*International specialized medium for agricultural mechanization in developing countries*

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# AMA

## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.20, NO.4, AUTUMN 1989

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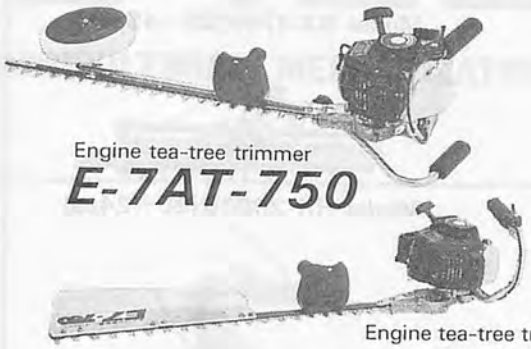

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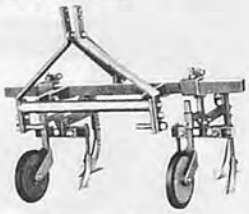

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This publication, published quarterly, has an objective to promote agricultural mechanization in developing countries. Its readers consist of so many people in various fields such as farmers, dealers, manufacturers, researchers, government officials, students, etc. not only in Asia but also in the whole world. To enrich contents and to reflect many opinions, we want contributors for **Agricultural Mechanization in Asia" Africa and Latin America.** Articles, comments, investigations, reports and so on will be received with open arms. If you hope to contribute, contact us without delay.


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# AMA

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## EDITORIAL

**Some Inequities in Agriculture and Farm Product Pricing**

Agriculture in any one country has its own peculiar problems. For example, Japan experienced a reduced per capita rice consumption since the 1960s due to changing food habits of the Japanese which, in turn, was an offshoot of the increased income levels that was brought about by the improved economy of the country. The net effect was an accumulation of substantial rice surplus which could not sell in the foreign markets because of its high production costs. Therefore, the government had to resort to rice acreage reduction and other schemes in the meanwhile that rice production technology efforts continue unabated. One irony of this example of agriculture problem is that rice in plentiful supply was not, and could not, be made available to starving children in many of the third world countries.

The United States is neither immune to inequities in agriculture. Whereas the US agriculture enjoys the highest productivity level, the agriculture policy seems loaded in favor of the large-scale farmers — at the expense of their small-scale counterparts.

These types of problems and inequities are aggravated by the farm product pricing mechanism that emanates from the trade capitals of the world such as the Chicago Board of Trade. When Chicago prices for commercial farm products are down, farmers in developing countries who export much of those products and upon which depends their livelihood are hit the hardest. When this is the case, isn't it high time that public opinion, if not indignation, be raised to influence the trade capitals of the world to come to grips with realities and the need to manipulate the pricing mechanism in a way that small producers/exporters from the developing countries may derive equitable shares from prices they receive?

In this way, the economic and technology gap that continues to distance the "haves" countries from the "have-nots" might be narrowed down. A more realistic pricing of farm products may also bring about a situation wherein children need not die from starvation in the face of surplus food. Unless this gap is narrowed down, international tension will continue to threaten the peace that mankind has since been keeping to enjoy.

Seen from another viewpoint, it is not difficult to comprehend that the trade off between farm product prices and those of other industries is directly or indirectly related to the progress of agricultural mechanization in developed or developing countries. In this particular regard, the AMA invites readers to come forward with comments, criticisms or research results on this particular trade off issue. Subsequent issues of the AMA should be able to accommodate those contributions from readers.

Yoshisuke Kishida
Chief Editor

Tokyo, Japan
October, 1989

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# PTO Performance Analysis on Small Riding Tractors

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## Abstract

An investigation was carried out for the PTO performance of tractors developed recently and now widely used in Japan. Such information on power, torque, specific fuel consumption, etc, were obtained by using the PTO test equipment with a computer data logging system. It was found that much improvement has been done for these tractors. Especially, because of the adoption of an angliech apparatus or a torque spring apparatus* to the engine governors, the PTO performance of many tractors have had a magnificent change compared with those reported before. Other useful pieces of information are also given for a better understanding of the design and adjustment of PTO or tractor engine performance.


*The apparatus are used to adjust the fuel injection quantity of the fuel injection pump and to control the torque performance.

## Introduction

The population of small riding tractors have rapidly increased in recent years to meet the needs of small scale farms. The PTO performance is one of the most important items of a tractor. It is well known that when a tractor is working in the fields, enough power, torque and a good fuel efficiency should be assured firstly. Besides, for a small tractor, in order to prevent the engine from stopping or a notable reduction of engine speed, the engine torque rise and elasticity index values normally used to evaluate the elasticity characteristics, are very important when they are used for heavy work like plowing or rotary tillage.

Unlike other automotive gasoline engines, a tractor engine is equipped with a variable speed governor since many farm operations have a frequent load variation within wide spread range and need a constant engine speed. It may safely be said that the tractor PTO performance is decided by the engine design, namely, the PTO performance could also be used to explain the condition of the engine. Further, the engine performance could be considered mostly dependent on the governor design provided the rest of the engine are the same. Many tractors, especially the small ones, have an angliech or a torque spring apparatus mounted in the governors as shown in Fig. 1. These apparatus normally have a significant effect on the tractor PTO performance according to their adjusting conditions.

In recent years, many new types of engines have been developed for the small tractors in Japan. It could be considered that there exists many differences in the tractor PTO performance, because most of the designs are still made mainly on the basis of the experiences and

know-how of the design engineers. Unfortunately, because most of the tractor tests are done following the OECD codes [1] or the country's industrial standards, only a few data, for instance, the data from the tractor test when the speed control lever is set at the maximum idling speed position, are measured.

This study was undertaken to give some useful pieces of information for the understanding and designing of the tractor PTO performance by making use of the performance data concerning the usable engine speeds and all the speed control lever positions. Eight tractors (the catalogue rated power is from 13.2 to 16.2 kW, 18 to 22 hp, manufactured by four Japanese companies) were analyzed.

## Materials and Methods

The main specifications of the engines mounted on the tested tractors are shown in **Table 1**. All of them are water-cooled diesel engines. The engines of B, C and E have the direct injection combustion chambers and the others have the indirect ones. A is four-cylinder, and the others are three-cylinder types. **Fig. 1** shows the schematic diagram of a typical mechanical variable speed governor. Parts A and B are the attachments called angliech, torque control, and torque spring apparatus, respectively. Though the angliech and torque spring apparatus are shown together here, only one of them is used commonly. The main designing parameters of these apparatus are: the spring constant; initial setting force of the spring; stroke that the spring can expand or be compressed; and position of the whole body against the governor case.

In the tested tractors which will be discussed here, A ~ C have the angliech apparatus, and D ~ H have the torque spring apparatus. The rated power, maximum torque, etc. could be changed easily by the design or adjustment of these apparatus.

A water cooled eddy-current-electro dynamometer (capacity 37 kW) was used to change the engine load ratio by increasing or decreasing the electric current to the dynamometer. A driving shaft of two universal joints and a rubber-coupling were used to connect the PTO shaft and the input shaft of the dynamometer. A load cell (capacity 500kgf) for measuring the dynamometer load and a tachometer with an analogue output for measuring the engine speed were used to get the PTO power. The fuel consumption was measured by using a flowmeter located between the fuel injection pump and the fuel tank or feed pump. The fuel return pipe normally connected to the fuel tank was connected to the pipe line of the output side of the flowmeter. The temperatures, as room temperature, air intake temperature, exhaust gas temperature, oil temperature, fuel temperature were measured by thermocouples.

All of the signals after converting into digital signals, were calculated by a microcomputer (NEC PC-9801vm2 16bit). The test results were displayed and printed out at once for monitoring.

Before starting the data acquisition, the warming up was performed over 30 min. The engine speed control lever was set at those positions keeping the intervals of idling (no load) engine speeds between 60 and 120 rpm. Two examples are shown in **Fig. 2**. More than 15 positions of the speed control lever were set for each tractor. Here, only five positions of the speed control lever will be picked up from all the test data for the detail analysis of the PTO performance.

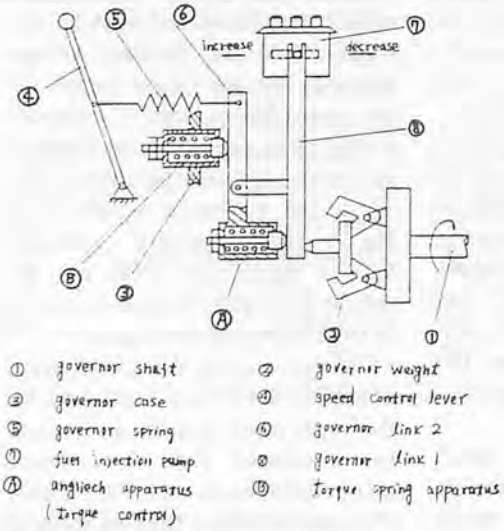


Fig. 1 Schematic diagram of mechanical variable-speed governor.

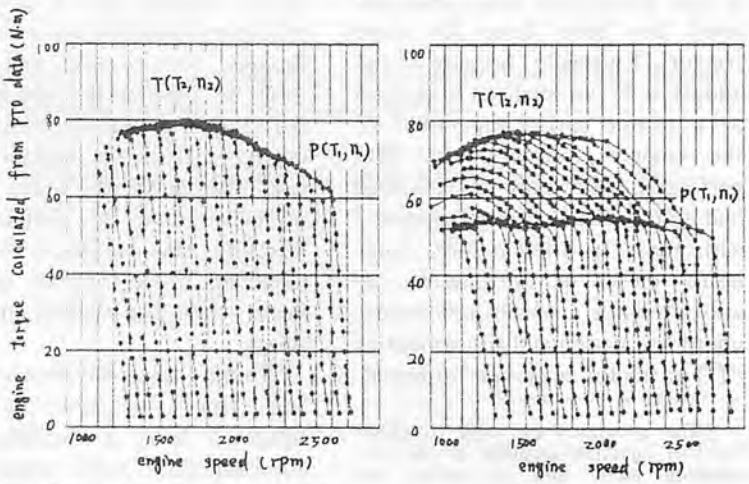


Fig. 2 Test data of tractor A and D.

## Results and Discussion

To evaluate the characteristics of the elasticity, as shown in **Fig. 2**, the torque rise Tr $(T_2/T_1)$, and elasticity index Ei $[(T_2/T_1) \times (n_1/n_2)]$ are generally used. Where $T_1$ and $T_2$ show the torques of a rated point and a maximum one, $n_1$ and $n_2$ show the speeds of those points, respectively. The real values of these points are commonly different from those given in the tractor catalogue. Moreover, the torque and power curves have two peaks sometimes as shown in **Fig. 2** (b). Therefore, taking the place of the rated point in the catalogue, the values of the first peak or the point P when the speed control lever was set at maximum idling speed were used for the calculation of torque rise and elasticity index. The main test results are shown in **Table 1**. The PTO power, the engine torque and the specific fuel consumption (SFC) curves are shown together in **Figs. 3** to **10**, respectively. The contour lines are iso-specific fuel consumption (ISFC) curves calculated by using the host computer of Kyushu University [2].

**Table 1** Main Specifications and Experimental Results of Tested Engines

| Model | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Cylinder | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Cooling | water | water | water | water | water | water | water | water |
| Displacement ($cm^3$) | 1 335 | 1 462 | 1 395 | 1 330 | 1 394 | 1 126 | 1 296 | 1 170 |
| Combustion chamber | indirect injection | direct injection | direct injection | indirect injection | direct injection | indirect injection | indirect injection | indirect injection |
| Output (rated) (kW/rpm) | 14.7/2 600 | 16.2/2 500 | 14.7/2 500 | 15.4/2 600 | 15.4/2 600 | 13.2/2 400 | 14.0/2 600 | 14.0/2 600 |
| Output (first peak) (kW/rpm) | 16.8/2 581 | 17.4/2 460 | 18.3/2 456 | 14.1/2 597 | 15.2/2 545 | 13.0/2 376 | 13.2/2 644 | 14.3/2 624 |
| Output (maximum) (kW/rpm) | 17.1/2 352 | 17.8/2 300 | 19.3/2 214 | 16.0/2 132 | 16.6/2 138 | 13.7/2 093 | 14.1/2 490 | 14.3/2 624 |
| Torque $T_1$ (N. m) (first peak) | 62.40 | 67.62 | 71.04 | 49.78 | 57.11 | 52.24 | 47.64 | 51.87 |
| Torque $T_2$ (N. m) (maximum) | 79.34 | 83.65 | 95.20 | 76.37 | 78.26 | 68.07 | 67.33 | 66.03 |
| Torque rise $(T_2/T_1)$ | 1.27 | 1.24 | 1.34 | 1.53 | 1.37 | 1.30 | 1.41 | 1.27 |
| Speed ratio $(n_1/n_2)$ | 1.57 | 1.45 | 1.61 | 1.75 | 1.37 | 1.63 | 1.92 | 2.12 |
| Elasticity index $(T_2/T_1)*(n_1/n_2)$ | 1.99 | 1.80 | 2.15 | 2.67 | 1.88 | 2.12 | 2.70 | 2.69 |
| SFC of first peak (g/kW·h) | 288 | 276 | 249 | 314 | 267 | 287 | 340 | 380 |
| Speed drop of governor (%) | 5.45 | 7.5 | 9.9 | 5.3 | 6.2 | 6.6 | 5.8 | 8.0 |
| Mean temperature (°C) | 12 | 26 | 15 | 14 | 16 | 13 | 12 | 16 |
| Mean humidity (%) | 50 | 84 | 53 | 57 | 61 | 70 | 66 | 65 |
| Mean atmospheric pressure (mmHg) | 778 | 765 | 778 | 780 | 777 | 774 | 777 | 780 |

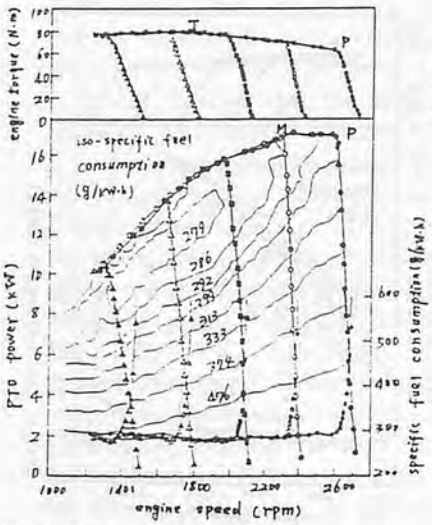


Fig. 3 The PTO performance of tractor A.

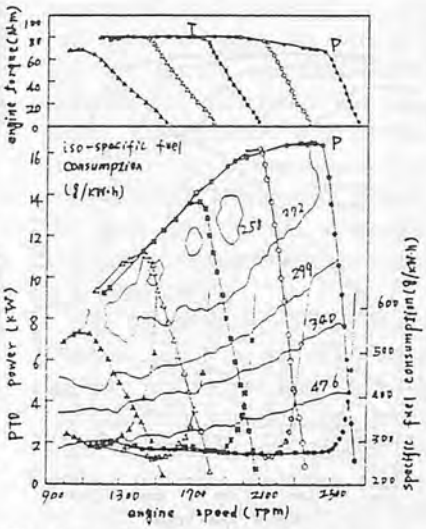


Fig. 4 The PTO performance of tractor B.

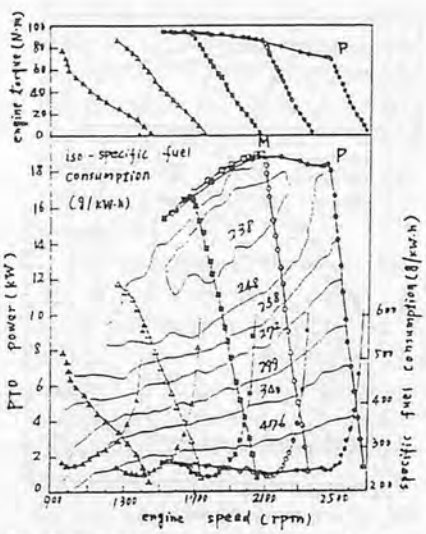


Fig. 5 The PTO performance of tractor C.

It could be seen that there are many considerable differences in their performance. Most of these were caused by the utilization of different injection combustion chambers and the structure of the governor attachments.

## Tractors Using Angliech Apparatus

Figs. 3, 4 and 5 show the performance of tractors A, B and C, respectively. An angliech apparatus was used in each engine of these tractors. It could be noticed that though the speed control lever was set at different positions, the torque and power curves got together in the full load area. In addition, their maximum values of power were 1.61 to 4.55kW and 0.22 to 0.95kW larger than the catalogue rated values and the values of point P which we called the "firstpeak". The angliech apparatus made the power curve become flat in higher engine speed zone when the engine is running under the full load conditions. The torque rise and elasticity index were from 1.27 to 1.34 and 1.99 to 2.15, respectively. These are larger than those reported by Nishizaki [3]. The reason is that these tractors were mainly developed for the rotary tillage of paddy fields, the heaviest farm operation. The speed drop at the maximum idling (no load) speed, an important item to evaluate the governor performance, shows the lowest value of 5.45% for tractor A, but C shows the worst one of 9.90% among the test tractors.

The ISFC curve through point P could be used to compare the fuel efficiency in a wider speed range, namely, the wider the area enclosed by the contour line through point P is, the wider the range that the engine can be operated in a better fuel efficiency is. These values are 288, 276 and 249 g/kW·h, respectively. The tractor C with a direct injection combustion chamber engine showed the lowest value in all the tractors and tractor A showed the lowest one in the rest with an indirect one.

## Tractors Using Torque Spring Apparatus

Figs. 6 ~ 10 show the performance of tractors D ~ H. The torque and power curves are very different from those of tractors with an angliech apparatus mentioned above. Further, it is clear that each

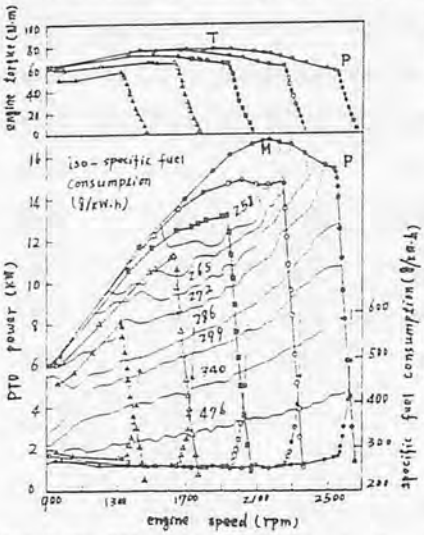


Fig. 7 The PTO performance of tractor E.

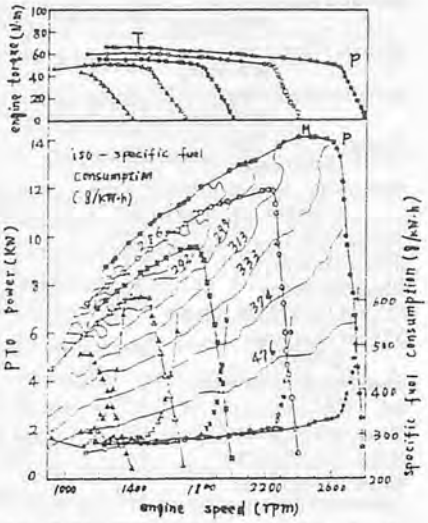


Fig. 9 The PTO performance of tractor G.

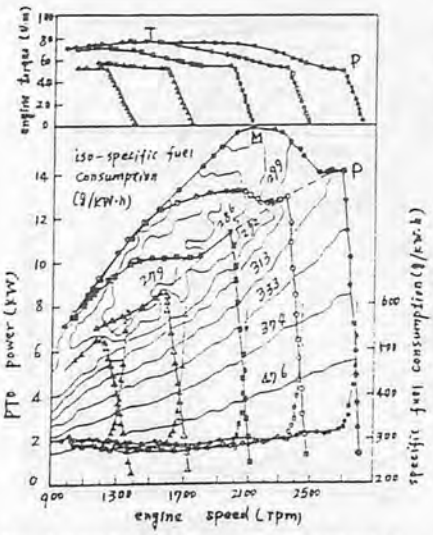


Fig. 6 The PTO performance of tractor D.

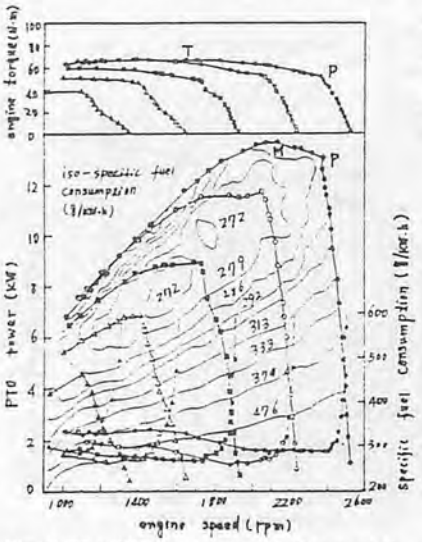


Fig. 8 The PTO performance of tractor F.

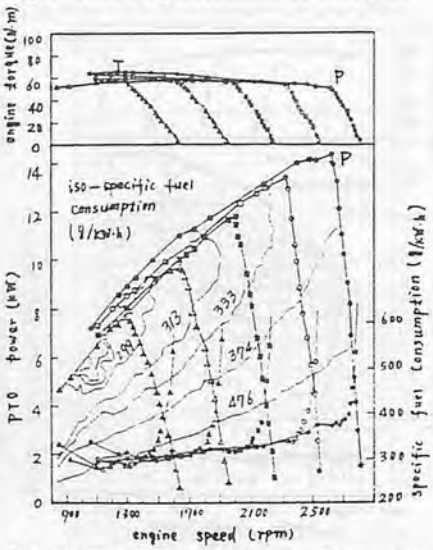


Fig. 10 The PTO performance of tractor H.

one has its characteristics even if they all use the torque spring apparatus.

Tractor D showed the most unique torque and power curves. Before the initial setting force of the spring is overcome by the difference between governor spring force and the thrust force of governor weights, the control rack of fuel injection pump was maintained at a fixed position. If there is no torque spring apparatus, the power will change like dot line PQ according to the fuel injection characteristics. Therefore, the curves are separated into two spheres taking the dot line PQ as the boundary. The maximum power is at a low speed (about 2100rpm) position, and 1.9kW larger than that of point P. This is the reason why the largest torque rise and a larger elasticity index values were obtained. This is effective to prevent the engine from notable reduction of engine speed or stopping when an overload was added. The speed drop of tractor D was 5.3%, showing a lower value in the tested tractors. The SFC of point P is 314 g/kW·h. And the lowest value is in the area above PQ line. Although the power and torque curves are different, the SFC values at the same speed are almost the same in the full load zone when the speed control lever is fixed at the different positions.

It was observed that the differences in performance of tractors E and F compared with tractor D are caused by the utilization of torque spring apparatus of which the initial setting force and stroke of the spring are smaller. Their SFC values of point P are 267g/kW·h and 287g/kW·h, respectively. F showed the lowest value in the tractors with an indirect injection combustion chamber as well as A. Furthermore, F shows a different type of SFC curves in the full load zone. According to the positions of the speed control lever, SFC curves have the different values in the full load area.

Because of the adoption of a small initial setting force and big spring constant of torque spring apparatus, tractor G shows another different pattern of performance, namely, the torque and power curves never got together all over the speed range of full load. In addition, the SFC of point P shows a higher value of 340g/kW·h

It could be considered that the performance of tractor H is obtained by giving a very big initial spring force of torque spring apparatus. This tractor shows the same type of SFC curves with tractor G. The value of SFC of point P is 380g/kW·h, the largest in the tested tractors.

## Basic Design Consideration for Angliech and Torque Spring Apparatus

As clarified above, the tractor PTO performance is much affected by the utilization of angliech apparatus and torque spring apparatus. Therefore, their design and adjustment are very important. The optimal design of these apparatus could be realized after the air intake efficiency feature of the engine and the characteristics of the fuel injection pump are obtained, and the tractor operating conditions are well understood. The basic design consideration will be discussed for the tractors and their engines which are assumed to have the same performance when the angliech or torque spring apparatus is not used.

**Fig. 11** shows the design model diagram, which is the relationship between the engine speed and the fuel injection quantity per stroke when speed control lever is set at two different positions. Curves $L_1$, $L_2$, $L_3$ and $L_4$ show the fuel injection characteristics of different

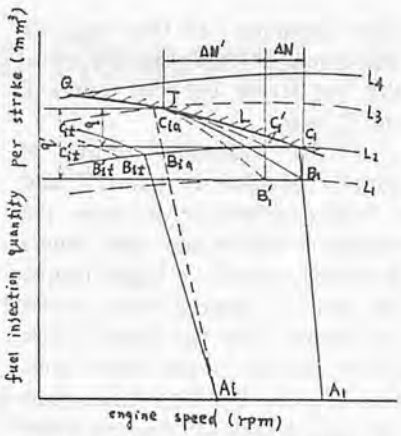


Fig. 11 Relationship between engine speed and fuel injection quantity per stroke.

control rack positions of fuel injection pump. Ordinarily, the air intake efficiency becomes lower and lower with the increase of engine speed, and the fuel injection quantity increases simultaneously like lines $L_1 \sim L_4$. Therefore, the ratio of air to fuel decreases gradually and the smoke boundary of the engine normally has the shape like curve L. In other words, if the fuel injection curve is below the smoke boundary line and has a similar curve, it could be said that a better matching has been realized within the engine body, the governor mechanism and the fuel injection pump. The angliech or torque spring apparatus has to be adopted in the engine governor for the best matching. Moreover, many special kinds of performance curves could be obtained by the adjustment of the elements of these apparatus like spring constant, initial setting force of the spring, stroke that the spring can expand or be compressed, etc.

