variety pattern and the costs were TK. 18 417 and TK. 16 976/ha, respectively. The net return was TK. 19 111/ha for rainfed double modern rice pattern. The highest net income was obtained from deep water cropping pattern (Potato-sesame+DWR) of TK. 29 861/ha. The benefit-cost ratio is also highest (2.43) followed by 2.06 and 2.04 for irrigated and

Table 3 Comparative Power Requirements for Different Kinds of Crop Production in Deep Water Area (hph/ha)

Operation	DWR		Mustard		Wheat		Potato		Sesame	
	Human power	Animal power	Human power	Animal power	Human power	Animal power	Human power	Animal power	Human power	Animal power
Land preparation	14.10	133	14.30	115	14.30	138	22.50	215	10.00	97.00
Sowing	.40	–	.50	–	.50	–	41.30	–	.30	–
Weeding	44.7	–	–	–	22.50	–	–	–	36.90	–
Fertilizer application	–	–	–	–	.40	–	1.80	–	.20	–
Insecticide application	–	–	–	–	–	–	–	–	–	–
Harvesting hauling	21.50	–	20.70	–	27.00	–	50.90	–	11.80	–
Threshing	5.50	25.0	10.00	–	6.50	15.00	–	–	12.40	–
Total	86.20	158.00	46.00	115.00	71.20	153.00	116.50	215.00	71.60	97.00
Yield kg / ha	3045		637		2945		37052		637	
Power consumption / Output (kg)	0.08		0.25		0.08		0.0089		0.26	

Table 4 Total Power Consumption, Cost and Return of Cropping Patterns in Different Environments

Environment	Cropping pattern * Boro/Robi-Aus-T.aman	Total power (hph/ha)	Total cost (TK/ha)	Yield (kg/ha)	Gross return (TK/ha)	Power consumption/ TAKA (hph)	Net return (TK/ha)	Benefit-cost ratio
Rainfed:	Fallow-MV- MV	598	18 417	8 830	37 528	0.016	19 111	2.04
	" - LV-MV	553	16 976	6 690	31 014	0.018	14 038	1.83
	" -LV-LV	504	15 920	4 051	22 321	0.023	6 401	1.40
Irrigated:	MV-Fallow-MV	3 365	21 882	10 622	45 144	0.075	23 262	2.06
Deep water area:	Potato-Sesame+DWR	744	20 879	37 052 637 3 045	50 740	0.015	29 861	2.43
	Wheat-Fallow-DWR	468	11 665	2 945 2 958	23 347	0.020	11 682	2.00

MV= Modern variety; LV= Local variety; DWR= Deep water rice; * Includes power cost, material cost, and land cost.
Land cost=TK.5988/ha/year.; Human labour = TK. 3.75/h; Animal labour = TK. 4.83/h; and irrigation cost = TK. 13.98/h.
1 US $ = TK. 31.25
* Summer (Aus) – April-May to July-August; Autumn (T.aman) – July-August to November-December; and Winter (Boro) – November-December to March.

rainfed environments, respectively.

But on the power consumption in terms of per unit Taka, the deep water cropping (Potato-sesame+ DWR) pattern used 0.015 hp h followed by 0.016 hp h for modern varieties in rainfed situation. The use of energy/Taka is less due to the double and triple cropping practice, high gross returns. In irrigated areas, the use of energy/ Taka is highest at 0.075 hp h due to high total power requirements for the application of mechanical power (Table 4).

Why Mechanical Power?

In Bangladesh usually the turnaround time between *Aus-T.aman* period is 30-32 days due to untimely rainfall, lack of human power and greater time requirement for land preparation by animal power, hence transplanting of modern rice varieties is delayed. From a multi-location trial programme at different sites in Bangladesh, modern variety (BR11) produced 0.05 t/ha less by one-day late transplanting beyond the middle of August (Fig. 1). This means that due to transplanting in the 1st week of September the yield was only 1.14 t/ha, hence double cropping needs to use mechanical power for quick land preparation, early transplanting (Fig. 2).

But are the small farmers of Bangladesh capable of purshasing small power tillers who are production-consumption oriented? Their major source of income is crop production. Both farming and family expenditures are carried out by the amount of cash obtained from selling products in the market. For this reason, the prices of inputs and outputs are very important determinants in supporting the whole farm income. But the prices of agricultural output are so low that the farmers are unable to recover their expenditures.

Fig. 1 Responce of modern variety (BR11) with different date of transplanting at 13 multi-location sites in Bangladesh, 1984.

Fig. 2 Utilization of human labour in a sample farm during the whole year. 1 year=8 periods.

Conclusion

1. Total power consumption per hectare of land in growing modern and local varieties of rice in *Aus* and *T.aman* seasons are not significantly different. But power used differs significantly in modern and local varieties for both cropping seasons due to the differences in production techniques than energy consumption.
2. In irrigated farms the power consumption in both total and per unit of output are highest and significantly different from the rainfed situation because of the use of mechanical power (deep tube well 15 hp). In deep water area the power requirements for potato differs from other rabi crops – mustard, wheat, sesame due to high cost of production.
3. In terms of net income from the different cropping patterns, the deep water pattern (Potato-sesame+DWR) produces the highest income of TK. 29 861/ha followed by irrigated double modern rice of TK. 23 262/ha and rainfed double modern rice of TK. 19 111/ha. The benefit-cost ratio was 2.43, 2.00, 2.04, respectively. (One Taka needs 0.075 hp h in irrigated, 0.016 hp h in rainfed and 0.015 hp h in deep water environments).
4. Because of untimely rainfall, lack of human power and greater time requirement for land preparation by animal power at peak period (July-August), leads to late transplanting of modern varieties beyond 1st week of September and causes less production and thus attributes to use mechanical power if the farms have ability.

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Computer Programme for Selecting Farm Machinery for Small Farms

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Abstract

A computer programmme has been developed in order to aid decision making in tractor and implement selection for the small farm sector in developing countries. The programme produces tractive performance and operating costs predictions for the tractor and implement under consideration, based on the combination of a number of technical, agricultural and economic factors concerned with the region within which the tractor and implement are going to operate. The programme is able to handle a wide range of tractors, implements, and working conditions because of its datafile structure.

Tractor-mounted implements were considered because of their advantages in use on small farms such as those in developing countries. The computer programme evaluates a traction theory based on the modified Mickletwaite equation to predict the tractive performance and well-known formulae to calculate the operating costs.

Introduction

Most developing countries are primarily agrarian societies in which agriculture is the main source of wealth (1). Thus, an increase in agricultural productivity is the primary requirement for setting the whole rural development process in motion, and for the overall economic development of these countries.

The profit achieved depends on the level of investment in machinery. The cost of labour and machinery for various farm operations constitutes more than 50% of overall production costs. Due to this situation there is a great deal of interest in the efficient selection and utilization of farm machinery in order to ensure maximum profits.

As the majority of the farm operations are carried out with tractor-drawn implement it is necessary to determine whether a given tractor is suitable for a given implement taking into account the tractive performance of the tractor. This must be considered when analyzing the operating cost, because if the tractor is not matched correctly to an implement, the costs will increase. To carry out a farm machinery planning analysis a computer programme can be a viable option because in this way planning decisions can be made to maximize profits and use of facilities, and also minimize costs, particularly for the small farm sector in developing countries.

The data on tractors, implements and working conditions are required as input information in the form of datafiles. Data of technical specifications of tractors and implements can be obtained from the manufacturers. However, information required about the proposed working conditions would ideally be derived from local resources.

The computer programme evaluates the tractive performance of different tractors matched with different implements working in different conditions and calculates the cost of every individual farm operation.

Development of the Programme

The most important criterion was that the prediction method would be of a type which could actually be used to aid decision making on the major aspects of tractor-implement selection for the small farm sector.

The information required in order for the programme to be able to predict tractive performance and operating costs must be provided in the form of three datafiles: one containing data on the technical specifications of the tractor, one

Table 1 Information Required to Produce the Datafile

Identifier	Characteristic	Units
A. TRACTOR DATA		
TRACTOR $	Type of tractor	–
POWER	Tractor engine power	kW
WFAXLE	Weight on front wheels	kg
WRAXLE	Weight on rear wheels	kg
READIA	Tractor rear tyre diameter	m
RWIDTH	Tractor rear tyre width	m
FRODIA	Tractor front tyre diameter	m
WHEELB	Wheelbase	m
FLRATE	Fuel consumption rate	1/kWh
COSTT	Cost of tractor	$
TLIFE	Expected life of tractor	years
REVALT	Resale value	%
B. IMPLEMENT DATA		
IMPLEM $	Type of implement	–
WIMPLE	Weight of implement	kg
WWIDTH	Working width	m
WDEPTH	Working depth	m
NUROWS	Number of rows in the case of planters	–
MAXTOS	Maximum typical operating speed	km/h
COSTI	Cost of implement	$
ILIFE	Expected life of implement	years
REVALT	Resale value	%

Identifier	Characteristic	Units
C. WORKING CONDITIONS DATA		
EQUIP $	Implement for which working conditions apply	–
COHES	Soil cohesion	KN/m²
ASHEAR	Angle of shearing resistance	–
SRESIS	Soil resistance	KN/m on KN/row
DEFCON	Soil deformation constant	–
CRRRW	Coefficient of rolling resistance on rear wheels	–
CRRFW	Coefficient of rolling resistance on front wheels	–
FIELDE	Field efficiency	%
WORKH	Working hours per annum	h
FUELCO	Fuel cost	$/1
CWAGES	Operator wages per hour	$/h
REPMAT	Tractor repairs and maintenance	%
REPMAI	Implement repairs and maintenance	%
INSUR	Insurance taxes and storage	%
INTER	Interest	

containing specifications of the implement; and another defining the physical, agricultural and economic conditions within which the former are to operate (**Table 1**).

It is, therefore, possible to predict tractive performance of a given tractor-implement combination in a range of working conditions. Also, it is possible to operate a range of tractor-implement in a specified set of working conditions. **Fig. 1** shows the flow chart of the computer programme. The effective work rate is displayed to show the working capacity of the tractor-implement combination. The cost per hectare is also displayed to show how much that specific agricultural operation is costing.

Performance figures are displayed in the form of values of tractor speed, actual drawbar power obtained within the programme and derived values of wheel slip. These figures can assist in identifying the performance limitations of the tractor considered and can provide information of use when planning tractor and implement specification changes.

The programme was developed taking into account the following factors: traction and slip, rolling resistance, weight transfer, depreciation spares/repair cost and fuel costs. Traction and slip are explained briefly.

Traction and slip – the method used in the computer programme to predict tractive performance of driving wheels is the modified Mickletwaite equation (2).

$$H = (AC + Q\tan\phi) \times (1 + K/SL\, e^{-SL/K} - K/SL)$$

where:

H is the tractive thrust developed
A is the effective tyre contact area
C is the soil cohesion
Q is the wheel load
ϕ is the angle of shearing resistance
K is the soil deformation constant
S is wheel slip
L is effective tyre contact length

The programme computes the available thrust H using the equation above, which is carried out in the same way as Crossley (3), firstly at 1% slip comparing H with the required thrust P which represents the rolling resistance and the implement draught force. If the developed thrust H is insufficient to provide the force P the programme increases the slip 2% and loops to produce a new value of H, and so on if necessary up to a maximum of 100% slip. The value of slip required to produce the necessary thrust is thus found when H is greater than P, and this value of slip is used later in the programme. Inss (4) suggests a slip between 12%-15% is a reasonable maximum level.

Excessive tractor wheel slippage is a commonly observed problem in many developing countries and wastes fuel, causes excessive tyre wear and compaction in certain soils. Decreasing wheel slip allows coverage of the land in less time with less fuel or allows coverage of more land in the same amount of time and with the same amount of fuel.

Discussions

The computer programme at this stage performs predictions of tractive performance and operating

Fig. 1 Flow chart of main computer programme.

costs for a specific agricultural operation which is being carried out, provided certain specific information on tractor and implement specifications and physical, agricultural, and economic conditions are supplied.

Tractor-mounted implements are considered because of their many advantages at the small-farm level. They are more maneuverable in small fields, take advantage of weight transfer, are very effective on uneven fields, etc. in comparison with trailed implements (5).

When certain information is not available as commonly occurs in developing countries and direct measurements to obtain it is not carried out, the user could supply local average data according to the conditions existing in the country concerned. The results obtained from the programme can be very useful for government officials, farmer advisers, extension personnel and agricultural machinery hiring contractors.

Conclusions

1. The computer programme can handle a wide range of tractors and implements provided the technical information and the physical, agricultural and economic conditions are properly supplied.
2. All the datafiles can be updated and simulations of tractor-implement specifications can be made to predict the tractive performance and operating costs.
3. Total operating costs and tractive performance can aid in decision making of tractor and implement selection when certain specific working conditions are specified.

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Design of Extended Octagonal Ring Dynamometer for Rotary Tillage Studies

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Abstract

A dynamometer was designed to measure the forces and resulting moments acting on a rotary tiller blade independently of their line of action. The dynamometer is based on an extended octagonal ring, provided with strain gauge bridges and can be fixed on the rotor flange for mounting the tiller blade. It showed linear force characteristics with negligible hysteresis and low interactions between measuring bridges. The mounting procedure for direct measurement of radial and tangential forces acting on the tip of the blade at different instant during cutting has also been described.

Introduction

In rotary tilling of the soil two reference systems can be adopted to represent the components of cutting resistance, viz; (a) the reference system connected with rotor shaft comprised of the lateral force or the axial component (ΔL), the vertical component (Ry) and the transverse component (Rx). This reference system does not depend upon the kinematics of cutting and is, therefore, stationary and (b) the reference system connected with the blades on the rotor disc consisting of an axial component (ΔL), the radial component (ΔS) and the tangential component (ΔT). The resolution of forces in both reference systems are shown in **Fig. 1**.

Little information is available on the direct measurement of the component forces related to the reference system (b). The torque of the rotor has been considered as the main parameter (Barnacki, 1962) to derive the circumferential force by assuming the arm of the resultant force as constant and equal to the radius of the tiller drum. Povlov (1952), however, measured the tangential and horizontal components of cutting resistance and determined the resultant force by graphical methods. Theoretical presentation of the component forces on the leg and blade of a rotary cutter was first reported by Sakai (1979) but their nature and magnitude have not been investigated. The relationship between the position of the tip of the blade and cutting resistance can be conveniently presented by choosing the reference system (b). The resistance pattern of an L-shaped rotary cutter can be used to develop the total torque reaction of a rotary axle installed with multiple cutters (Söhne, 1957). Keeping this in view it was thought logical to measure the tangential and radial force components of a single blade by designing a suitable dynamometer.

At the outset of the problem of selecting a dynamometer, an extended octagonal ring machined integrally into the leg of the cutter, similar to the one described by Godwin (1982) to separate the foot forces of a mole plough from its leg, was considered. However, this was later discarded because of questionable rigidity of such a small device and its limited future use. A separate extended octagonal ring

Fig. 1 Resolution of forces in rotary tilling of soil.

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dynamometer used by Siemens (1965), Godwin (1975) and O'Dogherty (1975) was found compatible and finally decided upon.

Design Requirements

The following are the important considerations for the design of a dynamometer: i) Two requirements that are always in opposition in dynamometer design are sensitivity and rigidity. The sensitivity of a good research dynamometer should be such that determinations are accurate to within ± 1% i.e., if a dynamometer was designed for a mean force of 100 Newtons, 1 Newton increment should be easily readable; ii) some deformation is associated with the operation of every dynamometer. However, a dynamometer should be rigid enough so that the cutting operation is not influenced by the accompanying deflections. All tillage tools operate with some vibrations but in powered tillage tools these vibrations may have large amplitudes. In order that the recorded force is not influenced by any vibrating motion of the dynamometer its natural frequency must be large (4 times as large) compared to the frequency of the exciting vibrations (Shaw, 1968); iii) the dynamometer for measuring the forces is mounted remote from the point of force application, the exact position of which is often unknown. The dynamometer, therefore, needs to be capable of accurately monitoring the forces independent of their position and the resulting moment, such that the point of application of the resultant force can be determined. Moreover, when force components act upon the tool in more than one direction, it is critical to ensure that the application of a load in one direction does not cause a significant output from the dynamometer measuring load in the directions; iv) it is convenient to use a system having a linear calibration. In such a case, the force is determined with the precision with which a strain increment can be measured relative to an arbitrary datum. If a system is not linear, it is then necessary that the zero load point be accurately known as well as the strain increment. This introduces an additional quantity that must be carefully measured; v) the dynamometer should be stable with respect to time, temperature and humidity. Once a calibration is made, it should only have to be checked occassionally; and vi) there are many other special dynamometer requirements that must be frequently met such as size, ruggedness and adaptability to several jobs.

Theory of Octagonal Ring Dynamometer

The basic design of an octagonal ring type dynamometer is dependent upon the principle of circular strain rings (Loewen and Cook, 1956). Strain rings provide a high ratio of sensitivity to stiffness at the same time having adequate stability against buckling. The fact that the inside is always in an opposite state of strain from the outside allows four active arms to be effectively used in a bridge circuit. The symmetry of a ring provides parallel paths for heat flow and hence it is expected that equivalent points on opposite sides of a ring will be at the same temperature. This enables drift due to temperature gradient in the vicinity of the dynamometer to be eliminated by connecting the gauges to form a complete bridge circuit. **Fig. 2(a)** shows a strain ring of radius R, thickness t, and axial width b. The ring fixed at the bottom while a radial force ΔS and a tangential force ΔT are applied at the top. The point of load application is maintained horizontal by a suitable moment M ΔT ΔS. When only ΔS is applied, the ring will deform as in **Fig. 2(b)**. Thin ring elastic theory shows the strain at the inside and outside surfaces of the ring at point A to be:

$$\in A = \pm \frac{1.09\ \Delta S.R.}{E.b.t^2} \qquad (1)$$

While the strain at a point B (39.6° from the vertical axis) is zero. When only ΔT is applied **(Fig. 2c)** strain at A is zero while the strain at B is:

$$\in B = \pm \frac{2.31\ \Delta T.R}{E.B.t^2} \qquad (2)$$

Therefore, by placing strain gauges at the inside and outside surfaces of a ring at points A and B **(Fig. 2)**, it is pissible to separate and measure the ΔS and ΔT components of the force. As long as the strains at A and B are within

Fig. 2 (a) Circular strain ring showing the type of deformation produced; (b) by a radial load Δs and (c) by a tangential load ΔT.

(a) Gauge positions (b) Bridge connections for Δs (c) Bridge connections for ΔT

Fig. 3 The octagonal strain ring.

the elastic limit of the ring material it is evident from equations (1) and (2) that the strains will vary linearly with the force, and hence the strain ring satisfies the desired requirement of linearity.

Rings are usually mounted by bolts extending through holes at the top and bottom surfaces. This gives a lower value of stiffness due to the difficulty of preventing rolling at the point of attachment which changes the end conditions from those assumed. The use of an octagonal ring **(Fig. 3)** gives greater rigidity in the ΔT force direction and higher stiffness for both forces. This provides points of stress concentration at positions on the horizontal axis and at 45° to the vertical axis. Centrally mounted strain gauges measure ΔS as before, while gauges on the 45° faces pick up ΔT. Although no exact solutions exist for this type of ring, the following approximate equations are satisfactory for most purposes (Loewen and Cook 1954):

$$\text{Force } \Delta S: \in \text{centre} = \frac{0.7\,\Delta S.R}{Ebt^2} \quad (3)$$

$$\text{Force } \Delta T: \in 45^\circ = \frac{1.4\,\Delta T.R}{E.B.t^2} \quad (4)$$

Here, E is the modulus of elasticity of the ring material.

Fig. 4 Moment sensitivity and stiffness of an extended round ring (After Loewen and Cook. 1954)

A single octagonal ring is not very useful as a tillage tool dynamometer but when extended by 2L **(Fig. 5)** the ring becomes sufficiently stable and approximately meets the requirement of zero rotation of the top surface. Such an extended ring may also be used to measure a moment, however, there will be rotation ϕ of the top member. The sensitivity and stiffness in this case can still be calculated using Castigliano's method (Loewen and Cook, 1954). For a round extended ring the results are shown below:

$$\in m = \frac{3\,M\,\Delta T\,\Delta S}{Ebt^2} \cdot \frac{0.36K + 0.137}{K^2 + 1.27K + 0.5} \quad (5)$$

$$\phi m = M\,\Delta T\,\Delta S.R/Ebt^2 \times \left[6\pi\left(2K + \frac{\pi}{2}\right) - 24\left(2K + \frac{\pi}{2}\right) + (2 + \pi K) + 3\pi(2 + \pi K)^2\right]/K^2\pi + 4K + \frac{\pi}{2}) \quad (6)$$

Where $\in m$ = strain at the central section.

ϕ = rotation of the top due to the moment $M\Delta T\,\Delta S$, and

K = ratio L/R; where 2L is the distance between ring centre and R is the mean radius of the ring.

The rotation of the top, ϕm, is generally 2 to 3 times the amount predicted by equation (6) due to elastic clamping and bending. To facilitate the calculations the sensitivity and stiffness of a round extended ring obtained from equations (5) and (6) are plotted as functions of K **(Fig. 4)**.

The Practical Design

The extended octagonal ring transducer was designed using the design criteria of Cook and Rabinowicz (1963) and Godwin (1975). The diameter and central distance between the rings, and the width of the ring were selected depending upon the practical application. The

Fig. 5 The extended octagonal ring dynamometer.

maximum moment was assumed as 250 NM (1 000N at 250 mm) which can be expected on a rotary tiller blade (Söhne, 1959). A load factor of 4 was taken to ensure linearity within the working range.

The material selected for the transducer was an alloy steel EN24A, subsequently heat-treated to an ultimate tensile strength of 1 132 MN/m^2 and yield stress of 1 052 MN/m^2 giving high strength for compactness. The modulus of elasticity was known as 206.7 GN/m^2. The size of the alloy steel EN24A stock is readily available and requiring least machining resulted in a K value of 2.5. For the simpler case of the extended ring (not octagonal ring) transducer given in **Fig. 4** the following was achieved for K = 2.5.

The strain dimensionless group

$$\frac{Ebt^2}{M\Delta T\,\Delta S} = 0.3 \qquad (7)$$

The deflection dimensionless group

$$\frac{\phi Ebt^3}{M\Delta T\,\Delta S.R} = 0.18 \qquad (8)$$

However, the sensitivity determined experimentally by Godwin (1975) for the moment bridge was 1.35 times larger than that expected from the prediction in equation (7). A similar figure has been quoted by O' Dogherty (1975). Therefore, a value of 1.35 times to those given in equation (7) was taken for strain dimensionless group as:

$$\frac{Ebt^2}{M\Delta T\Delta S} = 0.405$$

For a perfectly elastic material $E = \frac{\sigma}{\in}$, where σ is the working stress (558.63 MN/m^2) which gives the strain dimensionless group as:

$$\frac{\sigma\, bt^2}{M\Delta T\,\Delta S} = 0.405 \qquad (9)$$

Solving the above equation for the ring thickness (t) resulted in a value of 3.8 mm and from equation (8) the dynamometer deflection was determined as 4.76×10^{-3} radians (0.27°). The working drawing of the transducer is shown in **Fig. 5**.

Strain Nodes and Strain Gauge Bridges

Cook and Rabinowicz (1963) found the strain nodes at the following angular positions, θ for the forces ΔS and ΔT **(Fig. 6)**, respectively:

(a) Simple ring dynamometers
θ = 39.6° and 90° (estimated using strain energy theory)

(b) Octagonal ring dynamometers
θ = 50° and 90° (estimated using photoelastic methods)

During the use of an extended octagonal ring transducer with a simple tine, Godwin (1975) observed the force measuring bridge Fx (ΔS in the present case) was position-sensitive when clamped directly to its mountings and the tine. This problem was alleviated by the insertion of two plates of length less than the distance between the ring centres on both sides of the transducer. However, the insertion of plates shifted the strain node position of the force Fz (or ΔT) and resulted in serious cross sensitivity problems where the Fz bridge was sensitive to the force Fx. Godwin (1975) determined, experimentally, the new positions of gauges for Fz force at θ = 34°. The dynamometer was, therefore, machined with 2 mm thick plates on both faces to avoid any insertion of plates. The strain gauges were bonded to the transducer at strain nodes, θ = 34° and 90° and connected into three four arm bridge networks as shown in **Fig. 6**. In addition, a fourth bridge was added after Seig (1982) for determination of side moment.

Dynamometer Characteristics

The static calibration of the dynamometer was done using a constant voltage data scanner unit and loading/unloading with the help of known dead weights. The following characteristics were observed:

i) The transducer signal was highly linear with coefficient of determination (r^2) being ⩾ 0.9997.

ii) The variation of the output signal due to the position of the force was acceptable within the working range, the dynamometer is expected to be used and was less than 2.5%.

iii) The output hysteresis effect was practically zero.

Fig. 6 Strain gauge bridges of the dynamometer.

iv) The cross-sensitivity error was less than 3.5% for the moment and side moment of 60 NM when the dynamometer was loaded at 100 mm side and 100 mm across its centroid. However, the cross-sensitivity error increased to approximately 5.5% for a moment of 60 NM and side moment of 120 NM which can be reasonably accepted considering the practical utility of the dynamometer on the tiller blade.

v) The sensitivities of all the channels were found as follows:

$$\Delta T = 0.38\mu V\ N^{-1}\ V^{-1}$$
$$\Delta S = 0.39\mu V\ N^{-1}\ V^{-1}$$
$$M\ \Delta T.\Delta S = 6.16\mu V\ N^{-1}\ M^{-1}\ V^{-1}$$
$$M\ \Delta T.\Delta L = 14.12\mu V\ N^{-1}\ M^{-1}\ V^{-1}$$

Fig. 7 Mounting of the dynamometer and blade assembly on the rotor flange.