For example, as shown in **Fig. 11**, if the maximum torque and rated power are required to be at points T and $C_1$, respectively, an angliech or torque spring apparatus should be designed to make the fuel injection pump have a fuel injection curve of $A_1C_1TQ$ or $A_1C_1C_1'TQ$. $C_1$ and $C_1'$ can be changed by the setting of initial spring force of

these apparatus. In this case, the differences of fuel injection quantity per stroke between points T and $C_1$ is q.

If the maximum torque is initially decided at point T and a bigger difference between the maximum torque and rated points is needed, namely, a bigger torque rise and an elasticity index values are needed, then the point $C_1$ has to be moved to the lower position of point $B_1$. This means that the rated power will become lower than before. In order to keep the rated power point at the same position of $C_1$ still and to obtain a bigger torque rise, a method by increasing the engine displacements should be utilized. It has been done by Japanese manufacturers. By moving the whole body of these apparatus against the governor case and selecting a suitable spring, stroke and initial force (refer to **Fig. 1**), the fuel injection quantity could be adjusted to have the shape like $A_1B_1TQ$ or $A_1B_1B_1'TQ$.

Now, when the speed control lever is fixed at a lower idling speed position like Ai and the angliech apparatus is used, the fuel injection curves become AiBiaCiaQ. On the other hand, if the torque spring apparatus is utilized, then it becomes AiBitCitQ or AiBitBit'Cit'.

## Conclusions

A PTO test equipment with a computer measuring system was used to acquire the tractor PTO performance data. Eight representative tractors manufactured in Japan, the rated power from 13.2 to 16.2 kW, were tested and discussed. The following conclusions were reached in this investigation.

1) The torque rise and elasticity index of tested tractors were in a wide range of 1.27 ~ 1.53 and 1.80 ~ 2.70, respectively, are generally larger than those reported before. The reason is that these small riding tractors are mainly designed for rotary tillage for paddy fields, the heaviest farm work.

2) The maximum power of some tractors was larger than that of rated points. This makes the tractor very easy to be operated when an overload is added.

3) The specific fuel consumption of maximum full load speed (point P) were in the range from 249 to 380g/kW·h. The tractors with a direct injection combustion chamber showed lower values. Most of the tested tractors showed that their specific fuel consumption curves got together in the full load area though their power and torque curves were different.

4) A good PTO performance could be realized by the optimal design and adjustment of angliech and torque spring apparatus related to the load conditions. Their basic design and adjustment were explained on the basis of relationship between the engine speed and the fuel injection quantity.

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# Effects of Load on Physiological Response of Buffaloes in Rotary Mode

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## Abstract

Physiological responses in terms of pulse rate, respiration rate and rectal temperature of male Murrah buffaloes were studied in rotary mode of working. The load was varied using a proney brake type dynamometer mounted at the end of the output shaft of a rotary gear reduction unit. The buffaloes were made to work at varying drafts of 60 to 200 kg for a period of 1, 2 and 3 h continuously and, subsquently, given rest up to 2 h in a shade. All the physiological parameters increased with the load. The maximum variation was recorded in respiration rate (250 to 657%) followed by pulse rate (61 to 91%) and rectal temperature (4 to 9%) from its resting level. The power output of buffalloes remained constant at lower draft equivalent to 10% of the body weight but at higher draft, the power decreased substantialy to about 14% with the working hours.

## Introduction

Draft animal power has been complementary to petroleum-based power and needs full exploitation in view of the current escalation in prices and rapid depletion of fossil fuels and other conventional sources of energy. More than 90% of all Indian farms which constitute about 39% of cultivated area use draft animals as the main source of farm power up to an extent of about 34% of total power available for crop production. Bullocks and buffaloes are the main sources of draft power in India with a population of about 70 and 8 million, respectively, out of the total draft animals population of 80 million. A recent survey by FAO reveals that almost 90% of the draft power for agricultural operations in many of the developing countries in the Middle-east and South-east Asia is derived from buffaloes alone. Although buffaloes have many good characteristics as draft animal, they are far from being employed to their full capacity. Even in rice growing areas, they are hardly used up to 3 to 4 months in a year (Rai and Hedge, 1982). Srivastava (1986), however, reported the annual utilization of draft animal power in different regions to vary between 450 to 1500 h as against 2 500 h under ideal conditions. This has to be enhanced to take more work output from animals.

Draft animals are mainly used for tillage, seeding, weeding and interculture and transport. However, there is a considerable scope of utilizing them during idle periods on many stationary jobs requiring their rotary mode of operations. There is need to use the animal power for feed grinding, flour milling, rice milling, oil seed crush-

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ing, chaff cutting, sugarcane juice extraction and other such jobs right in the villages where animals are housed and fed regularly. In the past, comparatively more attention had been paid to the work output of animals in linear mode of farm jobs. The information on different work-rest cycles under rotary mode of work is lacking at present. It was, therefore, felt necessary to conduct elaborate studies on the physiological response of buffaloes while working in rotary mode to obtain maximum work efficiency without undue stress on their health.

## Review of Literature

Although buffaloes are the popular draft animals in India and South-east Asian countries, very little information is reported on their draftability.

The physiological response of 42 new born buffalo calves in Thailand was studied by Harber (1980) who recorded average body temperature, pulse rate and respiration rate of 38.6°C 177.8 beats/min and 59.2 bows/min, respectively. However, for mature buffalo bulls, same parameters had been reported by Teinkhao (1978) as 37.7°C, 30 beats/min and 20 blows/min. Agrawal, et al (1982) conducted extensive physiological studies when hauling 100 kg load with a single entire, vasectomised and castrated male buffalo for 3 h and, subsquently, recorded the responses after 1,3,8 and 20 h of rest. The body temperature, pulse rate and respiration rate reached to approximately normal value by about 8 h of rest in all the animals. Their results suggested that the castrated male buffaloes are equally efficient in their working capacity and physiological adjustments as compared to entire or vasectomised animals. Bunyavejchewin et al (1985) studied the use of buffaloes for the operation of a water lifting device. The main objectives of the study were to record the buffalo behaviours, changes in body temperature within one working hour and efficiency of buffaloes during different periods of a day. The relative efficiency of buffalo during a day was calculated in terms of revolutions/min and steps/min. Differences were not significant, however, the results indicated that buffaloes worked more efficiently in the morning than in the afternoon.

Keeping in view the research done so far, the importance of conducting further research on draft buffaloes for their optimum utilization and work output cannot be over-emphasized.

## Materials and Methods

Experiments were conducted on a mechanical gear reduction unit consisting of a large bevel pinion and set of spur gear reduction units enclosed inside a housing (Fig. 1). The total speed increase at the output shaft of the unit was obtained as 1:57.5 and can be further increased for operating agricultural product processing units. The unit is made operational by rotating the wooden beam with the help of animals.

The animal loading device was designed using the principle of a proney brake dynamometer (Fig. 2). The complete dynamometer is mounted at the end of the output shaft of the unit (Fig. 1) and can be loaded by tightening and locking the canvas belt around the flywheel by adjusting the swinging arm in a vertical plane. The torque arm of the dynamometer was kept constant at 325 mm and the turning force was measured with a spring dynamometer to determine the power output at the end of the shaft. The load on the animals in terms of draft was measured using another spring dynamometer which was mounted on the beam at a distance of 2.92 m from the centre of rotation of the unit. The dynamometer was mounted on a

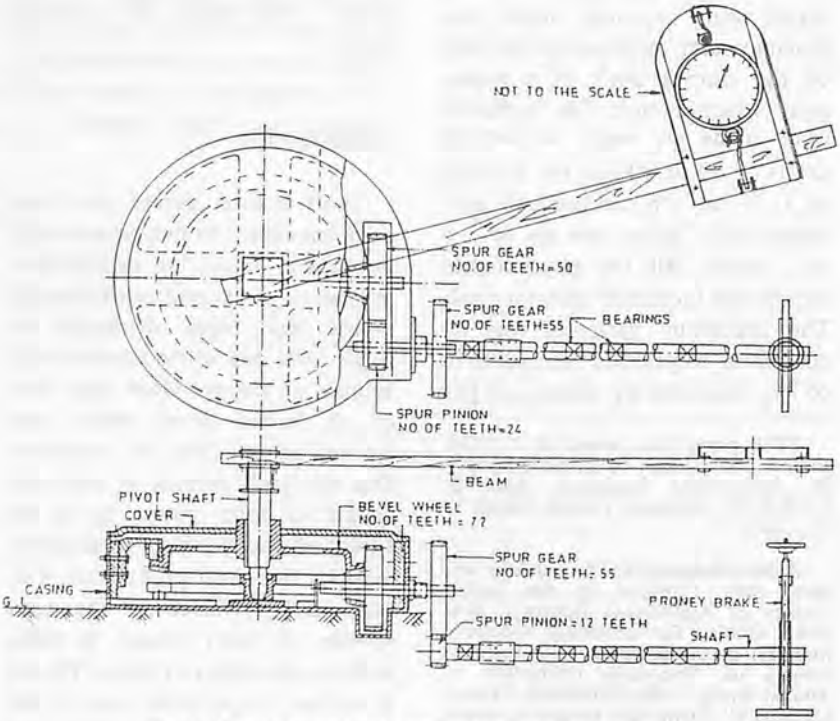


Fig. 1 Gear drive unit with power transmission system.

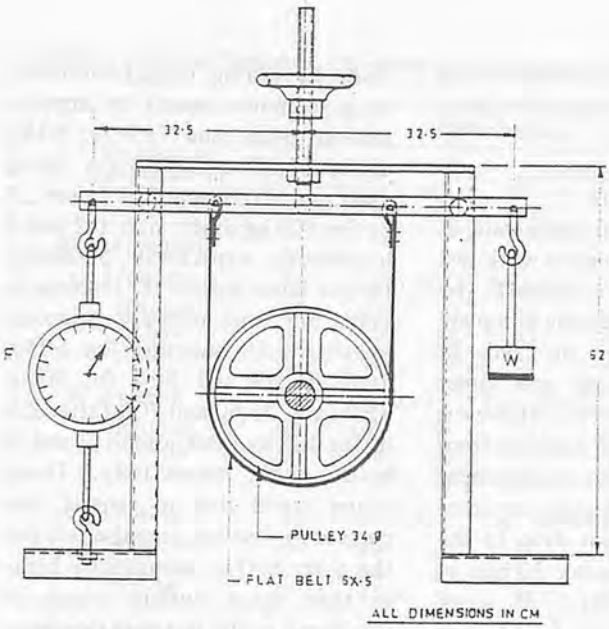


Fig. 2 Prony brake type dynamometer used for loading buffaloes.

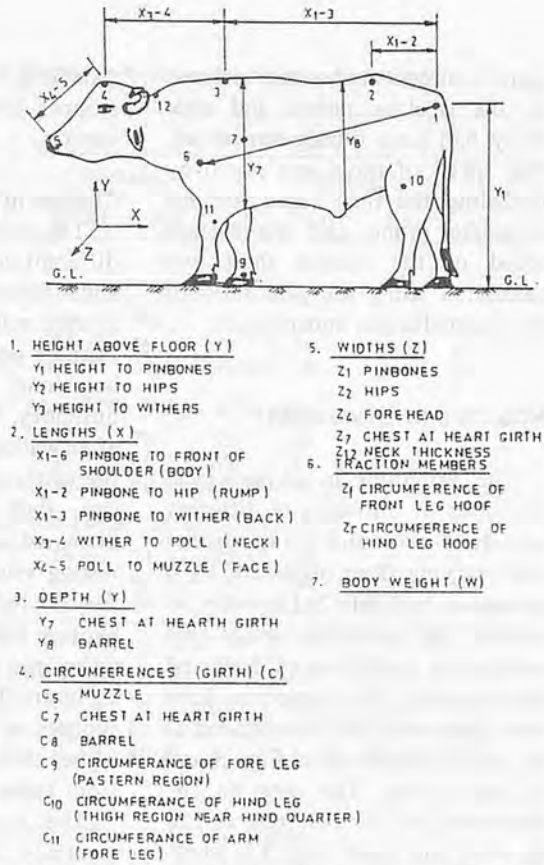


Fig. 3 Reference points for physical dimensions of buffalo.

**Table 1** Physical Dimensions of Buffaloes Used in the Experiment

| Item | Buffalo | |
|---|---|---|
| | Outer | Inner |
| Height above floor (Y-Plane) | | |
| $Y_1$ | 120 cm | 120.5 cm |
| $Y_2$ | 132 | 132 |
| $Y_3$ | 133 | 134 |
| Lengths (X-Plane) | | |
| $X_{1-6}$ | 146 cm | 142 cm |
| $X_{1-2}$ | 40 | 38 |
| $X_{1-3}$ | 117 | 115 |
| $X_{3-4}$ | 85 | 91 |
| $X_{4-5}$ | 52 | 55 |
| Depths | | |
| $Y_7$ | 79.5 cm | 75 cm |
| $Y_8$ | 75 | 72 |
| Circumstances | | |
| $C_5$ | 49.5 cm | 51 cm |
| $C_7$ | 205 | 201 |
| $C_8$ | 226 | 226 |
| $C_9$ | 31 | 30 |
| $C_{10}$ | 75.5 | 64 |
| $C_{11}$ | 46 | 44 |
| Width (Z-Plane) | | |
| $Z_1$ | 29 cm | 30 cm |
| $Z_2$ | 55 | 50 |
| $Z_4$ | 31 | 28 |
| $Z_7$ | 51.5 | 53 |
| $Z_{12}$ | 32.5 | 32 |
| Traction members | | |
| $Z_f$ | 52 cm | 50 cm |
| $Z_r$ | 50 | 48 |
| W, kg | 596 | 582 |

bracket such that when hitched with the animals it measured the draft directly.

Two male Murrah buffaloes in the age group of 6 to 7 years were used for the experimental studies. These animals were primarily maintained at the university farm for DAP research. The physical dimensions shown in **Fig. 3** in a cartesian coodinates represent the important measurements of a draft animal. The numerical values of physical dimensions of test buffaloes are shown in **Table 1** which reveals remarkably similar dimensions for both experimental animals.

The experimental buffaloes were trained by a skilled operator for seven days on the experimental apparatus to accustom them with the pattern of experiment. For conducting an experiment, the animals were harnessed with a yoke hitched to the wooden beam with a rope. An overall view of the experimental apparatus with the animals at work is shown in **Fig. 4**. The experimental loads were applied by the loading dynamometer so as to obtain 60,90,120,150 and 200 kg of draft. The animals were allowed to work at a particular load for 1,2 or 3 h continuously and given complete rest for a period of 2 h in a shed. All the experiments at loads were conducted between 8 and 11 A.M. on each day. The environmental conditions such as air temperature and relative humidity, and physiological responses, i.e., pulse rate (PR) respiration rate (RR) and rectal temperature (RT)

Fig. 4 A view of experimental apparatus.

were recorded at the start and end of the working period and after every half hour during rest period. The speed of travel was noted by recording the time taken for one complete round and the average speed of the output shaft was calculated using the gear ratio of the gear reduction apparatus.

## Results and Discussion

The variations in physiological responses of buffaloes at different periods of work and 2 h of rest for draft varying from 60 to 200 kg is presented in **Table 2**. However, to observe the variations under two contrasting conditions of draft and environment, the responses have been illustrated for 2 h work-rest at 90 and 150 kg draft in **Figs. 5** and **6**, respectively. The date on the responses for 3 h work-rest at 150 kg draft and more than 1 h work-rest at 200 kg draft were not obtained because the buffaloes were unwilling to work further and stopped frequently even after stimulation.

### Changes in Pulse Rate

The variations in pulse rate at different combinations of work-rest and draft is shown in **Table 2**. The average pulse rate during complete resting period was 36 and 38 beats/min for outer and inner buffaloes, respectively. However, after walking 2.5 km distance from the cattle shed to the experimental site, their physiological reponses increased and did not drop to the resting values even after 30 min of rest before the start of work because buffaloes were found more active and aggressive during morning hours. Therefore, their initial responses at the start of work were higher than resting values as evident from **Table 2**.

The pulse rate increased substantially after work and further increased at higher draft. For outer buffalo, the pulse rate increased from its resting level (considered as a reference point) by approximately 64,61 and 78% for 60 kg draft; 83,67 and 86% for 90 kg draft and 56,61 and 77% (after 2.5 h) for 120 kg draft; after 1,2 and 3 h of work, respectively. Similarly, for the inner buffalo the increase in pulse rate was recorded approximately 55,58 and 66% for 60 kg draft; 63,63 and 80% for 90 kg draft; and 45,60 and 70% (after 2.5 h) for 120 kg draft after 1,2 and 3 h of work, respectively. These values reveal that in general, the percentage increase in pulse rate for the outer buffalo was slightly higher than inner buffalo which is attributed to the fact that the outer buffalo travels a longer distance than the inner buffalo for the same amount of work.

The experiments were also conducted at 150 and 200 kg draft during winter season. Due to cold environment, the resting values of physiological responses were little lower than when the experiments

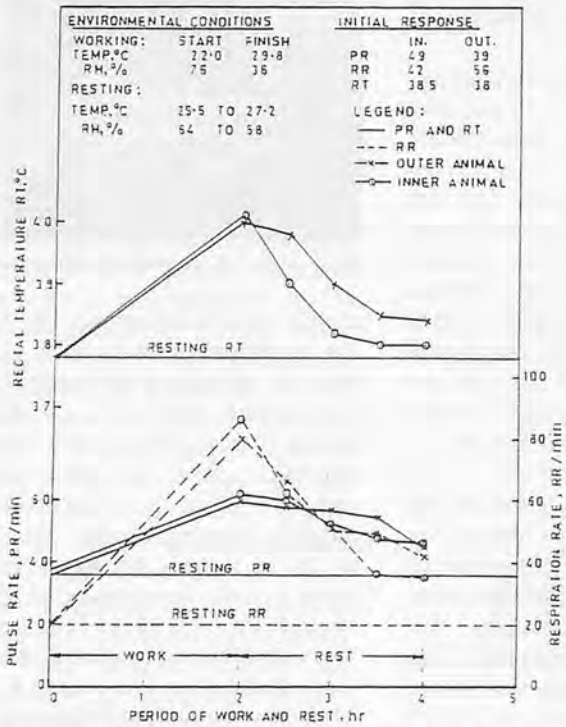


Fig. 5 Effect on physiological changes of buffaloes after 2-hour work and rest for 90 kg draft.

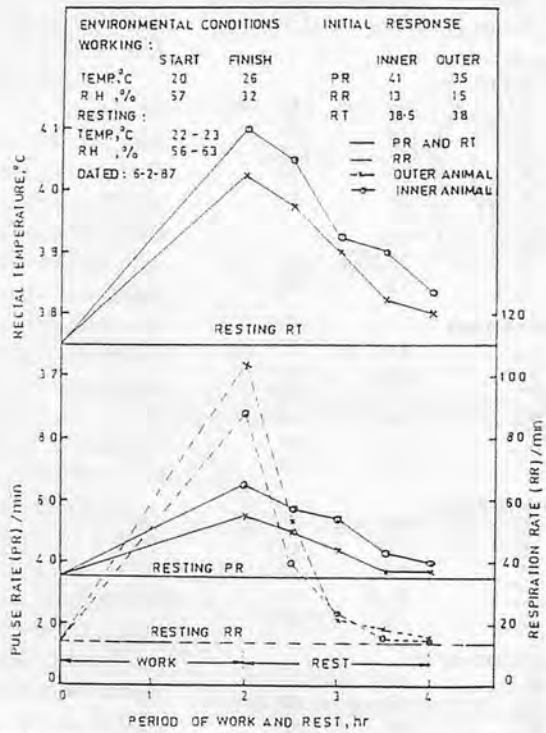


Fig. 6 Effect on physiological response of buffaloes after 2-hour work and rest for 150 kg draft.

Table 2 Effect on Physiological Responses of Buffaloes during Different Periods of Work and Rest at 60-to 200-kg Draft Loads

| Physiological responses* | Outer buffalo | | | | | | Inner buffalo | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Working | | Resting, h | | | | Working | | Resting, h | | | |
| | Initial | Final | 0.5 | 1.0 | 1.5 | 2.0 | Initial | Final | 0.5 | 1.0 | 1.5 | 2.0 |
| 60 kg draft load | | | | | | | | | | | | |
| a) 1 h work | $T_W$: ** 32 to 30°C; $T_R$: 29 to 24°C; $RH_W$: 58 to 54%; $RH_R$: 67 to 89% | | | | | | | | | | | |
| RR/min | 39 | 75 | 70 | 66 | 40 | 32 | 34 | 70 | 68 | 55 | 35 | 25 |
| PR/min | 34 | 59 | 54 | 45 | 38 | 37 | 44 | 59 | 55 | 50 | 42 | 41 |
| RT, °C | 37.80 | 40 | 39.75 | 39 | 38.50 | 38.25 | 37.90 | 39.90 | 39.50 | 39 | 38.90 | 38 |
| b) 2 h work | $T_W$: 28 to 32°C; $T_R$: 26 to 30°C; $RH_W$: 50 to 27%; $RH_R$: 42 to 69% | | | | | | | | | | | |
| RR/min | 48 | 107 | 96 | 51 | 50 | 29 | 40 | 78 | 55 | 26 | 21 | – |
| PR/min | 37 | 58 | 55 | 41 | 41 | 40 | 35 | 60 | 59 | 48 | 47 | 45 |
| RT, °C | 38 | 40.20 | 39.80 | 38 | 38 | 38 | 38.50 | 40.25 | 39.50 | 38.25 | 38.25 | 38.25 |
| c) 3 h work | $T_W$: 24 to 32°C; $T_R$: 28 to 30°C; $RH_W$: 65 to 40%; $RH_R$: 59 to 57% | | | | | | | | | | | |
| RR/min | 25 | 99 | 65 | 54 | 28 | 18 | 26 | 74 | 52 | 43 | 22 | 17 |
| PR/min | 43 | 64 | 63 | 53 | 46 | 45 | 48 | 62 | 59 | 60 | 54 | 52 |
| RT, °C | 38.50 | 40.20 | 39 | 38.80 | 38 | 38 | 38.50 | 40 | 39 | 39 | 38.90 | 38.40 |
| 90 kg draft load | | | | | | | | | | | | |
| a) 1 h work | $T_W$: 25 to 29°C; $T_R$: 24 to 25°C; $RH_W$: 68 to 48%; $RH_R$: 48 to 60% | | | | | | | | | | | |
| RR/min | 56 | 87 | 76 | 50 | 28 | 22 | 42 | 74 | 50 | 35 | 33 | 20 |
| PR/min | 39 | 66 | 53 | 48 | 45 | 36 | 49 | 62 | 48 | 46 | 42 | 41 |
| RT, °C | 38 | 40 | 39.80 | 39 | 38.50 | 38.40 | 38.50 | 40.10 | 39 | 38.20 | 20.38 | 38 |
| b) 2 h work: Refer Fig. 5 | | | | | | | | | | | | |
| c) 3 h work | $T_W$: 19 to 24°C; $T_R$: 26 to 24°C; $RH_W$: 72 to 37%; $RH_R$: 36 to 43% | | | | | | | | | | | |
| RR/min | 16 | 106 | 40 | 19 | 39 | 40 | 14 | 78 | 45 | 25 | 17 | 20 |
| PR/min | 33 | 65 | 63 | 40 | 39 | 40 | 40 | 63 | 61 | 53 | 50 | 45 |
| RT, °C | 37.75 | 40 | 39.70 | 38.50 | 37.50 | 37.50 | 37.50 | 40.50 | 40 | 39 | 39 | 38.50 |
| 120 kg draft load | | | | | | | | | | | | |
| a) 1 h work | $T_W$: 29 to 30°C; $T_R$: 26 to 22°C; $RH_W$: 42 to 45%; $RH_R$: 65 to 74% | | | | | | | | | | | |
| RR/min | 41 | 74 | 66 | 60 | 32 | 26 | 29 | 68 | 55 | 42 | 31 | 23 |
| PR/min | 36 | 56 | 52 | 47 | 40 | 38 | 40 | 55 | 50 | 45 | 44 | 41 |
| RT, °C | 38.50 | 39.75 | 39.50 | 39.30 | 39 | 38.25 | 38 | 40 | 39.50 | 39 | 38.50 | 38 |
| b) 2 h work | $T_W$: 20 to 28°C; $T_R$: 26 to 24°C; $RH_W$: 68 to 65%; $RH_R$: 45 to 68% | | | | | | | | | | | |
| RR/min | 22 | 97 | 87 | 40 | 37 | 22 | 21 | 88 | 52 | 40 | 28 | 31 |
| PR/min | 40 | 57 | 57 | 57 | 42 | 42 | 51 | 61 | 59 | 48 | 47 | 57 |
| RT, °C | 38.50 | 40.80 | 40.20 | 38.80 | 38.20 | 38 | 38.25 | 40.60 | 40 | 39 | 38.75 | 38.50 |
| c) 2.5 h work | $T_W$: 19 to 25°C; $T_R$: 26 to 27°C; $RH_W$: 68 to 35%; $RH_R$: 36 to 30% | | | | | | | | | | | |
| RR/min | 14 | 102 | 40 | 24 | 13 | 12 | 14 | 82 | 33 | 30 | 16 | 15 |
| PR/min | 35 | 62 | 46 | 44 | 36 | 33 | 39 | 62 | 55 | 45 | 40 | 41 |
| RT, °C | 38 | 40 | 38.50 | 38.50 | 38 | 37 | 37.50 | 41 | 40 | 39 | 39 | 38.50 |
| 150 kg draft load | | | | | | | | | | | | |
| a) 1 h work | $T_W$: 23 to 24°C; $T_R$: 21 to 22°C; $RH_W$: 45 to 30%; $RH_R$: 48 to 56% | | | | | | | | | | | |
| RR/min | 17 | 79 | 36 | 21 | 18 | 16 | 17 | 55 | 28 | 22 | 15 | 15 |
| PR/min | 40 | 50 | 47 | 44 | 41 | 38 | 35 | 55 | 58 | 55 | 47 | 46 |
| RT, °C | 37.50 | 38.50 | – | 38 | 37.50 | – | 37.50 | 39 | 38.90 | 38.50 | 37.75 | 37.50 |
| b) 2 hours work: Refer Fig. 6 | | | | | | | | | | | | |
| 200 kg draft load | | | | | | | | | | | | |
| a) 1 h work | $T_W$: 19 to 25°C; $T_R$: 22 to 19°C; $RH_W$: 67 to 44%; $RH_R$: 60 to 67% | | | | | | | | | | | |
| RR/min | 14 | 81 | 20 | 17 | 15 | 18 | 14 | 54 | 26 | 18 | 16 | 16 |
| PR/min | 45 | 67 | 47 | 44 | 40 | 42 | 40 | 61 | 56 | 52 | 45 | 44 |
| RT, °C | 37.50 | 39.50 | 39 | 38.50 | 38 | 37.50 | 37.50 | 39 | 38.75 | 38.50 | 38.25 | 37.75 |

*RR/min: Respiration rate (Blows/min); PR/min: Pulse rate (Beats/min); RT: Rectal temperature, °C

**T: Air temperature; RH: Relative humidity; Suffix W: During work, R: During Rest.
Resting Physiological Responses: PR, 36 beats/min for outer and 38 beats/min for inner; RR, 20 blows/min (for both animals and RT; 37.8°C (for both animals).

conducted during autumn at lower draft and recorded as 35 beats/min, 14 blows/min and 37.5°C. The increase in pulse rate for the outer animal was 43 and 57% at 150 kg draft after 1 and 2 h of work, respectively. However, at 200 kg draft it increased by 91% after 1 h of work. Similarly, for the inner buffalo at 150 kg draft the increase was recorded to be 57 and 86% after 1 and 2 h of work and for 200 kg draft, it was approximately 74% after 1 h work. A substantial increase in pulse rate of buffaloes after work was also observed by Agrawal et al (1982) when pulling 100-kg load for a period of 3 h. They observed 47 to 70% increase in pulse rate during first 1.5 h of exercise and only 1 to 16% in the later half which is in agreement with Singh et al (1968 a), Sastri (1970) and Maurya (1982).