Knife-edge Balance of Transducer Assembly and Mounting

Two L-shaped mild steel brackets were designed for mounting the leg of the cutter onto one side of the dynamometer while the second bracket was used for rigidly fixing the dynamometer on the rotor flange. Theoretically, the weight of the dynamometer, its supporting elements and the experimental cutter on blade would act always outwards due to the centrifugal force of the rotating mass at high peripheral speed of the rotor. It was, therefore, imperative that the complete assembly is balanced such that the centre of gravity of the assembly lies on the line passing through the centroid of the dynamometer and tip of the blade. This was done by supporting the leg of the experimental blade on washers placed on the L-bracket. The leg was supported such that to bring the longitudinal and transverse axes of the leg approximately in line with the respective axes of the dynamometer. The dynamometer was later secured rigidly on the L-bracket. A line was marked through the centroid of the dynamometer and tip of the blade and the complete assembly was supported on a knife edge by inserting the edge through the central slot of the dynamometer close to its centroid. A string with dead weight was hung from the outer end of the knife edge which represents one of the three axes (X-axis of radial) of the dynamometer. In practice, the string must superimpose the line marked through the centroid and tip of the blade. This was accomplished by adding necessary weights (280 g) onto one side of the L-bracket. The complete assembly was then turned through 90° and the leg was balanced on the knife-edge to determine the centre of gravity to approximately 83 mm from the centroid of the dynamometer on the marked line.

A rotor disc of 300 mm diameter and 120 mm thickness was fabricated from a mild steel plate and the leg mounting holes were drilled according to a standard 'Howard Rotavator Company's rotary tiller disc. The complete transducer assembly was mounted onto an L-shaped bracket and supported on the rotor disc such that the centre of the disc (O), centroid of the dynamometer (O') and tip of the blade (O'') are all in a line as shown in **Fig. 7**.

In-situ Dynamometer Calibration

In-situ calibration of dynamometer was done using the equipment shown in **Fig. 8** to determine the calibration constants when used in conjunction with the amplifier and recording units. The signal output levels from the transducer were

Fig. 8 Diagram of the signal conditioning and recording equipment.

Fig. 9 Calibration of the dynamometer on the experimental apparatus at a rotor speed 5 rpm.

obtained on analogue data logger, tape recorder and X-Y plotter, simultaneously, by loading each channel. The calibration constants were found at the outset of the experiments and a record of zero-cut was obtained on the tape recorder by turning the transducer from the top (zero position) to the bottom (180°). The zero cut data was replayed from the tape recorder onto the X-Y plotter (**Fig. 9**) which was considered as a standard record and checked periodically with a similar record obtained before the start and end of the experiments planned to determine the quasistatic components of soil cutting force.

Conclusions

The dynamometer output was linear when used separately during static calibration and independent of the position of the load on the tiller blade. It showed low hysteresis and cross sensitivity and meets the requirement of rotary powered tillage tools.

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Wet and Dry Tillage Practices in Paddy Production

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Abstract

The effect of tillage operations on paddy production with various implements was investigated. The tillage treatments used were: tine cultivation, three times (12-15 cm); dry rotary cultivation, two times (12-15 cm); dry mould board (M.B.) ploughing (25-30 cm) and wet tine cultivation (12-15 cm), once each; and wet rotary cultivation, two times (12-15 cm).

The wet rotary cultivation improved the paddy yield by 41% due to increase in tilling (25%) and 1000 grain weight (35%) over the tine cultivation practices. The economic gain due to rotary cultivator was Rs.30 for each extra rupee spent. Deep ploughing with M.B. plough gave a deficit of Rs.1.30 on the investment of each extra ruppe.

Introduction

Rice (*Oryza sativa* L.), being a major exportable commodity, is crucial for Pakistan's economy. It has 16.2% share in the total export value of the country (Anonymous, 1984). Paddy yield in the farmers' field vary widely. Apart from essential management practices, land preparation also influences the yield of paddy. In Pakistan, traditionally, land is tilled in dry and in flooded conditions with animal-drawn, chisel type, wooden plough or with spring loaded tine cultivator. These practices result in poor land preparation. This leads to serious weed problems, greater water loss and imbalance of nutrient supply to crop plants (Ponnamperuma, 1967). High yield of rice from puddled land has been attributed to less competition from weeds and the enhanced nutrient availability to rice plants by the increased surface area available for plant roots and by enhanced soil nutrients diffusion (Koenias, 1967). Tomer et al (1974) stated that transplanting of paddy seedlings under puddled condition produced high yields through increased number of tillers per hill, panicle length, number of grain per panicle, and grain weight. Singh et al (1977) observed higher grain yield of rice from puddled plots through increased number of panicles per hill.

Little work has been reported on tillage with respect to paddy production. The study was designed to evaluate tillage techniques for paddy production.

Materials and Methods

The effect of tillage on growth of paddy and yield was studied during 1982 and 1983 at the National Agricultural Research Centre (NARC), Islamabad and in the farmer's field at Sialkot (Punjab). The soils at NARC and Sialkot were characterized as loamy and clay loam , respectively. The

Table 1 Detail of Tillage Treatments

Treatment No.	Treatment details
T_0	Three tine cultivations with spring loaded tine cultivator (15-15 cm) + planking
T_1	Double dry rotary cultivation (12-15 cm)
T_2	Single dry mouldboard ploughing (25-30 cm) +single wet tine cultivation (12-15 cm) + planking
T_3	Double wet rotary cultivations (12-15 cm)

tillage treatments used are shown in **Table 1**.

All tillage treatments were performed two days before transplanting of paddy seedlings of the IR-6 variety. The crop was fertilized uniformly with single superphosphate (50 kg P_2O_5/ha) and ammonium sulphate (80 kg N/ha). Zinc sulphate was applied at the rate of 12 kg/ha.

The experimental design was randomized complete block design (RCBD) with four replicates. The plot size was 14 m x 40 m. Rainfall during the cropping season totaled 653 mm and 601 mm in addition to 12 and 14 irrigations during 1982 and 1983, respectively. Data on paddy yield, yield components and weed population were recorded. The infiltration rate was measured during the growth period of the rice crop. The data was statistically analyzed using analysis of variance (ANOVA) and the differences between the treatment means were tested by LSD test at 5% level of significance.

Results and Discussion

Weed population was taken at random at two different places from each plot on both experimental sites. Weeds, namely; *Fimbristylis littoralis* Gaudich.; *Cyperus rotandus* Linn. and *Echinochloa colonum* Linn. were found at NARC. In addition to these *C. irria Linn.*; *E crusgalli* (Linn.) Beauv and *Sphenoclea zeylanica* Gaertn. were also observed in the farmers' field (Sialkot). Weed density was higher in the farmers' field compared to the research station **(Fig. 1)**. Land preparation carried out with rotary cultivator in wet condition proved to be a superior technique among the tillage operations as weed stand was minimized **(Table 2)**. This was followed by the dry deep M.B. ploughing (20-25 cm) supplemented with shallow cultivation (12-15 cm). Deep ploughing reduced the germination of weed seeds through their deeper placement into the soil. The maximum number of weed plants (60/m) were recorded **(Table 3)** for tine cultivator. This confirms the findings of Ponnamperuma (1967). The difference in the infiltration rate was not significant among the tillage techniques. However, the water movement into the soil was high during the initial stage which decreased with the passage of time for each tillage operation **(Fig. 3)**.

Fig. 1 Response of weeds to different tillage techniques.

Fig. 2 Tillage effect on rice yield.

Fig. 3 Effect of different tillage techniques on infiltration rate.

The significant increase (25%) in tilling was noted with rotary operation. This increase was probably due to the availability of greater soil nutrients to rice plants as a result of less competition with weeds **(Fig. 1)**. A negative correlation (r = −0.76) was observed

Table 2 Effect of Wet vs Dry Tillage on the Yield and Components of Paddy (NARC), 1982

Treatments	Weed population (/m²)	Productive tillers (/m²)	Filled grain/ panicle	1000 grain weight (g)	Grain yield (kg/ha)
Tine cultivation (T_0)	10.0 a	334.0 c	102.9 b	18.7 d	8116 bc
Dry rotary cultivation (T_1)	6.2 b	385.8 abc	114.0 a	23.41 b	8659 ab
Dry M.B. ploughing + Tine cultivation (T_2)	3.9 cd	358.3 bc	112.5 a	21.31 c	7926 c
Wet rotary cultivation (T_3)	3.4 d	418.3 a	119.5 a	25.2 a	9289 a
LSD at 0.05 P	1.9	37.0	7.8	1.3	648

Note: Any two means in the same column not sharing the same letter differ significantly at 5% P.

Table 3 Effect of Wet vs Dry Tillage on the Yield and Components of Paddy (Sialkot), 1983

Treatment	Weet Population(/m²)	Productive tillers /m²)	1000 Grain weight (g)	Paddy yield (kg/ha)
Tine cultivation (T_0)	60.0 a	84.7 b	17.8	6336 b
Dry rotary cultivation (T_1)	21.2 d	94.7 a	18.5	8510 a
Dry M.B. ploughing + tine cultivation (T_2)	32.7 bcd	102.3 a	18.2	7368 ab
Wet rotary cultivation (T_3)	29.2 cd	96.5 a	19.0	8932 a
LSD at 0.05 P	24.1	8.5	NS	1696

Note: Any two means in the same column not sharing the same letter differ significatly at 5% P. NS = Not significant.

between the tilling capacity of plant and weed density. The rotary ploughing produced a fine puddled land bed and thoroughly mixed the weeds with the soil by chopping them and top sterlization of soil particles. The organic matter buried in the soil provided ready fertilizer (Awadhwal and Singh, 1985). The traditional cultivation operations lowered the number of tillers significantly (Tables 2 and 3).

The rotary puddling gave rise to a maximum (119.50) number of filled grains (Table 2). This quantitative increase in grain formation remained insignificant with the dry rotary operations and dry M.B. ploughing supplemented with tine cultivation having 114 and 112 filled grains per spike, respectively. The minimum grain formation (102.94) was obtained from the normal tine cultivation that is a common practice of farmers.

The difference in grain weight among the tillage treatments remained insignificant in the farmer's field (Table 3) while it was significant at the research station. The rotary operation in flooded conditions scored the heaviest grain weight (25.2 g) followed by the dry rotary cultivation (23.4 g). The significant increase ($P<0.05$) in 1000-grain weight through wet rotary ploughing over the traditional tine cultivation was 35% (Fig. 2).

The highest paddy yield (9289 kg/ha) at 22% moisture content was produced with the use of the rotary cultivator under puddled conditions (Table 2). The yield showed significant ($P<0.05$) difference with all tillage operations while it remained insignificant with dry rotary operation at NARC (Table 2). In comparison, the yield response by all tillage operations on the farmer's field, was insignificant ($P < 0.05$) except the traditional one which was used as check (Table 3). Rotary puddling induced an increase of 40.9% in the paddy yield over the tine cultivation (Fig. 2). The increase in paddy yield through rotary puddling was due to better availability of nutrients to plants as a result of less weed competition and proper decomposition of green matter incorporated in the soil. Results support the findings of earliest research (Koenigs, 1967; Singh et al, 1977 and Tomer et al, 1974). The paddy yield was adversly affected ($r=-0.64$) by the presence of weeds, while it was highly responsive to the productive tillers ($r=0.62$) and the grain weight ($r=0.54$).

The cost of seedbed prepared with M.B. plough supplemented by tine cultivator, was Rs. 301 per ha bearing a loss of Rs. 1.3 per extra rupee spent to the traditional tine cultivation (Table 4). The wet rotary puddling yielded maximum benefit of Rs. 29.7 on the investment of one extra rupee against the practices of spring loaded tine cultivator.

In the light of above cited discussion, the rotary cultivator is considered to be the best implement to produce a fine puddled bed, necessary for proper transplanting, and weed control, too. It's use is also economical. It requires no drawbar power and improves the traction efficiency of tractor (Sargana et al, 1985).

Table 4 Economics of Tillage Techniques

Treatment	Value of paddy yield (Rs./ha)	Cost of seedbed preparation (Rs/ha)	Net return (Rs)	Return per rupee extra spent to practices (Rs).
Tine cultivation (thrice) + planking	992.2	215.9	776.3	–
Dry rotary cultivation (twice)	1065.7	197.8	867.9	5.1
Dry M.B. ploughing (single) + tine cultivator (single) + planking	967.7	301.5	666.2	1.3
Wet rotary cultivation (twice)	1139.7	220.7	919.0	29.7

Note: MF-210 of 25 HP tractor was used for tillage operations. The price of the paddy was Rs.122.50/160 kg (Quarterly Economic indicator April-June, 1983 ADBP).

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A Compression Ignition Engine on Biogas-Diesel Fuel

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Abstract

A stationary, 10 bhp, constant speed, compression ignition engine was modified to run on biogas-diesel fuel. The comparative performance of the engine on diesel and dual-fuel was studied at different loading conditions. The engine was tested on diesel fuel at the standard inejction timing of 20° BTDC. The injection timing of 20°, 25°, 30°, 35° BTDC were selected for the dual-fuel operation. The brake horsepower developed, brake specific fuel consumption, brake thermal efficiency, volumetric efficiency, air-fuel ratio and percentage diesel replacement were studied.

Introduction

Energy from biomass in the form of a low-calorie gaseous fuel is technically feasible, economical and a viable source of energy. The gaseous fuel generated by anaerobic fermentation of biomass mainly consists of methane, carbon dioxide hydrogen and traces of hydrogen sulphide, nitrogen, etc. The gaseous fuel is used for cooking, lighting, operating internal combustion engines and generating electricity. Internal combustion engines operating on gaseous fuels are already known to exist. In India, biogas-run, small, constant speed, compression ignition engines of 5 bhp are commercially available. This size of engine is largely used for lift irrigation. The large-sized (10-15 bhp), constant speed, compression ignition engines are also used for various agricultural operations such as threshing, milling, crushing etc. A study was, therefore, undertaken with the objective of modifying a constant speed, compression ignition engine for dual-fuel operation and to investigate the comparative performance of the engine on diesel and dual-fuel.

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Engine Modification and Experimental Technique

A four-stroke compression ignition engine was selected for the study. The major specifications of the engine were as follows:

Rated bhp (with diesel)	: 10
Rated rpm	: 1500
Engine displacement volume	: 1106cc
Compression ratio	: 16.5:1
Injection timing (standard advance)	: 20° BTDC*
Number of cylinders	: Two (vertical, inline)
Cooling System	: Water coolerd

The modifications incorporated in the engine for dual-fuel operation included an entry point at the centre of the air inlet manifold for biogas-air mixture. A cylindrical mixing chamber of volume approximately equal to the engine displacement volume and having openings at the top and bottom was fitted to the air inlet manifold as

* Before top dead centre.

Fig. 1 Bio-gas air mixing chamber with inlet manifold.

Fig. 2 Diagram of experimental set-up.

Fig. 3 Drum type bio-gas plant (3 m^3/day).

shown in **Fig. 1**. The top opening in the mixing chamber was provided with the entries for biogas and air. The air into the engine through the mixing chamber was drawn from a large air stabilizing tank of capacity 0.11 m^3. A standard orifice of 15 mm diameter, fitted on the air stabilizing tank was used to measure the quantity of air induced into the engine.

The experimental setup consisted of the test engine coupled with a hydraulic dynamometer, air stabilizing tank, rotameter, gas pressure reduction tank, water column manometers, etc. **(Fig. 2)**. The biogas for the experiment was generated by anaerobic fermentation of cattle dung in a biogas plant **(Fig. 3)**. The Capacity of the plant was 3 m^3 gas per day. The plant essentially consisted of a masonary wall digester and a mild steel sheet gas holder supported by a central guide pipe. The plant had an asbestos cement inlet pipe for feeding of fresh slurry and an asbestos cement outlet pipe for the discharge of spent slurry. Daily about 85 kg of cattle dung mixed with water in 1:1 ratio was fed into the digester. The biogas generated due to anaerobic fermentation of cattle dung was collected in the gas holder which floats in the digester. The major constitutents of the biogas generated were methane, 65%; carbondioxide, 30%; and hydrogen 5% The constituents of the biogas remained the same as the feedstock (cattle dung) was used only to generate the biogas. Biogas from the plant was compressed at 5 kg/cm^2 pressure and brought to the test laboratory. In order to reduce the gas pressure before it is delivered to the engine, the biogas was released into the gas pressure reduction tank of capacity 0.15 m^3. Biogas consumed during the engine operation was measured by a rotameter.

In order to test the engine on diesel fuel, the engine was first run under no-load condition and its speed was set to 1 500 rpm. After a warming up period of 5 min, the engine was gradually loaded with the help of a hydraulic dynamometer and different observations were made. Loading of the engine was continued till the engine tended to stall. Engine performance on diesel fuel was studied at the 20° BTDC injection advance (standard advance) only. During the dual-fuel operation, the engine was initially started on diesel fuel. Biogas supply was then made which caused an increase in the engine speed. Diesel injection was then reduced by actuating the fuel control rack till the engine attained a speed of 1 500 rpm. The engine was then run for 5 min under no-load condition. Performance on dual-fuel operation was then made by gradually loading the engine and different observations were recorded. The loading was done until the engine tended to stall. The test on dual-fuel were conducted at 20°, 25°, 30° and 35° BTDC injection advance. In order to establish different levels of diesel replacement, the quantity of biogas supplied was throttled and the adjustment in diesel injection was made by actuating the fuel control

rack of the fuel injection pump.

The injection timing of the engine was varied up to 35° BTDC, because beyond this value the engine failed to start on diesel fuel.

Results and Discussion

Effect of Dual-fuel Operation on Brake Hosepower Developed

The brake horsepower developed by the engine on diesel and dual-fuel at the different settings of the injection timing is shown in **Fig. 4**. Since the engine was a constant speed type, there was a drop in engine speed with an increase in brake load and the corresponding increase in the brake horsepower. The engine developed 9.5 bhp at 1 300 rpm when it was run on diesel fuel at the standard injection advance. The maximum brake horsepower developed by the engine on dual-fuel at 20°, 25°, 30° and 35° BTDC injection timing was 82.1%, 78.63%, 81.6% and 74.7%, respectively, of the maximum brake horsepower developed by it on diesel.

The engine brake horsepower increased with an increase in brake load and there was a gradual drop in the engine speed. On dual-fuel at 20° BTDC injection timing, the engine developed 7.8 bhp and the corresponding engine speed was 1 300 rpm., whereas at 30° BTDC injection timing the engine developed 7.75 bhp at 1 410 rpm. Thus, by advancing the injection timing to 30° BTDC, it resulted in less drop in engine speed and no significant reduction in the brake horsepower. An advance in injection timing is needed to ignite biogas-air mixture considerably earlier in the cycle than the normal diesel operation because the combustion velocity of biogas-air mixture is lower than the diesel fuel.

Effect of Brake Horsepower on Brake Specific Fuel Consumption

Fig. 4 Effect of engine speed on brake HP developed.

The brake specific fuel consumption at the different brake horsepower developed by the engine, both on diesel at the standard injection advance and on dual-fuel at the different injection timings is shown in **Figs. 5** and **6**. On diesel fuel the minimum specific fuel consumption of 275.0 g/bhp-h was observed when the engine developed 9.5 bhp. When the engine was run on dual-fuel, there was a large variation in brake specific fuel consumption. The brake specific fuel consumption of diesel fuel at 20°, 25°, and 35° BTDC injection timings were 263.59,240.8 and 52.95 g/ghp-h, respectively. The corresponding specific biogas consumption was 0.807,0.642 and 0.887 m^3/bhp-h. The specific diesel consumption at 30° BTDC injection timing was 86.40 g/bhp-h and the corresponding specific biogas consumption was 0.813 m^3/bhp-h. Thus, by advancing the injection timing during the dual-fuel operation the brake specific diesel consumption can be reduced. The brake specific fuel consumption decreased with an increase in engine power and the corresponding decrease in engine speed to a certain extent and then it rapidly increased due to the fact that the engine developed more power with an increase in brake load and the corresponding decrease in engine speed.

Effect of Dual-fuel Opeartion on Brake Thermal Efficiency

The brake thermal efficiency of the engine was determined on diesel and dual-fuel (**Tables 1** to **5**). **Figure 7** indicates that the brake thermal efficiency of the engine increased with an increase in brake horsepower. The maximum brake thermal efficiency of the engine while running on diesel fuel was 22.96% and the corresponding brake horsepower was 9.5 bhp. The maximum brake thermal efficiency of the engine on dual-fuel at 20°, 25°, 30° and 35° BTDC injection timings were 12.4, 16.84, 14.8 and 14.84%, respectively. The engine developed maximum brake thermal efficiency at 35° BTDC injection timing on dual-fuel when the brake horsepower developed was 7.10 bhp. The maximum brake thermal efficiency on dual-fuel at 30° BTDC injection timing was 14.8% and the corresponding maximum horsepower developed was 7.75. The thermal efficiency of the engine at part load conditions was significantly low.

Effect of Dual-fuel Operation on Volumetric Efficiency

The volumetric efficiency of the

Fig. 5 Brake HP on brake specific fuel consumption (diesel) at different injection advance.

Fig. 6 Effect of Brake horsepower on brake specific fuel consumption of bio-gas at different injection advance.

engine was determined by measuring the air requirement at different loading conditions while running the engine on diesel and dual-fuel (**Tables 1-5**). The maximum volumetric efficiency of 58.88% was attained when the engine was run on diesel. During dual-fuel operation, the maximum volumetric efficiency of 44.06, 42.53, 40.51 and 39.64% were observed at 20°, 25°, 30° and 35° BTDC injection timings, respectively. The volumetric efficiency of the engine dropped significantly during dual-fuel operation because part of the air was replaced by biogas as the biogas-air mixture was admitted into the cylinder during the suction stroke.

Table 1 Results of Engine Performance Test on Diesel Fuel at 20° BTDC Injection Advance

Brake load (kg)	Brake horse-power (bhp)	Specific Diesel consumption (g/bhp-h)	Air-fuel ratio	Volumetric efficiency (%)	Brake thermal efficiency (%)
2	1.5	820.0	25.20	58.15	7.70
4	2.9	496.0	21.26	58.03	12.73
6	4.3	379.0	18.66	57.75	16.78
7	5.0	342.0	17.61	57.70	18.49
8	5.7	322.8	16.40	58.10	19.63
10	7.1	293.0	14.27	57.53	21.62
11	7.8	287.8	13.22	57.41	21.93
12	8.4	281.0	12.44	57.34	22.70
13	9.1	277.0	11.35	56.34	22.83
13.8	9.5	275.0	10.84	58.88	22.96
14	Engine stall				

Table 2 Results of Engine Performance Test on Dual-fuel at 20° BTDC Injection Advance

Brake load (kg)	Brake horse-power (bhp)	Specific Diesel consumption (g/bhp-h)	Specific biogas consumption (m^3/bhp-h)	Diesel replace-ment (%)	Air-fuel ratio	Volumetric efficiency (%)	Brake thermal efficiency (%)
2	1.5	293.33	4.40	64.61	2.96	40.83	2.90
4	2.8	185.71	2.35	63.66	2.88	41.28	5.38
7	4.9	146.94	1.28	57.94	2.95	42.33	9.20
10	6.8	121.17	0.93	60.36	2.92	42.23	12.40
12.0	7.8	263.59	0.81	12.88	2.47	44.06	10.48
12.5	Engine stall						

Effect of Injection Advance on Percentage Diesel Replacement

The percentage diesel replacement during dual-fuel operation of the engine at different injection timings are shown in **Tables 2** to **5**. By advancing the injection timing, a greater quantity of diesel fuel was replaced by the gas. The maximum replacement of the order of 83.11% was attainable at 30° BTDC injection timing. However, the corresponding brake horsepower developed was 7.10. At the same injection timing 7.75 bhp was developed by the engine when 70% diesel fuel was replaced by biogas. With an increase in brake load during dual-fuel operation, the percentage replacement of diesel increased to a certain extent and at very high load there was a considerable drop in diesel replacement.

Effect of Dual-fuel Operation on Air-fuel Ratio

Table 3 Results of Engine Performance Test on Dual-fuel at 25° BTDC Injection Advance

Brake load (kg)	Brake horse-power (bhp)	Specific Diesel consumption (g/bhp-h)	Specific biogas consumption (m^3/bhp-h)	Diesel replace-ment (%)	Air-fuel ratio	Volumetric efficiency (%)	Brake thermal efficiency (%)
2	1.45	441.38	4.34	48.05	3.04	41.68	2.79
4	2.86	201.40	2.20	60.00	3.01	41.44	5.60
6	4.23	133.33	1.41	65.40	3.11	41.57	8.67
8	5.56	92.5	1.03	72.04	3.16	41.32	12.03
10	6.80	76.47	0.83	75.00	3.20	41.64	14.77
11	7.37	66.21	0.73	77.98	3.31	41.52	16.84
11.5	7.47	240.80	0.64	23.73	2.95	42.53	12.38
Engine stall							

Table 4 Results of Engine Performance Test on Dual-fuel at 30° BTDC Injection Advance

Brake load (kg)	Brake horse-power (bhp)	Specific Diesel consumption (g/bhp-h)	Specific biogas consumption (m^3/bhp-h)	Diesel replace-ment (%)	Air-fuel ratio	Volumetric efficiency (%)	Brake thermal efficiency (%)
2	1.48	173.50	4.86	79.15	2.99	43.07	2.85
4	2.94	88.98	2.35	81.80	2.97	41.34	5.88
6	4.36	66.05	1.55	82.35	2.85	40.28	8.83
8	5.76	58.05	1.15	81.80	2.89	39.89	11.73
10	7.10	49.46	0.93	83.11	2.87	40.22	14.39
11	7.75	86.4	0.81	70.00	2.86	40.51	14.80
12	Engine stall						

Table 5 Results of Engine Performance Test on Dual-fuel at 35° BTDC Injection Advance

Brake load (kg)	Brake horse-power (bhp)	Specific Diesel consumption (g/bhp-h)	Specific biogas consumption (m^3/bhp-h)	Diesel replace-ment (%)	Air-fuel ratio	Volumetric efficiency (%)	Brake thermal efficiency (%)
2	1.48	210.81	4.46	74.6	3.57	47.79	3.03
4	2.94	108.84	2.24	75.0	2.93	29.53	6.02
6	4.38	82.19	1.47	80.4	2.96	39.69	9.04
8	5.78	63.67	1.12	80.0	2.87	38.95	11.88
10	7.10	52.95	0.89	81.9	2.94	39.64	14.84
11	Engine stall						

Fig. 7 Effect of brake horsepower on brake thermal efficiency at different injection advance.

Tests were conducted to determine the quantity of air required for combustion by the engine while running on diesel and dual-fuel. The results are shown in **Tables 1** to **5**. The air-fuel ratio of the engine when operating on diesel varied from 25.20:1 to 10.84:1. At 10.84:1 air-fuel ratio, engine developed maximum brake horsepower. The air-fuel ratio dropped considerably when the engine was operated on dual-fuel. During dual-fuel operation the air-fuel ratio varied from 2.96:1 to 2.47:1, 3.31:1 to 2.94:1, 2.99:1 to 2.85:1 and 3.57:1 to 2.87:1 at 20°, 25°, 30° and 35° BTDC injection timings. The reduction in air-fuel ratio during dual-fuel operation may be due to biogas, being a low calorie gas, needs less air for complete combustion.

Conclusions

1. A compression ignition engine can be modified for operation on dual-fuel
2. The modified engine should be started on diesel and after sufficient warming up it can be switched over to dual-fuel by adjusting the fuel rack for the reduction in diesel supply.
3. The injection timing of an engine shall be advanced to 30° BTDC for efficient operation.
4. At 30° BTDC injection timing the engine developed 81.6% of the maximum power developed by it on diesel. At this setting of injection timing during dual-fuel 70% of diesel replacement was attainable.
5. The biogas requirement for efficient operation is 0.813 m^3/bhp-h.
6. The brake specific fuel consumption (diesel) drops significantly at higher loads.

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A New Multi-crop Inverted-T seeder for Upland Crop Establishment

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Abstract

The paper describes the design of a new multi-crop inverted-T seeder (MITS) for upland crop establishment in rotation with lowland rice. Design parameters which have evolved from well researched fundamental scientific data on biological performance of the seeder components are described. Initial results from field experiments in both the previously tilled and untilled soil suggest superior seedling establishment with the seeder compared with traditional manual seeding methods as commonly practiced in developing countries at present.

Introduction

Over recent years there has been substantial effort made to increase crop production in the developing countries. However, with soil and irrigation resources stretched to their economic limits, there is now an urgent need for crop intensification in less favourable soil and climatic conditions. Priorities for further food production in rice-based systems appear to be in both dry season crop following rice in rainfed areas, and in rainfed direct-seeded rice.

Increasing crop production from rainfed lowland areas is of great importance as approximately two-thirds of the world's 137 million ha of rice land were estimated to be rainfed (Barker and Herdt, 1978). In general, a single puddled, flooded rice crop per year was a most common practice. One of the problems in crop production is how to adequately convert puddled and highly reduced soils to suitable seedbeds for upland crops (Syarifuddin and Zandstra, 1978). Opportunities to increase the rice area devoted to grain legumes and other crops after rice were constrained by limited capacity to till and seed fields in the short time available before the surface 10 cm of soil dried to a moisture level insufficient to support the crop for emergence and growth to maturity (Gomez, 1985). A significant reduction in N and P in such soils has also been reported (Syarifuddin and Zandstra, 1978). The above-mentioned time limit was most pronounced when tilling soils that have medium to high clay content, and 2:1 layer lattice clay species. These are characteristics of large tracts of rice lands. Unpredictable rains along with high and rapid soil moisture evaporation from surface soil necessitated speedy seedbed preparation and planting within days of the previous rice crop harvest.

Slow planting operation was identified as one of the major constraints to upland crop production in the Philippines (Villaruel and Duff, 1977). Relative lack of tractive power and low-capacity, traditional tillage (manual and animal powered) and seeding methods (broadcast or line hand sown) leave large tracts of rice lands unsown which are otherwise marked for upland crops. Also, the use of these traditional cultural practices made timely fertilizer application and weed control management either difficult or labour intensive.

Hence, there is a high potential for mechanization of tillage and seeding operations to improve land and labour productivity and to reduce human physical strain, particularly during seeding. The multi-crop inverted-T seeder (MITS) was developed with the objective of extending the range of soils and climatic conditions where adequate seeding and crop establishment could be achieved at increased work rates and with minimum risk of failure.

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Existing Seeding Machines and Practices

At present most upland seeding is achieved by broadcasting seeds onto a prepared seedbed, followed by one cultivation or harrowing. In the Philippines, for example, one common practice is to create furrows using a "lithao" (furrower) and to hand-dibble seeds into a prepared seedbed. This is followed by covering the seeds by harrows or compacting by human feet.

Over recent years a number of seeders have been developed to improve rice farming.

IRRI-designed Multi-crop Upland Seeder

This is a power-tiller or animal-drawn, 5-row seed-cum-fertilizer drill for seeding into conventionally tilled soils developed by the International Rice Research Institute (IRRI). These seeders have been found to be more economical to use than traditional methods for paddy and for furrow seeding of corn and mungbean (Singh and Mcmennamy, 1977). However, it has been suggested that the machine was heavy and expensive and the seed metering mechanism needed improvement. Local welding shops found it difficult to fabricate some critical parts of the seeder and, consequently, made inferior quality components which severely affected seeder performance, especially the metering mechanism. No formal extension work has been carried out to introduce the seeder to local farmers.

IRRI-designed Inclined Plate Planter

This planter has been designed for conventional and reduced tillage planting. The furrow opener is a specially-shaped narrow coulter that opens a slit into soil for seed placement. The depth of planting is adjustable. However, the seeder is limited for sowing into well prepared soils and seed metering ability is limited to a few seed sizes or species.

Seed-Fertilizer Applicator (SFA)

The SFA was developed jointly by the Philippines Ministry of Agriculture and Food, and the IRRI. It is an animal-drawn planting unit attached to the beam of a modified native plow. The modified plow makes a furrow in tilled soil. Guide tubes for seed and fertilizer are attached to both sides of the plow towards the underside of the modified mouldboard. A floating ground wheel drives the metering rollers using sprockets and chain. It appears that the seeder is limited to seeding into previously tilled soil. Seed depth control is problematic and the metering mechanism needs improvement. Also, seeding operation is limited to a single row at a time.

IITA/IRRI Rolling Injection Planter (RIP)

The RIP is a manual, push-type seed drill designed for reduced and zero-tillage. It is a modified version of the IITA/VITA punch planter. The RIP has performed well on untilled, light textured soil and on tilled, dry soil. However, in relatively wet heavy conditions, the soil sticks between the injectors stopping the seeds from falling into the seed holes. Occasional cleaning affects the efficiency of the machine. A similar observation was made by Singh et al (1977) and Choudhury (1985). In relatively dry, heavy soil which is characterized by a hard, dry surface but a moist sub-layer, inadequate penetration of the injectors causes shallow seed placement and low percentage germination. Seed metering is not accurate and seeds cannot be fully covered by the press wheel.

Development of Multi-Crop Inverted-T Seeder (MITS)

A number of major studies (Choundhary and Baker, 1980, 1981a, 1981b, 1982: Choudhary, et al, 1985) have established that seeder designs should incorporate soil openers which create soil microenvironments that enable superior seed germination and seedling emergence. Furthermore, these seeders should have the ability to sow both in previously tilled and in untilled soils.

At present, there are no appropriate seeding machines that could satisfactorily be used in a rice-based cropping system. Therefore, a new seeder for upland crop establishment has been developed. The seeder incorporates design features and components which have been evolved from well researched fundamental scientific data by the author and others at Massey University, New Zealand. The major components of the seeder (Fig. 1a) are as follows:

Groove Opener

The seeder used an inverted-T groove opener which created an in-groove seed micro-environment that has been shown to be tolerant to a wider range of field and ambient conditions than other openers (Choudhary and Baker, 1981b). The opener provided subsurface soil shattering which facilitates the proliferation of both plant shoots and roots. It allows surface soil and residue to remain intact and provide seed coverage in combination with the press wheel.

Seed Depth/Press Wheel

A 1.15-m circumference depth-cum-press wheel was used to pro-

Fig. 1a Schematic diagram of the multicrop inverted-T seeder (MITS).

Fig. 1b Side view of a two-row MITS pulled by a 2-WD tractor.

Fig. 1c A single-row MITS unit pulled by a carabao (buffaro).

vide accurate seed depth control since seeds, particularly smaller species, have been shown to be sensitive to sowing depth (Choudhary et al, 1985). A spring-loaded drag arm, adjustable over a range of heights, ensured even and predetermined seeding depth under varied field conditions. The wheel also provided required seed-soil contact for enhancing moisture conductivity at the seed-soil interface, particularly in soils with limited moisture.

The same wheel (utilizing its lugs) drove the seed metering assembly via standard (bicycle) sprockets.

Drive Sprockets

Two drive sprockets (9 teeth and 18 teeth) were attached to the drive wheel axle. These sprockets drove, via bicycle chain, two sprockets (36 teeth and 56 teeth) attached to the seed metering assembly, thus enabling a 4-speed drive reduction ranging from 2:1 to 6.2:1.

Seed Metering Assembly and Hopper

The seeder utilized a unique assembly that meters seeds with a high degree of accuracy and with minimum periodicity. The mechanism used a horizontally mounted circular foam pad attached to a steel plate. The pad rotated around the vertical part of a plastic hopper base. Seeds were delivered vertically downward through a throat-type opening moulded as an integral part of the hopper base. The hopper, made from galvanized iron sheet, was attached directly to the plastic base.

A range of seed species could be satisfactorily metered without any seed damage. The seed rate could be varied by changing 4 drive sprockets.

Plain Disc and Wheel

A plain disc (coulter) was attached in front of the groove opener for seeding into previously untilled soils. The disc cut a slit slightly deeper than the opener depth. The disc cut weeds and any crop residues remaining from the previous harvest thus avoiding opener blockages. This disc also slightly reduced seeder draught requirements.

The disc was easily replaced by a small wheel (7) for animal-drawn seeding operations. The front wheel stopped the seeder from trecking downwards when pull was applied from animals(s).

A hitch (8) which was easily attached to the dragbar allowed the seeder to be pulled by animal(s) for seeding into previously cultivated soils. For this purpose, a height-adjustable handle bar (9) could be attached for control by the operator.

Fig. 1b shows a two-row MITS unit being pulled by a two-wheel tractor and **Fig. 1c** shows a single row unit being pulled by a swamp buffalo.

Crop Establishment Experiments with MITS

Experiment 1

The first crop establishment experiment was conducted to evaluate the performance of the seeder by comparing it with the traditional sowing method. The experimental treatments were: 1. Conventional tillage and hand sowing (one pass by plow using swamp buffalo followed by two passes with

harrows, seed furrow (grooves) made by a "lithao", (furrower) and seed dibbled and covered by hand) (Tm); 2. Conventional tillage and sown by the MITS (TM); and 3. No-tillage and sown by the MITS (NM).

The mean soil moisture potential in the seed micro-environment at seeding was; Tm, −11 kPa; TM, −14 kPa; and NM, −19 kPa. Each tillage treatment area was divided into three plots (20 m x 3.5 m) which were sown with either corn, soyabean or mungbean at rates of 5, 7 and 18 seeds per meter of row, respectively, and at 0.3-m row spacings. Plant establishment counts for each plot were taken in 6 replicates representing 25% of the total planted area. The field was previously sown to a sorghum crop. Glyphosate herbicide at the rate of 4 l/ha was sprayed to control sorghum ratoons and other weeds in no-tilled plots before seeding.

Experiment 2

Upland rice establishment by traditional methods is laborious and time consuming. Poor plant establishment has been suggested as one of the reasons for crop failure or low yields using these methods. This experiment was conducted to compare rice establishment with both the MITS and precise hand placement (control) of two upland seed varieties (N22, a small seed, and IRAT 13, a bigger seed) without pre-germination. The seeds were sown in a well-prepared and moist (0.34 v/v) field. These experiments were conducted at the IRRI fields in the 1985/86 dry season. The soil was described as sandy clay loam.

Results and Discussion

Table 1 shows a seed and fertilizer calibration chart with the MITS. The seeder could satisfactorily be used to meter a wide range of seeds and granular fertilizers. There was a linear relationship between the rates of application and four forward speeds of the seeder. The foam pad metering system easily handled varied shapes and sizes of commonly sown seed species. This appeared to be a significant development in accurately metering difficult-to-meter seed species, as to date there has been no other units that accurately metered seeds such as rice and peanuts without damage.

Experiments 1 and 2

Results (Table 2) show significant advantages in plant establishment using the MITS compared with the conventional method. Seeder-sown plant establishment (mean of TM and NM plots) was improved by approximately 65% with corn and 300% with mungbean in magnitude compared with Tm plots. Establishment results with soyabean, although in favour of the seeder, were not clear. This was partially because, in retrospect,

Table 1 Seed and Fertilizer Calibration of Inverted-T Seeder (with 1.15-m circumference drive wheel)

Crop (Variety)	No. of seeds per meter (rate, g/m)[a]				Weight (g) per 1000 Seeds
	36T/18T (2:1)	56T/18T (3.1:1)	36T/9T (4:1)	56T/9T (6.2:1)	
Peanut (UPL PN-2)	13.25	9.00	7.40	4.15	312.57
Soybean (UPL SY-2)	25.35	20.00	14.60	10.30	150.47
Mungbean (PAGASA 1)	83.40	51.90	41.55	30.15	54.03
Cowpea (IT 82D-889)	44.75	28.90	21.00	13.05	111.19
Tepary	39.83	27.55	20.45	13.50	123.89
Phaseolus vulgaris	33.67	23.15	16.30	11.10	135.16
Pigeon Pea	63.33	42.25	32.95	22.80	71.55
Corn (IPB VAR 1)	22.50	13.85	8.75	5.50	264.62
Sorghum (SG-5)	(4.21)	(3.10)	(2.05)	(1.37)	20.00
Rice (IRAT 13)	(4.62)	(3.03)	(2.16)	(1.45)	35.40
Rice (UPL Ri-5)	(4.61)	(3.04)	(2.38)	(1.56)	23.90
Rice (N22)	(3.74)	(3.30)	(2.62)	(1.74)	14.90
Crotolaria	(3.92)	(3.41)	(2.38)	(1.63)	38.70
Sesbania rostrata	(4.70)	(2.94)	(2.27)	(1.40)	18.00
Wheat	(5.91)	(3.63)	(2.94)	(1.82)	20.20
Fertilizer	Application rate, g/m row				
Urea (Prilled) 46-0-0	2.80	1.73	1.27	0.88	
Urea (Forestry Grade)	5.36	3.51	2.74	1.67	
USG	5.28	3.97	3.22	1.87	
Complete (14-14-14)	5.28	3.42	2.54	1.60	

a: Average of 20 m. T = No. of teeth on sprocket.

Table 2 Effects of Tillage and Sowing Methods on Upland Crop Establishment

Tillage and sowing method	Plant emergence %					
	Corn*		Soybean		Mungbean	
Conventional tillage and hand sown (Tm)	41b	(49)	29b	(39)	15b	(15)
Conventional tillage and seeder sown (TM)	67a	(77)	24b	(46)	49a	(65)
No-tilled and seeder sown (NM)	69a	(73)	45a	(58)	46a	(56)

Unlike letters in each column show significant differences at $P < 0.05$.

Tm: One pass by plow using swamp buffalo followed by two passes with harrows, seed furrows (grooves) made by a "lithao" and seed dibbled and covered by hand.

TM: Conventional tillage and sown by the Multicrop Inverted-T seeder

NM: Previously untilled upland soil and sown by the Multicrop Inverted-T seeder.

( ): Plant emergence, including sub-surface surviving seedlings at day 12 after sowing

* Laboratory seed germination: Corn, 97%; soyabean, 47%; and mungbean, 75%

the seed quality was found to be suspect and laboratory germination was low at 46%.

Seed fate analysis of unemerged seeds recovered from seeded plots suggested a large percentage of seeds had remained ungerminated in Tm plots. In-groove soil studies suggested improvement of major soil physical parameters, particularly soil moisture. **Fig. 2** shows that there was much higher soil moisture potential loss gradient over time in Tm plots compared with both TM and NM plots which in themselves were not significantly different. Recovery of unemerged seeds showed that uneven depth of seed placement and low bulk density in Tm plots had resulted in low soil moisture conduction (particularly capillary) from the soil matrix, and low moisture availability at the seed interface. The mean seedling emergence percentage (from three seed species used) and the gradient of in-groove moisture loss were highly and inversely correlated ($r = -0.94$). On the other hand, more sub-surface surviving seedlings were found in both TM and NM, suggesting further potential for plant establishment if more moisture was available confirming earlier results by Choudhary and Baker (1981b).

Figs. 3a and **3b** show the results of upland rice establishment (Experiment 2). Mean emergence of over 70% was obtained with the N22 variety using both seeding methods (**Fig. 3a**). Emergence with the precision hand placement method was generally higher than where the MITS was used. These differences were more apparent with the IRAT 13 variety than with the N22 variety, the latter being significant only at $P < 0.05$. There was no clear explanation for such differences other than that IRAT 13 seed size and weight was twice that of the N22 variety.

The seeder was able to accurately meter and evenly place rice seeds in the moist soil. This has hitherto been challenging to achieve with most available seeders. Secondly, it was possible to achieve high plant establishment more reliably than the traditional farming method.

Fig. 2 Soil moisture characteristics as affected by different methods of land preparation and seeding.

Fig. 3a Effect of seeding methods on upland dry-seeded rice establishment.

Fig. 3b A view of typical precision hand and seeder dry-seeded rice establishment.

Conclusions

An evaluation of the MITS indicated that it created soil microenvironment better suited for seed germination than other seeder types. It provided accurate seed depth control, seed cover and seed-soil contact. The seeder proved its superior ability to seed in both previously tilled and untilled soil and adequately handled residue or trash left from previous crops.

Initial field studies showed biological advantages of the MITS compared with traditional methods of crop establishment, particularly where soil moisture was a limiting factor. Further evaluation of the

seeder has continued, including the effects of seed species and soil and ambient conditions. These latter studies, yet unpublished, have confirmed the usefulness of the seeder when sowing a number of crop seeds, including difficult-to-meter seeds such as rice and peanuts in both tilled and untilled soils.

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Compression Ignition Engine on Biogas-Diesel Fuel

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Optimum Sprout Length for Sowing Pre-Germinated Paddy Seed in Puddled Soil

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Abstract

Pre-germinated paddy seeding in puddled soil is often recommended as an alternative to manual transplanting. However, no information is available on the influence of the level of pregermination on crop growth parameters. Therefore, this study was conducted to determine the effect of sprout length of pre-germinated paddy seed on the plant population, crop growth and yield. Plant emergence, crop growth and yield were higher for sprouted seed as compared to dry and water-soaked seed. Sprout length of 2-5 mm was observed to be optimum for maximum plant population and grain yield.

Introduction

Pre-germinated paddy seeding in puddled soil is often recommended as an alternative to manual transplanting. However, the level of pre-germination of the seed is not clean. Also, suitable machinery for seeding paddy in puddled soil has been slow in developing and manual broadcasting of pre-germinated seed has been the main operation of sowing by the agronomist and the farmers. The seed used for broadcast sowing ranges from dry seeds to seeds sprouted up to 5 mm or more. No information is available on the influence of sprout length of the seed on the crop growth parameters. In the context of developing suitable machinery for seeding paddy, this information assumes a critical importance. Therefore, a study was undertaken to determine the effect of sprout length of the pre-germinated paddy seed on the plant population, crop growth and yield in puddled soil.

Table 1 Characteristics of Experimental Soil

Depth cm	Particle size distribution (%) Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	pH value	Bulk density g/cm³	Moisture retention (%) 1/10 bar	1/3 bar	15 bar
0-21	0.95	49.00	24.05	11.50	12.75	8.1	1.41	30.75	21.08	7.80
21-52	0.50	54.35	22.70	8.50	12.25	8.2	1.41	26.28	17.82	6.77
52-93	0.60	53-75	20.50	9.63	13.00	8.4	1.41	26.45	18.00	6.64

Type: Sand loam to loam

Material and Methods

Soil

Experiments were conducted in sandy loam soil of the experimental field at the Indian Agricultural Research Institute, New Delhi. The major characteristics of the soil are listed in **Table 1**.

Soil Preparation

Experiments were conducted in puddled soil prepared in the laboratory and field. The soil was puddled manually, for laboratory tests, in plot size of 1.5 m x 1.5 m, using a spade in standing water, until it was visually a homogeneous mixture of soil and water. The puddled plot was subdivided into 25 test blocks, each of 30 cm x 30 cm size using wooden partition frames.

The field plot of 16.5 m x 19.5 m size was puddled with two passes of a radial blade puddler of a power tiller in standing water. The field was subdivided into 9 test plots each of 6.5 m x 6.5 m size.

Seed

Paddy seeds of variety Pusa-33 (P-33) was used for the study. The seeds were pre-germinated by soaking in the water for 24 h and then incubating between two gunny bags. Pre-germinated seeds of varying sprout lengths were obtained by varying the incubation period.

Plan of Experiments

Experiments were laid out in the laboratory and field in Latin

Fig. 1 Layout plan for laboratory studies on effect of different levels of pre-germination of paddy seed on plant growth.

Fig. 2 Layout plan for field studies on effect of different levels of pre-germination of paddy seed on plant growth.

square design according to plans of Figs. 1 and 2. The sowing design was done with the seed of sprout length and at the seed rate included in Table 2.

Plant population was counted in each test plot of the laboratory and the test field on the 7th day after sowing. The crop growth was measured in terms of dry matter weight at regular intervals. Grain yield for all the tests were recorded. The observations were analyzed using F-test and critical differences. On the basis of plant population, crop growth and yield, the range of optimum sprout length of the seeds was determined.

Table 2 Plan of Experiments

Item	Laboratory	Field
Plot size	1.5 m x 1.5 m divided into 25 blocks each of size 0.3 m x 0.3 m	19.5 m x 19.5 m divided into 9 blocks each of size 6.5 m x 6.5 m
Seed condition	Dry, wet and pre-germinated seed of sprout lengths 2, 5.3 and 16.5 mm	Pre-germinated seed of sprout length 2, 4 and 6.5 mm
Method of sowing	Hand placement, uniformly and covering with a thin layer of soil	Manual broadcasting
Seed rate	300 nos/block	45 kg/ha, 50 kg/ha and 55 kg/ha for seed of sprout lengths 2, 4 and 6.5 mm, respectively

Results and Discussion

Laboratory Experiments

Plant population and yield – The plant population and grain yields from the crops of seed at five levels of germination are shown in Fig. 3. At 5% level of significance, the sprouted seed of 2 to 16.5 mm caused a plant population significantly higher than the plant population due to dry and water-soaked seed. Statistically, the differences in plant germination among treatments using sprouted seed were not significant. The plant germination from the water-soaked seed was 51% while the germination of the seed sprouted to 2, 5.3 and 16.5 mm sprout length was 75.6, 86.6 and 81.3%, respectively.

Grain yield was significantly higher from the sprouted seed compared to the yield from the dry and water-soaked seed Fig. 3. The grain yield per plant was maximum for all treatments with the use of 5.3 mm sprout length seed. The yield from the dry seed was 0.87 g/plant while, from the seed of 5.3 mm sprout length it was 1.95 g/plant. The seed of 16.5 mm sprout length resulted in a grain yield significantly lower than the yield from the seed of 5.3 mm sprout length. The difference in yields of treatments T_3 and T_4 were not significant at 5 % level.

Plant growth – Plant growth under the five treatments was observed up to 75 days after sowing. Generally, the dry matter weight of plant from the sprouted seed was consistently higher than the dry matter weight from the dry and water-soaked seed at various stages of crop growth (Fig. 4.) However, statistically, the differences in dry matter weight among various treatments, were not significant at 5% level except for the seed of 2-mm sprout length which indicated a significant difference in dry matter weight compared to the dry matter weight from the dry seed. The dry matter weight was 0.65 g/plant from the dry seed, 1.18 g/plant from the seed of 2 mm sprout length and 1.08 g/ plant from seed of 5.3 mm and 16.5 mm sprout length on 75th day after sowing.

Field Experiments

Based on the results of laboratory experiments, the dry and the

Fig. 3 Effect of different levels of pre-germination of paddy seed on plant germination and grain yield laboratory studies.

Fig. 4 Effect of different levels of pre-germination of paddy seed on plant growth laboratory studies.

water-soaked seeds were eliminated from the field experiments. Seed sprouted to 3 sprout lengths of 2,4 and 10 mm were broadcast in different treatments in the field.