The observation on recovery of pulse rate during rest shows a slow decrease. After 1 h work at 60 kg draft, the pulse rate approached close to its resting level within 2 h of rest. However, after 2 and 3 h of work, it did not drop to its resting level even after 2 h of rest. The reason for this may be because of longer duration of work and comparatively higher values of air temperature during both work and rest periods. While working for 2 h at 90 kg draft (**Fig. 5**), the pulse rate did not approach its resting level even after 2 h of rest. Although the draft was well within the allowable work capacity of buffaloes which was determined approximately 109 kg based upon the assumption that a single animal can pull a load of 10% of its body weight but when used in a pair, the efficiency is reduced by 7.5% (Watson, 1981). In the case of 3 h of work at 90 and 120 kg draft the pulse rate dropped to resting level for outer buffalo. Although the duration of work was greater this phenomenon was observed because of lower range (<25°C) of air temperature during work. This was also true at higher draft of 150 kg after 2 h work (**Fig. 6**) and 200 kg draft after 1 h work (**Table 2**).

### Changes in Respiration Rate

The increase in respiration rate was faster in comparison to other physiological responses as evident from **Table 2** and **Figs. 5** and **6**. For the inner buffalo, the increase in respiration rate after 1,2, and 3 h of work was approximately 250 290 and 270% for 60 kg draft, 270,330 and 457% for 90 kg draft; and 240,340 and 486% for 120 kg draft, respectively, from its resting value of 20 blows/min. Similarly, for the outer buffalo the increase in respiration rate during the same period was 275,435 and 395% for 60 kg draft; 335,300 and 657% for 90 kg draft; and 270,385 and 628% for 120 kg draft. The increase in respiration rate of the outer buffalo for the same period of work and load was substantially higher than the inner buffalo for the reasons explained earlier.

The increase in respiration rate for the outer animal at 150 kg draft (13% of body weight) was 465 and 643% from its resting value of 14 blows/min after 1 and 2 h of work respectively. During the same period, the increase for the inner animal was 293 and 529%. Similarly, for 200-kg draft, i.e., 17% of body weight, the increase was found to be 479 and 286% after 1 h of work for outer and inner animals, respectively. The increase at 150 and 200 kg draft after 1 h of work is approximately similar for both animals but willingness to work further and poor coordination between animals was observed during the work at higher draft of 200 kg. The increase in respiration rate of buffaloes was identical to the results obtained by Agrawal et al (1982) who reported an increase of 600 to 800% for male buffalo pulling 100-kg load continuously for 3 h. Such variations in respiration rate has also been reported by Sastri (1970), Rana et al (1978) and Maurya (1982).

While considering the respiration rate during resting period of 2 h in a shade, it is evident that the drop in respiration rate is much steeper and faster than the pulse rate. At smaller draft of 60 kg, the respiration rate reached its resting level after about 1.5 h of rest for all the work periods of 1 to 3 h duration. Similarly, at 90 and 120 kg draft and after 1 h of work, the respiration rate reached approximately its resting level only after about 2 h of rest. However, for longer work period of 2 and 3 h duration, the respiration rate dropped to its resting value within 1.5 h of rest when the weather was cool and humid during work (air temperature <25°C and RH> 50%). However, at higher air temperature (>25°C) during work and comparatively lower draft (90 kg), the respiration rate did not approach its resting value even after 2 h of rest (**Fig. 5**) and is in agreement with Agrawal et al (1982). It can, therefore, be postulated that environmental conditions, specially the air temperature, has profound effects on the physiological responses of animals during work and recovery rather than the magnitude of the draft. This can be further justified with the results obtained at larger draft of 150 (**Fig. 6**) and 200 kg (**Table 2**) in which case it is seen that after about 1 h of rest the respiration rate reached close to its resting value when the air temperature was below 25°C.

### Changes in Body Temperature

The resting level rectal temperature for both buffaloes was recorded approximately 37.8°C. For the inner buffalo the increase in rectal temperature after 1,2 and 3 h of work was recorded 5.55,6.48 and 5.82% for 60 kg draft; 6.08,6.08 and 8% for 90 kg draft; and 5.83, 7.40 and 9.33% for 120 kg draft,

respectively. During the same period the rectal temperature of the outer buffalo increased by 5.82,6.34 and 6.34% for 60 kg draft; 5.82 and 6.67 for 90 kg draft, and 5.15,7.08 and 6.67% for 120 kg draft after 1,2 and 3 h of work, respectively. Similarly, for the 150-kg draft it increased by about 4.00 and 9.34% for the inner buffalo; and 2.67 and 7.34% for outer buffalo after 1 and 2 h of work, respectively. At 200-kg draft the increase was approximately 4.00 and 5.34% for the inner and outer buffaloes, respectively. At 60,90 and 120 kg draft, the increase was slightly more than 150-and 200-kg because of variations in environmental conditions. The experiments at 150 and 200 kg draft were conducted during winter season under cool environmental conditions. It is also clear that the increase in rectal temperature of both buffaloes was approximately similar. Moreover, at different levels of draft, there is no appreciable increase in temperature in contrast to pulse rate and respiration rate.

The observation on the rectal temperature of buffaloes during rest reveals that there is a steep drop in temperature and the decreasing trend is similar to the respiration rate. The rectal temperature reached to its normal resting level similar to pulse rate and respiration rate after different hours of work.

The variations of pulse rate and respiration rate of inner buffalo at different period of work is shown in **Fig. 7**, i.e., after about 1.5 h of work, the pulse rate of the animals reached a fairly steady state. Maurya (1982) found half hour rest after 3 hours of work as insufficient to bring the physiological responses of bullocks to pre-rest condition and, therefore, suggested rest after every 1.5 to 2 h of work to check excessive increase in responses. According to Sastry et al (1970) the pulse rate did not reach a steady state before 1 to 1.5 h of continuous work in the case of Brown Swiss x Sahiwal bullocks. The respiration rate reached a steady state only after 2 h of work. A similar trend could be observed in the case of the outer buffalo.

### Relationships of Speed and Power Output with Period of Work

The relationships of speed and power output with different periods of work for all the draft is shown in **Fig. 8**. It is evident that after half hour work, the speed of buffaloes increased by about 10% for the draft of 5 to 10% of their body weight (i.e., 60,90 and 120 kg). For a small draft of 60 kg, the speed of buffaloes remained constant throughout the working period of 3 h. However, for draft values of 90 to 200 kg, there was a cyclic variation in the speed of buffaloes and showed decreasing trends with the working hours which was approximately 14% after 3 h from its maximum value. The variation in speed for all the draft was from 32 to 38 m/min.

The increase in speed after the start of an exercise can be expected because buffaloes could take some time to warm up. During this period, muscle stiffness is reduced and become more active. Moreover, the familiarization with the mode of work is also needed before each exercise even though they were trained animals. This phenomenon could also be observed in atheletes who limber up muscles before start of a run. Maurya (1982) recorded a reduction in speed of cross-bred bullocks with the increase in draft. However, in the case of buffaloes a reverse trend was noticed in that the speed at 90 and 120 kg draft was slightly higher than lower draft of 60 kg up to about 2 h of work

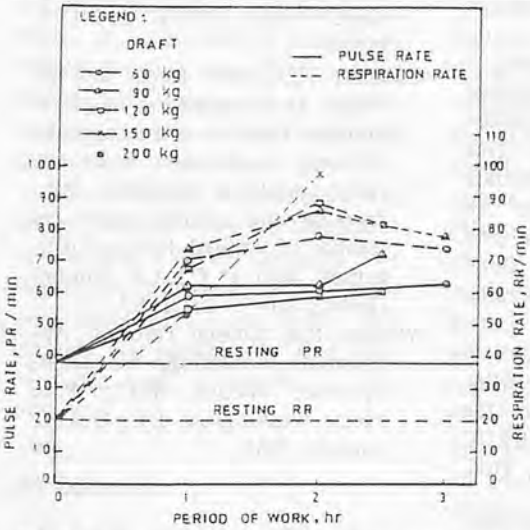


Fig. 7 Variations in pulse rate and respiration rate of inner buffalo at different draft during work.

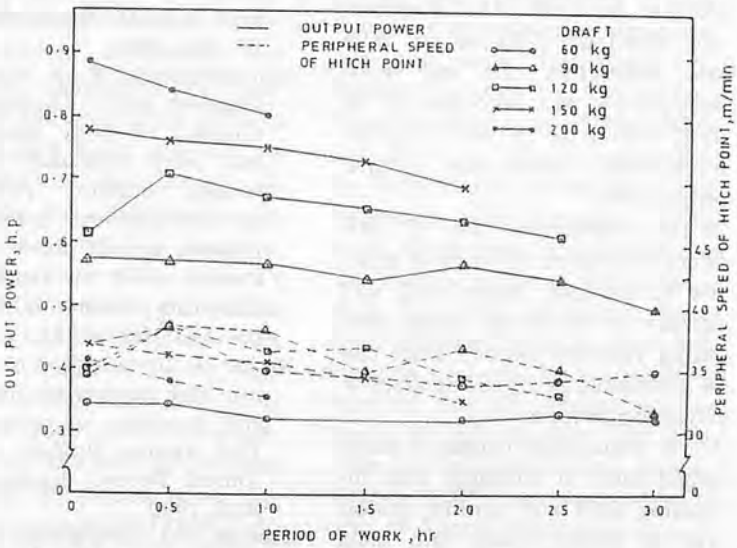


Fig. 8 Variation in peripheral speed of hitch point and power output of buffaloes at various draft during work.

but then after the speed was lower during a stage when animals showed some sign of fatigue. Buffaloes are docile by nature and even after stimulation their speed did not increase appreciably in contrast to bullocks. However, at draft of 10% of their body weight or more, they exerted pull by neck and shoulder, i.e., used the body weight to pull load which in fact have increased the speed slightly.

The relationship between power output and period of work reveals a constant power output for 60 kg draft. Even in case of 90 kg draft, the power output is constant up to 2 and half hours of work but thereafter it decreased by about 12% from its initial value. It is also clear that at different draft of 120,150 and 200 kg, the power output decreased steadily by approximately 14,12 and 9% after 2.5,2 and 1 hour of work, respectively. The power output of buffaloes increased with the increase in draft but at a decreasing rate.

## Conclusions

1. All the physiological responses increased steadily up to a limit from its resting level with the increase in draft. The minimum and maximum increase in pulse rate, respiration rate and rectal temperature was recorded 61 to 91%, 250 to 657% and 4 to 9%, respectively, from their normal resting level.
2. The respiration rate of buffaloes was found to be most sensitive to increase during work and decrease to its normal resting level during recovery period, hence can be considered as a good measure of physiological loads.
3. The percentage increase in rectal temperature of buffaloes with increasing draft and working period was of minor nature and thus, cannot be regarded as a good measure of physiological load for comparative studies.
4. The environmental conditions had profound effects on physiological responses during work and rest than the magnitude of draft. The recovery was faster while working under cool environment during winter with air temperature range of 19 to 25°C than with the higher temperature of 25 to 32°C during autumn season.
5. The pulse rate reached a steady state early after about 1 to 1.5 h of work followed by respiration rate which reached the steady state only after 2 h of work.
6. There was constant power output of buffaloes at draft lower than 10% of body weight but at higher draft of 120,150 and 200 kg (10, 13 and 17% of body weight), the power output decreased steadily by about 14,12 and 9% after 2.5,2 and 1 h of work, respectively.

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# Performance of Bullocks under Different Load and Climatic Conditions

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## Abstract

A study was conducted in India to investigate the performance of bullocks in terms of speed and power developed as a function of their body size, duration of work, draft load and climate.

At increased draft load, the speed decreased but power output increased. The speed and power output increased with an increase in body weight. The increase in power rating was 0.03 kW for an increase of 100 kg body weight per animal. In 6 hours, the speed and power developed declined to about three-fourths of those at the start of the work. It was found that the bullocks could pull maximum drafts of 13 to 16% of their body weight for 6 hours. Their average speed and power in a 6-hour working day were 3 km/h and 0.68 kW per pair, respectively.

The bullock's performance was better in warm climate than in hot or warm and humid climates. The respiration and pulse rates of bullocks increased during work. The increase was rapid in the first hour of work and, thereafter, it was slow.

## Introduction

In India more than 80 million draft animals are available for various farm operations. It is equivalent to nearly 30% of the total power available for agriculture (Sharma et al, 1987). The animals are going to remain an important source of power for many decades to come. It is essential that besides continuing research for alternate economical energy sources, more research and development efforts should be directed towards using the present vast animal power resource more efficiently. In order to make efficient use of the animals' capacity to work, a thorough knowledge of how fast and how steadily these animals move under different conditions of load is required. This knowledge is a primary requirement for the design of any bullock-operated equipment. The design and fabrication of such equipment has been going on for a long time now based primarily on rough estimates regarding bullock power. This has resulted in an inefficient use of this vast power resource. It is observed that bullock's work output depends on various factors such as the body size, their breed, draft, duration of work, field conditions and climate. The objective of this study was to investigate how the bullocks perform in terms of working speed and power developed as a function of their body size, draft, duration of work, and climate.

## Review of Literature

Information on population of draft animals in various countries and their contribution towards the total energy for farm operations has been compiled by RNAM (1978). Joshi and Phillips (1953) and Kaura (1957), reported that for various Indian and Pakistani breeds of bullocks (*Bos indicus*), the average body weight varies from 320 to 640 kg, height (up to withers) varies from 1.6 to 1.9 m and length (shoulder point to pin bone) varies from 1.7 to 2.2 m.

Studies of Mukherjee et al (1961), Anand and Sunderasan (1974) and Davadattam (1974) show that the pulse rate, respiration rate and body temperature of Haryana bullocks vary from 41 to 56 per minute, 12 to 35 per minute and 55.1 to 55.6°C, respectively. They found that the pulse and respiration rates increased during work, the increase was rapid in the first hour of work and slower thereafter. The body temperature, however, increased steadily with the duration of work. Ranjhan (1977) reported that the energy requirements of bullocks were less than those of the fast moving horses. Kleiber (1961) described the bullocks as homothermic animals and stated that they try to preserve their body temperature. He also

stated that the environment surrounding an animal at any particular instant influenced the physiological adjustments the animal must make to maintain a body heat balance.

Esmay (1974) reviewed the works of many researchers who attempted to express climate in the form of a single index. He reported that of all such indices, the Temperature Humidity Index (THI) as accepted by the U.S. Weather Bureau was being widely adopted by animal scientists.

$$THI = 0.55\ tdb + 0.2\ tdp + 17.5 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, tdb = dry bulb temperature, °F

tdp = dew point temperature, °F

Cargill and Stewart (1966) stated that when THI reached 70, 10% of the people would feel uncomfortable and 100% of the population would be uncomfortable at a THI of 79.

Yusuf (1963) reported that the bullocks' draft capacity was 1/10th of their body weight in a 6 hour working day. ICAR (1969) stated that bullocks' draft capacity varied from 8 to 20% of their body weight. It also stated that while ploughing, a pair of bullocks developed 0.2 to 1.4 kW power with a travel speed of 2.7 to 2.9 km/h. A FAO (1972) study stated that bullocks draft capacity varies from 10 to 14% of their body weight at an average speed of 2.3 to 2.7 km/h. Singh and Chancellor (1975) rated the bullocks in North India with average power of 0.2 to 0.5 kW. Cheema and Junjua (1976), while studying the performance of bullocks, concluded that the optimum draft for a Haryana bullock varied from 12 to 15% of its body weight. They found that a bullock on an average developed 0.5 kW and moved at an average speed of 3.26 km/h.

## Experimental Procedure

All experimental bullocks were selected from the Hallikar, one of the famous draft breeds in India. The animals selected exhibited all the visible signs of good health and had normal pulse and respiration rates. All the bullocks had been doing all types of farm operations. A balanced ration was given to the bullocks according to their body weight on the advice of an animal nutrition expert. However, on the days when the bullocks did not work, they were fed only half of the scheduled quantity of concentrate mixture.

A wheeled tool carrier with a sledge chained to it was used for the measurement of the draft. The operator was provided with a seat on the carrier. Bullocks tended to slow down their speed when pulling load and were inflicted with mild pains by the operators to keep them moving at a reasonable speed.

The body weights of the bullocks, average over three consecutive days, selected for experiments are given in **Table 1**. The average body weight, height, length (from shoulder point to the pin bone) and girth (at heart) were 436 kg, 1.42 m, 1.46 m, respectively.

It was decided to give maximum loads of only 1.1 kN to the first three pairs and 1.4 kN to the fourth pair. The minimum load given was 0.5 kN. Randomized Complete Block (RBC) design with replications forming the blocks in such a way that all the bullocks were worked on a given day was formulated. Operators were assigned randomly to the different treatments. This scheme was replicated three times in each of the three climatic periods warm (P1), warm and humid (P2) and hot (P3).

Four identical sledges, one for each of the four pairs of bullocks, were fabricated. They were attached to four identical wheeled tool carriers by chains. One of the wheeled tool carrier was fitted with a telescopic beam while the other three were fitted with ordinary G.I. pipe beams. An instrument box housing a signal amplifier and a chart recorder was mounted on wheeled tool carrier with a telescopic beam. A spring dynamometer of 5 kN range and 0.05 kN/division sensitivity and a strain gauge load cell of 5 kN range were mounted on a telescopic beam.

The experiment was conducted on a well-drained earth road of one-km length. The draft was measured as the bullocks pulled a loaded sledge. The angle of pull was maintained constant at 12.5°. The pull was obtained from the spring dynamometer as well as from the chart recorder. The chart recorder also provided information regarding the variation in pull as the bullocks moved on the road. A digital stop watch was used to record the time at a 200-m distance intervals. At the start of each experiment, the different pairs of bullocks were started at intervals of 10 minutes. This facilitated the recording of speed and physiological state of bullocks at intervals of 1 hour. A rest of 5 min was given to the bull-

Table 1 Body Weight of Bullocks Used in Experiment

| Pair No. | Bullock | Body weight (kg) | Average body weight of pair (kg per bullock) |
|---|---|---|---|
| 1 | Right | 370 | 370 |
| | Left | 370 | |
| 2 | Right | 385 | 388 |
| | Left | 390 | |
| 3 | Right | 410 | 435 |
| | Left | 460 | |
| 4 | Right | 550 | 553 |
| | Left | 555 | |

ocks at the end of each hour.

The physiological state, i.e., respiration and pulse rates of the bullocks, were observed before the start of the day's work and also during the work. The respiration rate was measured by visual observations of the movement of flanks. The pulse rate was recorded by feeling the coccygeal vein. An hourly climate data of dry bulb temperature and relative himidity were obtained from the meteorological laboratory for all experimental days. The average hourly temperature, relative humidity and temperature humidity index for the three climatic periods are given in **Table 2**.

The power developed was computed from speed and draft values. The work output of a pair of bullocks during a day can be obtained by multiplying the average power developed and the number of hours worked by the pair of bullocks.

Table 2 Average Hourly Temperature, Relative Humidity and Temperature Humidity Index (THI) for Three Climatic Periods

| Time interval (h) | Dry bulb temperature (deg (°C) | | | Relative humidity % | | | Temperature humidity index (THI) | | |
|---|---|---|---|---|---|---|---|---|---|
| | P1* | P2* | P3* | P1 | P2 | P3 | P1 | P2 | P3 |
| 0 | 21.1 | 25.5 | 30.0 | 59 | 73 | 43 | 67 | 75 | 77 |
| 1 | 21.7 | 26.7 | 31.7 | 58 | 67 | 35 | 67 | 76 | 78 |
| 2 | 24.4 | 27.2 | 33.3 | 44 | 61 | 30 | 71 | 77 | 79 |
| 3 | 26.1 | 29.4 | 35.0 | 31 | 55 | 25 | 73 | 78 | 80 |
| 4 | 28.3 | 30.5 | 35.5 | 23 | 51 | 21 | 74 | 78 | 79 |
| 5 | 29.4 | 31.1 | 36.1 | 18 | 45 | 18 | 75 | 79 | 79 |
| 6 | 30.5 | 31.1 | 36.7 | 14 | 42 | 16 | 76 | 79 | 79 |

*P1 = Warm climate; P2 = Warm and humid climate; P3 = Hot climate.

## Results and Discussion

The effect of duration of work on average power developed and speed of work was evaluated. It was found that as the working hours increased, the average power developed decreased (**Fig. 1**). The initial average power, 0.79 kW developed by a pair of bullocks decreased to 0.55 kW, a 30% reduction, after 6 working hours. The reduction in power developed showed proportionate decrease as the working duration increased. It was found that bullocks could pull drafts of 13 to 16% of their body weight for 6 hours. It was almost the same as observed by FAO (1971), Singh and Chancellor (1975) and Cheema and Janjua (1976).

**Fig. 2** shows the effect of draft on power developed by various body weight of bullocks. An increase in the draft caused increase in the power developed. It was found that the amount of power developed was related to the weight of bullocks. Bullocks with heaviest body weight (553 kg) developed highest power at all draft loads. All four pairs of bullocks developed approximately 90% more power when the draft was increased from 0.48 kN to 1.05 kN. The increase in power rating was approximately 0.03 kW for an increase of 100 kg body weight per animal.

An increase in working duration resulted in a proportionate decrease in the working speed (**Fig. 3**). The average working speed after 6 hours was 26% lower than the speed at the beginning of the work. The average speed and power output in a 6-hour working day were 3 km/h and 0.68 kW per pair.

For all pairs of bullocks, it was found that as the draft load increased the speed decreased (**Fig. 4**). The working speed was proportional to the body weight. The working speed of the heaviest bullocks (553 kg weight) was highest compared to all other

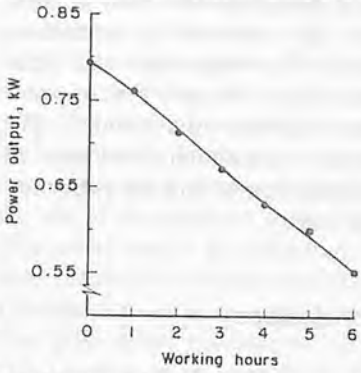


Fig. 1 Effect of working hours on the average power output of a pair of bullocks.

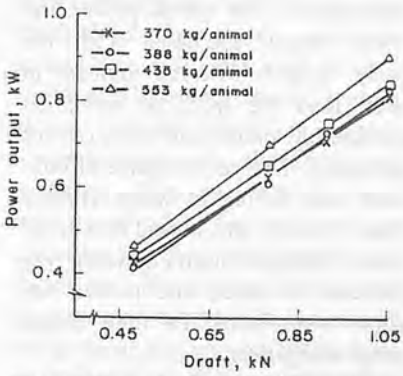


Fig. 2 Effect of draft on the power developed by various pairs of bullocks.

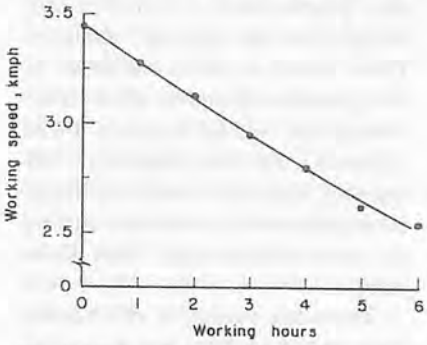


Fig. 3 Effect of duration of work on the speed of the bullocks.