Plant population and yield – The plant population and yield of the three treatments is shown in **Fig. 5**. Generally, the shorter the sprout length the higher was the plant population. The plant population was counted to be 85, 94 and 105 tillers/m^2, respectively, due to the seed sprouted to 10, 4 and 2 mm. Statistically, the differences in plant population among the three treatments were not significant. The grain yield was 0.76, 0.89 and 0.83g/plant, respectively, from the seed of 10 mm, 4 mm and 2 mm sprout length. The differences in yield among the treatments were not significant at 5 % level of significance.

Plant growth – The dry matter weight per plant was consistently higher from the seed sprouted to 4 mm sprout length among the three treatments, followed by the dry matter weight from 10 mm length sprouted speed (**Fig. 6**). Statistically, the differences in dry matter weight, among the three treatments at various stages of the crop, were not significant.

The differences in plant population and grain yield among treatments could be explained by the differences in germination. The water-soaked seeds resulted in higher plant population and yield compared to dry seed and the sprouted seed resulted in higher plant population and yield than from the water-soaked seed.

When paddy seeds germinate, the radicle is pushed through the coleorhiza enclosing the radicle. With moisture absorption, the husk, containing palea and lemma, is loosened. The loosening of husk facilitates the growth of radicle and leaves. However, the dry seeds need sufficient amount of initial moisture for loosening this husk. The time required to absorb moisture from soil is large and often results in damage to the seed. The traditional method of soaking seed in water enhances the process of moisture absorption. This also caused elimination of defective and weaker seeds. For this reason, the water-soaked seed resulted in higher plant population and grain yield as

Fig. 5 Effect of different levels of pre-germination of paddy seed.

Fig. 6 Effect of different levels of pre-germination of paddy seed.

compared to dry seed.

The pre-germinated seed resulted in higher plant population and grain yield as compared to dry seed.

Pre-germinated seed resulted in higher plant population as compared to the water soaked seed due to lesser mortality of pre-germinated seed. The sprouted seed required only adoption to soil condition for emergence whereas the water-soaked seed required the radicle to emerge in the soil. For initial germination of radicle, after soaking, a high temperature and relative humidity is required. Ideally, this condition is available inside an incubator. However, keeping the water-soaked seed between two moist gunny bags also provided a suitable environment in terms of temperature, relative humidity and aeration for the emergence of radicles. The time required for seedling emergence in soil of water-soaked seed was much higher than needed by an established pre-germinated seeds. Thus, there was higher mortality among the water soaked seed and hence, the pre-germinated seed, with radicle emerged, resulted in better plant germination.

The seeds with larger sprout length was due to absorption of nutrients during the germination process. This reserve nutrient is required during the adaptation of seed in the soil condition. Hence, due to reduced reserve nutrients below a certain level, the seeds with larger sprout length resulted in retarded growth as compared to seeds with smaller sprout length. Thus, the seeds with well established but of shorter sprout length were desirable for crop growth. Accordingly, sprout length within the range of 2 to 5 mm was considered optimum for maximum yield.

Conclusions

On the basis of the results from the laboratory and field experiments, the following conclusions are drawn:

i) The germination and grain yield from the dry and water-soaked seeds was significantly lower than from the pre-germinated seed.

ii) The dry matter weight of plants from the sprouted seed was higher than from the dry and water-soaked seeds.

iii) Sprout length of 2 to 5 mm was optimum for sowing to obtain maximum plant population and yield from pre-germinated paddy seed. Therefore, for mechanical sowing of the seed, sprout length of 2 to 5 mm would be the criteria for the design of pre-germinated paddy seeder.

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Performance Evaluation of Mechanical Reapers in Pakistan

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Abstract

Three locally manufactured and commercially available tractor front-mounted reapears (FMI, AMRI and Ittefaq) were field tested in 1984 on wheat crop in Pakistan. The average field capacity was about 0.4 ha/h with 4% grain loss. Labor input in mechanical reaping was about 5 man-h/ha compared to 84 man-h/ha in manual opeartion. The cost of mechanical harvesting was lower than that of manual harvesting. Farmers indicated preference for mechanical harvesting due mainly to shortage of harvest labor.

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Introduction

Pakistan is predominantly an agricultural country with more than 50% of the economically active population engaged in agriculture which accounts for about 30% of the gross domestic product (GDP). Of the total cultivated land area of about 20 million ha, 14 million ha (70%) is under irrigation from extensive canal networks, open wells and tube wells. In 1982, there were 3.76 million farmers with an average holding of 5.3 ha each. About 74% of the holdings were below 5 ha, 17% between 5 and 10 ha, and only 9% above 10 ha. Based on tenure, 42% of all farmers were owner-cultivators, 24% owner-cum-tenants, and 34% tenants only. There were about 8 million draft animals and about 14 million workers engaged in agriculture (1). There were about 150 000 tractors in 1984 with an annual demand of about 30 000 tractors (3). The number of tractors imported during 1969-70 to 1982-83 is given in **Fig. 1**.

Wheat and rice are the two main foodgrain crops with planted areas of 7.27 million ha and 1.98 million ha, respectively, in 1982-83. Harvesting is one of the most labor-intensive operations in the production of these crops. The total labor requirement for traditional manual harvesting with sickle is 80-160 man-h/ha, of which 60-100 man-h are used in cutting and laying the crop. The harvesting period is very short and crop losses increase rapidly with delay in harvesting. Delayed harvesting of mature crops also exposes it to many hazards like rains, wind storms and fires. Shortage of labor during the harvest period created the need for mechanical harvesting.

In Pakistan, reaper-windrowers are being introduced along with cutter-binders and combine harvesters. The import of harvesting machines and related sales figures are given in **Table 1**. The combine harvester is not acceptable to most farmers as they need chopped straw for animal feed. It also requires large fields, highly skilled operators and technicians to use and maintain it. Because of the

Fig. 1 Annual import of tractors.

Table 1 Import of Harvesting Machines in Pakistan

Machine and model	Years of import	Total import	Total sale
Combine harvester			
Allis Chalmer M. 72, USA	up to 1978	400	250
J. F. combine	up to 1982	40	5
M. S. 707, UK	1981–1983	100	100
Cutter-binder			
Augostini Italy	1979–1984	170	160
Reaper-windrowers			
Vertical Chinese 2.2 m	1982–1983	200	70

Table 2 Distribution of Agricultural Machinery Manufacturers in Pakistan, 1983

Province	Manufacturers				
	Small	Medium	Large	Total	% of total
Punjab	368	29	5	402	87
Sind	33	5	4	42	9
N.W.F.P.	17	1	0	18	4
Total	418	35	9	462	

Table 3 Local Manufacturing of Reapers in Pakistan

Year	Reaper manufacturing firms	Units manufactured and sold
1981-82	3	350
1982-83	14	675
1983-84	22	1300

high price of imported twine, farmers are hesitant to buy cutter-binders. Reaper-windrowers, which can cut and lay the crop with proper orientation in windrows for collection by farm labor and leaving the threshing operation to be carried out using the already popular mechanical thresher, are readily acceptable to the majority of Pakistani farmers.

There has been a considerable increase in locally-manufactured agricultural machinery in Pakistan. The number of agricultural machinery manufacturers increased from 83 in 1965 to 280 in 1979 (4). In 1983, the number of manufacturers increased to 462 with 87% of them located in the Punjab Province (**Table 2**). Research institutes and local manufacturers have been striving to develop reaper-windrowers. Recently, the Farm Machinery Institute (FMI) of the Pakistan Agricultural Research Council at Islamabad, the Agricultural Mechanization Research Institute (AMRI) at Multan and the M/S Ittefaq Brothers Limited at Lahore, have developed tractor front-mounted reaper-windrowers. The fabrication of these machines on a commercial basis started in 1981-82. Details on local manufacturing of reapers in Pakistan are given in **Table 3**. According to an estimate of the FMI, 4 000 units of reapers would have been built by the end of 1985 (5). In a demand survey conducted by the FMI, 62% of tractor-owning farmers indicated that they would like to own a reaper. About 75% of the reapers are of FMI design manufactured by small- and medium-scale manufacturers, whereas AMRI and Ittefaq designs are being manufactured by the large scale manufacturers. The Government of Pakistan has provided several incentives to the manufacturers of agricultural machinery, such as exemption from income tax and refunding of custom duty paid on the import of raw materials used for farm machinery production.

Since mechanical reaper-windrowers were developed only recently in Pakistan and no literature was available on their field performance, a study (6) with the following objectives was undertaken:

1. To measure and evaluate field performance of three locally manufactured tractor front-mounted reaper-windrowers for harvesting wheat crop.
2. To compare the costs of harvesting using these machines with conventional manual method.

Details of Reapers

FMI reaper

The FMI reaper (**Fig. 2**) is a

Fig. 2 FMI reaper.

Fig. 3 AMRI reaper.

Fig. 4 Ittefaq reaper.

modified version of the Chinese Vertical Reaper. The reaper is mounted on the front of a 4-wheel tractor and driven from the tractor PTO by a long drive shaft. The crop is cut, transported vertically to one side and laid down to form a windrow. The Chinese reaper was tested by Amjad and Gee-Clough (2) and found to work well. When harvesting at maturity and using the correct forward speed, losses could be reduced to 2-3%, about the same as harvesting by hand. Tiangco, et al (8) identified critical design parameters and developed a CAAMS-IRRI reaper which performed satisfactorily. The average field capacity of a 1.6 m reaper was about 3.8 ha/day. The FMI reaper has been described in detail by Rahman (7).

AMRI reaper

The AMRI reaper-windrower was designed and developed by the Agricultural Mechanization Research Institute (AMRI) at Multan.

The AMRI reaper-windrower (Fig. 3) is a tractor front-mounted, pto operated and hydraulically controlled machine. Its cutter bar is operated by pto shaft power through a pair of belt pulleys, a propeller shaft and a cam. An overhead reel is used to support and gather the crop being cut and to lay the same on the conveyor, while windrowing is done through a set of deflector wires.

Ittefaq reaper

The Ittefaq reaper, a tractor front-mounted machine, is a redesigned version of the Augostini cutter-binder without a crop binding mechanism (Fig 4).

The power from the tractor PTO is transmitted to the front with the help of a v-belt and a drive shaft. The front end of the shaft is properly secured with the gear box of the machine. Automotive power from the engine is transmitted to

machine gears bringing the cutting blades into a to-and-fro motion through belts and pulleys. The collecting hooks come into operation through chain and sprockets. These hooks, after collecting the wheat stalk, pass it on to the conveying channel which piles up the stalk in a uniform layer or windrow on the left side of the tractor.

Field Tests

The major wheat growing areas in Pakistan are located in Punjab and Sind provinces. In Sind wheat harvesting season starts around mid-March while in Punjab it starts around mid-April. Reapers were field tested at the Sanghar District of Sind and Sheikhupura District in Punjab. All three reapers used Massey Ferguson (MF265) tractors with a maximum rated power of about 45 kW at 2000 rpm.

Field capacity

Test results related to field capacity are given in **Table 4**. FMI and Ittefaq reapers had seven test runs each while the AMRI reaper had only three test runs. The size of the test fields varied from 0.2 to 0.75 ha. FMI and Ittefaq reaper tests involved four varieties of wheat crop and the AMRI reaper was tested only on two wheat varieties. The tractors mounted with reapers were operated in whether low third or low second gears. The average speed of travel was highest for the FMI reaper at 3.28 km/h. Average travel speed for the AMRI and the Ittefaq reapers were 3.01 and 2.63 km/h, respectively. The average working width of all three reapers was almost similar. The field efficiency of the FMI and the AMRI reapers was about 59% while it was about 65% for the Ittefaq reaper. The actual field capacity of the FMI reaper was highest (0.42 ha/h) compared to 0.37 ha/h for the AMRI reaper and 0.35 ha/h for the Ittefaq reaper. Fuel consumption was about the same for the tractor mounted with the FMI reaper (3.4 *l*/h) compared to the tractors mounted with the AMRI reaper (3.2 *l*/h) and the Ittefaq reaper (3.3 *l*/h).

Table 4 Field Capacity of Reapers Tested

Item	FMI Reaper	AMRI Reaper	Ittefaq Reaper
Number of tests	7	3	7
Crop varieties	4	2	4
Average travel speed (km/h)	3.28	3.01	2.63
Working width of cut (m)	2.01	2.04	2.06
Field capacity (ha/h)	0.42	0.37	0.35
Field efficiency (%)	59.4	59.5	64.6
Fuel consumption (*l*/h)	3.44	3.21	3.31

Table 5 Average Grain Losses in Mechanical Harvesting

Item	FMI Reaper	AMRI Reaper	Ittefaq Reaper
Number of tests	7	3	7
Crop varieties	4	2	4
Pre-harvest loss (%)*	0.05	0.45	0.11
Machine shattering loss (%)*	0.89	1.49	1.81
Uncut loss (%)*	1.02	1.14	0.95
Total machine loss (%)*	1.91	2.63	2.76
Gathering and bundling loss (%)*	1.40	1.99	1.69
Total harvesting loss (%)*	3.31	4.62	4.45

* Percent of crop yield.

The test results indicate that the farmers were operating the mechanical reapers at lower speeds than optimal speeds and, consequently, obtained low field capacities. The main reasons were unfavorable field conditions (i.e., many field bunds) and operators having little or no experience in mechanical reaping.

Field grain losses

Test results related to field grain losses are given in **Table 5**. The test runs made for field capacity determinations were also used for the measurement of field grain losses. Pre-harvest loss refers to grains and ears fallen on the ground due to natural forces like wind and rain. These were collected from five randomly-selected 1 m^2 areas in each test field and their weight was recorded. The average of these observations expressed as percent of the crop yield represents the pre-harvest loss. Machine shattering loss refers to ears and grains fallen on the ground due to machine operation, including formation of windrows. After the machine harvesting opeartion, the uncut crop which remained standing in the whole test field was manually harvested and threshed to determine uncut loss. Total machine loss is the sum of machine shattering loss and uncut loss. Gathering and bundling loss refers to grains and ears left in the field during gathering and bundling of the windrowed crop by the farm workers.

Field grain losses depend upon crop variety, maturity, time of harvest, field condition, forward speed of the machine and handling of the crop by the machine and the workers. It is impossible to have uniform conditions for all the test runs. Test results in **Table 5** indicate that machine shattering losses were lowest for the FMI reaper (0.89%) compared to 1.49% for the AMRI reaper and 1.81% for the Ittefaq reaper. Uncut loss, which mostly depends upon the operator's skill, was almost the same for all three reapers. Total harvesting losses were also lowest for the FMI reaper. The

average grain loss in manual harvesting was about 3.6%. It can be concluded that the average grain losses in manual and mechanical harvesting were about the same.

Cost of Harvesting

Labor inputs during the mechanical and manual reaping tests were noted for each individual operation. **Table 6** gives the labor inputs in harvesting for manual as well as mechanical reaping. Labor used in preparing fields includes cutting headline and corners for easy turning. On the average, machine reaping (tractor operator time and field preparation) needed 5 man-h/ha in comparison to 84 man-h/ha required for manual reaping. Labor used in gathering, bundling and transporting the crop to a collection place within a distance of about 100-150 m for the threshing operation, was 39 man-h/ha for mechanically reaped crop compared to 26 man-h/ha for manually reaped crop. Thus total labor input in mechanical harvesting was 44 man-h/ha compared to 110 man-h/ha for manual harvesting.

The AMRI reaper and the Ittefaq reaper had the same purchase price (Rs 18 000). Their field capacities were also the same at about 0.36 ha/h. For cost calculations, these two reapers were grouped together. The cost of mechanical reaping and related information are given in **Table 7**. Fixed cost (of both reaper and tractor) accounted for more than 50% of the reaping cost. Details on costs of harvesting using manual and mechanical reaping are given in **Table 8**. The cost of reaping using the FMI reaper (Rs 177/ha) was much less than the cost of manual reaping (Rs 268/ha) while for the AMRI and the Ittefaq reapers the cost (Rs 215/ha) was only slightly less than that of the manual reaping. The prevailing custom charge for mechanical reaping was Rs 250/ha.

The mechanically reaped crop required more labor in gathering than the manually reaped crop. However, the total cost of harvesting using the FMI reaper (Rs 300/ha) was still much lower than the manual method (Rs 352/ha) while it was only slightly lower for the AMRI and the Ittefaq reapers (Rs 339/ha).

The cost calculations in **Table 7** and **8** are based on the assumption that during the harvest season of about one month, a reaper would be used for about 300 h. It was also assumed that on an average, the annual use of a large tractor such as the MF 265 in Pakistan was about 1 000 h and with the addition of a front-mounted reaper, increased to 1 300 h. If the annual use of a reaper can be increased by more hours in the season and/or using it for custom reaping crops like rice in other growing seasons, the cost of mechanical harvesting can be reduced further. Even at equal costs, most of the farmers indicated preference for mechanical harvesting due to improved timeliness and shortage of harvesting labor.

Table 6 Labor Inputs in Harvesting Operation (man-h/ha)

Item	Manual	FMI Reaper	AMRI Reaper	Ittefaq Reaper
Preparing field	–	2.4	2.5	2.2
Reaping	83.7	2.4	2.7	2.9
Gathering, bundling, etc.	26.3	38.3	38.5	38.7
Total	110.0	43.1	43.7	43.8

Table 7 Cost of Mechanical Reaping

Item	Tractor MF 265	FMI Reaper	AMRI/Ittefaq Reaper
Purchase cost (Rs.)	113 900	14 000	18 000
Useful life (years)	10	5	5
Yearly use (h)	1 300	300	300
Salvage value (10%)	11 390	1 400	1 800
Fixed costs (Rs./h)			
Depreciation	7.88	4.20	5.40
Interest (14% on average investment)	6.75	3.59	4.62
Taxes, insurance and shelter (2.5% of initial investment)	2.19	1.16	1.50
Repair and maintenance (tractor 1.2% P/100 h) (reaper 7% P/100 h)	13.67	9.80	12.6
Total fixed cost (Rs./h)	30.49	18.75	24.12
Fixed cost (reaper and tractor) (Rs./h)		49.24	54.61
Field capacity (h/ha)		2.38	2.78
Labor input (man-h/ha)		5	5
Fuel consumption (1/ha)		8.2	9.1
Costs (Rs./ha)			
Fixed (including repairs)		117	152
Labor @ Rs. 4/h		20	20
Fuel (diesel) @ Rs. 4/1		33	36
Lubricants (20% of fuel cost)		7	7
Total cost (Rs./ha)		177	215

Table 8 Comparison of Harvesting Costs

Cost item	Manual	FMI Reaper	AMRI/Ittefaq Reaper
Reaping (Rs./ha)	268	177	215
Gathering, bundling, etc. (Rs./ha)	84	123	124
Total cost of harvesting (Rs./ha)	352	300	339

US $1 = Pakistani Rs. 14 (1984).

Response of Farmers

Just after the 1984 wheat harvesting season, 40 farmers owning FMI reapers and 19 farmers owning Ittefaq reapers were interviewed regarding their reapers' performance.

Thirty (75%) owners of the FMI reapers and 13 (68%) owners of the Ittefaq reapers were satisfied with the performance of their reapers and gave the following reasons:

1. Timely harvest reduced losses and risk due to delayed harvest.
2. Good field service was provided by the manufacturers. Defective parts were replaced by new ones at no cost to the owner.
3. Machine did not require highly skilled operator.

The farmers also mentioned that the tractor was very lightly loaded during the reaping operation and the machine required regular maintenance for satisfactory performance. As these reapers had large capacity, operations had to stop many times due to shortage of labor for gathering and bundling.

In comparison ten (25%) owners of the FMI reapers and six (32%) owners of the Ittefaq reapers were not satisfied with the machine performance and gave the following reasons:

1. Machine was not suitable for existing field conditions.
2. Valuable time was lost due to delay in getting spare parts and repair work.

Conclusions

Three locally-manufactured mechanical reapers, namely, the FMI reaper, the AMRI reaper and the Ittefaq reaper were field-tested in Sind and Punjab provinces during the 1984 wheat harvesting season. Operating in low second or third gear, the average speed of travel for the FMI, the AMRI, and in Ittefaq reapers were 3.28, 3.01 and 2.68 km/h, respectively. Their field efficiencies were 59%, 59% and 65%, respectively; field capacities were: the FMI reaper, 0.42 ha/h; AMRI reaper, 0.37 ha/h; and Ittefaq reaper, 0.35 ha/h. The average fuel consumption was: 3.4 *l*/h for the FMI reaper; 3.2 *l*/h for the AMRI; reaper and 3.3 *l*/h for the Ittefaq reaper.

The average grain losses in mechanical harvesting using the FMI reaper (3.3%), the AMRI reaper (4.6%) and the Ittefaq reaper (4.5%) were not significantly different from the total harvesting losses of 3.6% in manual harvesting using sickle.

The total labor input in mechanical harvesting was 44 man-h/ha compared to 110 man-h/ha for manual harvesting. Machine reaping needed only 5 man-h/ha compared to 84 man-h/ha required for manual reaping. The labor used in gathering, bundling and transporting the crop was 39 man-h/ha for a mechanically reaped crop compared to 26 man-h/ha for a manually reaped crop.

The cost of harvesting using the FMI reaper (Rs 300/ha) was much lower than the cost for manual harvesting (Rs 352/ha), while for the AMRI and the Ittefaq reapers (Rs 339/ha), it was only slightly lower than the cost for manual harvesting. The cost of mechanical harvesting could be reduced by increasing the annual use of tractors and reapers.

Most of the Pakistani farmers indicated preference for mechanical harvesting due to the shortage of harvest labor and that the timely harvest reduced losses and risk due to delayed harvest. Some farmers thought that existing field conditions were not suitable for mechanical harvesting and cited problems of spare parts availability and repairs.

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Cost of Using Power Reapers: Malaysian Experience

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Abstract

Field data on the repair and ownership costs of power reapers are presented. The power reapers were used for general purpose work like grass mowing and hedge trimming. The curves obtained in the study show the minimum of total accumulated cost ownership at 1200 accumulated usage hours and the wear out life at 2600 accumulated usage hours. Depreciation and repair costs were approximately 15% of the total cost of operation.

Introduction

The cost of using machinery continues to gain significance and importance. Repairs are important component of the total machine ownership costs, while the capital cost permits use decrease with age.

In Malaysia, high rainfall and favourable climate encourage undergrowth and grass to grow. Whether it is a lawn or farm, grasses have to be maintained to make it look beautiful and more productive, respectively. The use of power reapers are getting popular in grass maintenence (**Fig. 1**). On the average, Malaysia imported more than 6000 units of power reaper each year (**Table 1**).

The major objective of this study was to evaluate the relationship between accumulated use and repair cost of a power reaper.

Data Acquisition

Data on the repair costs of power reaper were obtained from the University of Agriculture's farm. Records of the repair costs were only for parts without labour. These power reapers were used generally for grass cutting along the highway and in the field and some other miscellaneous tasks. Power rating ranges from 1.5 to 2.0 PS.

Data for the following items were obtained: annual usage; repair cost (parts only); power reaper make and model; year of purchase; fuel consumption; and field capacity.

The following technique was used to collect the data: Each machine was grouped by age, and the mean annual use for the age group together with the mean annual repairs for that group were calculated. The annual repair costs were expressed as accumulated repair costs (TAR) and the annual usage were expressed as an accumulated use (TAU) by summation of the mean annual usage for all years up to and including that year.

Results and Discussions

The data obtained in this study is presented in **Table 2**. The range in the standard deviation for repairs (9.60 to 241.72) is an indication of the variation one can expect in repair costs from one power reaper to another. This

Fig. 1 Grass mowing with power reaper.

Fig. 2 Power reaper complete set.

Table 1 Importation of Power Reapers into Malaysia, 1983-85

Year	Units	Values (M$)
1983	6 678	1 703 450
1984	6 344	1 731 814
1985	7 012	1 716 081

Source: Statistical Department of Malaysia, 1983-1985

finding is in agreement with other machineries' repair cost (Ward et al 1985). For example, a survey of tractor repair cost shows that the average repair costs range from 50 to 200% of the mean value. Bowers and Hunt (1970) state that while formula can be used to determine the repair costs of specific machine type, it is not possible to predict accurately the repair costs for a single machine on a specific farm.

Table 2 Analysis of Repair Costs for Power Reapers

Machine age year	Number of machine per group	Accumulated repair		Accumulated use	
		TAR	Std.dev.	TAU	Std.dev.
1	25	28.62	9.60	363	106.43
2	20	120.66	88.67	1 038	399.96
3	15	307.48	72.39	1 746	514.29
4	5	699.66	241.72	2 811	656.80

Fig. 3 Influence of total accumulated usage (TAU) on total accumulated repair (TAR) on power reaper.

According to Fairbanks et al (1971), repair costs are difficult to estimate because both the amount and the nature of use and the kind of maintenence and care given to the machine vary with each operator, and these influence repair costs.

As can be seen from **Fig. 3**, repair costs increase with use. The repair costs are expressed as percentage of initial costs as suggested in the Agricultural Engineers Yearbook (1968). The repair costs vs time relationship for 25 power reapers show a rapid increase in total costs above 2000 h of accumulated usage.

As depicted in **Fig. 3**, there was an increase in repair costs and a decrease in fixed costs with accumulated use. It is desirable to replace the machine at the accumulated use value that corresponds to the minimum total ownership costs of the machine (Ward et al 1985). In this case, the minimum total ownership costs for the machine was about 1200 accumulated usage hours and beyond that, the total cost began to increase. The accumulated repair costs reached the equivalent amount of the initial price of the machine when the accumulated use reached 2650 h of total accumulated usage. This can be considered as the power reaper total wear-out life.

The average cost of ownership and cost of operation expressed as percentage of either ownership or operating costs, or of the total costs for the 25 power reapers is shown in **Fig. 4**. Labour represents the major cost item and depreciation and repair costs were approximately 15% of the total costs of the operation.

Fig. 4 Relative importance of all cost items for a power reaper.

Conclusion

It is important to realize the repair and maintenance costs curve and the ownership costs obtained in this study. They are suitable for determining the expected repair cost for a given power reaper type but large variations in repair costs can occur from one power reaper to another, due to differences in such factors as machine operation maintenence regime, operating practices and inherent machine defects.

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Threshing Efficiency of Pulses Using Step-wise Regression Technique

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Abstract

The step-wise multiple regression technique was used to study the relationship among different independent variables, namely cylinder types, concave clearance, cylinder peripheral speed and moisture content in relation to the two dependent variables, namely, threshing efficiency and invisible grain damage on pulse grains. An experimental model of pulse thresher without a cleaning and separating unit was developed. It had the provision to change the machine and operational parameters. The moisture content was found to have a significant effect on threshing efficiency and invisible grain damage. The effect of concave clearance and cylinder peripheral speed, though numerically small, was significant at 5 % level.

Introduction

Cereals and pulses are important components of the diet of the Indian people. Pulses are grown on an area of about 24 million ha and had a production of about 12 million t in 1982-83. *Gram* (Bengal gram), *Urad* (black gram), *mung* (green gram) and *arhar* (red gram) account for as high as 75 % of the total production of pulses in the country.

Adequate attention has been paid to the varietal aspects of the pulses by the Government of India but the crop production technology, especially mechanization of main production operations, has not been given due attention. Consequently, the time, labour and cost requirements for the production of pulses in India continue to be high and the quantitative and qualitative losses at various stages are excessive. One of the most critical post-harvest operations is the threshing of the crop which is still being threshed manually. The cereal threshers if used for pulse threshing results in excessive kernel damage, in some crops, as high as 40 to 50 %. There is also the problem of separation and cleaning of the seeds from the straw.

Very little information is available at present about the crop, machine and operational parameters pertaining to the performance of the pulse thresher. In developing a pulse thresher such parameters as cylinder peripheral speed, type of beaters, concave clearance, and moisture content have to be studied. The present investigation was, therefore, planned to study the interaction of different machine and crop variables. In order to identify the contribution of each variable, prediction equations were developed using step-wise regression analysis. This method has a specific advantage of identifying the independent variables in the order of their contributions to the total variation to the dependent variable. This information could be useful in assessing the relative importance of various factors influencing the dependent variable.

Materials and Methods

A number of machine-crop parameters are known to influence the performance of a thresher. After considering the relative contribution of these parameters, only four were selected for the study: cylinder type, peripheral speed, concave clearance and moisture content of the grains. The levels of the variables used for T9 variety of the pulse grains are given in **Table 1**.

An experimental model of a pulse thresher without a separating and cleaning unit was fabricat-

Table 1 Levels of Variables for Threshing Trials with Type 9 Variety of Pulse Grains

Cylinder type	Speed (m/min)	Moisture content (%, d.b.)	Concave clearance (mm)
A1 = Rasp bar	B1 = 448	C1 = 8.80	D1 = 25
A2 = Peg tooth	B2 = 373	C2 = 11.72	D2 = 20
	B3 = 336		
	B4 = 298	C3 = 14.40	D3 = 10

ed. There were provisions to change the machine as well as the operation parameters. Step-wise multiple linear regression equations were obtained for predicting the threshing efficiency and invisible grain damage on the test grains.

Results and Discussions

The linear multiple regression model for threshing and invisible grain damage for T9 variety were as follows:

$$T_{th} = A_1 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \quad (1)$$

$$D = a_1 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \quad (2)$$

Where,

- T_{th} : Threshing efficiency, %
- D : Invisible grain damage, %
- X_1 : Moisture content, %
- X_2 : Cylinder concave clearance, mm
- X_3 : Cylinder peripheral speed, m/min
- X_4 : Type of cylinder beater, where X_4 = O for rasp bar beater and x_4 = 1 for peg tooth beater.

Table 2 Regression Equations for Threshing Efficiency and Invisible Grain Damage as a Function of Grain Moisture Content Only

Variety of pulse	Fitted regression equation	Value of multiple correlation coefficient (R^2)
T9	$T_{th} = 129.40249 - 7.11890\, x_1$**	0.62741
	$D = -6.95864 + 1.39190\, x_1$**	0.40546

** Significant at 1 % level.

The resulting equations for the ratio of threshing efficiency and invisible grain damage for T_g variety are given below:

$$T_{th} = 121.77845 - 7.11953X_1 - 0.66994X_2 + 0.02347X_3 + 2.97475X_4 \quad \ldots (3)$$

$$D = 4.68525 + 1.39208X_1 - 0.21800X_2 + 0.00671X_3 - 0.084918X_4 \quad \ldots (4)$$

Where T_{th} X_1 ..... x_4 are same as given in equations (1) and (2). The regression coefficients of x_3 (speed), equation (3) indicated that threshing efficiency increased with speed.

The regression coefficients of x_2 was negative (Equation 4), which indicated that as concave clearance increased the invisible grain damage decreased. The positive value of regression coefficient of x_1 and x_3 showed that the invisible grain damage increased with an increase in the cylinder speed and the moisture content (Equation 4).

Influence of Moisture Content (x_1)

As per the results of the step-wise regression analysis carried out by treating the threshing efficiency (T_{th}) and invisible grain damage (D) as dependent variable and moisture content (x_1) as independent variable (**Table 2**), the moisture content (x_1) had a significant influence on the threshing efficiency (T_{th}) and invisible grain damage (D). The regression coefficient of threshing efficiency (T_{th}) and invisible grain damage (D) on moisture content (x_1) were highly significant at 1 % level in all the cases.

Furthermore, the extent of variation in the threshing efficiency explained by x_1 alone was 63 %. The extent of variation in invisible grain damage explained by x_1 alone was 40 %.

Appendix A1 Step-wise Multiple Regression Analysis of T9 Variety of Pulse Grains for Threshing Efficiency (T_{th}) (Multiple Regression Equation for T9 variety: $T_{th} = 121.77845 - 7.11953x_1 - 0.66994X_2 + 0.02347X_3 + 2.97475X_4$*)

Variable		Multiple correlation coefficient (R)	R^2	R^2 change	Simple correlation coefficient (r)	Regression coefficient (B)	Standard error of (B)
Index	Name						
X_1	Moisture content (% wet basis)	0.79209	0.62741	0.62741	+0.79209	−7.11953	0.43132
X_2	Concave clearance (mm)	0.81133	0.65825	0.03084	−0.17561	−0.66994	0.15829
X_3	Cylinder speed (mpm)	0.82151	0.67488	0.01663	0.12896	0.02347	0.00779
X_4	Cylinder beater	0.82454	0.67986	0.00498	0.03239	2.97475	2.02308
a	(constant)					121.77545	

* Where X_4 = 0 for rasp bar beater. X_4 = 1 for peg tooth beater.

Appendix A2 Step-wise Multiple Regression Analysis of T9 variety of Pulse Grain for Invisible Grain Damage (D) (Multiple Re-ession gression Equation for T9 Variety: $D = 4.68525 + 1.39208X_1 - 0.21800X_2 + 0.00671X_3 - 0.84918X_4$*)

Variable		Multiple correlation coefficient (R)	R^2	R^2 change	Simple correlation coefficient (r)	Regression coefficient (B)	Standard error of (B)
Index	Name						
X_1	Moisture content (% wet basis)	0.63676	0.40546	0.40546	0.63676	1.39208	0.12752
X_2	Concave clearance (mm)	0.69117	0.47771	0.07225	−0.26880	−0.21800	0.04680
X_3	Cylinder speed (mpm)	0.72119	0.52011	0.04240	0.20591	0.00671	0.00230
X_4	Cylinder beater	0.72593	0.52697	0.00686	−0.13252	0.84918	0.59811
a	(constant)					−4.68525	

* Where X_4 = 0 for rasp bar beater. X_4 = 1 for peg tooth beater.

Influence of Other Variables

The other dependent variables were included in the regression model depending upon the value of F (variance ratio). The variable having a higher value of F was included first in the model and the one with the least F value was included last. The order of the variables included in the regression equation in the descending order were grain moisture content, cancave clearance, cylinder peripheral speed and cylinder beater (**Appendix A1** and **A2**).

The inclusion of another vairable in the regression equation like concave clearance (X_2), in addition to moisture content, lead to only a marginal increase, viz; less than 7 % in the extent of the variation already explained in the case of the threshing efficiency and invisible grain damage. However, the partial regression coefficient of T_{th} on X_2 was significant at 5 % level of significance.

The inclusion of X_2 in addition to X_1 accounts for 66 % of variation in threshing efficiency as against 62 % explained by X_1 alone (**Table 3**). The partial regression coefficients of T_{th} in x_2 was significant at 5 % level.

The inclusion of X_2 in addition to X_1 accounts for 48 % variation in invisible grain damage as against 40 % explained by x_1 alone (**Table 3**). The partial regression coefficient of D on X_2 was significant at 5 % level of significance.

The inclusion of X_2 and X_3 along with X_1 accounted for 68 and 52 % variation in threshing efficiency and invisible grain damage, respectively, as against 67 and 47 % that is explained by X_1 and X_2. The partial regression coefficient of T_{th} and D on X_3 was significant at 5 % level only.

The inclusion of cylinder beater did not account for an increase greater than 1 %.

Table 3 Regression Equations for Threshing Efficiency and Invisible Grain Damage as a Function of Machine and Crop Variables (V9 Variety)

	Fitted regression equation	Value of R^2
T_{th}	$= 131.01373 - 7.1189x_1^{**} - 0.57879x_2^{*}$	0.65825
D	$= 124.61273 - 7.1189x_1^{**} - 0.57879x_2^{*} + 0.01990x_3$	
T_{th}	$= 121.778.45 - 7.1189x_1^{**} - 0.56994x^{**} + 0.0237x_3^{*} + 0.29747x_4$	0.67986
D	$= -3.00825 + 1.39190x_1 - 0.21548x_2^{**}$	0.47771
D	$= -5.49423 + 1.39190x_1 - 0.21548x_2^{**} + 0.00773x_3^{*}$	0.52011
D	$= -4.68525 + 1.39208x_1^{**} - 0.21800x_2^{**} + 0.00671x_3^{*} - 0.84918x_4$	0.52697

Where T_{th} = predicted value of threshing efficiency (%).
D = predicted value of invisible grain damage (%).
X1...X4 are same as given in equations. (1) and (2).
*Significant at 5 % level.
**Significant at 10 % level.

Table 4 Independent Variables Used in Regression Analysis for T9 Variety of Pulse Grains

Variable	Mean (μ)	Standard deviation (σ)	Range of acceptable values ($\mu \pm \sigma$)
Moisture content (% dry basis)	11.6400	2.2949	11.6400 ± 4.5898
Concave clearance (mm)	18.333	6.2579	18.333 ± 12.5158
Cylinder peripheral speed (m/min)	321.7500	133.6873	321.6873 ± 267.3746

Conclusion

From the above discussion it may be concluded that the moisture content has a significant effect on threshing efficiency and invisible grain damage. The effect of concave clearance and cylinder speed on T9 variety, though numerically small, was significant at 5 % level. The prediction equations for threshing efficiency and invisible grain damage were obtained.

It should be mentioned that the above statistical analysis was based on experimental data. The experiment would be conducted with certain finite range for each of the independent variables. The regression equation obtained by using this data obviously are valid within the ranges of the variables used. This assumes that the set of values obtained experimentally constitute the samples having simple normal distribution. The range of the variables can be logically extended to twice the standard deviation on either side of the mean value, i.e., $\mu \pm 2\ \sigma$. Accordingly, the range of validity for T9 variety is given in **Table 4**.

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Storage of Farm Products in Rural Papua New Guinea

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Abstract

Papua New Guinea has a population of about 3.5 million. Majority of the population live in rural areas and their main occupation is farming. Subsistence farming is picking up in addition to big plantation crops such as coffee, cocoa, copra and palm. Food habits are almost similar throughout the country. However, the products grown in a particular location have definite share in their diet. Rootcrops like taro, yams, sweet-potato and cassava are widely consumed where imported rice may not be available. Maize and sago are also consumed in limited scale while chewing of betelnut is common everywhere.

The country's weather is highly humid and frequented by rain. As a result green crops like cabbage, cauliflower and leafy vegetables are grown throughout the year and thus constitute part of the meal.

In this paper different types of storage structures being used to store food products are discussed with their merits and demerits and possible improvement envisaged. The information is based on personal interviews with individuals in different provinces of the country. Economics of such structures are discussed in the light of social, economic and traditional values prevalent in the country.

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Introduction

In most of the developing countries during 1960's and 1970's developmental activities were mainly concentrated on industrialization, although there had been some revolutionary development in agricultural research as well. Industrialization resulted in mass emigration from rural areas to urban areas. Such situation is still prevailing in Papua New Guinea. While rural labourers are unable to find lucrative and sustained employment in rural areas, the industrial and/or urban areas are able to absorb huge numbers of migrant labour. In addition, industrialization has changed the life style of the people. In the rural areas there is little or no agro-based rural industries for employment. Agriculture, therefore, needs employment-oriented strategy to cope up with the present situation.

Agriculture is an important sector and priority must be given on all aspects of agriculture like crop and animal production, processing, storage, transport, marketing and welfare of the subsistence farmer-cum-labour. Subsistence farmers still farm in traditional ways and technical advances made elsewhere is rarely applied in farming. Traditional techniques are proven ways practised over centuries and is less efficient. Storage of surplus farm products is a major consideration and storage loss occurs due to faulty structure and/or improper care and maintenance. Food loss is the loss in the weight of food which, otherwise, would have been consumed if preserved. Any change in availability and quality of food during storage that prevents it from consumption contributes to storage loss.

In rural Papua New Guinea almost all the food products are stored in traditional structures. This paper briefly describes different type of structures used in storing farm products. The structures differ in shape and size depending upon the type of products and duration of storage.

Storage of Farm Products

If the farm products are immediately consumed after harvest there would not be much time lag between harvest and consumption. However, it is evident that the

Table 1 Monthly Rainfall, (mm) in Lae, Papua New Guinea. (1971–1985)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Av.
Jan.	283.0	215.2	352.8	106.8	196.0	298.8	224.4	524.0	96.8	315.4	200.8	243.4	174.8	87.4	196.0	234.373
Feb.	247.6	208.2	280.6	389.0	235.4	135.0	299.6	164.6	205.8	232.0	250.2	251.4	444.2	179.6	235.4	250.573
Mar.	311.4	271.4	250.2	260.4	232.0	244.4	440.0	311.6	429.0	153.6	141.8	406.6	215.0	248.6	232.0	276.533
Apr.	429.2	245.2	507.2	344.0	312.0	326.5	287.4	330.4	578.6	447.2	350.8	273.0	293.4	294.8	312.0	355.446
May	262.4	295.0	586.2	187.8	267.0	264.2	441.2	464.8	502.2	363.4	318.4	361.6	236.4	474.6	267.0	352.813
June	336.0	416.0	532.6	670.6	567.8	165.0	843.6	244.8	578.8	400.4	574.2	594.4	465.8	667.0	576.8	508.920
Jul.	216.6	362.4	647.2	499.6	414.0	206.4	377.0	677.6	784.2	585.0	341.0	512.6	583.2	768.4	414.0	492.613
Aug.	256.0	151.0	883.4	308.2	964.0	516.4	603.6	482.4	578.8	1127.8	440.8	484.2	870.8	656.2	964.0	619.173
Sep.	213.2	143.6	495.8	368.2	264.0	624.2	692.2	352.4	354.4	533.2	569.8	226.0	1042.0	310.0	264.0	430.200
Oct.	423.8	174.2	575.6	653.0	310.0	276.2	916.2	331.6	351.0	378.2	457.2	466.8	507.6	450.6	310.2	438.813
Nov.	57.8	248.4	292.8	404.0	452.4	186.4	519.0	421.4	208.6	447.4	377.0	401.0	479.0	223.0	452.4	344.706
Dec.	112.6	389.8	198.6	374.0	204.4	136.6	424.8	262.6	504.8	619.2	470.4	131.4	297.6	459.6	204.4	323.386
Av.	267.47	260.03	466.92	380.47	368.25	281.68	505.75	380.68	431.08	466.9	374.37	362.70	467.48	401.65	369.02	

(Lae Weather Station, Papua New Guinea)

prevailing weather may not always be the same throughout the year as a result of which one type of food crop has to be harvested in order to plant another type. The storage of crops is, therefore, a must to meet family consumption, seed purposes and also to fetch some profit by selling them during off-season.

Farmers in Papua New Guinea use some kind of storage facility to store their farm products for a period of few days to some months. Farm products vary from highly perishable vegetable to semi-perishable root crops and cereals like maize and sorghum. Traditional structures of different shape and sizes are in use without knowing the principles involved during storage. The main purpose of a structure is to keep a product cool and dry and to protect it from insects and rodents. Ambient temperature, product moisture and initial condition of the product are the major factors regulating the quantity and quality of the stored product. Although a farmer uses certain structures, often it is not clear to him as to why, how and under what circumstances the storage principles operate. For example, carrots perspire at least five times more than potatoes. Similarly, green crops like cabbage, cauliflower and other leafy vegetables can be stored for a prolonged period at a very low temperature, say 0°C, and at high relative humidity, say 90 to 95%. Papua New Guinea is relatively humid where high temperature prevails throughout most of the year and also the rainfall is high. The rainfall data for the location of Lae in Morobe Province of Papua New Guinea is shown in **Table 1**. A high temperature prohibits storage of food product and high humidity helps insects and micro-organisms multiply. Therefore, on-farm storage is an important activity.

Farm Products Grown and Consumed

Traditionally grown food crops are still being consumed by the majority of the people in Papua New Guinea. The trend is, however, changing in towns where industralization has started and people from other countries share their type of foods and feast together. This has resulted to a certain extent in change in the techniques of food preparation mixed with European and Asian flavours and spices.

In the swampy areas of Papua New Guinea people eat the product of sago palm. In addition, sea-food and wild games supplement the need for protein. In lowland areas staple food consists of yam, taro and cassava with green vegetables, betelnut and edible lime are a common commodity for sale in rural markets. In addition, fruits like banana, coconut, mango, pineapple, papaya, and passion fruits are also consumed as seasonal food supplements. Imported rice and some milk products are also consumed by those who can afford it.

People residing in the highlands eat mainly sweet potato, taro and their diet normally includes some *kumu* (greens). Pig meat is very common in rural areas and is cooked mainly during feast in ground oven along with vegetable, taro and chicken. The dish is locally called *Mumu*. *Pandanus nut*, *Galip nut*, peanut, green beans, cucumber and green maize are also grown and eaten. Some greens like Amaranth (*Amaranthus spp.*), swamp cabbage (*Ipomoea aquatica*), tomato and pumpkin vine-tips are also sold and consumed. In lowland market *malay apple* and *custard apple* are also sold and eaten. However, they are on seasonal basis. Among these items some are eaten fresh, some are boiled, some are smoked and some are cooked with other items grown in family gardens.

Therefore, it is important that farm products, so different in their nutritive values, market prices and availability, be stored in inexpensive, secured, and efficient structures.

Fig. 1a Maize cobs hanging on stick.

Fig. 1b A woven string bag (bilum).

Fig. 1c Holed clay pot used as storage structure.

Storage Systems

Storage of maize

Maize is one of the many corps introduced to the South Pacific countries by the early European settlers and missionaries. It is cultivated by rural families to supplement their diets of root and tuber crops. The Melanesian race of the South Western Pacific which includes Irian Jaya, Papua New Guinea, Solomon Islands, Vanuatu and New Caledonia have a staple food which comprise almost entirely of tuber and root crops.

Maize storage structure is probably the simplest of all the storage structures. The maize ears must be fully mature when cobs are harvested. Whatever surplus maize cobs are left, after family consumption, are dehusked (leaf sheaths covering the cobs are pulled upwards exposing the ears but are not ripped off). The leaf sheaths are tied together as shown in **Fig. 1a**.

Ten cobs are tied and hung on a strong stick over an oven or fire site so that smoke from the oven and fire site can reach the exposed ear. Within a month or so a layer of smoke deposit will be formed around the ear. The smoke prevents the insects from attacking the ear and the layer of deposit protects microbial infection. By hanging the cobs on a strong stick, the other end of the stick is pushed into the thatched roof of the house preventing rat damage as rats can hardly walk upside down. The diameter of the sticks is between 20-25 mm and the length is between 70 cm and 100 cm. Approximately half of this length is stuck into and tied to the frame thatched roof of houses.

A number of items, including maize cobs, are also stored on temporary basis in a woven string as shown in **Fig. 1b**. The bag is also used as a means of carrying purchased items from local market. Clay pots having holes (for air circulation) are also used for storing seeds. There is a cover to take out things from the pots. **Figure 1c** illustrates two shapes of clay pot. These are cheap and easily available but easily accessible to moisture is very easy which is the main cause of food deterioration.

Storage of pandanus nut

The pandanus fruits are found in the highlands. A round fleshy part forms the major part and houses the nuts. After harvesting the fruits the nuts are pulled out and dried. The protein content of the nuts is high and taste like peanut. A diagramatic presentation is given in **Fig. 3**.

Structure – A small hand-made structure of bamboo strip is used in storing pandanus nut. This is called *Amug-Su* and is shown in **Fig. 2**. To construct Amugsu, split bamboo strips of 50 cm long, 0.5 cm wide and 1 to 2 mm thick are used. Well spaced circular rings reinforcement of strips are tied with other strips forming a hollow space inside. Strong strings tie the strips together. One end is tied together and the other end is used as opening to fill

Fig. 2 Structure (amug su) for storing pandanus nut.

Fig. 3 Diagrammatic representation of pandanus nuts; (a) Newly harvested pandanus nut fruit from its tree. (b) Pandanus nuts removed for storage. (c) Pandanus nuts. (d) Edible pandanus nuts.

the pandanus nut. When full of nuts, the structure is placed above the fire place after patching the open extreme end with banana leaves. It is made by the villagers for their own use and it can hold 2 to 3 kg of nuts. The useful life of the sturcutre is about 5 years.

Storage of other crops

The structures used in storing such seeds in rural area are dried, mature gourds and hollow bamboo tubes although plastic and glass bottles are also seen in villages near town areas. A special variety of gourd is specifically grown for the purpose of using it either as water and oil container or to store beans and other seeds. It has a thin, long neck and the bigger middle portion is about 35-40 cm around, and is about 50 cm high. When the fruit becomes very hard, it is harvested and placed on a shelf over the fire place. Afterward the soft portion is removed where seed is stored. **Fig. 4** illustrates some gourds called *dirmingi* in local dialect in Simbu Province. The container is capable of holding 10 to 15 kg of seeds although oil and pig fat is also stored in it. The price of gourds these days vary from Kina 2.00 to Kina 4.00. The useful life of a gourd is dependent on how well they are handled.

A long, hollow bamboo tube is also used as storage structure to store seeds of wing beans and other seeds. The quantity of seeds a bamboo tube can accommodate depends on its length and diameter. Normally, the bamboo is cut with ten nodes and is made hollow inside with one end closed and other one open. Thereafter it is loaded with seeds and placed near the fire place. A bamboo tube or segment is shown in **Fig. 5**. It is traditionally made at very little cost. As long as the segment is exposed to heat and smoke, the product is safe. if the product is already infested, heat would help insects multiply.

Fig. 4 Pots for storage of seeds and oil.

Fig. 5 Bamboo segment used as storage structure.

Storage of ngali nut (canarium indicum)

Ngali nut (known in Papua New Guinea as "Galip") is important in Papua New Guinea. This nut is known to contain oil but no nutrition study is available for review.

This nut is crushed and used in banana, taro and yam pudding. The galip nuts are picked annually from galip nut trees which are perennial trees that can grow up to 30 cm high. The cross section of the nut consists of outer layer (endocarp) black in colour; the inner layer (mesocarp) is yellowish-orange; and thick kernel, very hard and brown in colour.

Inside the kernel is the endosperma and embryo surrounded by a protective coating. The nut is 40 to 50 mm long and about 30 mm in diameter. The black endocarp and yellowish-orange mesocarp is either left to rot away or is removed. Once this is done the hard brown kernel is exposed to the surrounding, its hardness helps preserve the inner edible nut (which consists of the endosperm and embryo). If the kernel is not picked, it can stay dormant on the ground for a very long time.

After the outer fleshy layers rot away or are removed the kernels are placed in baskets woven from coconut leaves. The baskets of galip kernels are transferred to the *Bella* where they are spread over the oven and fire site.

Storage structure – The structure is built like a table as shown in **Fig. 6**. The four legs or posts are dug into the ground and stand 1.5 m-2 m high above the ground. The length is 2-3 m and width 1.5 to 2 m. The surface area ranges from 3 m^2 to 6 m^2. The top surface is built of parallel set of sticks on which the galip nut are spread.

Capacity – The capacity of the storage structure is dependent on its size and age. The surface area of 6 m^2 can store up to 200 kg ngali kernel but the edible portion weighs only about ¼ of the total kernel weight thus 6 m^2 can store only 50 kg of edible nut.

Materials used – The posts and cross beams are made of wood. The floor of the *Bella* on which things are stored is made of reeds. The reeds are used for the flooring. In the past, bush ropes known as *Pinau* were used to tie the cross beams to the post and reeds so that they become strong and immovable. Nowadays nails are used instead. The overall structure almost looks like a large table over the fire and over the fire site with its post dug deep down into the ground. The cost of building this structure is K20 to K50 depending on its size.

Fig. 6 Typical kitchen of Florida islanders showing various storage structure.