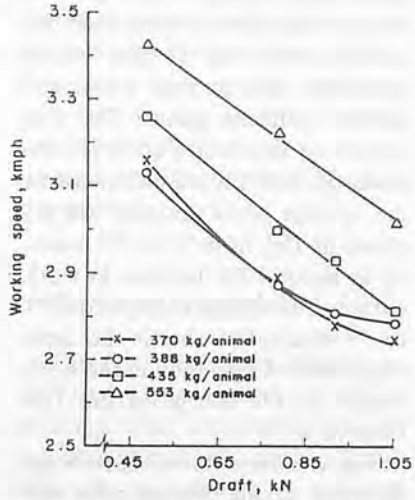


Fig. 4 Effect of draft on the working speed of the bullocks.

bullocks. When the draft increased from 0.48 kN to 1.05 kN, the speed of bullocks decreased by about 13%.

The effect of climate on the speed and power output of different bullocks was studied. For all bullocks the working speed in warm climate was higher than that during the hot, and warm and humid climates (**Table 3**). There was not much difference in working speed in hot, and warm and humid climates. The highest working speed was observed with the 553-kg weight bullocks in warm climate while lowest was observed with 370-kg weight bullocks in warm and humid climate.

The effect of climate conditions on the power output of different bullocks is also shown in **Table 3**. The power developed by bullocks was proportional to their body weights under various climates. There was not much variation in the power developed by the 370-kg, 338-kg and 435-kg bullocks under different climates. However, the heaviest pairs of bullocks (553 kg) developed much more power during the same climate than other three pairs.

The work output of all bullocks was highest during the warm climate and was lowest in the hot climate. The average THI values in warm, warm and humid, and hot climates were 72, 77 and 79, respectively. The average work output by bullocks against THI was plotted as shown in **Fig. 5**. The increase in THI caused a decrease in the average work output. An increase in THI from 72 to 79 resulted in about 13% decrease in work output. The change in THI from 77 to 79 resulted in almost the same magnitude of reduction in the work output as the change in the THI from 72 to 77.

**Fig. 6** shows the effect of work duration on the average pulse and respiration rates of the bullocks. As the duration increased, both respiration and pulse rates also increased. However, this increase was rapid during the first hour of work and later showed a diminishing trend. The respiration and pulse rates after 5 h and 6 h of work were almost the same. The average respiration rate/min of bullocks was 45 and the pulse rate/min was 67.

Table 3 Effect of Climate on Average Speed and Power Developed per Pair by Different Weight Bullocks

| Bullocks body weight (kg) | Work speed (kmph) | | | Power (kW)/pair | | |
|---|---|---|---|---|---|---|
| | Climate | | | Climate | | |
| | Warm | Warm and humid | Hot | Warm | Warm and humid | Hot |
| 370 | 2.94 | 2.84 | 2.90 | 0.66 | 0.63 | 0.64 |
| 388 | 2.95 | 2.88 | 2.90 | 0.66 | 0.64 | 0.65 |
| 435 | 3.06 | 2.98 | 2.98 | 0.67 | 0.66 | 0.66 |
| 553 | 3.17 | 3.09 | 3.13 | 0.79 | 0.77 | 0.79 |

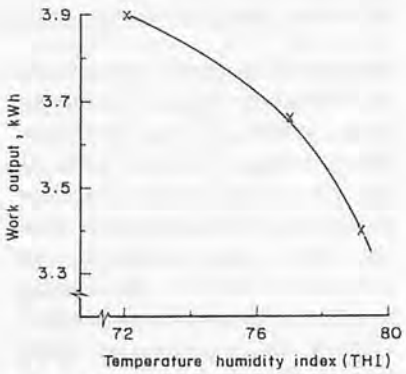


Fig. 5 Effect of temperature humidity index on the average work output of a pair of bullocks.

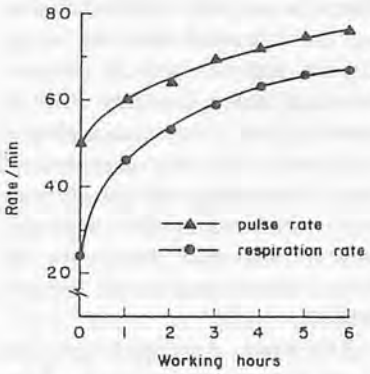


Fig. 6 Effect of working hours on the average respiration and pulse rates of bullocks.

## Conclusions

The bullocks' body weights proved to be better measure of their size than their linear body dimensions. The speed, power and work output increased with the body weight. With an increase in draft load the speed of work decreased but power and work output increased. The performance of bullocks was better in warm climate than in warm and humid or hot climate. During 6 hours of work, the decrease in speed and power was about one fourth of their initial speed and power.

The Hallikar bullocks could pull maximum drafts of 13 to 16% of their body weights for 6 hours. The average speed and power output of Hallikar bullocks were 3 km/h and 0.68 kW per pair in 6 hours of continuous work, respectively.

The respiration and pulse rates of bullocks increased during work. The increase was rapid in the first hour of work and thereafter it was slow. The respiration rates increased with draft but pulse rate was unaffected.

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# Comparative Evaluation of Different Methods of Raising Mat-type Paddy Seedlings

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## Abstract

A study was conducted to evaluate three different methods of raising mat-type paddy seedlings. A maximum initial investment of Rs.1 600 followed by Rs.800 was made for sowing seedling mats per hectare by single trays having base and single frame with no base, respectively. A minimum investment of Rs.150 was made for growing seedling mats with 10-mat frames. Any number of seedling mats can be grown in a season with only two 10-mat frames whereas a higher investment is required for growing additional number of mats with single frames. No appreciable difference was observed in the quality of the nursery mats raised by different methods. The total cost of nursery sowing and uprooting with 10-mat frame method was most economical in comparison with other methods.

## Introduction

The need for paddy transplanters in India is being felt in order to overcome labour shortages, achieve desired plant population and reduce human drudgery. Machines also help to transplant the crop in rows making weeding easier in addition to reducing the cost of transplanting. Transplanters use either washed root or mat-type nursery. Transplanters using washed root seedlings have an advantage over the nursery-grown seedlings. However, an evaluation of these types of machines has indicated that labour is not saved for the total transplanting system. The high labour requirements are mainly on uprooting, washing and arranging of seedlings in the boxes. One of the major reasons of labour savings in the use of transplanters is not fulfilled which makes the adoption of these machines by farmers difficult. Transplanters using mat-type seedlings (also called soil-bearing type) have gained more popularity in countries like Japan because of their labour saving feature as well as better quality of transplanting. Individual seedlings are not uprooted in this type but a specified piece of seedlings along with the soil known as mat is lifted. Uprooting of mats is much faster than the traditional seedlings. However, the nursery raising methods as followed in these countries involves high initial investments. Plastic trays with perforations are used in these methods for each of the mat which remains in the field for full growth period of the nursery. Obviously, this method cannot be adopted by the Indian farmers because of high initial investment. Also, the double frame method used in Philippines to grow mat-type seedlings is costly to suit Indian conditions. In this case also, the frames are kept in the field for full growth period of the seedlings. Efforts were, therefore, made to evolve a method wherein the initial investment can be substantially reduced. The quality of the nursery raised by selected alternate methods needs to be compared with the nursery grown in trays which remain in the field for full growth period of the nursery. Labour requirements, economics as well as initial investment need to be compared before recommending the most suitable methods for raising mat-type nursery under Indian conditions with special reference to Punjab. Such a study was, therefore, taken up along with the research and development of paddy transplanters.

## Methods and Materials

Three methods were adopted in the study for growing mat-type seedlings. The methods used, number of mats actually prepared and some of other details are given in Table 1.

Table 1 Characteristics of Mat-type Methods of Raising Paddy Seedings

| Treat-ment | Treatment description | Mat size cm | Size of tray/frame cm | Material of construction of trays/ frames | Number of mats actually prepared | Number of trays/ frames used |
|---|---|---|---|---|---|---|
| $M_1$ | Single tray with base | 40 x 22.5 x 2.0 | 42 x 24.5 | Rectangular wooden strips of size 2 x 1.0 cm | 400 | 400 |
| $M_2$ | Single mat frame without base | 40 x 22.5 x 2.0 | 42 x 24.5 | Rectangular wooden strips of size 2 x 1.0 cm | 400 | 400 |
| $M_3$ | 10-mat frame without base | 40 x 22.5 x 2.0 | 118.5 x 83 | M.S. rectangular pipe of size 2.0 x 1.0 cm | 400 | 2* |

* Seedlings for 10 ha or more can be grown with only two 10-mat frames in a season.

## Preparation of Seedling Mats

A plot of 25 x 8 m was properly levelled after harrowing twice to grow seedling mats. Twelve beds of 12 x 1 m were prepared in the field as shown in **Fig. 1**. Each bed was sufficient for growing 100 nursery mats of 40 x 22.5 cm each. Polythene sheet of 50-60 gauge thickness and 90 cm wide was spread on 8 nursery beds numbering from 5 to 12 where the nursery was grown with the help of single mat frames without base ($M_2$) and 10-mat frames without base ($M_3$). No polythene was spread on 4 nursery beds numbering from 1 to 4 where the nursery was grown with the help of single trays having base ($M_1$). Four hundred single trays were placed on the four beds having no polythene sheet and another 400 single mat frames on beds 5 to 8 where polythene sheet was spread. Two 10-mat frames without base were placed over one of the beds (9 to 12) having polythene sheet. Well prepared soil collected from irrigation channels and mixed with farm yard manure in equal proportions was filled in the trays/frames, urea at the rate of 1.0 kg was also mixed in the soil sufficient for growing seedlings for 1 ha. About 0.80 $m^3$ mixed soil is required to sow 400 mats. Care was taken to remove any stone from the mixed soil. Soil at the top of the trays/frames was scrapped. About 50-60 g of disinfected and pregerminated seeds was evenly spread in each tray/ single frame or in each compartment of the 10-met frame.

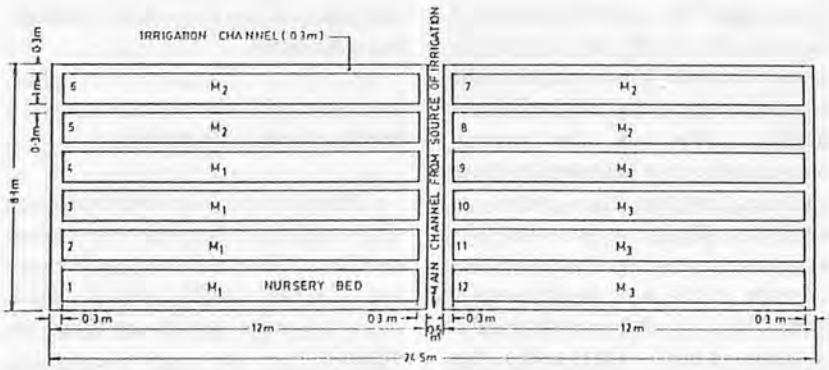


Fig. 1 Plan of nursery beds for growing nursery mats.

The seed was then covered by a thin layer of mixed soil. After this, water was sprinkled by hand sprayer over the 10-mat frames for proper settling of the soil. The 10-mat frames were then lifted immediately after sowing and sprinkling water and placed at the adjoining place for sowing additional nursery mats. The method of sowing was repeated to get the required number of mats. Thus only two 10-mat frames were used in this case to sow 400 mats in the study. The same two 10-mat frames can even sow seedlings for 10 ha in a season. The single trays/frames were not lifted after sowing but kept in the field during the whole nursery growing period. The nursery fields were then filled with water by flooding immediately after sowing and irrigated daily.

Water used to be drained from the beds at noon and refilled again in the evening. Care was taken that mats always remained wet. Two sprayings of urea with concentration of 1% at the rate of 200 g per bed were applied after 10 and 20 days of sowing. Observations on leaf stage and height of plants after 15,20 and 25 days of sowing were recorded from different treatments and are given in **Table 2**. Labour requirements and economics for different nursery growing methods are shown in **Table 3**.

## Nursery Uprooting

Water from the nursery beds was drained 2-3 h before uprooting. The nursery mats grown by trays/single frame method were uprooted directly by pulling from the top. The mats grown by 10-mat frames were uprooted by cutting along the mat boundries. The blade cut is essential in separating the mats which join together during mat growing period due to flooding. Mat thickness, plant density and general condition of the nursery mats were also

Table 2 Nursery Growth Data with Different Methods of Raising Paddy Seedlings

| Method | Height of plants after | | | Leaf stage after | | | Plant density per 25 cm² at time of uprooting | Mat thickness at time of uprooting |
|---|---|---|---|---|---|---|---|---|
| | 15 days (cm) | 20 days (cm) | 25 days (cm) | 15 days | 20 days | 25 days | | |
| Single tray method with base ($M_1$) | 11.4 (8.4-17.8) | 18.7 (15.5-26.0) | 20.7 (19.8-30.0) | 3.0 (2-4) | 3.0 (3-4) | 4.0 (4-5) | 44 (35-54) | 2.3 (2.0-2.5) |
| Single mat frame without base ($M_2$) | 13.0 (8.9-18.0) | 15.1 (12.0-23.4) | 19.6 (14.5-25.5) | 3.0 (2-4) | 3.5 (3-4) | 4.0 (3-4) | 40 (26.70) | 2.1 (1.5-3.0) |
| 10-mat frame without base ($M_3$) | 15.5 (9.3-25.3) | 16.7 (11.2-26.2) | 23.3 (14.5-31.0) | 3.0 (2-4) | 3.0 (2-4) | 4.0 (3-5) | 40 (26-66) | 2.2 (1.0-2.8) |

Note: Values within parenthesis show the range while without parenthesis are the average of number of seedlings.

Table 3 Economics of Raising Mat-type Seedlings by Different Methods

| Description | Single tray method with base ($M_1$) | Single mat frame method without base ($M_2$) | 10-mat frame method without base ($M_3$) |
|---|---|---|---|
| Cost of trays/frames for growing 400 mats sufficient for 1 ha, Rs. | 400 x 4 = 1 600 | 400 x 2 = 800 | 75 x 2 = 150 |
| Life of trays/frames | 5 | 5 | 10 |
| Annual use, ha | 1 | 1 | 10 |
| Annual interest, % | 15 | 15 | 16 |
| Depreciation cost | Straightline method | Straightline method | Straightline method |
| Sunk value | 10% | 10% | 10% |
| Repair & maintenance | 5% of the initial cost | 10% of the initial cost | 5% of the initial cost |
| Labour charges, Rs./h | 2.5 | 2.5 | 2.5 |
| Labour required for nursery sowing man-h/ha | 15 | 20 | 20 |
| Labour requirement for nursery uprooting man-h/ha | 4 | 5 | 5 |
| Polythene sheet required kg/ha | – | 1.0 | 1.0 |
| Cost of polythene sheet Rs/kg. | – | 30 | 30 |

Assumption : 1. Nursery sown with 10-mat frames in a year is for 10 ha. 2. The cost of single tray, single mat frame and 10-mat frame has been estimated to be Rupees 4, 2 and 75 respectively. 3. 400 mats have been considered to be required for transplanting 1 ha.

observed at the time of uprooting and are reported in **Table 2**.

## Results and Discussion

A maximum initial investment of Rs.1 600 was made for sowing seedling mats for 1 ha with single trays with base and minimum of Rs.150 with 10-mat frames. An initial investment of Rs.800 was made for growing seedling mats for 1 ha with single mat frames without base. Any number of seedling mats for 10 ha can be grown in a season with only two 10-mat frames whereas to grow additional number of mats with single trays/frames, the initial investment will increase in the same proportion. Single mat frames without base were used to avoid damage to the sides of the mats and to improve the nursery condition, in general. However, nursery condition data recorded in **Table 2** shows that nursery growth was also not better than the 10-mat frame nursery. Some single mat frames without base floated when the beds were irrigated because of their light weight. This affected the quality of the seedling mats. The labour requirements for nursery mats sowing and uprooting were also the same in both cases. Nursery quality in single trays with base also did not justify additional investment. However, there was a marginal decrease in labour requirements for nursery mats sowing and uprooting with single trays having base as compared to other methods but the overall cost is very high in this case as shown in **Table 3**. The total cost of nursery sowing and uprooting is highest (Rs.655.5) in single trays with base and lowest Rs.96.85/ha in 10-mat frames whereas it was Rs.436.5/ha in the single mat frames without base. It can be observed from **Table 2** that there is no appreciable difference in the quality of the nursery for the various methods. Variations observed in height of plant and leaf stage were more random due to variations in methods used. Plants height of 20-25 cm were transplanted without much problem which can be achieved after 20-25 days of sowing. There was some variation in mat thickness and seedlings density in the 10-mat frames due to some soil erosion from the boundaries, yet the difference in the quality of the nursery mats did not justify the additional cost of other methods. Hence, it is concluded that nursery mats of 20-25 days old and grown with 10-mat frames are suitable under Indian situations.

Table 4 Costs of Raising Paddy Seedling

| Cost component | | Cost for single tray method ($M_1$) | Cost for single frame method ($M_2$) | Cost for 10-mat frame method ($M_3$) |
|---|---|---|---|---|
| Interest, | Rs/year | 240 | 120 | 22.5 |
| | Rs/ha | 240 | 120 | 2.25 |
| Depreciation, | Rs/yr | 288 | 144 | 13.5 |
| | Rs/ha | 288 | 144 | 1 35 |
| Repair and maintenance cost | Rs/yr | 80 | 80 | 7.5 |
| | Rs/ha | 80 | 80 | 0.75 |
| Labour charges for nursery sowing, | Rs/ha | 37.5 | 50 | 50 |
| Labour charges for nursery uprooting | Rs/ha | 10.0 | 12.5 | 12.5 |
| Cost of polythene sheet | Rs/ha | – | 30 | 30 |
| Total cost of nursery sowing and uprooting | Rs/ha | 655.5 | 436.5 | 95.85 |

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# Direct Sowing:

# An Alternative to Paddy Transplanting

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## Abstract

In Pakistan, rice establishment is practised through manual transplanting of paddy seedlings, usually by hired labour. Manual transplanting is not only labourious, time consuming and costly operation but also results in non-uniform and inadequate plant population. Poor plant population is one of the basic reasons of low rice yields in the country. In an effort to mechanize rice transplanting operation, both root-washed and mat seedling type transplanters were tested but none of them was found suitable to the country requirements. The other problem of transplanting is preparation of puddled fields, as none of the four-wheel drive tractor and rotary cultivator with water tight seals is available in the country. Wheat yields of the paddy harvested fields are also quite low mainly due to puddling operations.

Direct seeding of rice on dry soils has been found most appropriate alternative to transplanting. It not only avoids puddling operations, raising and transplanting of nursery seedlings but also gives better yields than existing manual transplanting. In an experimental study, transplanting produced maximum paddy yield of 7 875 kg/ha. Whereas the highest paddy yield (8 666 kg/ha) of KS-282 was recorded by direct rice cultivation on dry soils with an increase of 10% over transplanting. Weed infestation was greater in the dry, direct rice cultivation (30 plant/m$^2$) compared with manual transplanting (7 plant/m$^2$). Future research needs are being focused on weed control through mechanical/chemical means, documentation of water requirements and mechanized harvesting and threshing operations.

## Introduction

Rice is both a food and a cash crop in Pakistan. It occupies an area of 2 million ha with an annual production of 3.5 million t (Anonymous, 1987). It is the third largest crop in terms of area in the country. Its cultivation is mainly concentrated in four distinct rice zones (Fig. 1). Besides, being a number two food staple of Pakistani people, it is one of the major export commodities in the agriculture sector. Pakistan is earning a sizeable foreign exchange from its export.

In Pakistan rice is cultivated as a kharif crop. Its planting coincides with the onset of monsoon rains which meets the major portion of its water requirements. The weather is usually clear and sunny with immense solar radiation during the reproductive and ripening periods of paddy which is very much con-

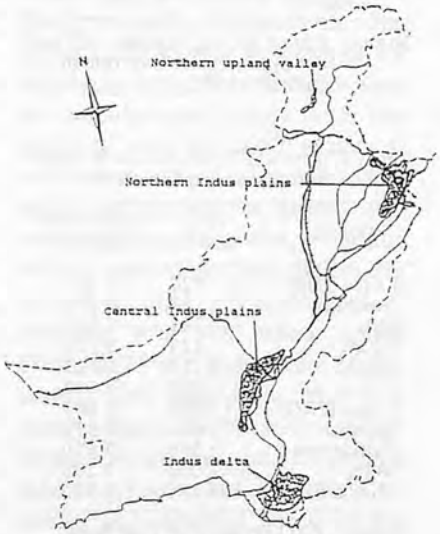


Fig. 1 Pakistan rice zones.

ducive for good yield. The disease and insect problems are not very acute. The soils are fertile with alluvial plains. Irrigation facilities are vast as there is the world's largest man-made irrigation system in the country. Despite of all these favourable conditions, the national average yield of rice is almost at a standstill for the past decade (Table 1) and quite low than most of the developed countries of the world (Table 2). One of the main reasons of low rice yield is non-availability of suitable farm machines for major rice production operations, namely; land preparation (puddling), transplanting, fertilizer and pesticide application, weeding and harvesting and threshing operations.

This paper describes the present practice of paddy transplanting and problem associated with this technique, and various research efforts made in the country to adapt direct sowing of rice as an alternate to paddy transplanting. Future research thrusts on dry direct seeding of rice, as most successful technique for our rice-wheat cropping system is also highlighted.

Table 1 Yield of Rice in Pakistan

| Year | Yield (kg/ha) |
|---|---|
| 1970-71 | 1 463 |
| 1971-72 | 1 549 |
| 1972-73 | 1 577 |
| 1973-74 | 1 623 |
| 1974-75 | 1 439 |
| 1975-76 | 1 531 |
| 1976-77 | 1 565 |
| 1977-78 | 1 553 |
| 1978-79 | 1 615 |
| 1979-80 | 1 581 |
| 1980-81 | 1 616 |
| 1981-82 | 1 736 |
| 1982-83 | 1 741 |
| 1983-84 | 1 671 |
| 1984-85 | 1 741 |
| 1985-86 | 1 616 |
| 1986-87 | 1 670 |

Source: Planning Unit, Ministry of Food and Agriculture, Government of Pakistan, 1987.

Table 2 Area and Yield of Rice in Major Rice Producing Countries

| Country | Area (ooo ha) | Paddy yield (kg/ha) |
|---|---|---|
| Korea (DPIZ) | 820 | 6 341 |
| Australia | 83 | 6 295 |
| Italy | 181 | 5 856 |
| Egypt | 423 | 5 768 |
| Japan | 2 273 | 5 701 |
| U.S.A. | 878 | 5 153 |
| China (PRO) | 33 980 | 5 067 |
| Pakistan | 2 020 | 2 579 |
| Philippines | 3 300 | 2 470 |
| India | 41 000 | 2 195 |
| Thailand | 9 400 | 1 972 |

Source: FAO Production Year Book, 1983.

## Paddy Transplanting

Paddy transplanting involves raising of rice seedlings, preparation of puddled fields and transplanting of rice seedlings in the puddled field.

Raising of nursery seedlings involves uniform broadcasting of the sprouted seeds on well puddled land. Initially, paddy seeds are soaked in water for 24 h and then kept moist in gunny bags for another 24 h or more until they sprout. Then the sprouted seeds are broadcast on well-prepared puddled field. The nursery field is irrigated in the morning and drained in the evening daily at least for the first 7 days after sowing. The water is then kept standing until the rice seedlings are ready for transplanting.

Puddling of rice fields consists of working 10-15 cm of the top soil at moisture content above field capacity until most of the aggregates are destroyed and the soil is transformed into a flowable slurry. In puddled field a laminar structure due to slow sedimentation of puddle mass is formed (Snachez, 1968). Its thickness varies from 2-5 mm in dry/wet cultivation and 9-17 mm in wet cultivation (Scheltema, 1974). Puddling destroys the system of micropores and fine clay particles seal the bottom of puddled layers and thus reduce water percolation rate.

In Pakistan, for puddling, the soil is tilled in saturated condition with either animal-drawn wooden plow and wooden plank or tractor-operated spring loaded tine cultivator and wooden plank. The use of tractor PTO-operated rotary cultivator for puddling was found superior to tine cultivation (Majid et al, 1985). But it is used on limited scale due to; initial high price (Rs. 40 000); high operating cost; and lack of water-tight seals for gear box and sprocket chains transmission cases.

There is also a need for four wheel drive tractor with water tight seals to prevent entering of muddy water in tractor engine to do the better puddling operations. These tractors are about 30% more expensive and are not on standardized list.

Wheat-rice is a common cropping pattern in rice growing zones. Seedbed preparation requirements for paddy transplanting and wheat crop are quite different from each other. Paddy needs puddled field with hard pan to retain water whereas finely prepared and well drained seedbed is required for wheat. The average yield of wheat in the transplanted paddy field is below average (1 330 kg/ha) compared with irrigated non-paddy areas where the average yield is 2 050 kg/ha (Majid, 1983). The low yields of wheat sown in paddy harvested fields can be attributed to poorly prepared seedbeds due to puddling (Byerlee, 1984). Though proper puddling facilitates transplanting operations, reduces water percolation rate and checks weed growth, it does not fit in the rice-wheat cropping pattern commonly practiced. Moreover, farm tractors for dry land farming are only available in the country.