Storage of root crops

Yams and taros are traditional crops. Sweet potato was introduced by early missionaries some 150 years earlier. These crops are the main staple food of almost all the Melanesian islands.

Root crops are very hard to store in the humid tropics. A similar storage structure to that of galip nut is used for the storage of yams, taros and sweet potato. The harvested yam, taro and sweet potato are stacked or packed next to each other in separate heaps on a double table-like structure. Taros are packed next to each other with their shoots and stems still on the corm but the leaves are removed. The sweet potato and yam can be stacked in a pile with the large tubers and roots at the bottom.

Storage structure – As illustrated in **Fig. 7** the structure is raised above ground level whereby the posts are dug into the ground to a depth of 0.5 m. The lowest table-like structure is approximately 0.5 m above the ground level and the highest table-like structure is approximately 1 m above ground level.

This structure can store approximately 50 kg sweet potato and 50 kg yam and 60-80 kg taro corm. The storage capacity also depends on the surface area of the table-like structure. Some rural people build larger ones.

The materials used for post and cross beam are strong wood obtained from the forest. The rope used to tie the structure is known as *Pinau* and is also collected from the forest. The structure is good for 10-15 years. The reeds are usually planted in a distance away from the house. Sometimes *Betelnut* stems are used instead of reeds. The storage structure costs approximately K10 to K15 each. The shelf-life of stored root crops is about 1 to 2 months. The tuber, roots and corms can stay longer if 2-3 mm thickness of soil is left around the skin of the roots; tubers and corms.

A farmer can make the whole set-up using wood and bamboo plus rope. The set-up lacks in keeping the product-moisture almost the same as it is exposed to ambient condition. Besides no fumigation is done.

Storage of banana

Banana is a fruit crop whose rate of respiration during ripening increases to a peak and then declines within a very short time. Such fruits are very difficult to store because they are highly perishable. Modern-day storage of banana uses refrigeration to increase the shelf-life of the fruits. However, the traditional way of storing banana is to prevent pest damage by birds and rats. The banana bunch is harvested when they are mature but not yet

Fig. 7 Yam, sweet potato and taro storage structure.

ripe. The banana bunch is taken home and hung using a rope to suspend it from cross beams of the thatched kitchen. However, nowadays 44-gallon drums are used, when empty. The hands of the banana bunch are cut and stored in the drum. Some varieties of banana are harvested only when fully ripe.

Storage structure – As illustrated in **Fig. 8** the traditional way of storing bananas using the rope is the cheapest method. But when many of the banana bunch are tied all over the kitchen, it makes movement restricted. Storage in the 44-gallon drum is good but the bananas at the bottom of the drum are squashed upon over-ripening. A piece of plywood covers the drum and a weight atop the plywood cover ensures that birds and animals are kept away from it.

Capacity – The traditional method of suspending the banana bunch from a cross beam can support one bunch only at a time. The drum storage is variable depending on the size of fruits and bunch. It can store up to 10-15 banana bunches. The total cost of materials is about K5.00.

Fig. 8 Banana storage in drum.

Fig. 9 Raised bed used for storage of fish.

Storage of fish

Fish is widely consumed in Papua New Guinea and short term storage is essential. The structure used is like a raised bed having 4 to 6 poles 50 cm high as support. The length of storage bed is about 100 cm and width about 50 cm. Lengthwise, bamboos are tied to the frame giving a 5 cm spacing in between two bamboos. A wire mesh is spread to the table and well secured. Fish is spread on top and the whole setup is kept either above the fire site or very near to it. The cost of the structure is about K35.00 and lasts about 4 to 5 years. It can hold about 12 to 15 kg of fish. The setup is shown in **Fig. 9**. It is not very hygienic beside big fishes cannot be stored unless moisture is reduced to a greater extent. However, it is simple and easy to construct using wood and bamboo.

Storage of other commodities

These food crops are stored in one of those type of structures already discussed in the preceding sections. However, a brief description of additional techniques in storing them is made here. Sago is stored in a basket made of bark of a special wood. It is semi-circular in shape and with a diameter of about 60 cm. It can hold about 40 kg of sago which can be retained for 3 to 4 months. The basket itself can last up to 10 years. It is an open basket and is prone to insect infestation in unhygenic condition. Cocoa storage islike a shed having iron-sheet roofing with proper ventilation. As cocoa is a cash crop, a businessman can afford to have concrete floor and cocoa beans in sacks are kept on wooden platform. The walls of the shed are normally made of wood. The structure is very costly and a small farmer cannot afford it. Copra is stored normally just above the drying chamber. Once copra is dried on the platform fixed above the fire pit, the fire is put off and the dried copra meat is bagged and stored on the drying platform. Necessary ventilation is provided. The drying chamber costs between K800-K1000 each. It is a costly method for small farms which is why only the big farmers can take the advantage of a drying-cum-storage structure. Breadfruit is harvested green and after roasting in the direct fire a basket-type structure woven from palm leaves is put around the breadfruit covering the fruit completely. It is then hung by a string. After about four weeks, it becomes hard and this way it can be stored for 6 to 9 months or longer. Virtually, this method costs nothing except the

time spent in weaving.

Economics of Storage Systems

Certain storage structures may be highly uneconomical when they are under-utilized. Some may be profitable but are beyond reach of the farmers. Similarly, certain structures are maintained because a farmer wants to keep them as a matter of personal pride. However, no in-depth economic study in this aspect is available. Sketchy information about some methods of storage to store cardamum, yam, peanut and maize (**Table 2**) provides some cost-benefit ratio estimates.

Other related information was obtained through interviews with villagers. The cost-benefit ratio differs by commodity. Hessian bags are costly because they are imported.

Table 2 Cost-Benefit Ratio of Some Storage Techniques

Storage method	Commodity	Fixed cost,* Kina	Variable cost,* Kina	Storage cost, Kina	Benefit, Kina	Cost-Benefit ratio
Table-type structure kept above fireplace	Yam	3.13	4.50	7.63	42.37	0.18
Hessian bags	Peanut	8.20	2.50	10.70	9.30	1.15
Cement structure of 20 kg capacity**	Cardamum	35.00	20.50	55.50	144.50	0.38
Cement structure of 125 kg capacity**	Maize	5.60	3.00	8.60	27.4	0.31

* Cost has been calculated for 100 kg commodity and 6-months period.
** Not in common use. The appropriate technology development institute in Lae make such structure.

Note: 1) Prices of yam during harvest and off season are Kina 50 and 100, respectively.
2) Prices of peanut during harvest and off season are Kina 40 and 60, respectively.
3) Prices of cardamum during harvest and off season are Kina 400 and 600, respectively.
4) Prices of maize during the harvest and off season are Kina 50 and 80, respectively.

Suggested Improvements

Traditional methods of storage of farm products by farmers in Papua New Guinea has evolved mainly on the basis of their past experience passed on to them by their forefathers. Such practices may not always be scientific. The following suggestions are made keeping the present situation in mind:

1. Keep storage room clean. Insects, rats, and mice live in dirty places.
2. Fill and seal bamboo structures with mud and/or use polythene lining inside of the structure.
3. Apply paint or whitewash on the surface of wood or bamboo. This helps in filling up microholes. Insects like these small holes.
4. The roof must be well secured to keep out rain water.
5. Area around the storage place both inside and outside should be clean and if possible disinfected.
6. Once a batch of stored farm products has been consumed or sold, the storage space should be thoroughly cleaned, dried and disinfected before another batch is put in for storage.
7. If any insecticide is to be used, it is good to make sure that they are handled properly. As the insecticides are poison, the extension worker must be consulted before use.
8. As far as possible treated wood should be used to make the structure durable, it lengthens the life of the structure.
9. As and when bright sunshine prevails, stored farm product should be dried to give chance for cleaning the structure before refilling.
10. Aerations should be adequate for storage of tuber crops.
11. Periodic inspection of the storage facility should be undertaken.

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Husk Utilized as Fuel

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Abstract

More than 16 million t of rice husk is produced in India every year. The husk has a heat content of over 3×10^3 kcal/kg. Substantial quantity of rice husk is available at each rice mill. The physical and chemical characteristics of rice husk which influence its use are discussed. The relative cost of husk evergy and using it for the operation of paddy drying and parboiling has been reviewed. Rice husk energy cost is much lower compared to the cost of energy obtained from coal and mineral oils. The devices and equipment which use rice husk as fuel are also discussed.

Introduction

An unprecedented energy consciousness has developed throughout the world during the last eight years. It started with a three-fold increase in petroleum price in 1973. An energy crisis was gradually developing during this period because of the increasing demands for commercial energy sources, particularly petroleum, and the restraints that have become operative in petroleum production. The more optimistic estimates of petroleum resources project a downward trend in production within the next 20 years. The industrialized nations which consume large quantities of commercial energy (USA 33×10^{10} J per caput/year; Australia 17×10^{10} J per caput/year; Sweden 15×10^{10} J per caput/year; West European countries 12×10^{10} J per caput/year; and Japan 11×10^{10} J per caput/year)[2] are worried because the future supplies of commercial energy, 58% of which is derived from petroleum and natural gas[9] have become very uncertain. Without the supply of adequate quantities of commercial energy these countries cannot maintain high levels of productivity and high standards of living. The developing countries which consume relatively small quantities of commercial energy (India – 0.47×10^{10} J per caput/year)[5] at present but which have initiated comprehensive programme of modernization of technology, are worried because the targets of higher level of productivity and reasonable standard of living for its people will not be achieveable if petroleum supplies become expensive or restrictive. It is now commonly realized that global cuts on energy supply will effect developing countries with inadequate fossil fuel resources most seriously. These countries will be ill-equipped to compete with the richer developed countries in the world market for fossil fuel, particularly petroleum, as the fuel supplies become restricted.

The commercial energy resources of India presents a mixed picture. The proven renewable oil resources, estimated at a little over 300 million t, are sufficient to meet the needs of the next 10 years only at the present rate of consumption. This has forced the country to import more than 50% of its oil needs, putting a very heavy strain on the foreign exchange resources. The coal and hydro-electric resources of the country are substantial but their development is a slow process. The shortage of commercial energy is, therefore, likely to continue for many years.

It is estimated that more than 200 million t of agricultural waste is produced in India every year[5]. Much of this waste is utilized as feed and household fuel. However, some of the waste is not suitable for either of the above two uses. Agricultural waste has about 50-66% heat value compared to coal. When available in adequate quantities, agricultural waste and residue can be successfully converted into heat and mechanical energy. Rice husk is one such example of a biomaterial available in considerable quantity at one location, namely the rice mill.

Availability of Rice Husk in India

The term rice husk and rice hulls are used interchangeably. The husk comprises the protective layer on the rice grain which is removed during milling to expose the grain and is the largest byproduct of rice milling constituting about 20% of paddy by weight. It is estimated that more than 60 million t of rice husk

is produced in the world each year. A considerable portion of this husk is produced in India as evident from **Table 1** below:

Table 1 Availability of Rice Husk in India

Year	Production (Million t)	
	Paddy	Husk
1970-71	60.00	12.00
1971-72	60.70	12.14
1972-73	59.77	11.99
1973-74	67.30	13.46
1974-75	60.42	12.08
1975-76	74.76	14.95
1976-77	63.38	12.67
1977-78	70.47	14.09
1978-79	82.23	16.44

Source: Times of India Directory and Year Book 1979.

Characteristics of Rice Husk

Percentage of husk – The percentage of rice husk in paddy varies widely. Some varieties yield only 14% husk while others give as much as 27% husk. For the varieties grown in India, 20% husk may be taken as a fair average.

Specific weight – Rice husk has a low apparent density varying from 122 kg to 145 kg/m^3 [3]. The apparent density increases substantially after size reduction and has been reported to be between 270 kg to 400 kg/m^3. The real density of rice husk is around 720 kg/m^3.

Colour – Fresh rice husk is golden in colour. However, exposed to weather it gradually turns to greyish brown shade.

Size and shape – The size of the husk depends on the variety, the length ranging from 5 mm to 10 mm and the width being 1/2 to 1/3 of the length. The husk, when separated from the kernal, is boat shaped. Its concave and convex shape is maintained by size reduced husk particles and this affects the bulk density.

Thermal conductivity – The whole rice husk has a 'K' value of 0.2484. When ground, the value increases slightly to 0.25 or above.[1]

Heat content – The heat content of rice husk varies substantially depending on the variety. Even in the same variety measurable differences can be observed in the calorific value of different samples. **Table 2** gives the calorific value of husk obtained from different varieties of paddy grown in India. With the calorific value ranging from about 3200 to 3800 kcal/kg (dry basis) a heat content of 3400 kcal/kg (dry basis) might be considered a fair average for rice husk obtained from different varieties grown in India.

Burning characteristic – At ordinary temperature rice husk acts as a flame retarding material. The peculiar silica-cellulose structural arrangement of rice husk results in an object that does not burn and

Table 2 Calorific Value of Husk Obtained from Different Varieties of Paddy

Variety of paddy	Higher calorific value (kcal/kg w.b)	Lower calorific value (kcal/kg w.b)	Moisture content (% w.b)	Higher calorific value (kcal/kg w.b)
IR 8	2 937.29	2 737.29	8.67	3 216.13
Patnai	3 355.43	3 044.70	10.38	3 744.06
Padma	3 105.99	2 828.96	6.62	3 326.18
Dular	3 461.31	3 161.25	10.50	3 867.38
Basmati	2 994.20	2 697.61	6.16	3 190.75

Source: Rice husk conversion to energy. FAO Agril. Service Bulletin 31, 1978.

Table 3 Composition of Rice Husk (% by weight)

Investigator	Description	Year	Moisture	Ash	Protein	Fat	Fiber	N.F.E.	Insoluble
Auriol	50 S Variety Vietnam		10.23	18.32	1.94	0.52	39.39	29.60	17.64
Borasio	Neruvialong	1928	10.50	15.68	3.62	1.20	41.10	27.90	14.50
	Tolmino	1928	10.00	18.24	2.94	0.88	42.40	25.54	17.50
	Originario	1928	10.30	18.20	3.10	0.90	42.80	24.20	17.20
	Originario	1928	9.80	17.80	3.00	0.95	42.10	26.35	16.70
	Maratelli	1928	11.00	16.10	2.98	1.10	42.90	25.92	15.50
Browne	Not known	1004	8.97	18.29	3.50	0.49	41.89	27.86	17.24
Fontilles	Not known	1941		24.91	2.19	2.69	49.22	20.67	
Fraps	Minimum	1916	6.11	14.83	1.78	0.54	31.43	24.56	13.69
	Maximum	1916	10.95	22.00	5.00	1.98	46.37	36.83	20.84
	Average	1916	8.49	18.59	3.56	0.93	39.05	29.38	17.52
Grist	Not known	1959	9.02	17.14	3.27	1.18	35.68	33.71	
Joachim	Caylon	1928	11.35	17.43	3.90	1.26	40.22	25.83	
Morrison	Not known	1956		19.10	3.0	0.8	40.7	28.4	
Morse	California	1956	7.08	25.51	2.37	0.24	42.23		
Possenti	Italian	1941	10.3	18.2					
Reed	Minimum	1917	5.00	16.4	1.75	0.51	36.57	15.27	
	Maximum	1917	9.69	22.03	4.12	1.31	46.82	20.98	
	Average	1917	7.91	19.54	2.66	0.80	41.29	18.58	
Rose	Not known	1889	8.27	13.85	2.89	0.85	38.15	34.99	
Wise	Hondourus	1916	6.62	18.70	2.56	0.50	35.99		
	Japan	1916	6.12	20.10	2.69	0.86	36.08		

Source: Rice-husk conversion to energy FAO Agricultural Services Bulletin No.31, 1978.

line-rate heat in a manner resembling that of other organic substances. If the husk pile is very thin and there is adequate air blanket turbulence, true burning of husk will occur in an atmospheric pile.

Other physical peculiarities – Rice husk surface is rough and abrasive. It is a free-flowing material with an angle of repose of about 35° and can be bulk handled easily. Rice husk has low inertia and high air resistence due to which mechanical throwing of the husk is difficult. Because of its free flowing characteristic, low weight and high air resistance, rice husk is drifted easily by wind when stored in outdoor piles. Because of its abrasive surface, the rate of wean in husk handling machinery is high.

Composition – The composition of the rice husk depends on the variety, pre-milling processes and method of removal of husk. Rubber roll shellers yield husk with higher percentage of silica and less cellulose compared to the husk obtained from a disc type huller. This is explained by the fact that the latter method (using disc huller) results in the removal of the epidermils of the rice grains along with husk, thus adding to the cellulose content of the husk and epidermis mixture. The parboiling of paddy minimizes grain breakage and germ damage. The husk is, therefore, free from these constituents to a much larger extent than chemical composition of the husk.

Table 3 gives the composition of rice husk by weight as reported by different investigators.

Fuel-related characteristics – The fuel-related characteristics of rice husk are its heating value, total carbon, fixed carbon, volatile matter, hydrogen, sulphur and silica content. For reviewing the potential of rice husk for use as fuel, the fuel related characteristics are more important than the chemical composition, given in **Table 3**. The fuel-related characteristics of rice husk vary over a wide range depending on the variety. For example, the carbon content of rice husk has been reported to vary from 38% to 55%. The ash content is quite high, exceeding 15% for all rice varieties. This affects the fuel value of the husk unfavourably. **Table 4** gives the fuel-related characteristics of rice husk as reported by different authors.

Products of combustion and air requirements – The products of combution and air requirements for complete combustion have been estimated by Maheshwari and Ojha and are reported **Table 5**.

Composition of rice husk ash – As mentioned earlier ash comprises 15 to 25% of the husk by weight. Rice husk ash is very rich in silica. **Table 6** gives the composition of rice husk ash as reported by different investigators.

Rice husk availability – Unlike certain countries in the West where high capacity rice mills process the annual product of paddy within a short period of 2-4 months, the rice mills in the paddy growing areas of India tend to operate for a larger part of the year. The rice mills in Punjab, for example, work for about nine months in a year. The availability is, therefore, spread over the year more uniformity than it would have been if the milling operation was completed within a short period.

Table 4 Fuel-related Characteristics of Rice Husk

Variety	Heating value kcal/kg	Percent					
		Ash	Carbon	Hydrogen		Sulfur	
Maheshwari-IRS	3 090	17.4	39.26	4.99	0.10	68.6	14.0
Patmai	3 560	15.8	38.92	5.10	0.12	69.3	14.9
Paoman	3 065	18.6	38.19	4.67	0.11	68.7	12.7
Dular	3 560	16.5	38.51	4.88	0.10	67.6	15.9
Basmati	2 980	16.5	38.68	5.08	0.10	66.6	16.9

Source: Rice Husk conversion to energy – FAO Agricultural Services Bulletin 31, 1978.

Table 5 Products of Combustion and Air Requirements

Variety of paddy	Percentage of products of perfect combustion				Air required per kg of husk
	CO_2	N_2	H_2O vapour	SO_2	
IR-8	16.80	69.40	13.80	0.016	3.82
Patnai	16.94	68.64	14.40	0.016	4.76
Padma	17.37	68.76	13.86	0.018	4.57
Dular	17.14	68.71	14.13	0.016	4.55
Basmati	16.95	68.66	14.37	0.016	4.73

Source: Proceedings of the International Conference on Rice Byproducts Utilization, Valencia, Spain, 1974.

Table 6 Composition of Rice Husk Ash

Investigator		SiO_2	CaO	MgO	Na_2O	K_2O_5	Fe_2O_3	P_2O_5
		1	2	3	4	5	6	7
Beagle		95.00	0.70	0.015			0.09	
Borasio		94.50	0.25	0.23	0.78	1.10	TR	0.53
		94.23	2.27	0.12	0.39	2.22	0.53	0.24
		93.95	2.28			3.15	1.01	
Fraps		96.97	0.57	0.12		0.58		0.57
Garbarino	IGN	90.27	0.94	0.67	0.40	1.25	TR	0.51
	CHAR	65.00	0.65	0.49	0.34	0.95	TR	0.37
Joschim				0.27				0.50
Jones		96.50	0.25	0.25	0.40	1.00	TR	0.30
Thai 863	IGN	95.7	2.70					0.30

Source: Rice Husk conversion to energy – FAO agricultural services bulletin 31, 1978 and Proceedings of the International Conference on Rice Byproducts Utilisation, Valencia, Spain, 1974.

Cost of Rice Husk Energy

Rice husk is obtained as a by-product of rice milling. Unlike rice bran, removal of husk does not involve any reduction in the net weight of rice. No cost is, therefore, assigned to husk production. In fact, in the rice milling operation, the disposal of rice husk if often considered to be an item of expenditure. It would, therefore, be logical to assume that rice husk is available free of cost at the rice milling site.

The use of rice husk as fuel requires its storage at the conversion site. In a rice mill, irrespective of where the rice husk is used as fuel or disposed of in some other way, the storage space requirements are likely to remain unaltered. However, the use of rice husk as fuel or any other purpose would involve the provision of additional storage space. Rice husk being a light and voluminous material is stored in the open. For 5 m high pile in the open, 1.4 to 1.5 m^2 of storage area is required per tonne of rice husk stored on dry basis.

The handling and transport of rice husk from the rice mill to the site of utilization are the major items of cost when the husk is used as fuel outside the rice mill. The man-h requirements to load and unload a truck and its rice husk carrying capacity were measured during the 1980-81 milling season at Ludhiana[4]. The summary of these observations is reported Table 7.

The holding capacity of the truck was about 40 quintals of rice husk.

On the basis of the above observations it was concluded that a truck manned by the driver and six labourers can carry two truck loads of rice husk from the rice mill to the site of utilization in one day provided the distance between the mill and the utilization site is within 10 to 15 km involving a total travel (both ways) of 50 to 60 km. The daily cost of use of a truck running about 60 km a day has been estimated at R. 280. The cost of handling and transport of rice husk, therefore, is about Rs. 35 per tonne. The market price of rice husk delivered at the site of utilization has varied from Rs. 5 to 8/quintal between January and May 1981 at Ludhiana. On the above basis, the energy cost of rice husk is compared with the energy costs of coal and diesel in **Table 8** below: In terms of the gross energy cost, rice husk is by far the cheapest material compared to fuels like coal and diesel oil. However, it can be converted into steam and mechanical power at lower efficiencies only. **Tables 9** and **10** gives the various operations:

Table 7 Man-Hours Needed to Load/ Unload Husk

Operation	Number of labourers engaged	Time (h)	Man-hours needed
Loading	6	2.5	15
Unloading	6	0.75	4.5

Use of Rice Husk as Household Fuel

The restricted supply of kerosene oil and coal have created a serious shortage of fuel in the Indian household. A survey carried

Table 8 Energy Costs of Rice Husk, Coal and Diesel

Material	Calorific value kcal/kg	Cost / t (M)	Energy cost (Rs/GJ)
Rice husk			
a. Cost price	3 060	35.00	2.73
b. Market price	3 060	60.00	4.68
Coal	5 560	425.00	18.26
Diesel	10 000	2 870.00	68.55

Table 9 Cost of Steam Production

Fuel	Calorific value kcal/kg	Cost of fuel (Rs)	Boiler efficiency (%)	Steam output kg/kg of fuel (kg)	Cost of steam production /100 kg (Rs)
Coal	5 560	425/t	50	6	141.10
Oil	10 000	2870/1000 *l*	75	16	239.00
Husk	3 060	60/t	25	2.2	108.00

Talbe 10 Comparative Cost of Fuels for Various Operations

Fuel	Cost (Rs./kg)[a]	Mechanical drying of raw paddy		Mechanical drying of parboiled paddy		Parboiling of paddy	
		Fuel required[b]	Cost of fuel (Rs)[a]	Fuel required[b]	Cost of fuel (Rs)[a]	Fuel required[b]	Cost of fuel (Rs)[a]
Diesel	1.25	5.16	6.45[c]	15.6	19.50[c]	16.4	20.5
Kerosene	1.20	5.12	6.17[c]	15.5	18.60[c]	16.3	19.6
Furnace oil	0.63	11.50	7.25[d]	34.4	21.60[d]	17.1	10.8
Coal	0.12	54.00	6.50[d]	163.0	19.60[d]	45.5	5.47
Electricity	0.15/kWh	52.40 kWh	6.88	158.0 kWh	22.70	147.0 kWh	21.0
Rice hus	0.01	50.00	0.50[c]	152.0	1.52[c]	140.0	1.40

a. One U.S. doller = 7.5 rupees, b. Kg fuel per ton of paddy, c. Without heat exchanger, d. With heat exchanger

Source: Proceedings of the International Conference on Rice Byproducts Utilization, Valencia, Spain, 1974.

out in a village community in district Ludhiana in 1979 showed that on the average 3.5×10^6 kcal of energy are used as kitchen fuel per person per year[4]. This is more than the total energy utilized to produce a good crop of wheat on one hectare of land. Rice husk cannot be used as a fuel in the conventional stove and 'chulahs', the combustion become very slow. Special stoves have been developed to burn rice husk. One such stove, reported by Singh and Garg[7] holds 4 kg of husk at a time and supplies heat smoke free flame for 1 to 2 h. The husk in this stove burns while in suspension in the combustion chamber. This is feasible because regulated amount of husk flows from the husk/holding section of the stove to the combustion chamber in the form of a continuous stress. Good air-husk contact and availability of excess air create favourable combustion conditions. Such stoves are not yet in common use. Rice husk is also used in the stoves originally designed to burn saw dust. These stoves consist of upper shell of about 25 cm dia and an inner removable pipe of about 8 cm dia. The space between the two concentric pipes is packed with a mixture of rice husk and saw dust in the ratio of 75:25. The Inner pipe is then pulled out. The inner periphery of the 8 cm rice husk and saw dust tube is then ignited from below. The central opening left after the removal of the inner tube acts as a chimney. The fire spreads outwards and upwards till the total fuel is consumed.

Briquetted rice husk apparently more suited for household fuel as it can be conveniently burnt in the conventional "angithis". The char produced from the carbonization of rice husk has been successfully briquetted with and without petroleum by-product additive. Rice husk char has also been mixed with small quantities of low grade anthracite for briquetting. Rice husk briquetted on a Swiss machine was reported to have a bulk density of 700 kg/m^3 and had at least the same calorific value as loose husk[6]. Ground husk was briquetted at Punjab Agricultural University using binding materials like molasses and sodium silicate up to 10% or more by weight at pressure exceeding 300 kg/cm^2[8] The briquettes were stable and their heat value varied from 3110 to 3568 kcal/kg. Although these briquettes were burnt in an experimental furnace, it was anticipated that these could be used as fuel in an "angithi".

Rice Husk as Furnace Fuel

The furnace design and operational factors influence the efficiency of rice husk combustion. It is possible to obtain a very high percentage of heat conversion – using rice husk as fuel. However, it is not always compatible with high capacity and high combustion temperatures. The basic criterion for the design of a furnace for burning rice husk should be to allow a thorough exposure of each husk particle to the air for efficient combustion. There are several types of furnaces in use at present which can satisfactorily operate on rice husk. These include fixed bed, flat grate, inclined grate, inclined step grate, movable inclined step grate, fluid bed, air suspended, gas combuster and dual fuel furnace.

Stoking – The methods of feeding rice husk vary with each type of furnace. Gravity feed is the simplest method of stoking. Rotary valve in conjunction with gravity feed provides a satisfactory control over feeding rate. Vibratory feeders also provide controlled stoking. A fluid bed furnace must have an in-line pressure feed. The air suspended cyclonic type furnace injects the husk either with the full amount of air or with separate feeds tangentially. Pneumatic feeding of the husk is sometimes practised. The transport air is in the range of 3.75 m^3/kg of husk. Since this is less than the amount of air required for proper combustion, additional air is to be supplied even in a cyclonically fed furnace. Arora used pneumatic feeding in the jet type furnace also[1].

Fixed bed furnace – The fixed bed furnace has no grate. The husk burns in a pile on the floor. The brick kiln can be considered as an example of this type of turnace. The fixed bed furnace does not generate high temperatures with rice husk.

Flat grate furnace – These are normally not used for burning rice husk exclusively. These are essentially meant for burning wood and coal. However, in case of short supply of wood and coal, husk is sometimes used as a supplement fuel on top of the wood and coal layer burnt over the flat grates.

Inclined grate furnaces – These are commonly used in India for burning husk. This design has been derived from the inclined step grate furnace. It is simpler and less efficient. One or more sections of the grate are used at a time, the common dimensions of a section being 3m x 0.7m. The grate is put at an incline of 45°. The material is fed at the top and as it slides down the grate combustion starts. In a satisfactorily designed and operated system, the combustion is completed before the material reaches the bottom and of the grate where it piles up in the form of burnt husk. The residue is occasionally pulled out manually from the gap provided between the lower end of the grate and the bed of the residue pit into which it opens. The combustion gases are directed to the boiler and exhausted through the chimney. Arrangements are incorporated for trapping the ash in the furnace and, subsequently, in the duct connecting the boiler with the chimney.

Such grates are commonly used with Lancashire boilers for generating process steam.

Inclined step grate furnace – This is a superior version of the inclined grate. The installation is the same as of the inclined grate. However, the mixing with the air is better, the choking of the grate is more or less avoided and the combustion can be controlled to some extent.

Other versions of the inclined step grate furnaces are pull-away grate which can be moved away from the boiler to facilitate boiler tube cleaning. The adjustable inclined step grate is a further improvement on the traditional design. In this type of furnace, the grate slope can be adjusted hydraulically to regulate the combustion zone for obtaining maximum control over combustion.

Fluid bed furnace – Beagle[6] reported a typical desing of a 26 ft diameter fluid bed reactor operating at 1 100°C and consuming about 10 670 kg of rice husk/h to produce about 36 000 kg of steam/h.

Cyclonic turbulent flow furnaces – These are efficient heat conversions for rice husk fuel. No grate is necessary in this case. High temperatures can be attained for efficient boiler operation at high steam pressure using air suspended furnace. A high air volume is used in this furnace to keep the husk in suspension.

Gas combuster – This combuster is essentially a carboniser which releases the volatiles from the rice husk for combustion and heat production. The residue is a mixture of carbon and ash in equal proportion. The design of the gas combustor is essentially similar to the design of a gasifer.

Dual fuel furnace – These furnaces have an arrangement for burning oil in addition to rice husk. Oil burner is mounted in such a way that the pneumatically injected husk is blown into the furnace around the path of the oil burner flame. The husk moving spirally starts burning and releases its own heat. The oil burner functions as a pilot burner and also provides additional fuel at peakloads.

Gasification of Rice Husk

When rice husk is burnt in the presence of limited supply of air, it gives rise to a mixture of gases, consisting principally of nitrogen, carbon monoxide, hydrogen, and carbon dioxide along with some water vapour. The composition of these gases and their heat values is given below:

Table 11 Composition of Rice-husk Producer Gas

Gas	Content
CO_2	4.2 – 7.7%
O_2	2.4 – 2.8%
H_2	4.8 – 7.8%
CH_4	7.2 – 4.5%
CO	25.0 – 22.7%
N_2	56.4 – 54.5%
Heat	1586-1350 kcal/m³

Source: Rice-husk conversion to energy. FAO Agril. Services Bulletin 31, 1978.

These gasses can be burnt as fuel in a boiler or utilized for part replacement of diesel oil in internal combustion engines. The work on gasification of biomass, including rice husk, has been started afresh in many countries recently. It is expected that gasification of rice husk would become an important method for utilizing the heat value of rice husk.

Conclusion

Rice husk is available in large quantities at the rice mills. Some of it is used by the rice mills for generating steam for parboiling and paddy drying. However, a substantial quantity of rice husk remains surplus. With the growing energy crisis, surplus rice husk, which was earlier disposed of through open air burning, is being used in increasingly large quantities as furnace fuel in many industries, primarily for process steam generation. There is substantial scope for improving the rice husk combustion by the selection and installation of the right type of rice husk furnaces. Only small quantities of rice husk is burnt as household fuel.

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Improved Equipment for Castor Bean Crop Cultivation

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Introduction

Castor (*Ricinus communis*) bean is an important commercial crop grown mainly in Andhra Pradesh, Gujarat, Karnataka, Orissa and Tamil Nadu states of India. The total area under castor bean cultivation was 175000 ha in Gujarat in 1981–82. Castor oil is used in the manufacture of soap, paint, varnish, hydraulic brake fluid, grease and lubricating oil, perfumed hair oil, medicine and in textile industry. Castor cake serves as good fertilizer. The castor bean crop can be grown under rainfed conditions. In view of the important uses of castor oil and cake and its ability to withstand drought conditions, the castor bean crop has attracted the farmers and researchers.

Indian farmers use local equipment and indigenous practices in performing various farm jobs. The equipment used by most of them are inefficient and not conducive to reducing production costs nor improving the quality and quantity of the farm products. The present paper details with some of the improved equipment which can be used in the castor bean crop cultivation. Only bullock-drawn implements have been considered for this paper even as there is a wide scope to develop complete farming system for commercial castor bean crop production.

Improved Equipment

Land Preparation

Castor bean crop requires a weed-free and fine seed bed. Normally, one operation with indigenous plough, two operations with Gandhi Allen hoe and one planking are done to prepare the seed bed under light soil conditions. However, the operations may be increased if the intensity of weeds is great. However, the use of such implements as mould board plough, disc harrow and spike-tooth harrow is rare in the preparation of land. A study conducted at the Department of Rural Engineering (Table 1) shows that mould board (Fig. 2) and indigenous iron plough (Fig. 3) can prepare fine, compact and weed-free seed bed which is evident from the data of mean weight diameter of clods, bulk density and quantity of weeds removed. However, the cost of seed bed preparation is greater, hence not significant considering the removal of weeds and better plant stand of the crop. Disc harrow, spike-tooth harrow and planker (Figs. 4, 5 and 6) can be used for secondary tillage operations. The research data are lacking to relate the degree of tilth with the set of operations of the implements and other agronomical parameters like plant stand, weed growth and yield of the crop. Therefore, there is a need to establish the degree of tilth for the castor bean crop in order to save

Table 1 Effect of Various Implements on Tillage Parameters (Texture of Soil, Loamy Sand and Moisture Content, 8.1% (d.b.)).

Observations	Indigenous plough	Mold board plough	Baroda hoe	Cultivator
Total draft, kg	133.0	103.0	108.0	104.0
Unit draft, kg/cm²	0.432	0.429	0.33	0.355
Effective field capacity, ha/h	0.0485	0.0456	0.1050	0.1079
Field efficiency, %	53.01	50.53	58.50	55.68
Mean weight diameter of clods, mm	5.55	5.32	6.04	6.79
Bulk density g/cc				
I) Before tillage	1.697	1.657	1.69	1.677
II) After tillage	1.622	1.601	1.503	1.595
Weeds turned, %	91.43	99.50	86.88	84.20
Quantity of weeds removal (green), kg/ha				
In first weeding	137.27	131.16	151.04	145.48
In second weeding	181.14	155.72	188.08	222.55

Fig. 1 A view of castor crop.

Fig. 2 Mould board plow.

Fig. 3 Indigenous plow.

Fig. 4 Disk harrow.

Fig. 5 Spike-tooth harrow.

Fig. 6 Planker.

time, energy and money. Much of Gujarat State is under rainfed condition, hence the need to standardize the operations keeping in view the concept of minimum tillage which is important from the point of view of moisture conservation.

Fertilizer Application and Sowing of Seeds

The farm yard manure is mixed in the soil by ploughing with indigenous plough or hoe. Afterwards the land is smoothened by a planker. The fertilizer is applied manually in the furrow opened by indigenous plough. The planking is done to cover the fertilizer and smoothen the land to facilitate the dibbling operations. The dibbling of seed is done by marking the furrows and placing the seed by hand.

Fertilizer drilling and planting the crop in 1 ha area require about 30 man-h and animal energy of 8 hp-h. As the seeds are drilled manually, the spacing between seeds is not exactly maintained. Moreover, the drilled fertilizer is not used efficiently due to uneven spacing between rows.

Considering the high energy consumption and inefficient fertilizer application and speed placement, the Department of Rural Engineering, Gujarat Agricultural University, Sardar – Krishinagar has developed a bullock-drawn castor bean crop planter which automatically places the seed at predetermined spacing and to drill the fertilizer near the seed for efficient use.

GAU Castor Planter

The caster bean planter (**Fig. 7**) is provided with two separate hoppers: one for seed and the other for fertilizer. An inclined plate with four edge cells is provided for metering the castor bean seeds. The shape and size of cells were decided on the basis of the ovate shape of castor seeds. The fertilizer is drilled through a horizontal star plate with four openings. The arrangement of seed and fertilizer plates is made in such a way that the delivery of fertilizer and seed coincides.

An inclined single disc is provided to open the furrow for the seed while two shoe type furrow openers are provided for delivering the fertilizer into the soil in bends on both sides of the seed. The lateral spacing between the disc furrow opener and shoe furrow openers is kept 5 cm.

The power is supplied to the inclined seed plate and horizontal fertilizer plate from ground wheel through gears. A clutch is provided to engage or disengage the power between the ground wheel and rotating parts. Two ground wheels also serve the purpose of pressing the convering for seed and fertilizer and provide balancing and stability

Fig. 7 G.A.U. castor bean crop planter.

Fig. 8 Blade harrow.

Fig. 9 Sweep cultivator ("Baroda" hoe).

to the machine. One adjustable type marker is provided to make a scratch for the ensuing trip.

Field Performance of Planter

The characteristics of the castor bean planter follow:

Actual field capacity, ha/h	0.20
Field efficiency, %	80.00
Draft, kg	70 to 80
Depth of seed, cm	6 to 7
Energy consumption	
I) Human, man-h/ha	15
II) Bullock, hp-h/ha	5
Spacing between plants, cm	60 ± 5
Gaps, %	15
Viability of seed, %	86
Fertilizer placement	Near the seed at a depth of 7.5 cm
Range of fertilizer rate adjustment, kg/ha	0.00 to 150

The economic analysis shows that the expenditure on planting seed and drilling the fertilizer in 1 ha area by the planter is Rs.46 as against Rs.61 by conventional method. Therefore, there is a saving of Rs.15 per ha which is 25% of the total expenditure. The added advantage of the use of the planter is that precision in placement of seed and fertilizer can be maintained.

Equipment for Interculture

As the castor bean crop is grown at wide spacing, bullock-drawn implements like blade harrow and sweep cultivator **(Figs. 8 and 9)** can be used for interculture.

Spraying and Dusting

The castor bean crop is susceptible to disease like wilt, root rot and bacterial blight. Therefore, the pesticides in the form of liquid or dust are applied to the crop. Knapsack sprayers **(Fig. 10)** are best suited for the application of liquid chemicals. These sprayers have provision for automatic agitation, easy to operate and sturdy in construction. There is provision of changing nozzles of different types to suit the job. For the application

Fig. 10 Knapsack sprayer.

Fig. 11 Hand rotary duster.

Fig. 12 G.A.U. sickle.

of dust, a hand rotary duster (**Fig. 11**) has been found very efficient. These dusters can be used to apply dust on all plants and the shoulder straps can be adjusted easily.

Harvesting

When one-third of the capsules of the loom are dried, the crop is considered as ripened. The looms are then harvested by a sickle. The Department of Rural Engineering, Gujarat Agricultural University, Dantiwada has developed a sickle (**Fig. 12**) which can be used to harvest the looms of castor bean crop.

Shelling

The decortication or shelling of castor bean is done by beating the dried fruits with a stick or treading under the bullock feet or tractor. These conventional methods are not only uneconomical but give poor quality of grains. Therefore, a castor decorticator was developed at the Department of Rural Engineering, Gujarat Agricultural University, Dentiwada.

The GAU castor decorticator (**Fig. 13**) consists of one raspbar cylinder. On the periphery of the cylinder, flats of 430 mm x 6 mm size are welded at the spacing of 20 mm. On each flat three round bars of 9.5 mm diameter and 430 mm length are attached. The optimum peripheral speed of the cylinder is 207 m/min which was decided by varying the speed of the cylinder and studying the parameters like shelling efficiency and kernel damage. Below this cylinder, one concave was provided which had elliptical holes of 14 mm x 7 mm size. The clearance between cylinder and concave is kept at 35 mm which was found optimum on the basis of shelling efficiency, kernel damage and capacity.

A blower is mounted for the separation of chaff and castor bean kernels. The effective flow rate of air is kept at 60.0 m^3/min by adjuting the speed.

Two sieves are provided for the separation of the kernels from cells (unshelled kernels) and other foreign material. The upper and lower sieves have round perforations of 8.75 mm and 6.25 mm diameters, respectively. The perforation fraction, inclination and speed of upper sieve were fixed at 0.378, 5° and 270 strokes/min, respectively, on the basis of optimum performance. The lower sieve retains the clean kernels and discharges to the outlet. The broken kernels and foreign material are sieved on to the ground.

Fig. 13 G.A.U. castor bean decorticator.

Performance Tests

The decorticator was evaluated for its performance at the Regional Research Station, Gujarat Agric. University Farm where the machine was used for shelling the castor bean in large scale. The results of the performance test are given below;

Capacity, q/h	2.55
Shelling efficiency, %	97.13
Cleaning efficiency, %	98.41
Visible damage, %	0.28
Grain loss, %	0.07
Germination, %	83.00
Energy consumption	
i) Electric energy	8.9 kWh/t of kernel
ii) Human energy	15 man-h/t of kernel

Fig. 14 Pick-axe.

Fig. 15 Plant puller.

Pulling of Stem

In order to uproot the plant after picking the capsules, a pick-axe (**Fig. 14**) or plant puller (**Fig. 15**) can be used. Uprooting of plant is an essential operation as the plants may put obstructions during ploughing for next crop. ■■

Run-off Farming in Ghana: A Mathematical Approach

by
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Abstract

This paper discusses the principles of run-off farming, its advantages and limitations and makes some recommendations as to how it can be applied in small scale farming in Ghana and other developing countries. In a simple mathematical approach, it shows how to estimate the quantity of water available from run-off and direct precipitation at farm level to support plant growth, since run-off farming is a purely rainfed farming.

Introduction

Agriculture is the largest user of water in the world today and accounts for some 80% of global water consumption (Biswas, 1978). Whilst the emphasis is on irrigated agriculture, rainfed agriculture is still widely practised in Ghana and many other developing countries. For irrigated agriculture, effectiveness and efficiency of water supply is important in achieving best results, whereas in the case of rainfed agriculture, the emphasis is on improving farm practises in order to conserve soil moisture to support plant growth.

Run-off farming, which is a purely rainfed farming, is the natural or artificial catchment of rainwater for crop growth. It is an old art practised for many years by small farmers in Ghana and elsewhere. In the world today, the practise of rainfed farming is being supported by scientific research and makes it possible to artificially harvest rainwater to grow crops, especially in the arid and semi-arid regions where every single drop of water means a lot. For example, in the Middle East where rainfall could be as low as 20-40 mm annually, ancient farmers cleared hillsides to increase run-off water and built rock walls along contours to collect it and ditches to convey it to lower lying fields (National Academy of Sciences, 1974).

Run-off farming has a number of advantages which include lowering the risk of crop failure under natural conditions, erosion control due to water spreading and dissipation of water energy and increasing yield without costly irrigation. However, the limitations on the choice of crops and soils, the dependence on unpredictable natural conditions, the danger of prolonged water-logging and the non-uniform distribution of water over cultivated area are its main disadvantages.

Mathematical Analysis

In run-off farming, water supply at the farm level for crop growth is obtained from run-off from catchment and direct precipitation on farm.

It should, therefore, be possible to estimate the amount of water that is made available to the crop at the farm level from these sources of supply.

The following assumptions are made in doing the mathematical analysis:

(i) The minimum crop water requirements should be less than or equal to the effective water contributed from run-off and direct precipitation at the farm level; and.

(ii) Only certain percentages of run-off and direct precipitation are available for crop use, which means that there are farm losses.

The main parameters that are considered in the mathematical analysis are:

(i) The average precipitation per growing period over catchment area and farm, p(mm);

(ii) The area of catchment, A_1 (ha);

(iii) The area of run-off farm, A_2 (ha);

(iv) The run-off index of catchment area, C;

(v) The effective percentage run-off available for crop growth, X(%);

(vi) The effective percentage direct precipitation available for crop growth, Y(%); and

(vii) The minimum crop water requirement per growing period, D(mm).

Therefore,

Volume of water from catchment per growing period = CPA_1 (1)

Effective volume of water

from catchment $= \frac{XCPA_1}{100}$ (2)

Volume of water from direct precipitation per growing period $= PA_2$ (3)

Effective volume of water from direct precipitation

$= \frac{YPA_2}{100}$ (4)

Volume of water required by crops for growth period $= DA_2$ (5)

Since crop water requirements should be less or equal to the water supply from run-off,

then $DA_2 \leqslant \frac{XCPA_1}{100} + \frac{YPA_2}{100}$ (6)

therefore $D \leqslant P(\frac{XCA_1 + YA_2}{100A_2})$ (7)

or $D \leqslant kP$ (8)

where $k = \frac{XCA_1 + YA_2}{100A_2}$ (9)

Equation (8) shows that all crop water requirements are from precipitation which implies that run-off farming is rainfed farming.

An Example

Problem: About 10 ha of land below a natural catchment area of 65 ha is a flood plain and the area is intended for run-off farming to grow rice. The soils in the area are described as deep and heavy with periodic water-logging. The average precipitation during the growing period of 90 days over the catchment area and the farm is 300 mm and assumed to be well distributed. Estimate the total amount of water available for crop growth and compare with the crop water requirements for the growing season given that the average run-off index (C) = 0.45; effective percentage run-off (X) = 40%; effective percentage average precipitation (Y) = 60%.

Solution: From equation (7)

$$D \leqslant P(\frac{XCA_1 + YA_2}{100A_2})$$

$$\leqslant 200(\frac{40 \times 0.45 \times 65 + 60 \times 10}{100 \times 10})$$

$$\leqslant 354\text{mm}$$

The minimum water requirements for a 90-day variety rice is about 350 mm for the growing season (Doorebos and Kassam, 1979). The estimated volume of 354 mm means that there is enough water supply to support the growth of the crop.

Discussion

The formula derived is to enable water supply at the farm level to be estimated from run-off and direct precipitation. This will enable decisions on crop selection to be made with some certainty. The formula can be used for both natural and artificial catchments but easier to use for the latter catchment because the physical parameters used in the formula are easier to determine.

Generally, there are a number of methods for predicting run-off from small catchments and one of the most widely used is the rational method which is also used in this analysis. The problem with the use of this formula is the apparent difficulty in selecting the appropriate run-off index, the effective percentage run-off and effective percentage precipitation on the farm. The selection of these parameters will very much depend on vegetation, soil type, topography and climate in the area and some experience, also.

Recommendation

There are no artificial catchments built for run-off farming in Ghana today and even though it may be a thing of the future, small farmers should be encouraged to take advantage of natural conditions for water supply and conservation for plant growth. It must be noted that already, many small farmers living around the Volta Lake practise something very similar to run-off farming. Briefly, what is done here is that the farmers crop very close to the edge of the lake and as the lake recedes, they follow it and when it rises, they retreat. Agriculture in Ghana today is largely rainfed and lowering the risk of crop failure can be achieved by more innovative farm practises such as run-off farming.

Conclusion

Artificial rainwater harvesting for agricultural purposes is still a thing of the future in Ghana but run-off farming under natural conditions remains to be practised. It is hoped that this simple mathematical approach to comparing water availability at the farm level and crop water requirements will help in the choice of crop for this type of farming.

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Effect of Restrained and Un-Restrained Linkage on Implement Performance

by
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Introduction

Since World War II, integral implements have become increasingly popular, their attachment with tractor is either by restrained linkage or un-restrained linkage. In the case of restrained linkage, the gauge wheel is lacking, hence uniform depth on undulating fields cannot be obtained. However, better weight transfer is obtained. In this system draft can be controlled automatically. In the case of un-restrained linkage, the gauge wheel is present, hence uniform depth on irregular surface of the field is obtained. In this system draft is not constant.

Heithshu (1952) studied the kinematics of tractor hitches both free link operation and restrained link operations. From his study the following conclusions are drawn:

1. The position of the implement relative to the tractor, and not the type of hitch, determined the weight transferred to the rear wheel of the tractor;
2. Weight transfer within the tractor depends upon line of draft, its angle and magnitude and relation to point 'C' (point at centre of contact of wheel with ground);
3. The vertical component of P is added to total downward forces of tractor, and distribution of this load is determined by the point of application of P to the tractor;
4. In a free link type of hitch the length of links and angles formed in both horizontal and vertical planes have great effect on implemet performance;
5. The tractor mounted implement with a steep line of draft shows greater advantage in the field because of a greater weight transfer;
6. The free link or un-restrained linkage type of hitch is sensitive to changes in the line of draft; and
7. As the implement moves to the left, the instantaneous swing point (VHP) moves to the right and vice versa.

The objective of this study was to evaluate the effect of the restrained and un-restrained linkages on implement performance. This type of study will provide guidelines for farmers' choice upon the selection of either mould board plow with gauge wheel or without gauge wheel, depending upon type of soil so that they could derive maximum benefit from mechanized cultivation.

Method of Study

The 3-link hitch has many advantages over trailed hitch such as manoeuvrability, weight, cost and transport ability. And yet there were problems of uniform depth control over uneven surfaces of the field and uniform draft over the field with different strength characteristics. Therefore, to solve these problems the 3-point link with gauge wheel and without gauge wheel was used. To evaluate the effect of free link and restrained link on performance of the implement, the following parameters were studied : moisture content; type of soil; slippage and travel ratio; pull; depth and width of cut; speed of operation; effective field capacity; volume of soil disturbed; weight transfer and addition; and tilth condition.

Moisture Content

With any given structure, the soil properties of resistance to compression and shear, as well as friability, plasticity and stickiness depend upon moisture content which is the most important soil factor contributing to soil metal friction. At low moisture content the soil is hard and very coherent because of cohesion effect among the dried particles. Clods will be produced if the soil is tilled in this condition. As the moisture content increases, water molecules are adsorbed on the surface of the particles and decrease the co-herence and impart friability to the soil

Table 1 Moisture Percentage on Wet Weight Basis

(mean: 9.56)

Depth m	Weight of materials (g)						Percentage of $Mc = \frac{Ww - Dw}{Dw} \times 100$
	Wet sample + container	Dry sample + container	Container	Wet soil	Dry soil	Water	
0.305	70	64.5	19.1	50.9	45.4	5.5	12
0.305	93	85.2	20.0	73	65.2	7.8	11.96
0.178	138	131.1	27.8	110.2	103.3	6.9	6.68
0.178	88	83.2	20.8	67.2	62.4	4.8	6.69

mass. The zone of friable consistency represents the range of soil moisture in which conditions for tillage are at an optimum. Soils are usually in good tilth when they are friable. The individual granules are soft; cohesion is at a minimum. There is sufficient moisture between individual particles to minimize the cohesion effects that are dominant in the zone of harsh consistancy. Nichols (1931) divided soil moisture content into three phases: friction, adhesion, and lubrication. **(Fig. 1)**

In the friction phase, adhesive forces are small and the coefficient of friction is essentially independent of moisture content. Soils in friable condition usually have moisture content in this range. Moisture content in this phase is 0-10% in silt loams and 0-15% in silty clay loams. In the adhesion phase moisture films develop between the soil particles and the metal thus creating adhesive forces that cause apparent coefficient of friction to increase rapidly with moisture content. When the soil has enough moisture to act as a lubricant, the coefficient of friction decreases as more water is added.