In Pakistan, transplanting of paddy is done manually either by hired labour or on contractual basis. Manual transplanting is the most laborious and time consuming practice in paddy cultivation. Approximately, more than 25% of the total working hours for paddy

production is spent for the process of transplanting and nursery raising. Plant spacing is an important production factor in paddy cultivation. Planting paddy seedling closer than necessary increases the cost of transplanting and contributes to increased probability of lodging. On the other hand, too wide spacing results in lower yields (De Datta 1981). The hired/contractual labour tends to transplant less plants in the centre of field. The average plant population of paddy is much less than the required one (Khan et al, 1979). Transplanting paddy seedlings at the right time of the season has a pronounced effect on production. In the past few years, due to the migration of rural youth to urban areas for better emoluments, the shortage of labour during peak planting season has resulted in increased labour wages and delayed transplanting operations. A delay in transplanting of one month reduced the yield of rice by 25% and delay of two months resulted 70% reduction (Rao and Pradhan, 1973). The inadequate number of paddy seedlings per unit area transplanted by manual labour and delay in transplanting operation due to non-availability of labour during peak season, stress the need for mechanized rice crop establishment operation in the country.

In an effort to mechanize the paddy transplanting operation in Pakistan, both root washed seedling and mat seedling type transplanters from China, Korea, India, Philippines and Japan were tested for their suitability. These machines were not found suitable for the country because they required precise field levelling, high soil organic matter, better water management and high technical skills for growing mat type nursery seedlings. Such type of situation demands the replacement of transplanting by convenient alternative technique.

## Direct Sowing of Rice

In the light of the transplanting problems discussed in the previous section, direct sowing of rice does offer an alternative substitute to transplanting. This method is being practiced in the United States, Italy, Brazil, Greece, France, Morroco, India, Thailand, China and Turkey as it needs minimum labour (Mabbayad and Obordo, 1970) and ensures timely sowing of the crop. Direct sowing of rice can be done by seeding on puddled soil, seeding on dry soil, seeding with coated rice in submerged paddy field, and water seeded rice.

Direct sowing can be done either by drilling or through broadcasting. Drilling is the most efficient method because of lower seed requirement, uniform sowing in lines and uniform crop stand and it reduces the cost and labour requirement to nearly one-third as compared to transplanting (Rao and Pradhan, 1973).

The use of manually-operated and animal-drawn seed drills has been reported at IRRI, India, Africa (IRRI, 1979, Khan, 1975, Singh et al, 1983; UATP, 1979 and Wanders, 1974). IRRI manual seeder was tested at Rice Research Institute (RRI) Kala Shah Kaku in early 1970s but was not found suitable because it required precise water depth of about 1-2 cm; it was difficult to maintain uniform seeding depth; and walking in puddled field was a tiring task.

The RRI has also conducted a few studies on broadcasting of sprouted rice seed in puddled fields. The results were not encouraging because of high seed rate as compared with drilling; uneven germination, initially stunting and low growth, and more and earlier chances of lodging.

The Crop Maximization Programme (CMP) of the Pakistan Agricultural Research Council (PARC) also conducted field studies on wet direct sowing of rice. Sowing was done with pre-soaked seed by broadcasting with fertilizer spreader on well puddled soils. The land was puddled with the use of water-proof rotary cultivator. After applying sufficient water, levelling was done with smoothing bar mounted on a water tight tractor equipped with narrow iron wheels. After seed sowing, fresh water, almost every day was applied for a period of 3 weeks. The water was kept standing in the field until crop maturity. Although yield results were encouraging, this technology requires the following: water-proof four wheel tractor, rotary cutivator and iron wheels and seed broadcaster, etc; abundant quantity of irrigation water; selective weeding measures; precisely levelled field; and proper drainage systems.

In order to cope with the problems of weed control, poor seedling growth, poor lodging ressitance and bird damage in wet direct sowing, a new rice cultivation system called DSSP system (direct seeding with coated rice in the submerged field) has been developed in Japan. The DSSP system is a systematic modification of the direct rice cultivation techniques. In this case seeds are soaked with a chemical called calper and are placed in the wet field at a depth of about 1 cm. The calper helps in seed germination by supplying oxygen to the rice seed in the submerged paddy field. The yield of rice by DSSP system is similar to that of mechanized transplanting and in some cases even higher. Moreover, working hours required for this system are also less than mechanical transplanting, with 30% labour saving (Washio, 1984). Despite the labour savings and high yield, this is a costly and complicated system because it requires wet rice drilling machines/equipment, coating machines and chemical necessary for rice seed preparation and pyrazolate

herbicide for initial weeding. In this system, the seeds should be precisely placed at a depth of 1 cm for higher seedling emergence and minimum crop lodging.

Water seeding of rice originated in California, USA, and is still practiced in many parts of Asia, America, Southern Europe, Russia, and Australia. Precise water control and good seed viability are required. There is also a need for more seeds per hectare than direct seeding.

In California, water seeding of rice started to control barnyard grass (*Echinochloa spp.*). Rice seeds were soaked for 18-24 h, drained for 24-48 h, and seeded by airplane into fields with a depth of 7.5-15 cm (Jhonston and Miller, 1966).

Higher grain yield was obtained with pre-germinated seed than with dry seed in a study comparing different practices for seeding rice in water in Louisiana (Faulkner, 1960). A need for keeping the field flooded until rice emerges was also pointed out in this study.

Oxygen is essential for early root development. In Arkansas, soil tilled to a depth of 20 cm is irrigated with cold water that contains dissolved oxygen. Seeding is done as promptly as possible because a poor stand is usually obtained where the water has been on the field longer than four days before seeding (Adair and Engler, 1985). In Pakistan rice is sown in summer when the temperature is around 40°C. These is also limited irrigation water available at this season. Therefore, this technique cannot be adapted in Pakistan.

## Direct Seeding on Dry Soil

In this method, the soaked seeds are drilled directly into the well prepared field at field capacity or higher moisture contents. The drilling time is approximately one week later than rice seeds sown for nursery raising. The first irrigation is applied about 15 days after sowing. Mechanical weeding is practiced when the fields come in "wattar" condition after first irrigation and then later on fields are kept super-saturated like in transplanting. Dry seeding eliminates the raising of seedlings, puddling operations and decreases the water requirement of the rice crop substantially. In China an average rice yield of 6.75 t/ha was recorded with direct dry cultivation by using one-third as much water and two-third as much manure as needed with traditional method (Qinghua, 1985). Another study in China reveals that direct sowing of rice on dry soil save about 1/3 of irrigation water and 90 man-hours as compared with transplanted rice (Guo Yixian, 1986). Dry direct seeding of rice may be the most suitable substitute to conventional transplanting because of;

1. Saving in water requirements by elimination of seedling raising and puddling operations.
2. Minimum production cost by less labour requirement.
3. Timely sowing of rice crop.
4. Optimum plant population of rice crop.
5. More time available for wheat sowing through early maturing of rice crop (10-15 days).

Dry rice establishment is similar to growing wheat crop. Dry sowing of rice is to be helpful for improving the wheat yields in the rice areas. According to a study carried out in India, an increase of 6% in wheat yield was recorded in the area which was previously under direct seeded rice (Chatterjee and Khan, 1978).

The Farm Machinery Institute (FMI) of PARC initiated a pilot study in 1982 to compare different rice growing methods, mainly; (a) broadcasting of pre-germinated seeds in puddled soil, (b) drilling in dry soil and transplanting. The grain yield and other components were found higher in pre-germinated seed sowing. In 1983, these findings were further confirmed at the farmer fields. Weeding was a serious problem noted in direct broadcasting of pre-germinated seed. In dry seeding, fresh water had to be applied daily for about 10 days and it appeared as a maximum water consuming technique. Another study of different direct sowing techniques was conducted at the National Agricultural Research Centre, Islamabad in 1985. The seeding techniques used were puddle broadcasting; dry seeding and dry broadcasting. The maximum grain yields of 4 365.3 kg/ha was recorded from dry seeding technique **(Table 3)**. It was proved that direct drilling on dry soil was superior to broadcasting of the soaked seeds on puddled soil and dry soil. Moreover, shallow root establishment was noted in puddle broadcasting which, consequently, resulted in crop lodging and uprooting of plants during harvesting. The major problem with dry direct seeding, so far noticed by FMI, is heavy weed infestation. This can be solved either by developing a suitable mechanical rotary weeder or by the use of selective herbicide. In 1986-87, FMI trials conducted at farmer fields and Millat Tractor Limited (MTL) farm Lahore, properly weeded direct seeded rice gave maximum yield of rice grain **(Table 4)**. Similarly, another weeding study was tested with Basmati-385 at MTL farm in 1987. It was concluded from these studies that integrated weeding, i.e., mechanical weeding plus chemical application, is a most effective approach for proper weed control in direct sowing on dry soil **(Table 5)**. Saving of irrigation water has been noted on the basis of qualitative observations. Since no quantitative information is available on water requirement by dry direct sowing of rice, there is a great need to assess

Table 3 Effect of Different Direct Sowing Methods on Rice Yield

| Treatment | Yield (kg/ha) |
|---|---|
| Puddle broadcasting (BS) | 4 343 |
| Dry line sowing (DLS) | 4 565 |
| Dry broadcasting (DBC) | 3 849 |

Note: This study was carried out at National Agric. Res. Centre, Islamabad in 1985.

Table 4 Effect of Irrigation and Weeding Measures on Yield of Dry Direct Seeding of Rice (KS-282)

| Treatment | Yield (kg/ha) |
|---|---|
| First irrigation 10 DAS and weeding Nil | 3 208 |
| First irrigation 10 DAS and Saturn @ 15 kg/ha and manual weeding | 67 791 |
| First irrigation 15 DAS and Machete @ 2 *l*/ha and manual weeding | 8 416 |
| First irrigation 20 DAS and manual weeding | 8 666 |
| Conventional transplanting | 7 875 |

Note: DAS = Days after sowing.

the actual water requirement of this technique.

## Future Thrusts

Mechanized technology package for dry direct seeding of rice may be commercialized by:

i. Finalization of irrigation scheduling.
ii. Development of mechanical weeder and screening of the selective herbicide for weed control.
iii. Development of the seed cum fertilizer drill.
iv. Determination of the optimum seed rate.
v. Evaluation of the optimum fertilizer requirements.
vi. Selection of rice areas for dry direct rice cultivation.

Table 5 Comparative Weeding Measures for Direct Dry Fine Rice Cultivation (BASMATI 385)

| Treatment | Yield (kg/ha) |
|---|---|
| Control | 3 611 |
| Mechanical method | 6 661 |
| Herbicide application | 6 500 |
| Mechanical + herbicide | 7 666 |
| Manual weeding | 7 444 |

Note: Stam-F34 used as a herbicide @ 10 litres per hectare.

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# Agricultural Machinery Inventory, Type and Condition in Nigeria, 1975—85

## — Salient Findings and Recommendations of an Investigative Survey —

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### Abstract

Many factors tend to limit the successful development and application of agricultural mechanization technology in Nigeria. Prominent among them is the absence of records and information on agricultural machinery used in the country. Over the years, a lot of agricultural equipment have been imported into the country in an attempt to improve the level of mechanization of agricultural processes. Effective planning, operation, maintenance and management of agricultural machines depend on the availability of data and information for the past and existing situations.

A national investigation survey was embarked upon at the National Centre for Agricultural Mechanization (NCAM), Ilorin in collaboration with the Department of Agricultural Engineering, University of Nigeria, Nsukka in 1983 in order to establish the quantity and quality of agricultural machinery utilization in Nigeria. A total of 182 establishments were surveyed throughout the country, most of them government establishments. The data and information collected were limited to the period of 1975-85, during which the largest number of machinery were imported into the country.

In this paper, the salient findings of the survey are presented, while some recommendations are being tabled for national and sectoral as well as professional adoption, for meaningful agricultural mechanization system programmes and strategies to be followed.

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### Introduction

The effort to improve agricultural production through improved technology and use of agricultural machines and gadgets began during the British Colonial Era of Nigerian national history. The emphasis then was placed on cash crops (cocoa, palm oil, coffee, groundnut and rubber) which were in great demand by the British industries. This trend continued in the first Republic (1960-65) in a dire need to improve foreign earnings. However, with the significant decline in income from cash crops and the increasing unemployment problems of qualified youth, the need was felt to encourage young school leavers to take up farming, through the introduction of simple mechanical and engineering systems that will ensure higher productivity and income while reducing farm drudgery. The decline in the agricultural sector continued into the first military era (1966-1979) with greater degeneration during the Second Republic (1979-83). However, there has been an increasing awareness of the need to improve agriculture through the application of appropriate engineering techniques and systems.

Over the years attempts have been made to translate this awareness into the formulation and implementation of agricultural mechanization policies and programmes through government ministries and establishments.

The factors which tend to limit

the successful development and application of improved agricultural mechanization as defined by FAO (1981) are socio-economic, cultural and technical in nature. These have been discussed extensively by many researchers (Odigboh 1976, Makanjuola, 1976 and Makanjuola et al, 1978 and summarized by Anazodo in 1986) to include: lack of technical manpower for operation and maintenance; fragmented farm holdings which hinder efficient use of machinery; agronomic practices (e.g. mixed cropping); inadequate repair and maintenance facilities; poor credit facilities; inadequate infrastructural facilities; lack of incentives for local manufacturing of farm equipment; inadequate research and development facilities; inadequate agricultural extension services; lack of classified data and information on the suitability; and performance of commercially available agricultural equipment as related to the types and condition of crops and soils.

Amidst the growing awareness of the importance of agricultural mechanization, a proposal was mooted by the Federal Ministry of Agriculture for the establishment of a National Centre for Agricultural Mechanization with mandate to develop and propagate appropriate agricultural mechanization in the country through adaptive research and development, testing, standardization, promotion of local manufacture and organization of training programmes in areas of current interests.

In order to embark on these projects meaningfully and successfully, the Centre in cooperation with the Department of Agricultural Engineering, University of Nigeria, Nsukka decided to carry out a comprehensive investigation on the past and present inventory, location, type and use of agricultural machinery in the country.

## Objectives of the Survey

In the past years, information and data on the type, condition and pattern of agricultural equipment distribution and use in the country was quite scanty. The various Federal and State Governments had accepted agricultural mechanization as a means of enhancing greater productivity on the farm, thus, substantial amounts of money were spent on procurement of various kinds of agricultural machinery and gadgets. Druing 1980-1982, the Federal Government alone through the Federal Ministry of Agriculture had distributed to all States tractors and implement sets (disc ploughs, harrows, ridgers, planters with fertilizer attachment, tipping trailers, etc.) and other equipment for operations ranging from land preparation to crop processing and storage as depicted in **Table 1**. Apart from these, several agricultural equipment were procured by other government agencies, such as the River Basin Development Authorities, Agricultural Development Projects (ADPs), State Ministries, institutions and private entrepreneurs.

The main objective of this study was, therefore, to establish a relia-

**Table 1** Distribution of All Equipment Procured by Federal Ministry of Agriculture, Nigeria (1980-82)

| States | Tractors with tipping trailers | Disc ploughs | Disc ridgers | Irrigation pumps with accessories | Mobile workshop | Boom & knapsack sprayers | Planter/fertilizer drills for rice | 2-wheel walking tractors | Rice trans-planters | Rice harvesters (tractor operated) | Hand-carried motorised harvesters | Rice threshers (votes) | Pre-cleaners |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anambra | 46 | 46 | 33 | 42 | 1 | 143 | 9 | 38 | 26 | 30 | 25 | 31 | 26 |
| Bauchi | 30 | 30 | 24 | 18 | 1 | 63 | – | 14 | 12 | 30 | 25 | 31 | 26 |
| Bendel | 48 | 48 | 21 | 50 | 1 | 168 | 25 | 11 | 8 | 31 | 30 | 36 | 31 |
| Benue | 46 | 34 | 46 | 42 | 1 | 143 | 12 | 38 | 28 | 30 | 25 | 31 | 26 |
| Borno | 49 | 49 | 29 | 47 | 1 | 158 | – | 50 | 37 | 31 | 28 | 21 | 29 |
| Cross River | 42 | 42 | 29 | 33 | 1 | 113 | – | 27 | 20 | 29 | 19 | 25 | 20 |
| Gongola | 41 | 41 | 32 | 34 | 1 | 118 | 2 | 32 | 24 | 30 | 25 | 31 | 26 |
| FCT (Abuja) | 35 | 25 | 19 | 7 | 1 | 33 | – | 6 | 6 | 24 | – | 6 | 1 |
| Imo | 46 | 46 | 38 | 42 | 1 | 143 | 9 | 45 | 33 | 28 | 27 | 33 | 28 |
| Kaduna | 39 | 39 | 32 | 31 | 1 | 108 | – | 32 | 23 | 29 | 19 | 30 | 20 |
| Kano | 38 | 28 | 40 | 45 | 1 | 153 | – | 48 | 35 | 31 | 27 | 33 | 28 |
| Kwara | 57 | 28 | 40 | 45 | 1 | 198 | 8 | 50 | 37 | 32 | 36 | 11 | 37 |
| Lagos | 33 | 33 | 19 | 11 | 1 | 38 | 2 | 6 | 4 | 26 | 2 | 12 | 7 |
| Niger | 59 | 59 | 49 | 37 | 1 | 223 | 6 | 65 | 48 | 33 | – | 50 | 45 |
| Ogun | 36 | 36 | 16 | 27 | 1 | 93 | 8 | – | – | 29 | 20 | 26 | 21 |
| Ondo | 40 | 40 | 16 | 33 | 1 | 113 | 12 | – | – | 29 | 20 | 21 | 21 |
| Oyo | 32 | 32 | 16 | 20 | 1 | 68 | 8 | – | – | 27 | 11 | 17 | 12 |
| Plateau | 49 | 49 | 40 | 47 | 1 | 158 | – | 50 | 36 | 28 | 28 | 28 | 29 |
| Rivers | 33 | 33 | 23 | 10 | 1 | 28 | 22 | 15 | 10 | 27 | 10 | 16 | 11 |
| Sokoto | 64 | 64 | 59 | 77 | 1 | 258 | – | 87 | 63 | 36 | 50 | 56 | 51 |
| Total | 863 | 812 | 621 | 712 | 20 | 2 530 | 123 | 614 | 450 | 590 | 427 | 545 | 495 |

ble national information and data base of the inventory, type, condition and location as well as the quality of usage of all agricultural equipment available in the country. It was hoped that the resultant information will aid in a meaningful analysis and evaluation of agricultural machinery for the development of appropriate strategies for mechanizing Nigerian agriculture as well as providing a system basis for proper selection and efficient management of agricultural machinery.

## Methodology and Procedure

### Design of the Study

The nation-wide study was carried out by adopting the Investigative Survey Research Approach (ISRA) developed by Anazodo (1975a-1983b). Two kinds of data were collected from each establishment surveyed. The first kind were quantitative in nature and were based on observations, measurement, existing records and authoritative publications which gave the inventory of equipment, personnel, agronomic and infrastructural resources of the various sources of information; as well as the system performance and cost-benefit indices. The second kind of data were qualitative in nature and were also based on observations, expert opinions and questionnaires. These dealt with the organizational and financial procedures, physical and operational relationships and flows in the systems.

This approach entailed visits to each selected establishment in order to accomplish the following tasks:

i) Completion of the questionnaires from available records maintained by the establishments and also from inventories and interviews held with relevant staff of the establishment.
ii) On-the-spot and motion study of agricultural operations being performed;
iii) Management of farm areas, equipment size, building layouts and other single linear quantities; and
iv) Taking of photographs of typical equipment, building and agricultural activities being performed during the visits.

Also in order to facilitate the efficient conduct of the survey a comprehensive one-week training workshop was organized for the participants drawn from the field offices of the Federal Department of Agriculture, Engineering Division and the National Centre for Agricultural Mechanization. Furthermore, some field and data compilation assistants were trained at the University of Nigeria, Nsukka (UNN).

### Brief Description of Questionnaires

The questionnaires designed for the survey were in two parts. The first was for the reconnaissance survey to get the inventory of almost all agricultural equipment presently being used in Nigeria with regard to the quality of different types and models. The main targets of the questionnaires were the States and Federal Government Ministries of Agriculture, Parastatals, Cooperatives and Local Governments. These establishments are the main users of engine-powered machines in the country. Besides, the government bodies were being involved in the supply and distribution of machinery to farmers and also it was expected that they maintained records of their activities. Other important targets of the survey were the dealers and suppliers of farm machinery and equipment.

Data and information were collected for the period of one decade (1975-85), as it was assumed that machinery procured earlier than this period might have become obsolete and/or cannibalized. The outcome of this was used to determine the sample nature and simple distribution for the second part of the study. The second questionnaire was more detailed and was subdivided into four sections, namely:

a) Description of the farm or establishment visited in terms of type of ownership, type of farming system, farm land size and development.
b) Classification and evaluation of farm tractors available to determine the make, model, size, year of purchase, the present condition, frequency of breakdowns and repairs.
c) Classification and evaluation of implements, machines and any other categories of equipment being used on the farm.
d) Identification and evaluation of the manpower resources and essential infrastructural facilities such as technical personnel, fuel supplies, road, water, electricity, farm buildings, storage facilities and processing facilities.

### Conduct and Coverage of the Survey

The conduct of the survey which was planned to be nation-wide was confronted with several limitations, including the discouraging political atmosphere in 1983/84, inadequate and untimely funding, frequent changes in Ministry's organizational set-up and poor response from establishments visited. However, by 1985, almost all States of the Federation were covered. The establishment in other States were covered in 1986. On the whole, a grand total of 225 establishments in all States of the Federation and Abuja Federal Capital Territory were visited. Out of these, 182 responded, with a few giving complete information and data, while others did not keep proper records as required.

The type and number of establishments visited are indicated in Table 2.

Table 2 Number and Type of Establishments Surveyed by State

| Name of state | Total number visited | Total number responded | Number of responding establishments* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | TEHU | SGOMS | FGOMS | IOMS | FCMS | IOMS |
| Anambra | 8 | 7 | 2 | 1 | 2 | 2 | 0 | 0 |
| Bauchi | 11 | 10 | 0 | 0 | 1 | 0 | 0 | 9 |
| Bendel | 13 | 3 | 2 | 0 | 1 | 0 | 0 | 0 |
| Benue | 7 | 7 | 0 | 0 | 0 | 0 | 7 | 0 |
| Borno | 6 | 6 | 1 | 0 | 2 | 3 | 0 | 0 |
| Cross River | 23 | 18 | 6 | 0 | 1 | 1 | 7 | 3 |
| Gongola | 5 | 3 | 1 | 0 | 1 | 1 | 0 | 0 |
| Imo | 5 | 4 | 1 | 1 | 1 | 1 | 0 | 0 |
| Kaduna | 12 | 11 | 0 | 1 | 1 | 2 | 6 | 1 |
| Kano | 7 | 7 | 3 | 0 | 2 | 0 | 1 | 1 |
| Kwara | 46 | 46 | 19 | 9 | 3 | 9 | 0 | 6 |
| Lagos | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 1 |
| Niger | 12 | 9 | 2 | 0 | 4 | 2 | 0 | 1 |
| Ogun | 14 | 14 | 6 | 0 | 3 | 2 | 0 | 3 |
| Ondo | 9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Oyo | 11 | 11 | 2 | 2 | 1 | 6 | 0 | 0 |
| Plateau | 9 | 8 | 2 | 1 | 2 | 2 | 1 | 0 |
| Rivers | 9 | 4 | 1 | 0 | 1 | 0 | 1 | 1 |
| Sokoto | 13 | 10 | 5 | 0 | 2 | 1 | 1 | 1 |
| Federal Capital Territory (FCT) Abuja | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| Total by ownership management system | 225 | 182 | 55 | 15 | 29 | 32 | 24 | 27 |

*TEHU – Tractor and Equipment Hiring Unit; SGOMS – State Government Ownership and Management System; FGOMS – Federal Government Ownership and Management System; IOMS – Institutional Ownership and Management; FCMS – Farmers Cooperative Management System; POMS – Private Ownership and Management System.

## Summary of Salient Findings and Recommendations

This study highlights the need to identify, introduce and manage the appropriate level of agricultural mechanization technology which is based on reliable data and records in order to enhance productivity and development of the agricultural sector. The main salient findings and recommendations are as follows:

1. The Federal and State Governments' efforts in the transformation of Nigerian agriculture from subsistence level to a market-oriented, modernized sector have not been very successful because of the immense ramification and contributions of agricultural mechanization have neither been truly understood nor exploited. Agricultural mechanization, therefore, must not be seen as an input only as in the 1973-85 National Plan but a system of development and introduction of mechanized assistance of different form and level of technology in agricultural production, in order to reduce human drudgery, improve timeliness and efficiency of operations, bring more land under cultivation, preserve the quality of agricultural products, provide better living conditions, and markedly advance the economic growth of the rural sector.

2. A general framework for data collection and analysis is presented in the study to facilitate the adoption of the Investigative Survey Research (ISRA) as developed by Anazodo (1975-1983b) in planning agricultural mechanization development in Nigeria.

3. The survey has shown that frequent reorganization of establishment and projects has a great influence on the agricultural machinery situation in Nigeria. The study has, therefore, recommended the streamlining, harmonizing and revitalizing the engineering divisions and parastatals so that they can more vigorously and affectively play their roles in the crucial task of proper selecting machinary for farm operations in Nigeria.

While some eingineering divisions would need more agricultural engineers, all States need to engage more technical officers, maintenance superintendents, craftsman, and artisans in order to maintain an acceptable and productive ratio of engineers, technical officers, intermediate technicians/skilled craftsmen/artisans. In this respect, training programmes and opportunities for improving the technical competence of agricultural engineering technologists and artisans and the generally accepted ratio of one agricultural engineer to three senior technical officers and nine intermediate technicians/skilled craftsmen/artisans would be more vigorously pursued and implemented in the country.

4. The rate of mechanizing family farms in Nigeria was rather slow, while the size of family farms was gradually decreasing. There was also a relative progressiveness of agricultural mechanization from one locality to another. The study, therefore, emphasized the adoption of selective agricultural mechanization approach in the gradual transformation of traditional farming systems to appropriately mechanized, business-oriented agricultural enterprises.