To evaluate the moisture content of the experimental plot, soil samples before plowing were collected and weighed in physical balance and then kept in an oven for 24 h at 105°C. After 24 h the soil samples were weighed and moisture content was calculated **(Table 1)**.

Fig. 1 Soil moisture content and the coefficient of friction between soil and steel.

Type of Soil

The type of soil has profound effect on the performance of the farm implement. Clay soils offer more shearing resistance to the tillage tools as compared to that offered by sandy soils. The reaction of the soil forces applied by tillage tools are affected by the resistance of the shear, adhesion and frictional resistance. As the tool advances, the soil in its path is subjected to compressive stresses which, in a friable soil result in a shearing action. Shear strength composed of cohesion and internal friction, has an important influence on the draft of a tillage tool. From Coulombs equation for shear strength it is obvious that shearing stress of cohesive frictional soils is greater than the frictional soil. It was, therefore, imperative to determine the type of soil of the test plot. The soil samples were brought to the Department of Agricultural Chemistry, Sind Agriculture University, Tandojam to determine the type of soil. The soil samples were subjected to mechanical analysis. Results indicate that the soil was clay loam.

Slippage

The slip of a driving wheel defines the magnitude and efficiency of tractive performance. Slip (travel reduction) of the drive wheels is the primary independent variable. Both tyre efficiency and dynamic ratio are a direct function of the amount of slip of the drive wheels. Dynamic ratio may vary from over 0.80 at 15% slip on concrete to as low as 0.30 at approximately 30% slip in sand. Slip is calculated from the following formula:

$$\text{Slip} = 100 \frac{(1 - As)}{S_0}$$

As = Aclual travel speed in miles/h with load

S_0 = No load travel speed

or

Slip = 100 (Wheel revolutions with load-revolutions without load) / (Wheel revolutions with load)

Slip = 100 (Distance travelled without load-distance travelled with load / (Distance travelled without load)

Slip = 100 (Velocity without load-velocity with load) / (Velocity without load)

Slip is expected to increase with increasing load. Power efficiency decreases as slip increases. To evaluate the slippage of the rear wheel drive tractor, loamy soil on Latif Farm of the University was selected. A 30-m distance was measured and the tractor without load and with load under both free link and restrained link was run over that distance. The revolutions without load and with load were counted and recorded to calculate slip in percent **(Fig. 2)** and **(Tables 2 and 3)**.

Travel ratio = (Velocity with load) / (Velocity without load) **(Tables 4 and 5)**

Fig. 2 Measuring of wheel slip.

Talbe 2 Slip in Percent (un-restrained linkage)

	Revolutions to cover 30 m distance		Percent slip
	without load	with load	
	7	7.50	6.66
	7	7.60	7.89
	7	7.45	6.40
Average	7	7.51	6.86

Talbe 3 Slip in Percent (restrained linkage)

	Revolutions to cover 30 m distance		Percent slip
	without load	with load	
	7	8.75	20.0
	7	8.90	21.34
	7	8.70	19.54
Average	7	8.78	20.29

Table 4 Travel Ratio (restrained linkage)

	Revolutions to cover 30 m distance		Travel ratio
	without load	with load	
	7	8.75	0.8
	7	8.90	0.78
	7	8.70	0.80
Average	7	8.78	0.79

Table 5 Travel Ratio (un-restrained linkage)

	Revolutions to cover 30 m distance		Travel ratio
	without load	with load	
	7	7.50	0.93
	7	7.60	0.92
	7	7.45	0.93
Average	7	7.51	0.93

Depth and Width of Cut

Depth and width of cut are factors that may affect draft and energy utilization efficiency for a specific soil condition. The effects of these parameters vary with different types of implements and with different soil conditions. The depth and width of cut in un-restrained and restrained condition of the implement was measured with steel ruler (**Tables 6** and **7**).

Table 6 Depth and Width of Cut (restrained linkage) (unit: cm)

	Depth of cut	Width of cut
	30.5	101
	31.0	100
	30.0	101
Average	30.5	100.66

Table 7 Depth and Width of Cut (un-restrained linkage) (unit: cm)

	Depth of cut	width of cut
	18	100
	17.4	101
	17.5	99
Average	17.63	100

Speed of Operation

The speed of operation has a profound effect on implement performance. The maximum permissible forward speed is related to such factors as nature of operations, condition of field and amount of power available. Increased forward speed increases the draft with most tillage implements because of the rapid acceleration of any soil that is moved appreciably. The soil thus accelerated produces acceleration forces that increase normal loads on soil engaging surfaces, thereby increasing the frictional resistance. To evaluate the speed, a distance of 30 m was measured and ranging poles at the two ends of the measured distance were fixed, and time taken for that distance was recorded by stop watch, the speed was calculated from the formula:

Speed m/s = 30 m test run/time taken for test run (s)

(Table 8)

Effective Field Capacity

Effective field capacity represents the actual average rate of coverage in acres or ha/h by the machine and is the function of the rated width of the machine, percentage of rated width actually utilized, speed of travel and amount of field time lost during the operation. The effective field capacity is calculated from the formula:

$$C = \frac{5280 \times SWE}{43560 \times 100}$$

$$= \frac{SWE_f}{825} \text{ [EPS system]}$$

or

$$C = \frac{SWE_f}{1000} \text{ [MKS system]}$$

where,

C = Effective field capacity in acres or ha

Table 8 Speed of Operation

Type of Linkage	Average time taken for 30 m strip (s)	Speed (km/h)
Restrained linkage	35	3.09
Un-restrained linkage	31	3.48

S = Speed of travel in miles or km/h

W = Rated width of implement in feet or m

E_f = Field efficiency which is 75 to 90% for mold board plow

Volume of Soil Disturbed

The volume of soil worked is the criterion of implement performance and is the product of depth of cut and field capacity, hence the width and depth of cut were measured *in situ.*

Results and Discussion

Moisture Content

The shear strength, friability, plasticity and stickiness depend upon moisture content. **Table 1** reveals that moisture content of the test plot was 9.56% which shows that the soil was in a friable condition which is reasonably quite good for plowing because in this range of moisture the adhesive forces are small and the coefficient of friction is essentially independent of moisture content.

Type of Soil

The soil samples of the test plot were analyzed in the laboratory of the Department of Agcitultural Chemistry, Sind Agriculture University, Tandojam and the results obtained show that the soil was clay loam.

Slip

Table 2 revelas that the slip for un-restrained linkage was 6.86% and **Table 3** shows that slip for restrained linkage greater load was exerted by the implement due to deep penetration of the plow, hence better dynamic ratio was obtained.

Pull

Fig. 3 Measurement of angle ϑ.

Fig. 4 Measuring of rolling resistance (two-force)

Table 9 Tractive Effort (H) (restrained linkage) (lbs)

	1	2	3	Mean
	2400	2500	2400	2433.33
	2500	2600	2600	2666.66
	2600	2800	2700	2700
Mean	2500	2633.33	2566.66	2566.66

*Tractive effort=2566.66 lbs=1164.54kg

Table 10 Tractive Effort (H) (un-restrained linkage) (lbs)

	1	2	3	Mean
	1400	1400	1500	1433.33
	1500	1500	1600	1533.33
	1500	1500	1550	1516.66
Mean	1466.66	1466.66	1550	1494.44

*Tractive effort = 1494.55 lbs = 678.05 kg

Pull is the total force exerted by the tractor on the implement. With tillage implement, it is generally at some angle above the horizontal, and it may or may not be in a vertical plane parallel to the line of motion. Pull for un-restrained and restrained linkages was determined from the following formula:

P for un-restrained linkages $= H - R$

$\therefore P = H - R = 1164.549 - 156.282$
$= 1008.67$ kg

P for restrained linkages $= H - R$

$\therefore P = H - R = 1164.549 - 156.282$
$= 1008.67$

This pull is assumed to be the pull of tractor pulling implement without towed tractor. H and R were measured by using RNAM procedure **(Figs. 3 and 4) (Tables 9, 10 and 11).**

Depth and Width of Cut

In the case of unrestrained linkage the gauge wheel was fitted to the implement. The average depth of cut and width of cut were 17.63 cm and 100 cm. For the restrained linkage these were 30.5 cm and 100.66 cm.

Table 11 Rolling Resistance (R) (towed Tractor) (lbs)

	1	2	3	Mean
	300	300	500	366.66
	200	500	400	366.66
	400	300	200	300
Mean	300	366.66	366.66	344.44

Rolling resistance of towed tractor = 344.44lbs = 156.28kg

Speed of Operation

The test tractor was operated in low third gear with 1500 rpm of the tractor engine. The time to cover the distance of 30 m was recorded by a stop watch. The average speed for the un-restrained and restrained linkage were 3.48 and 3.08 km/h **(Table 8)**, respectively, which is within acceptable range of speed for mould board plows.

Effective Field Capacity

The width of the cut of plow before operation was 100 cm. The experimental cut for the un-restrained and restrained linkages was 100 cm and 100.66 cm, respectively. The effective field capacity in both cases was 0.28 and 0.42 ha/h, respectively.

Volume of Soil Disturbed

The volume of soil disturbed = E.F.C. x D x 10000. For un-restrained linkages the volume of soil disturbed was 506.243 m^3 and for a restrained linkages, 1293.2 m^3.

Weight Transfer and Addition

Weight transfer is the amount of weight transferred from front wheels of the tractor to the real wheels of the tractor when tractor is rear wheel drive and the implement is rear mounted or trailed. Weight addition is the amount of weight transferred from implement wheel to the rear wheel of the tractor.

$$\text{Weight Transfer} = \frac{P \times Y}{L}$$

P for un-restrained linkage = 521.77 kg

P for restrained linkage = 1008.67 kg

Y for un-restrained linkage = 0.7 m

Y for restrained linkage = 0.7 m

L (Wheel base) in both cases = 2 m **(Table 12)**

∴ Weight transfer for un-restrained linkage

$$= \frac{521.77 \times 0.7}{2} = 182.62\text{kg}$$

and weight transfer for restrained linkage

$$= \frac{1008.67 \times 0.7}{2} = 353.03\text{kg}$$

weight addition for both the cases = P sin θ.

Where P is pull and is 521.77kg for unrestrained linkages and 1008.67 kg for restrained linakges, θ was calculated from **Fig. 3** and was 8°. Hence, weight addition for un-restrained linkage = 521.77 x Sin 8° = 521.77 x 0.13 = 67.830 kg and for restrained linkage = 1008.67 x 0.13 = 131.12 kg.

Table 12 Height of Line of Pull (unit: m)

Restrained linkage	Un-restrained linkage
0.70	0.70

Table 13 Summary of Results

Parameters	Restrained linkages	Un-restrained linkage
Slip %	20.26	6.86
Width of cut (cm)	100.66	100
Depth of cut (cm)	30.5	17.63
Effective field capacity (ha/h)	0.42	0.28
Hitch height (cm)	70	70
Volume of soil disturbed (m^3)	1 293.2	506.24
Tractive effort (H) (kg)	1 164.54	678.05
Rolling resistance (kg)	156.28	156.28
Pull (kg)	1 008.26	521.77
Weight transfer (kg)	353.03	182.62
Weight addition (kg)	131.12	67.83
Dynamic weight of rear wheel R_R = (kg)	1 903.02	1 672.37
Coefficient of traction (R/R_R)	0.52	0.31
Travel ratio	0.790	0.93
Tilth condition	Fine	Coarse

Tilth Condition

Different methods for determining the tilth condition have been adopted but among them photographic technique is the simplest possible method to describe tilth condition. Therefore, photographs of tilled soil with un-restrained and restrained linkage were taken. It is obvious from the photographs that the tilth condition was fine under restrained linkage and coarse under un-restrained linkage.

Conclusions and Suggestions

The following conclusions are drawn.

1. Slip was greater in case of restrained linkage;
2. Depth of cut was greater in case of restrained linkage;
3. Effective field capacity was better under restrained linkage;
4. Pull was also double with restrained linkage,
5. Weight transfer was greater with restrained linkage;
6. Weight addition was better un der restrained linkage system;
7. Travel ratio was less in case restrained linkage as compared with that of un-restrained linkage; and
8. Tilth condition was fine under restrained linkage system. The overall conclusion was that the implement performance was much better under restrained linkage system. Summary of results is shown in **Table 13**.

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ABSTRACTS

The ABSTRACT pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors. The requests from the readers for publishing the whole contents among the articles introduced here may also be sent to editorial staff. Regarding the article of many requests, the publication of whole contents will be reconsidered.

Systems Approach to Cropping Pattern and Irrigation Water Management: B.K. Bala and A.T.M. Ziauddin, Prof. and Assoc. Prof., respectively, Dept. of Farm Power and Machinery, Bangladesh Agricultural Univ., Mymensingh, Bangladesh.

Previous efforts in the systems approach to cropping pattern and irrigation water management are reviewed and critically examined. A linear programming model for optimal cropping pattern and irrigation water management is developed. The model has tried out at the Agriculture Farm, Bangladesh Agricultural University, Mymensingh. The results of the trial show that the implementation of the programme for optimal cropping pattern, irrigation, draft power, labour (permanent and hired), fertilizer and land utilization within the constraints of these resources available could be expected to increase production. Sensitivity analysis of the constraints that affects the optimal solution is presented. This study implies that the linear programming model can be of great value in the design and analysis of farm level crop production system in less developed countries like Bangladesh.

Development of a Bullock-operated Dung-cleaner: Hem Chandra Joshi, Scientist, S-2, (Farm Machinery and Power) and Har Narain Pandey, Scientist, S-2, (Livestock Production and Management), Indian Veterinary Research Institute, Izatnagar, U.P. 243122, India.

The various functional components of a bullock-operated dung cleaner were decided and its first prototype was developed. The developed machine was tested for the collection of dung from the flat surfaces and necessary modifications were incorporated for its efficient working. The machine rests over two ADV pneumatic wheels of size 8.00-19 which are attached to standard ADV axle of bullock-carts. The machine has a collection blade of size 170 cm x 40 cm which can be lifted or lowered through a suitable lever mechanism. The developed machine was tested and its capacity on dung collection was found to be 73.92 square meter per minute.

Rationale of Reducing Noise, Dust and Vibrational Fatigue in Mechanized Farms: A.C. Srivastava, Scientist, Agricultural Engineering Division, Indian Institute of Sugarcane Research, Lucknow, India.

Farm Mechanisation is no longer a myth. There is a heavy competition in manufacturing, marketing and using larger and still larger size of farm machinery in agricultural farms. These machines have a built-in problem associated with noise and vibration; and suspended dust particles which are hazardous to human health. Tractor operators, who have worked in a mechanized farm for a longer duration, usually suffer from listening at a higher pitch, asthma and spinal cord injury.

This paper discusses the research findings of various organizations reported at different stages along with the possibilities of reducing such injuries.

A Comparative Study of the Performance of Different 100 cc Motorcycles as a Farmer's Light Vehicle: Abdul Razzaq, Senior Subject Matter Specialist (Engineering), Adaptive Research Farm, Sheikhupura, Pakistan.

The study was carried out to assess the comparative performance of different 100-cc motorcycles used in farming communities. Three types of motorcycles viz, H100S Honda, A100X (Special) Suzuki and YB100 Yamaha were studies. It was found that the operational cost of Yamaha was less comparatively. The running cost of Honda was more than Suzuki and Yamaha. Suzuki was the cheapest in respect of price. However, Honda tended to surmount road obstructions more easily and also possessed weight carrying and climbing ability on higher side. ■■

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Egyptian Society of Agricultural Engineering
The First Annual Conference
February 22-24, 1988, Cairo Egypt

The opening plenary session.

The conference was held under the title "Spotlight on Agricultural Engineering in Egypt and the Arab World". Attended by 250 members it discussed subjects which cover the following aspects.

- Farm mechanization, problems and application;
- Irrigation and drainage, development;
- Economics of farm machines, and related social interaction;
- Farm buildings and environmental control; and
- Engineering analysis and planning of agricultural production systems.

Two round table discussions were held to cover two main problems.

- Local manufacture of agricultural implement; and
- Training present, future.

The organization committee was formed by Dr. Said Yosef Gohniem, Dr. Abdel Ghany El Gindy and Dr. Samy Mohamed Younis.

Amir U. Khan Has Been Awarded the 1988 Kishida International Award

Amir U. Khan, an agricultural mechanization adviser at the Agricultural Research Center in Cairo, Egypt, has been awarded the 1988 Kishida International Award by the American Society of Agricultural Engineering (ASAE).

The award was presented during the Society's 1988 International Summer Meeting, June 26-29, Rushmore Plaza Civic Center, Rapid City, South Dakota. The Kishida International Award is presented annually to a member of ASAE for "outstanding contributions to food and fiber production, improved living and education of people outside the United States of America."

Established in 1978, the award is sponsored by Shin-Norinsha Co., Ltd. of Japan, publisher of Agricultural Mechanization in Asia magazine and other publications. It is named after Yoshikuni Kishida, founder of the publishing firm and widely acclained pioneer in agricultural mechanization in Japan and Asia. Khan is presented the Kishida International Award in recognition of "his outstanding contributions to engineering, mechanization and technology related programs throughout the world."

Internationally, Khan is most recognized for his leadership in the development of the International Rice Research Institute's (IRRI) axial-flow grain thresher. Widely used by rice farmers, 60,000 threshers are currently being used in southeast Asia alone. Khan has also worked with philanthropic groups and members of Congress to help set policies for improved technology transfer to developing countries.

Khan received the "Lesser Developed Country (LDC) Innovation Award" at the 1984 ASAE Winter Meeting. He was also the recipient of the "International Inventor's Award for Industry" from H.M. Carl Gustaf, King of Sweden in 1986.

ASAE is a professional and technical organization of members worldwide interested in engineering knowledge and technology for agriculture, associated industries and related resources. Headquartered in St. Joseph, Michigan, the Soceity's membership includes 11,000 members in 50 states and over 100 countries.

Intensive Weed Management Course by the International Plant Protection Center Oregon State Univ.
July 10-28, 1989
Corvallis, Oregon, U.S.A.

The International Plant Protection Center at Oregon State University (USA) will again conduct an intensive 3-week, "hands-on" Weed Management Strategies shortcourse in 1989.

The course, well-received in 1986 and 1987, emphasizes appropriate research strategies and methods for developing countries. It is specifically designed for specialists in agriculture and offers practical information ranging from familiarization with equipment to socio-economic considerations.

"Participants in previous courses were enthusiastic about the experience they gained," said IPPC Director S.F. Miller. "We were pleased to attract participants from 10 countries on three continents, interchange information with them and, we felt, provide them with applicable knowledge that was useful both to their nation's de-

velopment and to their personal work and careers."

The 1989 WMS course, will utilize university facilities including a nearby 90-ha research farm where participants will observe and discuss ongoing research and then design and conduct their own weed management experiments.

Research results will be reported in a classroom where activities are more "interactive information sharing sessions than stiff, one-way directed lectures," according to M.D. Shenk, IPPC weed scientist and training coordinator.

Each WMS course participant receives a mini-library of up-to-date weed management technical publications (worth approximately US$272) for use during the course and, after course completion, free shipment to the participant's duty post.

The WMS course is designed for researchers, graduate students, and government specialists involved with conducting or administering weed management programs, particularly in situations where resources are often limited. Participants need a command of spoken English and the minimum of a bachelor's degree or equivalent.

The basic course fee (tentatively US$2,900) covers matriculation, individual rooms, most meals, and all supplies and transportation during the course. Participants are responsible for their own financial support including the course fee, transportation to and from Oregon, and personal expenses, IPPC is not able to offer scholarships.

A free descriptive brochure is available from: WMS89 Course, International Plant Protection Center, Oregon State University, Corvallis, OR 97331-3904/USA.

11th International Congress on Agricultural Engineering
September 4-8, 1989
Dublin, Ireland

Provisional Programs:

The Congress will cover the following themes

1. Land Use
* Use of peatlands, remote sensing;
* Soil/water engineering and transportation;
* Environmental and biotechnological aspects.
2. Agricultural Buildings
* Modern and future designs;
* Technological and environmental considerations;
* Engineering control systems.
3. Agricultural Mechanization
* Soil cultivation and seedbed preparation;
* Crop harvesting, storage and on-farm processing;
* Fertilizer and pesticide application.
4. Power and Processing
* Electronic control systems, robotics;
* Off-farm processing of agricultural products;
* Topic to be announced.
5 Operations Research
* Developments in computers and information technology;
* Ergonomics and safety, rural sociology;
* New techniques in teaching, research;
* And development.

Call for Papers and Posters:

Abstracts, preferably in English and not exceeding 200 words, should be submitted to Mr. John Carvill, before September 30th, 1988. Each abstract will be reviewed and the decision of the editorial board will be conveyed to each author.

The Armand Blanc Prize will be awarded for the best paper from a young researcher.

For further information please contact Professor Paul McNulty at the Agricultural & Food Engineering Department, University College Dublin 2 Ireland. ■■

ERRATA

AMA Vol. 19, No. 2, Spring 1988 "Development and Fabrication Techniques of Improved Grubber", p. 45, Col. 3, Lines 5-6 should read:

$$L = L_1 + L_2 + L_3 + (\frac{\pi}{180}\alpha)(r + Kt) \quad \ldots\ldots\ldots\ldots \quad (10)$$

Ditto, P. 46, Col. 1, Line 1 should read:

The dimensions $L_1 + L_2 + L_3$ and α

Ditto, P. 46, Col. 2, Lines 1-7 should read:

Right and left side tyne:

$$L = 130 + 60 + 10 + \frac{\pi}{180}(180 - 0) \times (40 + 0.5 \times 10) + \frac{\pi}{180}(180 - 135) \times (10 + 0.5 \times 10) = 352 \text{ (say 350)}$$

Central tyne:

$$L = 70 + 10 + \frac{\pi}{180}(180 - 0) \times (40 + 0.5 \times 10) = 220 \text{ mm}$$

Appropriate Technology for Developing Countries

(Australia)

by A.J. Francis and D.S. Mansell

This book has developed from the notes prepared by one of the authors for a Master's program in development technologies which has been running at the University of Melbourne since 1981 with generous support from the Australian Development Assistance Bureau and UNESCO. The program was intended primarily for engineering teachers from developing countries, to give them an insight into the general problems of national development and, in particular, into how engineering technologies of an appropriate kind can contribute to that development. It has also, however, proved attractive to practising engineers from these countries.

In some areas of technology, notably food production, manufacturing and energy, therefore, we have been obliged to be very selective; and some areas of engineering technology of great value for poor countries and people (bio-medical engineering, for example) have not been touched upon at all. On the other hand, since we were writing with engineering teachers primarily in mind, there is a chapter on engineering education, which can be looked on as a "software" technology of central importance, as distinct from the "hardware" with which most of the book is concerned. But throughout it we have tried to relate our discussion of specific technologies to the basic principles of appropriateness outlined in Chapter 2.

Size: 23.5 cm x 16.5 cm, 259 p, soft-cover

Published by Research Publications Pty. Ltd., 12 Terra Cotta Drive, Blackburn, Victoria 3130, Australia

The Proceedings of the National Conference on Energy in Production Agriculture and Food Processing Held at the Punjab Agricultural University, Ludhiana, India on October 30-31, 1987

(India)

The Proceedings contains over 55 papers by leading researchers and administrators and runs in over 500 pages. The Proceedings contains wealth of information on the following topics: Energy perspective, norms and scenario; Energy requirements in crop production; Energy requirements in livestock production; Energy requirements in rural households; Energy management and conservations; Energy requirements in food processing; Alternative energy sources and Computer application in energy studies.

Prices for non-members and libraries: US$44 (airmail) or US$36 (seamail).

Published by Indian Society of Agricultural Engineers, 305-306, Satya mansion, Community Centre, Ranjit Nagar, New Delhi 110 008, India

Trickle Irrigation for Crop Production – Design, Operation and Management

(The Netherlands)

F.S. Nakayama & D.A. Bucks

This multi-purpose handbook brings together current knowledge from various engineering and scientific disciplines (crop, hydraulic, irrigation and soil sciences) needed for understanding the trickle irrigation system for crop production. The two dozen contributors are experts on the various subjects, which range from the basic to the more practical aspects of trickle irrigation. Major topics include design, operation and management – with individual chapters convering historical development, emitter construction and clogging, system design, water and salt distribution, automation, water treatment, irrigation scheduling, maintenance, fertilization and salinity.

The book greatly expands the scope of research papers, reviews, extension bulletins, and updates earlier text with new information on trickle systems. A multi-disciplinary approach has been taken on a multi-faceted subject. The material contained in the book is the most comprehensive yet developed on the topic. Illustrative sample problems and solutions provide field operators and extension personnel with information needed to install and maintain trickle systems. As it is up-to-date, it is useful as a teaching and reference source for students, manufacturers and irrigation system operators as well as irrigation and crop specialists, and consultants.

Size: 25 x 17 cm, X+384p, hardbound

Price: Dfl. 160.00

Published by Elsevier Science Publishers, P.O.Box 211, 1000 AE Amsterdam, The Netherlands

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□ Dr. S.R. Verma, a co-operating editor from India, will stay in Nigeria for next two years. He was invited by the Commonwealth Secretariat, London to help the Government of Nigeria in the establishment of a National Centre for Agricultural Mechanization. He will continue to serve as a co-operating editor for AMA in Nigeria.

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