5. The total number of crawler tractors available in the 182 agro-allied establishments surveyed was 469. Out of these, 49% were in operational condition, 33% in serviceable condition, while 17% were in unserviceable condition. There

were also 154 units of single-axle tractors, with 68% in operational, 21% serviceable and 11% in unserviceable condition. Inspite of low level of mechanization in the country, use of single-axle tractors was fairly limited. In fact, most of the single axle tractors had been virtually abandoned.

6. The inventory of conventional or standard four-wheel farm tractors show that a total of 51,866 were available in the 182 establishments that responded properly. This is approximately 10 times the number of crawler and sing-axle tractors combined. Indeed, for every single-axle farm tractor, there were three crawler and 38 conventional four-wheel farm tractors of which 60% were found to be in operational condition, 27% in serviceable condition and 13% in unserviceable condition. The highest annual purchase or importation was recorded in 1981: a total of 5,288 units. Incidentally, the year 1981, could be considered as the peak of the Federal Government s Green Revolution Programme and also the climax of the oil boom in the country.

7. The number of different makes of farm tractors available in each State of the Federation ranged from two to seven, while the three most popular makes of tractors are Steyr (24.8%), Fiat (20.9%) and Messy Ferguson (20.5%) (Table 3a).

8. The predominant size of standard 4-wheeled conventional farm tractors available in the country was found in the 66- to 75-HP range. Based on the data collected, 56.7% of the total number of properly classified tractors were in the 66- to 75-HP range. Those with less than 45 HP were the least in number being only 2.7% of the total number properly classified (Table 3b).

9. From the comprehensive inventory of all modern (tractorized/electric-motor-powered/improved manual) agricultural equipment available in the 182 establishments surveyed, disc ploughs and disc harrows used for primary tillage operation were most numerous being 3 660 and 2 640 in number, respectively. The third predominant equipment was the knapsak sprayers with a population of 2 208, followed by disc ridgers, 1 609 and tipping tractors 1 542. Other modern agricultural equipment such as planters, cultivators, harvesters, threshers, shellers, dryers were not common in most of the establishments surveyed.

Table 3a Summary of Inventory of Makes of 4-wheeled Farm Tractor in Nigeria (1975-85)

| Makes | Number available | Percent of total |
|---|---|---|
| Fiat | 1 223 | 10.85 |
| Steyr | 1 457 | 24.84 |
| M.F. | 1 201 | 20.47 |
| Ford | 513 | 0.75 |
| D.B. | 514 | 8.76 |
| J.D. | 387 | 6.60 |
| I.H. | 90 | 1.53 |
| Others | 481 | 8.20 |
| Total | 5 866 | 100 |

Table 3b Summary of Inventory of HP Sizes of 4-wheeled Tractors in Nigeria (1975-85)

| Size (HP) | Number available | Percent of total | |
|---|---|---|---|
| | | I | II |
| Less than 45 | 125 | 2.13 | 2.7 |
| 45-46 | 553 | 9.43 | 12.01 |
| 66-75 | 2 610 | 44.49 | 56.65 |
| Above 75 | 1 319 | 22.49 | 28.63 |
| Unclassified | 1 259 | 21.46 | – |
| Total | 5 866 | 100 | – |

N.B.: I) Percent distribution of total by size including unclassified.
II) Percent distribution of total by size excluding unclassified.

10. In the investigative survey, an evaluation of the nature and frequency of agricultural equipment breakdowns was considered very crucial. Based on the data collected in this study and previous studies carried out by the Department of Agricultural Engineering, University of Nigeria, Nsukka and the Institute of Agricultural Research, Ahmadu Bello University, Zaria the following conclusions could be drawn:

i) The electrical system of farm tractors broke down most frequently while the brake system of the tractors broke down the least frequently. The frequency of breakdown of tractor components in some selected States are in Table 4 while Table 5 is a comparison of results of this study with others;

ii) The breakdowns due to worn out parts, poor adjustments and operation of equipment and poor field conditions were considered as major factors. The breakdowns due to worn out parts were found, in this study, to be the most critical factors causing the high frequency of equipment breakdowns; and

iii) Because of the high frequency of farm tractor breakdowns and the difficulties encountered in obtaining spare parts, this study strongly emphasizes the need for timely provision of spare parts and workshop facilities for effective maintenance and repairs of farm tractors and associated equipment. The need for improving the training and career prospects of agricultural equipment operators and mechanics cannot be overemphasized. The systematic development of guidelines for the selection, operation and maintenance of agricultural machinery and equipment in Nigeria should be vigorously pursued.

11. Tractorization Intensity (defined as the tractor horse-power in use per unit area of land cultivated) determined for those establishments that responded with reliable information was 0.46 hp/ha. This represents the tractorization intensity for those establishments which owned and/or used one or more 4-wheel farm tractors. However, calculated on a national basis (i.e., taking into consideration the entire land cultivated in Nigeria with or without tractor equip-

Table 4 Frequency of Breakdown of Tractor Component Systems by States*

| Tractor component system | Percent frequency by states | | | | Average frequency (%) |
|---|---|---|---|---|---|
| | Cross River | Sokoto | Bendel** | Niger** | |
| Engine | 5.73 | 28.37 | 15.73 | 0.72 | 12.64 |
| Power transmission | 18.11 | 24.18 | 17.98 | 1.44 | 15.43 |
| Electrical | 17.12 | 8.25 | 16.85 | 21.07 | 15.82 |
| Hydraulic | 6.58 | 10.06 | 20.23 | 2.60 | 9.87 |
| Fuel | 6.67 | 7.58 | 10.11 | 0.72 | 6.27 |
| Cooling system | 1.97 | 13.07 | 0.00 | 2.31 | 4.34 |
| Traction | 29.46 | 2.61 | 6.74 | 68.11 | 26.73 |
| Brake system | 2.88 | 2.87 | 0.00 | 0.00 | 1.44 |
| Others | 11.48 | 3.01 | 12.36 | 3.03 | 7.47 |
| Total percent | 100 | 100 | 100 | 100 | 100 |

* Many of the establishments surveyed did not keep proper record of equipment breakdowns. Included above are the few that supplied the required information for the determination of percent frequency of breakdowns of components.
** Only one establishment used in Bendel and also only one in Niger.

Table 5 Comparison of Results of Frequency of Farm Tractor Breakdown in Nigeria Obtained from Three Studies

| Item | Percent frequency of breakdown (national averages) from | | | Average |
|---|---|---|---|---|
| | Present study | UNN* study | IAR** study | |
| Electrical | 15.82 | 16.4 | 16.1 | 16.1 |
| Power transmission | 15.43 | 18.4 | 11.9 | 15.2 |
| Hydraulic | 9.87 | 12.0 | 22.0 | 14.6 |
| Traction | 26.73 | 10.9 | 2.8 | 13.5 |
| Engine | 12.64 | 10.0 | 14.3 | 12.3 |
| Fuel | 6.27 | 8.6 | 21.0 | 12.0 |
| Cooling system | 4.34 | 2.8 | 7.3 | 4.8 |
| Brake system | 1.44 | 3.7 | 2.5 | 2.6 |
| Others (or unclassified) | 7.47 | 17.2 | 2.1 | 8.6 |

* (Anazodo, 1986); ** (Yiljep and Gwarzo, 1985).

ment), the National Tractorization Intensity (NTI) is estimated at 0.024 hp/ha. Considering that generally recommended tractorization intensity as 1.5 hp/ha, the tremendous scope for increased use of farm tractors and associated equipment in Nigeria could be easily appreciated.

12. Based on results of the survey but subject to the accuracy of the information obtained on the total number of farm tractors sold in Nigeria over the period (1978-83), and also on the correctness of the percentage distribution of the number sold that are actually used by agricultural establishments. The estimated grand total number of various agricultural machinery currently (as at the end of 1985) in use for agricultural purpose in Nigeria is shown on **Table 6**.

13. The Government-owned Tractor and Equipment Hiring Units (TEHU) constituted the major farm machinery use system in Nigeria. **Table 7** is an analysis of various systems of farm machinery ownership and management. An estimated 67% of the total number of farm tractors available were owned and operated under the government TEHU system, while 63% of the total area mechanically cultivated was being served by them. Thus, despite the advantages of the privatization strategy, it was apparent that the TEHU remained a realistic approach to the introduction of agricultural mechanization system and techniques to the agricultural sector.

14. Furthermore, in the study the progress made in the area of indigeneous design and development of appropriate agricultural equipment for effective mechanization of major crops was examined and it was, consequently, considered that the Federal Government should support with greater vigour and determination the National Centre for Agricultural Mechanization to establish and adequately fund Zonal Centres or sub-stations for Agricultural Machinery Testing and Evaluation, Adaptation, Design and Development (AM TEADD) in different ecological zones commencing with the well-equipped Department of Agricultural Engineering.

Table 6 Estimated Agricultural Machinery in Use in Nigeria at the End of December, 1985

| Agricultural machinery, (including Post-harvest technologies) | Total number in use |
|---|---|
| Farm tractor (four-wheel or two-axle tractors) | 15 906 |
| Crawler tractors | 1 256 |
| One-axle tractors | 419 |
| Trailers | 4 529 |
| Disc ploughs | 9 544 |
| Disc harrows | 7 953 |
| Sprayers | 6 362 |
| Ridgers | 4 529 |
| Grain planters | 1 361 |
| Root and Tuber crop planter | 5 |
| Cultivators/mechanical weeders | 258 |
| Grain harvesters | 163 |
| Grain threshers | 1 022 |
| Grain shellers | 2 710 |
| Crop dryers | 263 |
| Modern storage structures | 128 |

## Conclusions

The findings of this study are a revelation of the importance of establishing a national data base for effective planning and implementation of agricultural mechanization programmes and strategies. Such vital information and data could be secured only when adequate records are kept. There was, therefore, an urgent need to promote proper record keeping by users, agents, distributors, dealers and manufacturers of agricultural machinery and equipment in Nigeria. Efforts are also necessary to

generate standardized formats for keeping records on agricultural equipment by all concerned. A central data bank should be located at the National Centre for Agricultural Mechanization (NCAM), Ilorin which should also be charged with the responsibility of co-ordinating and disseminating information on agricultural mechanization.

Since agricultural production is a dynamic process, the situation of agricultural machinery in the country is bound to change with time. It is, therefore, essential that the publication of such information be reviewed at specific periodic intervals. As the present survey covered the period of 1975-85, it is advisable to consider a review, for another publication by 1990.

In summary, the central role of the National Centre for Agricultural Mechanization in propagating, promoting, designing, developing, testing and management of agricultural mechanization systems for Nigerian agriculture is becoming more obvious. The Federal Institutions, therefore, need a strong financial, physical and manpower support for its development and realization of its mandates.

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## ERRATA

AMA Vol. 20, No. 2, Spring 1989, Page 12. The following figure should appear in the third column.

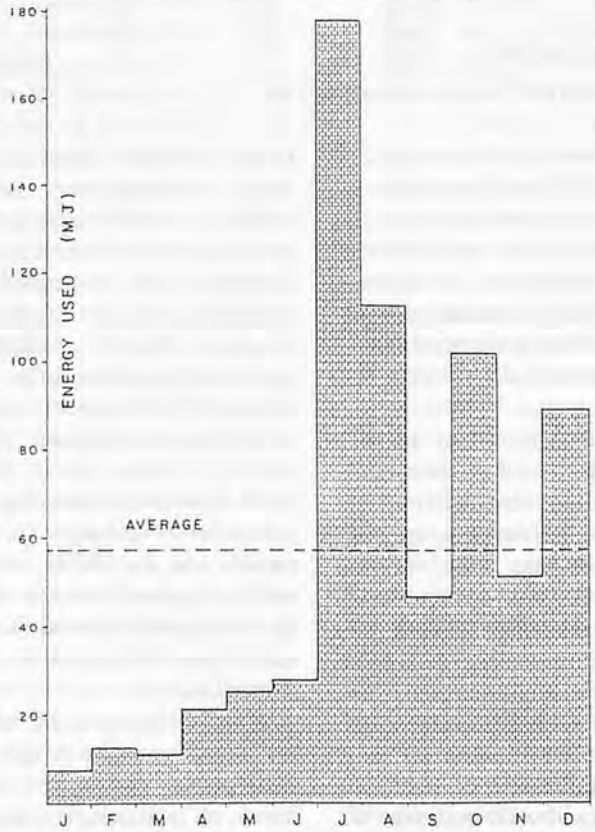


FIGURE: 3. THE ENERGY USED BY DRAFT ANIMALS THROUGHOUT THE YEAR

# Development of An Insect Detector

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## Abstract

The multiplication of storage insect is so rapid that regular inspection and detection is essential. Available detection methods are very slow and labour consuming. A batch type insect detector by fluidization is designed to separate insects and damaged grains from sample and convey them to a sampling jar for inspection. The performance and effectiveness of this machine is compared with the earlier continuous model. The chi-square ($X^2$) test shows that the machine type has an effect on insect detection. On the basis of the percentage of insect separation, and adjustment, operation and control of the machine, the batch type insect detector is found to be effective and suitable for insect detection from grain samples.

## Introduction

Insects are commonly the most serious pests of durable commodities. Their multiplication generally proceeds fastest at temperatures in the range of 25-30°C. Development periods, from egg to mature adults will be about 4-5 weeks, and multiplication rates are likely to be at least ten-fold per generation. The damage done by a single insect in terms of actual food loss is, therefore, very little. It is the capacity for extremely rapid population growth that makes insects the major causes of food losses in storage. A population of 10 weevils, for example, in a 100 kg bag of grain at about 27°C can increase in 2-3 months to about 100 000 weevils that will have consumed about 1 kg of grain. The next generation of that population may consume more than 10 kg of the grain in 4-5 weeks. The contamination of commodities by residual waste matter and dead insects adds to the spoilage and can lead to considerable further loss of food value. Detection of insect infestation at low population densities is made more difficult by their tendencies to aggregate in concealed places.

It is difficult to detect insects from the sample, so a sub-sample is generally used, but this may give absurd results. Available detection methods are slow and inefficient. Therefore, it would seem that the way lies open for the development of a simple, quick, but effective machine for the detection of insects.

The aim of this project was to develop a machine, to detect insects from small samples of grain, working on the principle of fluidization. An investigation has been carried out using two prototype models of the batch device, and an earlier continuous model to determine the optimum conditions for efficient separation of insects.

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## Concept of Fluidization

A fluidized bed is a suspension of granular solids in the upward stream of gas, usually air. At the point of suspension the frictional drag of the particles is equal to the effective weight of the bed. The particles, in this case the grains, tend to float, due to the effect of air slippage past them, the amount of lift provided by the air being dependent on the velocity of the air and the amount of drag offered by the particles. At the fluidizing point the bed is expanded.

Vanacek, et al (1965) suggested 6 different types of fluidized beds, as can be seen in **Fig. 1**. Fluidization is said to be particulate (dense phase) if the volumetric concentration of solid is uniform throughout the bed and does not change with time. When particle fluidization does not exist, the bed exhibits 'aggregative fluidization', i.e., the concentration of solids is not uniform throughout the expanded bed and varies with time. Subsequent to the bed expansion, several other stages are observed. These are: the 'boiling bed', where bubbles occur, the size of which are approximately equal to the size of the particles, the 'bubbling bed', where bubbles are bigger than individual particles, the 'slugging bed', where bubbles occupy the whole cross section of the vessel, dividing the bed into layers as they rise upwards; the 'channelling bed', where the fluidizing medium forms vertical channels through which most of the fluid

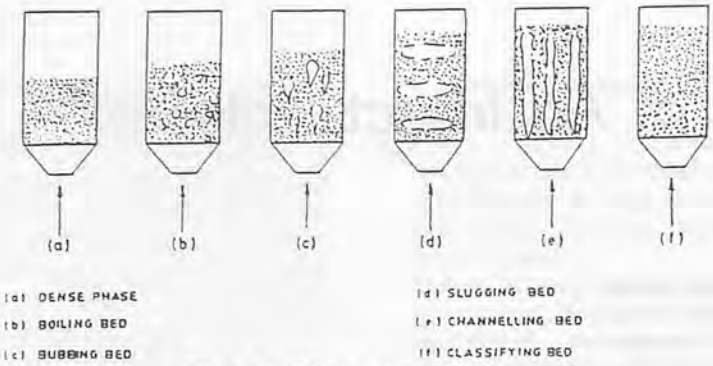


Fig. 1 Six different types of fluidized bed.

passes; and finally the 'classifying bed', where a mixture of particles of different densities and/or different sizes is fluidized into layers for classification. The dense, heavier grains tend to move downwards through the bed, while the less dense, lighter particles are carried towards the surface.

## Present Insect Detection Method

It is important to bear in mind when sampling grain that one can never say that grain is uninfested; merely that pests have not been detected by the technique employed. The size of sample and method of collection will influence the likelihood of pest being detected. A typical lorry load of 20 t, for example, might contain 10 000 insects, but assuming a random distribution of insects, a sample of 1 kg would have only a 50% chance of containing an insect.

A sample unit is the maximum volume of commodity from which a sample is extracted. A primary sample is the initial sample obtained from the sample unit, using a standard sampling method. In commercial practice, the primary samples cannot be examined individually due to bulk for each lot. Final lot samples should be obtained after careful mixing of the bulk samples. Working samples (subsamples) derived from the final lot sample should always be obtained by a recognized dividing method. FAO (1983) suggested 'coneing and quartering'; 'tray dividers' and 'the Boerner divider' sample dividing methods for analysis.

The most widely used method of detecting insects in the grain sample is by sieving. It is difficult to extract the insects which are inside the grain. Hand sorting or other means of extraction has to be resorted to as a final check on free living infestation. The X-ray method is relatively quick but expensive. Nuttall (1985) designed a continuous type insect detector to handle a manageable quantity of samples. But his machine was able to detect only up to 40% of insect presence.

## Design

A batch type machine was designed, based on 'fluidization'. Air is supplied to the plenum chamber from a fan, where it expands and subsequently passes through the porous deck to the fluidizing chamber containing the grain. The insect and damaged grain being less dense than undamaged grain and having more aerodynamic drag, are blown off the bed of grain. They are subsequently collected from the fluidizing chamber by means of a suction tube passed into a cyclone, where they are decelerated, and drop into the bottle.

The batch type insect detector, as can be seen in **Fig. 2** consists of two small cylinders, having the same diameter (115 mm I/D). The lower cylinder (150 mm height) serves as a plenum chamber and the upper cylinder (250 mm height) as a fluidizing chamber. The porous deck was made of two perforated metal sheet (2 mm holes) with an ordinary cotton sheet in between them. It was clamped in between two cylinders by means of a mounting ring, held in place with screws. A perforated metal sheet was placed above the air inlet for mixing and creating turbulence in the air stream before passing through the deck.

The head was made of perforated sheet and a ring with a hole at the middle for collecting insects. It could be clamped to the upper cylinder with the help of screws. Two holes were drilled on the insect collecting tube to reduce suction air velocity. The collecting tube was placed on the head cover with the help of a rubber band to move up, down and sideways during collection. A clear flexible

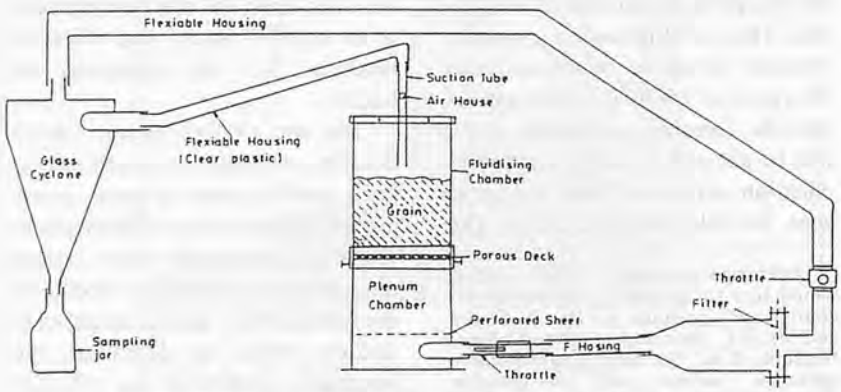


Fig. 2 Schematic layout of batch type insect detector.

tube and a glass cyclone were used to observe any insects left there. Two throttle valves were placed, one before the fan air inlet to alter the insect collecting tube air velocity and the other before the air inlet to the plenum chamber to change the fluidized air velocity. A vibrator was also used during operation.

## Materials and Methodology

*Sitophilus zeamais, Tribolium castaneum* and *Cryptilestes* Spp. insects and wheat of 12.7% moisture content, wet basis, were used in this study.

Preliminary work was necessary to observe the behaviour of insects when fluidized and to determine the optimum working conditions of the detector. Many tests were carried out using wheat and live/dead insects to find the optimum working conditions. It is impossible to supply constant air flow, as it varied due to change of sample, temperature of the air and adjustment of the machine. An experimental design test was carried out at different fluidizing air velocities to observe any effect of air velocities on samples.

An experimental comparison test was set up, bearing in mind the information gathered during the preliminary work. Both batch type and earlier continuous type detectors were adjusted at optimum operating conditions. One kilogram of wheat samples with 10 insects were analyzed statistically to observe whether the machine type had any effect on insect detection.

## Results and Discussion

The fluidizing air velocities were found 0.87 m/s using vibrator and 1.07 m/s without vibrator for batch type detector and 1.8 m/s for the continuous type (**Tables 1** and **2**).

Table 1 Insects Detected by Batch-type Detector with or without Vibrator

| Insects type | Condition | Insects detected (percentage) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Without vibrator | | | | Using vibrator | | | |
| | | 1 | 2 | 3 | Mean | 1 | 2 | 3 | Mean |
| *Sitophilus zeamais* | Live | 40 | 40 | 30 | 36.67 | 50 | 40 | 40 | 43.33 |
| | Dead | 60 | 70 | 60 | 63.33 | 100 | 90 | 100 | 96.67 |
| *Tribolium castaneum* | Live | 40 | 50 | 40 | 43.33 | 40 | 40 | 60 | 46.67 |
| | Dead | 70 | 60 | 60 | 63.33 | 90 | 100 | 90 | 93.33 |
| *Cryptolastes Spp.* | Live | 50 | 50 | 60 | 53.33 | 70 | 50 | 50 | 56.67 |
| | Dead | 70 | 60 | 60 | 63.33 | 70 | 60 | 80 | 70.00 |
| Grand mean percentage | | | | | 53.87 | | | | 67.78 |
| Air flow, m/s | | 1.07 | 1.07 | 1.08 | 1.07 | 0.87 | 0.88 | 0.87 | 0.87 |

Table 2 Insects Detected by Continuous-type Detector at Different Adjustments (using dead *Sitophilus zeamais*)

| Section tube position | Feed valve position | Air flow m/s | Insects detected (percentage) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Without vibrator | | | | Using vibrator | | | |
| | | | 1 | 2 | 3 | mean | 1 | 2 | 3 | mean |
| 0mm above bed | 1/2 opening | 1.6 | 30 | 20 | 20 | 23.33 | 30 | 30 | 40 | 33.33 |
| | | 1.8 | 20 | 40 | 30 | 30.00 | 40 | 50 | 30 | 40.00 |
| | | 2.0 | 30 | 40 | 40 | 36.67 | 40 | 30 | 50 | 40.00 |
| | 3/4 opening | 1.6 | 30 | 40 | 30 | 33.33 | 50 | 40 | 40 | 43.33 |
| | | 1.8 | 50 | 50 | 60 | 53.33 | 60 | 50 | 60 | 56.67 |
| | | 2.0 | 40 | 50 | 50 | 46.67 | 50 | 60 | 50 | 53.33 |
| 3mm above bed | 1/2 opening | 1.6 | 20 | 10 | 30 | 20.00 | 30 | 20 | 30 | 26.67 |
| | | 1.8 | 20 | 30 | 10 | 20.00 | 30 | 30 | 20 | 26.67 |
| | | 2.0 | 20 | 20 | 30 | 23.33 | 30 | 40 | 30 | 33.33 |
| | 3/4 opening | 1.6 | 30 | 30 | 20 | 26.67 | 30 | 40 | 20 | 30.00 |
| | | 1.8 | 30 | 40 | 30 | 33.33 | 40 | 50 | 40 | 43.33 |
| | | 2.0 | 30 | 30 | 20 | 26.67 | 40 | 30 | 40 | 36.67 |
| Grand mean | | | | | | 31.11 | | | | 38.61 |

Full opening – difficult to control

The fluidized air velocity for the continuous type detector was very high due to the very small residence time (only a few seconds). Within this time, the grain sample must be fluidized, so that the insects and trash float on the bed. But, practically, the grain was aspirated. The fluidized air velocity was less using a vibrator than without. The vibration helped to pass the air through the bed, as well as to move the lighter grain upward and heavier downward. On the other hand, the insect detection was higher using a vibrator than without. That is 'vibration had an influence not only on fluidization but also on insect detection'. The vibration would also help to break down the 'hot spots' if present and detach insects clinging to the grain.

It is very difficult to adjust the air flow at a constant velocity as it depends on the type of grain and bed depth. A design test was conducted using storage wheat and dead *Sitophilus zeamais* and analysed statistically, using randomized block design, considering air velocities as treatments and sample as blocks. The F-values shows that there were no effect of air velocities and samples (**Table 3**).

It was found that the insect collecting tube of the continuous type detector should be close to the bed (**Table 2**). But it is difficult to maintain a constant depth of bed. If the bed depth suddenly increased, then grain was blown to the cyclone, creating problems during

operation. The feed rate had an effect on fluidization. Sometimes, due to bridge formation the feed rate was low; after breakdown of the bridge, the feed rate was suddenly high, which also increased the bed depth. It is difficult to operate this machine, not only by unskilled, but also by skilled person.

On the other hand, the batch type insect detector was very easy in operation. There was no limited residence time. Insect and damaged seeds could be collected when observed. For small variation in adjustment, this machine would be able to detect insects. This machine was simple in construction, its maintenance and cleaning were very easy.

The comparison test results are presented by bar diagram as can be seen in **Fig. 3**. On average, only 26.11% of insects were detected by the continuous type, against 68.68% by the batch type detector. The results are also statistically analyzed, a $X^2$-test was used to observe that the machine type had no effect on insect detection (**Table 4**). Four out of six resuls are significantly different from tabulated values at 1% level and the remaining

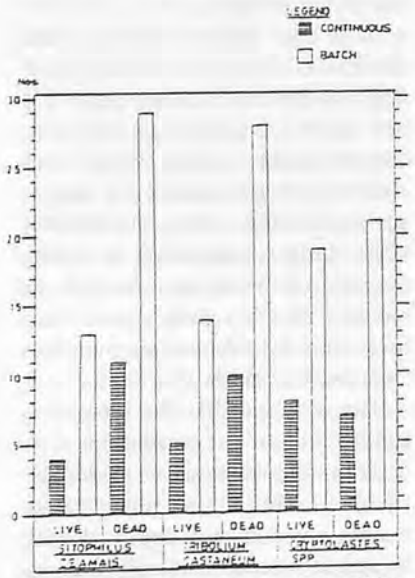


**Fig. 3** Bar-diagram of insect detected by two different detectors in comparison test.

Table 3 Insects Detected at Different Air Velocities without Vibrator (using dead *Sitophilus zeamais*)

| Air velocity (m/s) | Insects detected (percentage) | | | |
|---|---|---|---|---|
| | 1 (%) | 2 (%) | 3 (%) | mean (%) |
| 0.97 | 70 | 60 | 60 | 63.33 |
| 1.02 | 60 | 70 | 60 | 63.33 |
| 1.07 | 80 | 60 | 70 | 70.00 |
| 1.12 | 70 | 60 | 70 | 66.67 |
| 1.17 | 60 | 50 | 60 | 56.67 |
| mean | 68 | 60 | 64 | 64.00 |

Analysis of Variance

| Source of variation | Degrees of freedom | Sum of squares | Mean squares | F value |
|---|---|---|---|---|
| Treatments (airflow) | 4 | 293.333 | 73.333 | 1.913* |
| Blocks (samples) | 2 | 160.000 | 80.000 | 2.087* |
| Error | 8 | 306.667 | 38.333 | |
| Total | 14 | 760.000 | | |

* Insignificant at 1% level.

Table 4 Chi-square ($X^2$) Test

| Insect type | Condition | Continuous type detector | | Batch type detector | | Chi-square ($X^2$) |
|---|---|---|---|---|---|---|
| | | Detected (nos) | Undetected (nos) | Detected (nos) | Undetected (nos) | |
| *Sitophilus zeamais* | Live | 4 | 26 | 13 | 17 | 6.72** |
| | Dead | 11 | 19 | 29 | 1 | 24.3 ** |
| *Tribolium castaneum* | Live | 5 | 25 | 14 | 16 | 5.08** |
| | Dead | 10 | 20 | 28 | 2 | 19.13** |
| *Cryptolastes spp.* | Live | 8 | 22 | 17 | 13 | 5.55** |
| | Dead | 7 | 23 | 21 | 9 | 13.12** |

* Significant at 5% level; ** Significant at 1% level.

are significantly different at 5% level. This proves that the machine types had an effect on insect detection.

## Conclusions

i) There was no significant difference in insect detection at different fluidized air velocities;

ii) Vibration reduced the air flow required to fluidize and increased the number of insects detected; and

iii) The batch type insect detector was suitable for handling a sample of grain approximately 1 kilogramme for detection and inspection.

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# Determination of Drying Curves of Two Varieties of Peanuts

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## Abstract

A laboratory experiment investigated the drying curves of two varieties of peanuts at the laboratory of the Agricultural Engineering Department, Faculty of Agriculture, Shambat. The effects of air velocity, entering air temperature and relative humidity, and initial pod moisture content on drying were studied.

Results show that varying air velocity between 1.1 and 2.6 m/s did not affect the pods' final moisture content when ambient air was used for drying. Drying equations and the values of the corresponding drying constants were determined for various drying conditions.

## Introduction

Peanuts play an important role in the economy of Sudan. It was reported by Hassan (1983) and the News Trade letter (1982) that the sale of Sudanese peanuts dropped in the world market due to the high incidence of aflatoxin and the high percentage of shrivelled pods. This problem was attributed to some of the practices which were followed by the farmers. Among these practices are pre-harvest irrigation and washing of the peanuts to get rid of the clay clods clinging to the pods. These practices resulted in increasing the crop moisture which contributed greatly to rapid growth of *Aspergillus flavus* and, consequently, to toxin production as reported by Siriwardana (1984).

It is envisaged that lowering the moisture contents of the pods would contribute greatly to lowering the incidence of aflatoxin. It is, therefore, anticipated that designing and constructing a dryer to be used by farmers mainly in the irrigated schemes would partially solve the problem. However, to embark on such a dryer design basic data on the drying curves of peanuts is required. This stimulated the objective of determining the drying curves and the prediction equations for two varieties of peanuts cultivated in the country.

## Materials and Methods

A laboratory dryer (Fig. 1) was constructed to be used for artificial drying of peanuts. It consisted of a centrifugal fan driven by a variable speed electric motor of maximum power of 1.4 hp at 960 rpm. Other components included a heating chamber, plenum chamber, a movable tray bin and ducts. Around the inner wall of the heating chamber heating coils of varying output (300, 500, 800, 1 000 W) were fixed and each coil was controlled by a separate switch.

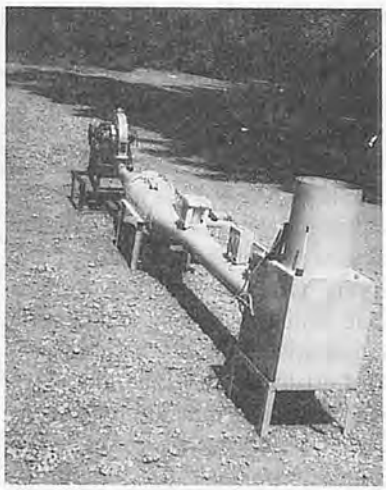

Fig. 1 A laboratory dryer.

The instruments used included a thermograph for measuring the room temperature and relative humidity, copper-tungstan thermocouple for measuring the temperature of the entry and exit air. Other instruments included a hot wire anemometer for measuring the air velocity, and a hygrometer for measuring the exit air relative humidity.

The equipment used included a sensitive balance for periodic weighing of the peanuts and a forced convection oven for drying the peanuts for moisture content determination.

## Procedure

A sample of peanuts to be artificially dried was washed to clean the mud and dirt and was allowed to dry at room temperature. Three sub-samples each of 200 g were taken to determine the initial moisture content using the procedure suggested by the ASAE (1983). After determining the initial moisture content, a batch of 1 000 g was conditioned to the required moisture content by thorough mixing with the required amount of water.

Prior to the start of the drying test, the dryer was allowed to run for 15 min with the selected electrical coil switched on and the required velocity adjusted by the variable speed motor. After maintaining a constant temperature, a sample of 345.3 g was placed in the drying bin which was placed on the plenum chamber. The start of the drying test was recorded using a hand watch. The room temperature and relative humidity were recorded. Initially at zero time, the entry and exit air temperatures and relative humidty were measured. The sample was dried for 4 h during which periodic weighing, every 15 min, of the drying time was made. To minimize pods loosing or gaining moisture while weighing, the balance was situated very close to the plenum chamber and the weighing of the sample did not take more than 20 s. Other measurements, which were taken every 15 min during the drying process, included entry and exit air temperatures using the thermocouples and exit air relative humidity using the hygrometer. At the end of the drying test the moisture content of the dried sample was determined as described by the ASAE (1983).

## Results and Discussion

The collected data was analysed to investigate the drying of peanuts pods under both ambient and heated air conditions. The effects of air velocity, entry air temperature and relative humidity on drying rate and drying constants of the peanuts were investigated. The data was analysed using the logarithmic model employed by Henderson and Pabis (1961):

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-k\theta)$$

where:

MR = Moisture ratio, dimensionless

Mo = Initial moisture content, %(d.b.)

M = Moisture content at any time, %(d.b.)

Me = Equilibrium moisture content, %(d.b.), at the contions of the drying air

K = Drying constant, $h^{-1}$

$\theta$ = Drying time, h

The equilibrium moisture content in the previous equation was computed from the collected data using the following equation suggested by O'callaghan and Nellist (1971):

$$Me = \frac{M_i + M_f - (M_m)^2}{M_i + M_f - 2\,M_m}$$

where:

$M_i$ = initial moisture content at time zero, %(d.b.)

$M_f$ = Final moisture content %(d.b.)

$M_m$ = Moisture content at half time, %(d.b.)

### Ambient Air Conditions

The ambient air at room temperature was forced through the peanut at different air velocities. Figs. 2 and 3 show the effect of air velocity using ambient air on drying of both Barberton and MH 383 peanut varieties. The results indicate that velocities in the range of 1.1 to 2.6 m/s had very little effect on the pod final moisture content when the pods were dried for 4 h

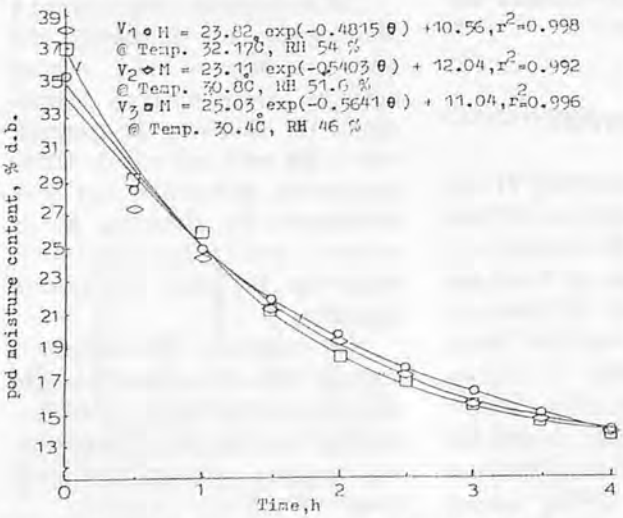


Fig. 2 Effect of air velocity on drying Barberton variety.

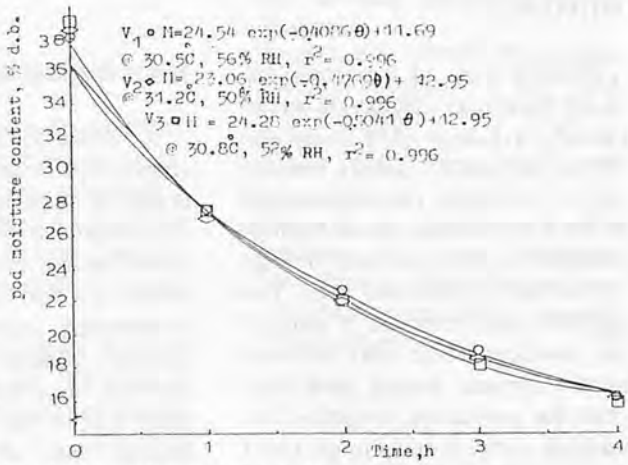


Fig. 3 Effect of air velocity on drying MH383 variety.

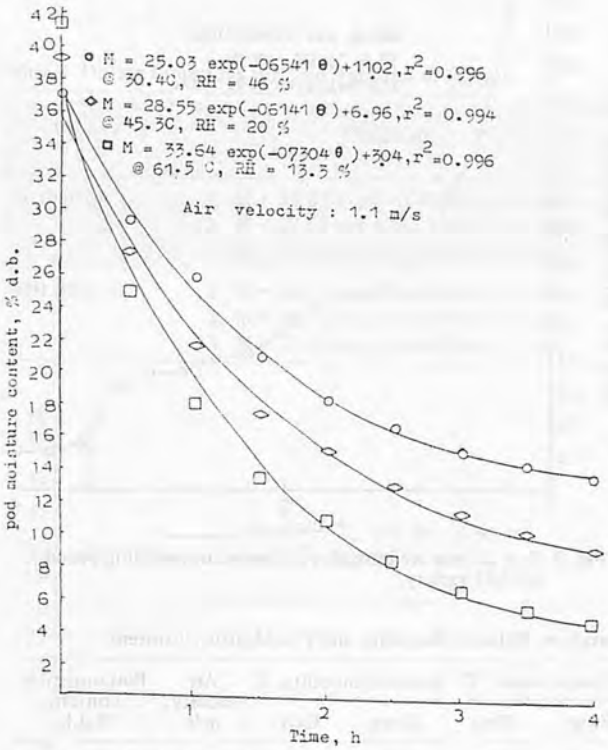


Fig. 4 Combined effect of temperature and relative humidity on drying Barberton variety.

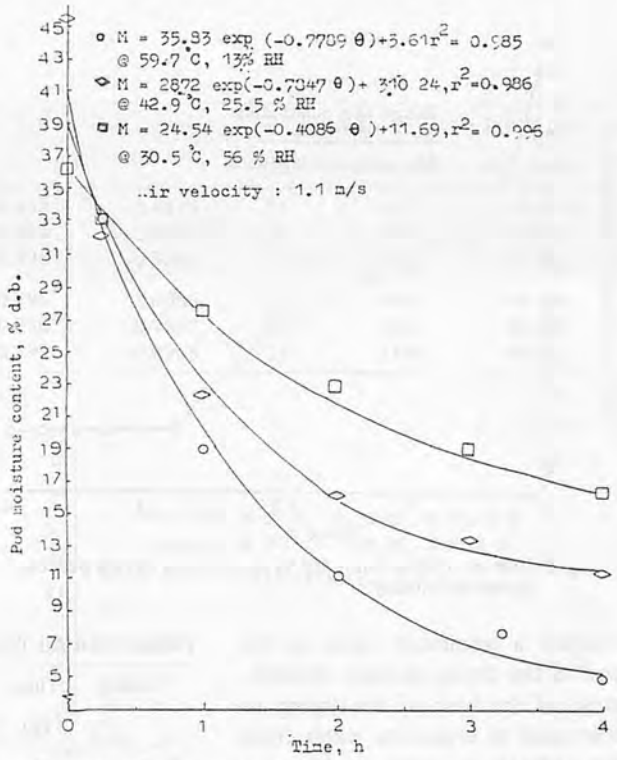


Fig. 5 Combined effect of entry air temperature and relative humidity on drying of MH 383 variety.

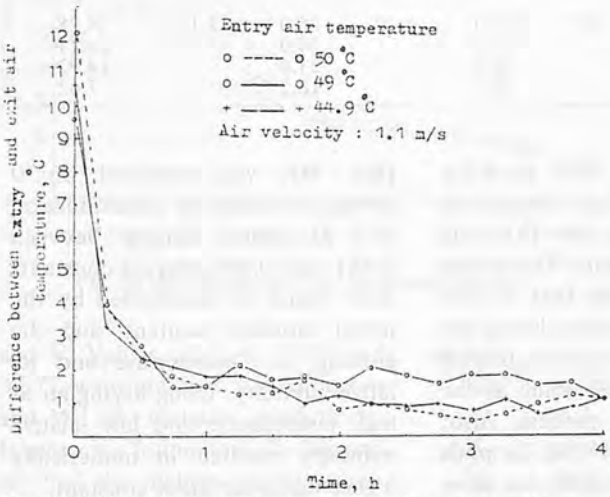


Fig. 6 Difference between entry and exit air temperature vs time, Barberton variety.

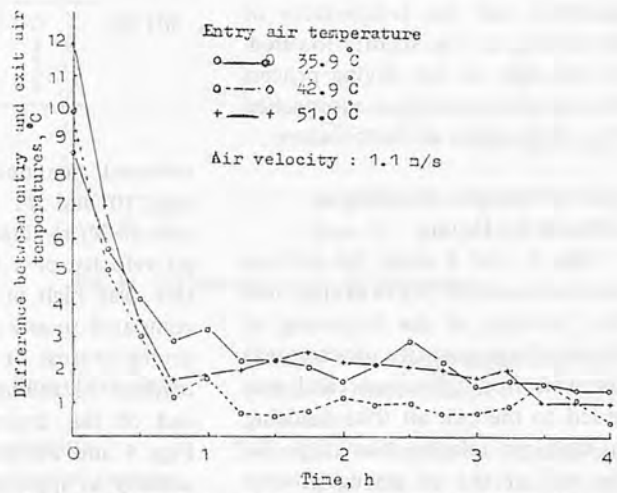


Fig. 7 Difference between entry and exit air temperature vs time, MH383 variety.

using ambient air conditions.

In those tests the ambient air was heated using electrical coils. The average entering air temperature ranged between 35.9 and 61.4°C for the air used for drying the Barberton variety and 39.3 to 62.1°C of that for MH 383 variety. The average entering air relative humidity ranged between 12.7 and 32% for Barberton and 10 and 22.5% for MH383. The effects of entering air conditions of the drying of peanuts and the change in air conditions as drying progressed are discussed in the following sections.

## Effect of Entering Air Temperature and Relative Humidity on Drying

Figs. 4 and 5 show the combined effect of entry air temperature and relative humidity on drying a thin layer of peanut when airflow at velocity of 1.1 m/s was used for drying. As anticipated, Figs. 3 and 4 show that the higher the air temperature and the lower the relative humidity the lower was the final moisture content.

## Exit Air Temperature as Affected by Drying

Figs. 6 and 7 show the difference between the entry and exit air temperature when various entry air temperatures were used. The difference between the entry and exit air temperatures was higher at zero time, then it decreased until it

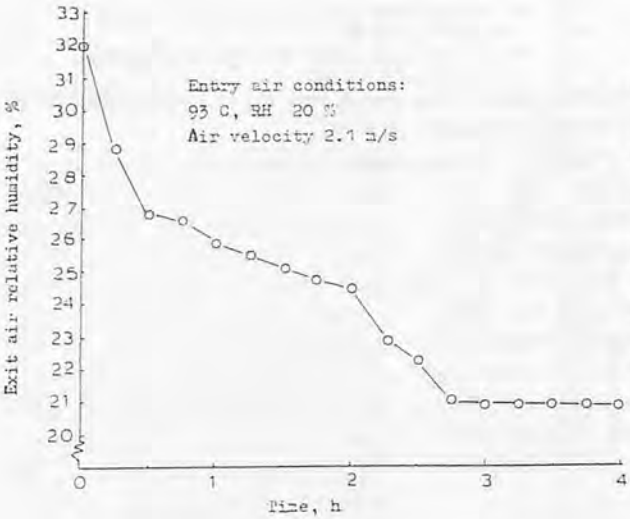


Fig. 8 Exit air relative humidity vs time during drying process, Barberton variety.

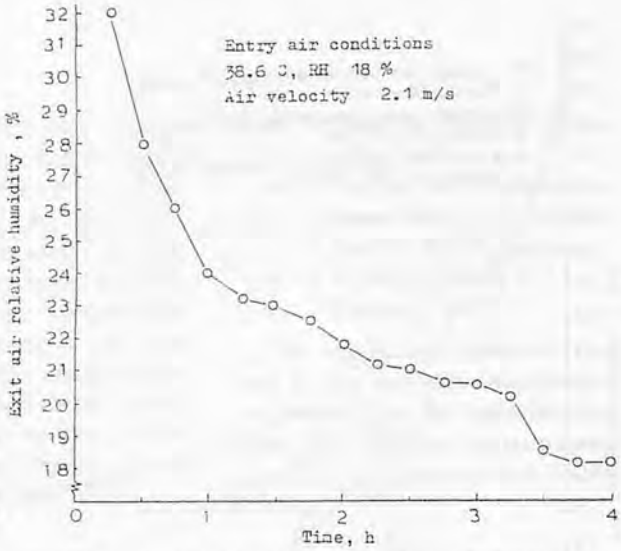


Fig. 9 Exit air relative humidity vs time during drying process, MH383 variety.

reached a minimum value at the end of the drying process. Initially, most of the heat of the drying air was used to evaporate water from the pods thus resulting in lowering the air temperature. As the drying process progressed less water was removed and the temperature of the drying air was slightly lowered. At the end of the drying process the exit air temperature approached that of the entry air temperature.

Table 1 Exit Air Temperature, Relative Humidity and Pod Moisture Content

| Variety | Time (h) | Temperature, °C Entry | Temperature, °C Exit | Relative humidty, % Entry | Relative humidty, % Exit | Air velocity, m/s | Pod moisture content % d.b. |
|---|---|---|---|---|---|---|---|
| Barberton | 0 | 40.8 | 31.7 | 20.7 | 32 | 2.1 | 35.65 |
| | 1 | | 39.5 | | 26.2 | | 21.75 |
| | 2 | | 40.5 | | 25.5 | | 15.50 |
| | 4 | | 40.6 | | 19 | | 8.65 |
| MH 383 | 0 | 38.7 | 32.1 | 16.0 | 36.0 | 2.1 | 38.28 |
| | 1 | | 37.8 | | 24.0 | | 20.11 |
| | 2 | | 38.4 | | 21.8 | | 14.92 |
| | 4 | | 38.5 | | 18.2 | | 7.62 |

### Exit Air Relative Himidity as Affected by Drying

Figs. 8 and 9 show the exit air relative humidity (%) vs drying time (h). Initially, at the beginning of drying a large quantity of water was removed from the pods and was added to the exit air thus resulting in high air relative humidity. At the end of the of drying process water removal was negligible resulting in negligible increase in exit air relative humidity.

Table 1 shows the relation between the exit air temperature (°C) and relative humidity (%) and the pod moisture content (%) during the drying process. It is clear that both exit air temperature and relative humidity are indicative of the stage of drying.

### Drying Rate

The drying rate was expressed as the percentage moisture dry basis removed per unit time (% M/h). Figs. 10 and 11 show the drying rate (% M/h) versus time (h) using air velocity of 1.1 m/s. The drying rate was high at the first 15 min compared to any period during the drying process. It decreased until it reached its minimum value at the end of the drying process. Also, Figs. 9 and 10 show that for pods initially at approximately the same moisture content the drying rate was higher for pods subjected to air at high entry temperature and low relative humidity. This can be explained by the fact that at those conditions the moisture carrying capacity of the air is high compared to air at low temperature and high relative humidity.

### Drying Constants

Various values for the drying constants (K) were obtained for various entering air conditions. The best results were obtained when Ln (Mo – Me) was regressed on 0 giving coefficient of determination ($r^2$) of values ranging between 0.981 and 0.998. Drying constants were found to be affected by the initial moisture content, and the entering air temperature and relative humidity. Using drying air at high temperature and low relative humidity resulted in numerically higher values for the K constant.

A number of drying equations were predicted for both Barberton and MH 383 varieties under different drying conditions. Table 2 shows some of those equations obtained for drying the two peanut varieties.

Further regression analyses were conducted to determine the factors that had the greatest role in determining the K value. Regressing K on $M_O$-$M_O$, $M_e$, V, RH, $M_f$ and $T_{abs}$, the highest coefficient of determination ($r^2$) was found when regressing K on $M_e$, $M_f$ $1/T_{abs}$, RH

Table 2 Drying Equations for Two Varieties of Peanuts

| Variety | Equation | $r^2$ | K ($h^{-1}$) | Entry air RH, % | Entry air Temp. °C | Initial pod M.C, % d.b. |
|---|---|---|---|---|---|---|
| Barberton | 1. $M = 23.82 \exp(-0.4815\theta) + 10.56$ | 0.998 | −0.4815 | 54 | 32.7 | 35.67 |
| | 2. $M = 28.55 \exp(-0.6141\theta) + 6.96$ | 0.994 | −0.6141 | 20 | 45.3 | 39.44 |
| | 3. $M = 33.64 \exp(-0.7304\theta) + 3.04$ | 0.996 | −0.7304 | 13.3 | 61.4 | 41.62 |
| MH 383 | 1. $M = 24.54 \exp(-0.4086\theta) + 11.69$ | 0.996 | −0.4086 | 56 | 30.5 | 38.18 |
| | 2. $M = 28.72 \exp(-0.7847\theta) + 10.24$ | 0.986 | −0.7847 | 25.5 | 43.0 | 45.89 |
| | 3. $M = 34.43 \exp(-0.6955\theta) + 2.89$ | 0.995 | −0.6955 | 16 | 51.6 | 43.92 |

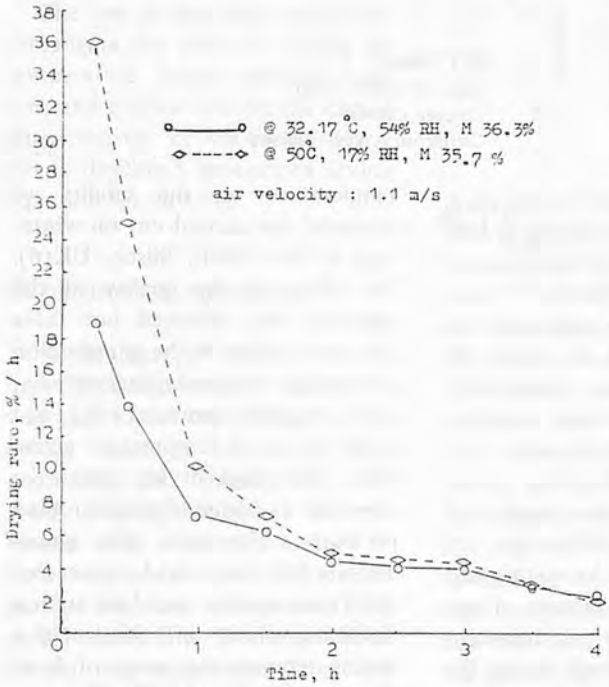


Fig. 10 Drying rate vs time, Barberton variety.

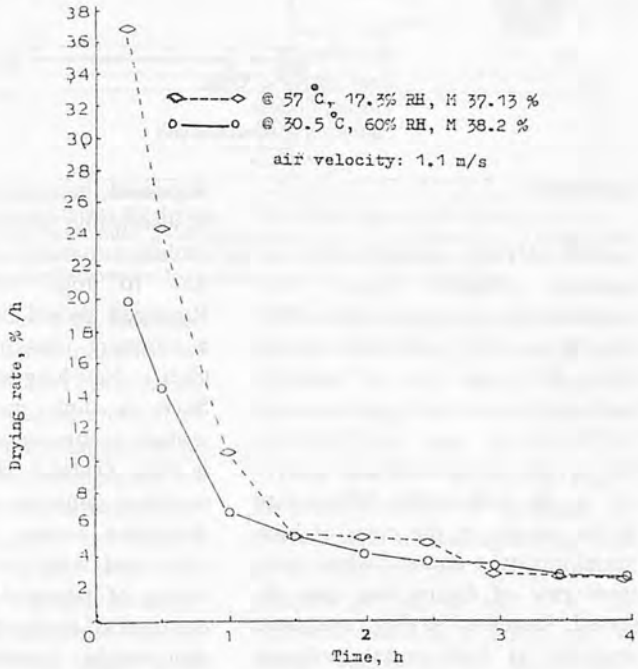


Fig. 11 Drying rate vs time, MH383 variety.

and V. Values of $r^2$ of 0.917 and 0.877 were obtained for Barberton and MH 383 varieties, respectively. It was also found that the $M_e$ and $M_f$ had the highest partial regression coefficients indicating their significant influence in determining the K value. The following equations were obtained for the K values for the Barberton and MH 383, respectively:

$$K = -2.367 - 7.8573\,Me + 0.0971\,RH + 0.004\,V + 6.7137\,M_f + 523.7173/T_{abs}$$

$$K = -3.1596 - 6.1002\,Me + 0.488\,RH + 0.0183V + 3.411\,M_f + 791.9261/T_{abs}$$

where,

RH : relative humidity, decimal

V : air velocity, m/s

$M_f$ : final moisture content, % d.b.

$T_{abs}$ : absolute temperature, °K

## Conclusions

The following conclusions have been drawn from this study:

1. The air velocity tried in the range of 1.1 to 2.6 m/s had little effect on the final pod moisture content when ambient (unheated) air was used for drying.
2. The drying rate was more affected by the drying air conditions than by the initial pod moisture content.
3. Results of the regression analysis of (K) value on various drying parameters showed that $M_e$ and $M_f$ influenced the K value most.
4. Drying equations of the form:

$$M = (M_o - M_e) \exp(-K\theta) + M_e$$

could predict the drying performance of the tested two varietes with coefficients of determination ranging between 0.981 and 0.998.

*(Continued on page 58)*

# Heated Air Drying of Rapeseed

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## Abstract

The drying characteristics of rapeseed (*Brassica napus*) were studied with air temperature of 60, 50, 40 and 30°C, air flow rates of 0.53, 0.33 and 0.21 $m^3 (s\,m^2)^{-1}$ and initial moisture contents of 24.98, 18.15 and 13.77%(d.b.). The drying of rapeseed was observed to lie within the falling rate period except in the cases of high initial moisture content where constant rate of drying was also observed. Increased drying rates were observed at high initial moisture contents and at higher drying air temperatures. The generalized drying prediction equation in the form of thin layer drying equation has been developed using the experimentally determined drying characteristics. The functional relationships between drying constants and drying parameters have been established. The generalized drying equation is suitable for use in the modelling of the rapeseed drying process.

## Introduction

Harvesting of rapeseed is normally done at about 15 to 20% moisture content(w.b.) to maximize yield. Rapeseed at a moisture content above 11%(w.b.) requires drying to avoid spoilage during storage. Rapeseed, being an oil-bearing seed, is susceptible to overheating at high moisture contents and temperatures due to high respiration rates. Rapeseed should be dried down to a moisture content of about 7% (w.b.) for long-term storage (1). Such a low moisture content seldom occurs naturally in the field in New Zealand. Harvesting at low moisture contents also causes high shattering losses. Difficulties are associated with the harvesting and drying of rapeseed because of unevenness of maturity and unfavourable weather conditions during the harvest season. To achieve high yields, drying of rapeseed is essential. It is recommended that rapeseed be dried to 10%(w.b.) for short-term storage in New Zealand (2). Drying of rapeseed to very low moisture contents is achieved by using heated air.

Rapeseed is a small, round, clean-looking seed and roughly globular in shape. It is a free-flowing seed and is generally considered as a quick-drying seed(3). Rapeseed heated to a temperature of above 50°C has been observed to be less viable(4). McKnight and Moysey(5) concluded that drying air temperature in excess of 71°C reduced the viability. The threshold air temperature for safe drying was also affected by the initial moisture content of the rapeseed. The first study on the effect of drying air temperature on the quality of rapeseed was carried out on winter rape at the NIAE, Silsoe, UK(6). No effect on the quality of the rapeseed was observed but there was a reduction in the germination percentage of rapeseed harvested at 26% moisture content(w.b.) and dried by air at temperature above 66°C. Very high drying rates were observed at higher drying air temperatures. The new low glucosinolate-low erucic acid rapeseed of the Tower variety was dried with a fluidizing velocity of 1.5 m/s with a drying temperature range of from 40 to 70°C for 8 h(7). The germination percentage was not affected up to a drying temperature of 60°C. In both drying studies of Nellist et al(6) and Sutherland and Ghaly(7), the drying of rapeseed was done either to a given moisture content of between 6 and 8% or to a fixed time period of 8 h. The drying was not continued to the equilibrium moisture content of the rapeseed in either case but some samples at higher temperatures such as 60 or 70°C might have reached the equilibrium moisture content. It is not possible to develop a generalized drying equation for a wide range of airflow rates, drying air temperature and initial moisture contents from these data. A systematic study of the drying characteristics of rapeseed is needed to develop a drying prediction equa-

tion suitable for use in the modelling of the drying process. Most of the previous studies have concentrated upon the effect of the drying parameters on the germination and quality of rapeseed oil rather than upon the nature of the drying process itself and the effect of the drying parameters on the drying characteristics of rapeseed.

The aim of this study was (i) to investigate the effect of drying air temperature, initial moisture content and airflow rate on the drying characteristics of the rapeseed and (ii) to develop a generalized drying equation for rapeseed.

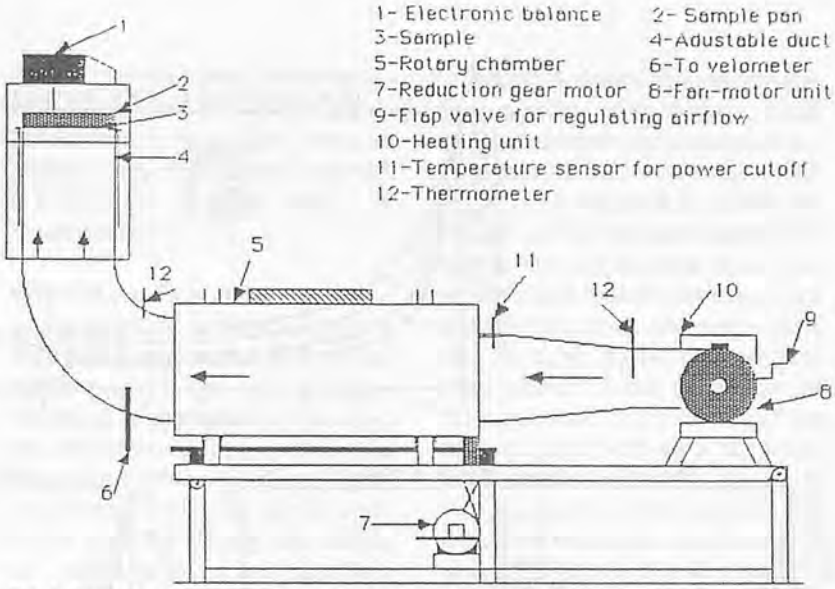


Fig. 1 Experimental equipment for drying; 1–Electronic balance, 2–Sample pan, 3–Sample, 4–Adjustable duct, 5–Rotary chamber, 6–To velometer, 7–Reduction gear motor, 8–Fan-motor unit, 9–Flap valve for regulating airflow, 10–Heating unit, 11–Temperature sensor for power cutoff, 12–Thermometer.

## Experimental Apparatus

A laboratory rotary tumble dryer modified to dry 1 kg sample was used in the study (**Fig. 1**). The drying assembly consisted of a centrifugal fan, heating unit and rotary holding bin which was extended with a cylindrical duct to hold 1 kg sample pan. The vertical part of the duct was covered with an adjustable duct. This was used to detach the sample pan from the dryer while taking the mass of the sample directly without the buoyancy effect of the drying air. The air was drawn through a heating unit of 6 kW capacity and was forced into the drying plenum. The airflow was regulated by operating a flap valve installed between the heating unit and the centrifugal fan. The drying air temperature was controlled using an air temperature cut-off system.

## Procedure

The clean, combine-harvested Tower variety of oilseed rape was used for the study of the drying characteristics. The moisture content was found by the standard oven method, i.e., drying the sample of 10 g at 130 ± 2°C for 2 h (8). The sample of 5 kg was conditioned to moisture contents of 24.98, 18.15 and 13.77%(d.b.) by sprinkling the required amount of water slowly over the sample while stirring the grains continuously for thorough mixing and, subsequently, allowing the sample to achieve equilibrium for about 48 h in a sealed polythene bag to avoid moisture loss. The conditioned sample was dried in a thin layer with airflow rates of 0.53, 0.33 and 0.21 $m^3 (s\,m^2)^{-1}$. The drying air temperature range was selected as between 60 and 30°C. Drying was continued until the moisture content was in equilibrium with the temperature and relative humidity of the drying air.

## Results and Discussion

### Drying Characteristics

In order to determine the effect of the drying parameters on rapeseed drying, the relationships of the moisture content and drying rate with time were analyzed and studied. The computer program DRYING(9) was used to analyze the drying data.

### Effect of Drying Air Temperature

The effect of drying air temperature on the drying characteristics of rapeseed for the initial moisture content range of from 24.98 to 13.77%(d.b.) and air flow of 0.21 $m^3 (s\,m^2)^{-1}$ is given in **Fig. 2**. Moisture content of rapeseed decreased with increasing drying time at all values of the drying air temperature 60, 50, 40, and 30°C. The rapeseed dried at a faster rate at higher values of air temperature owing to the greater sensible heat in the drying air. The drying time required to dry the rapeseed to the equilibrium moisture content was affected by the drying air temperature. Drying at a temperature of 60°C can dry rapeseed to about 2.28% moisture content (d.b.) within a time period of about 7 h. The equilibrium moisture content of rapeseed also varied with the drying air temperature. Similar results were observed for the other two values of the initial moisture contents of 18.15 and 13.77%(d.b.). Similar trends were also found for the other two air flow rates of 0.33 and 0.53 $m^3 (s\,m^2)^{-1}$.

### Effect of Initial Moisture Centent

The effect of initial moisture content on the drying of rapeseed is shown in **Fig. 3**. The relationship

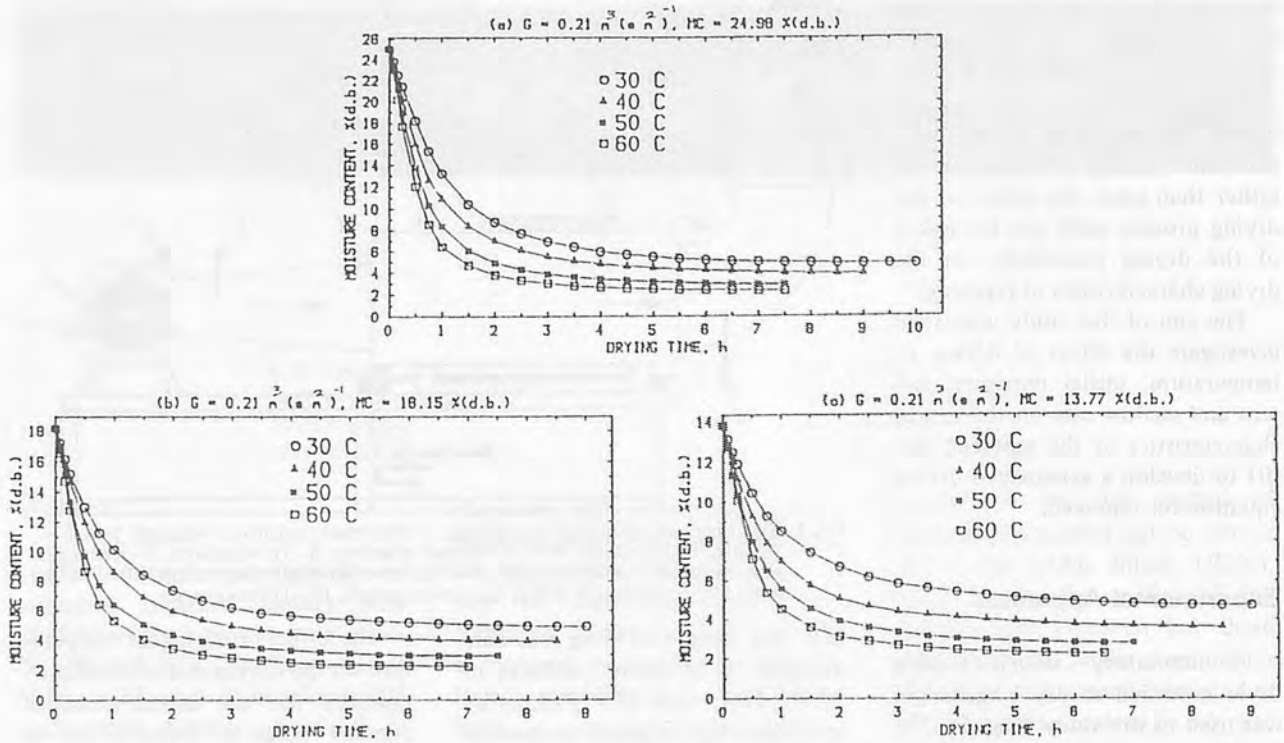


Fig. 2 Effect of drying air temperature on moisture content and drying time at 0.21 $m^3/s\ m^2$ airflow rate for various initial moisture contents.

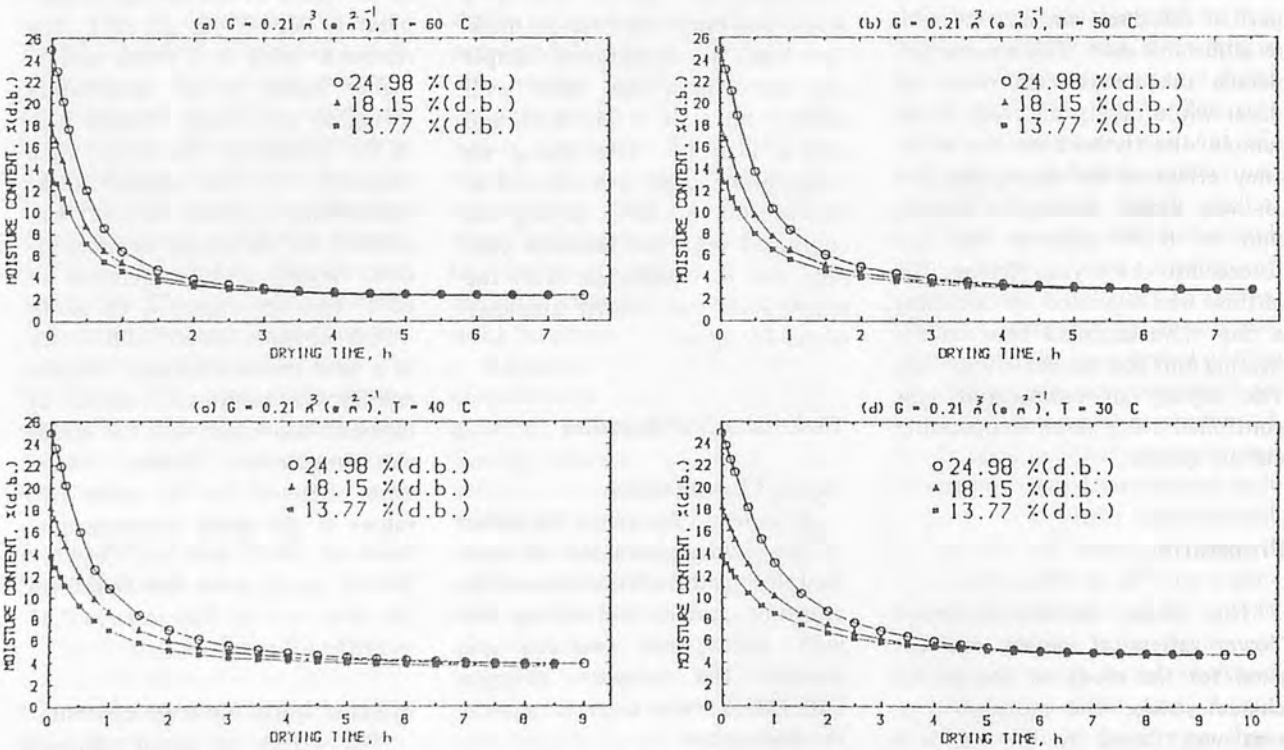


Fig. 3 Effect of initial moisture content on the moisture content and drying time at 0.21 $m^3/s\ m^2$ airflow rate for various drying air temperatures.

between moisture content and drying time shows that the drying of rapeseed, having different initial moisture contents, terminated at approximately the same equilibrium moisture content when subjected to the same constant drying air temperature and constant air flow rate (Fig. 3) (a). At the same drying period the moisture content of the rapeseed was higher for samples having higher initial moisture contents. This effect diminished as drying of the rapeseed proceeded until it vanished at the end of the drying process. Approximately the same equilibrium moisture content was achieved under similar conditions of constant airflow rate and air temperature. This shows that the initial moisture content does not affect the equilibrium moisture content. This is advantageous as drying samples having different initial moisture contents attain the same moisture at the end of drying. This enables different sample lots to be mixed and dried together. Similar results were observed at temperatures of 50, 40 and 30°C. Similar trends were also found at airflow rates of 0.33 and 0.53 $m^3 (s\,m^2)^{-1}$ for various drying air temperatures.

### Effect of Air Flow Rate

The effect of air flow rate on the drying of crops has not been found significant (10). This has been confirmed at higher airflow rates and no observable effect on drying was found for turbulent airflow (11). In the present study, the air flow affected only the drying rate during the initial periods and its effect diminished as the drying process proceeded. The diminished effect of airflow rate during the later steps of drying indicated that it did not affect the value of equilibrium moisture content.

## Effect of Parameters on Drying Rate

Figure 4 shows the higher rates for samples with higher initial moisture contents at a constant airflow rate of 0.21 $m^3 (s\,m^2)^{-1}$ and drying air temperature of 60, 50, 40 and 30°C. The gradients of the drying rate curves were higher for higher initial moisture contents at a given drying time. The high drying rate at higher initial moisture contents is due to the availability of more moisture at the surface of the rapeseed grain whereas at the lower initial moisture content, the moisture has to be transferred from the interior of the grain. Similar results were observed for 50, 40 and 30°C air temperatures and for 0.33 and 0.53 $m^3 (s\,m^2)^{-1}$ airflow rates. In addition, the drying rate initially increased with the drying time, reached a peak and then decreased during drying under constant airflow rate and air temperature. This is due to the initial heating of the rapeseed grain to the equilibrium drying air temperature and the consequent variation in the mois-

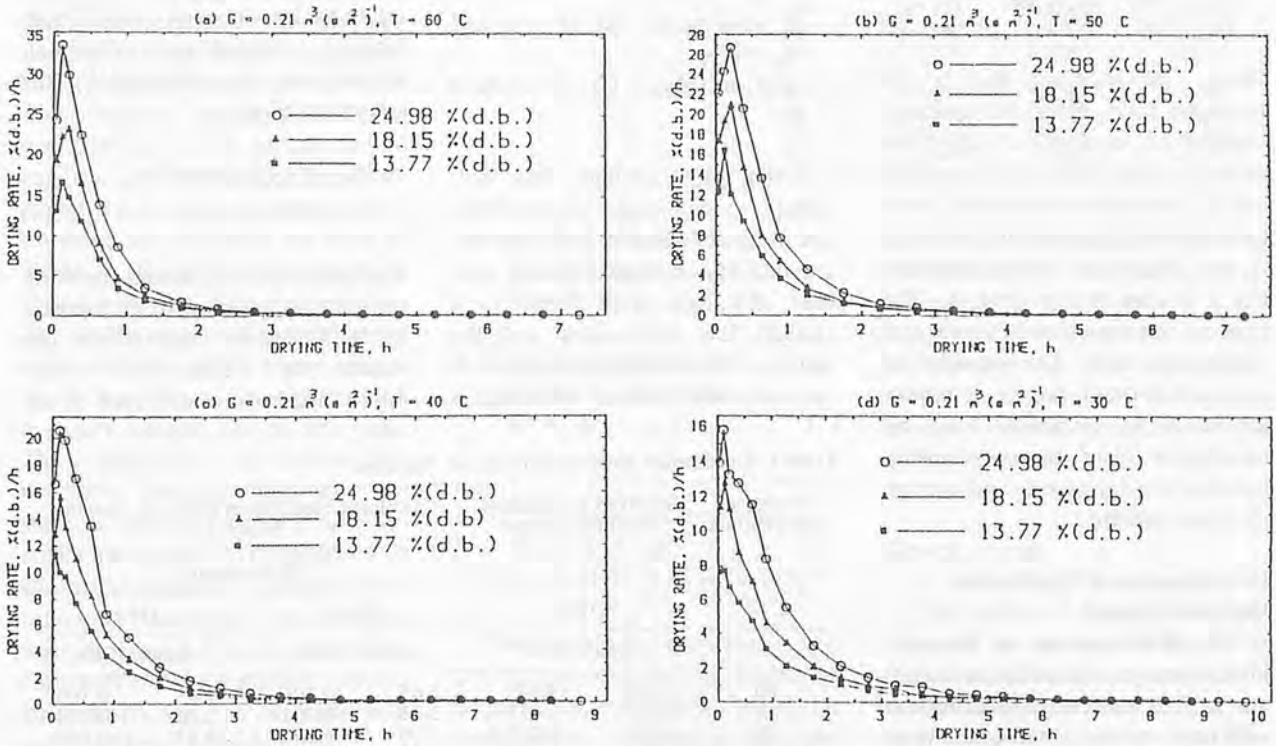


Fig. 4 Effect of initial moisture content on the drying rate and drying time at 0.21 $m^3/s\,m^2$ airflow rate for various drying air temperatures.

ture content across the interior section of the grain kernel. As drying progressed, the values of the drying rates approached closer to each other and the drying rate was no longer affected by the airflow rate and initial moisture content. The common drying rate was observed to approach zero at the equilibrium moisture content during the later periods of drying.

## Generalized Drying Prediction Equation

The second objective of the study of the drying characteristics was to develop a generalized drying equation applicable to a wide range of airflows, air temperature and harvesting moisture contents. The generalized equation could then be used in the modelling of the deep-bed drying process. The thin-layer drying equation was used as a basic equation (12).

$$\frac{M - M_e}{M_o - M_e} = A\,e^{-B\theta} \quad \ldots\ldots (1)$$

Where, $(M-M_e)/(Mo-M_e)$ is the moisture ratio, M is the moisture content of rapeseed at any time druing drying, %(d.b.), $M_o$ and $M_e$ are the initial and equilibrium moisture contents, respectively, %(d.b.), A and B are the drying constants and $\theta$ is the drying time, h. The form of the equation is simple and commonly used. The equilibrium moisture content can be determined either by experiment or by calculation from the relationship between the drying rate and average moisture content.

### Determination of Equilibrium Moisture Content

The determination of the equilibrium moisture content is important as it is used in calculating the moisture ratio. Attempts were made to find the equilibrium moisture content both from drying tests and from drying rate and average moisture content data. The drying rate ($dM/d\theta$) is proportional to the moisture potential.

$$\frac{dM}{d\theta} = -k\,(M - M_e) \quad \ldots\ldots (2)$$

The moisture potential is the difference between the moisture content at any time and the equilibrium moisture content at the same relative humidity and air temperature. By analogy, if the drying rate and average moisture content data are fitted to a straight line relationship, then:

$$\frac{dM}{d\theta} = k'M_{av} - C \quad \ldots\ldots\ldots (3)$$

Where $M_{av}$ is the average moisture content, %(d.b.), k' is the slope of the line and C is the intercept on on the vertical axis.

$$\frac{dM}{d\theta} = k''(M_{av} - C) \quad \ldots\ldots (4)$$

at equilibrium $dM/d\theta = 0$ and $M_e = M_{av}$
then, $k''(M_{av} - C) = 0$ and $M_e = C'$

Using this analogy and procedure to determine the equilibrium moisture content from the drying rate and average moisture content, the data were fitted to a straight line relationship and the values of the equilibrium moisture contents were found. Although a high correlation was observed for the relationship between drying rate and average moisture content, the relationship was not capable of providing accurate values during the final stages of drying. Towards the end of drying, the grain moisture content approaches so closely to the equilibrium moisture content that the loss of weight during the drying time interval is so small that the drying rate determination became inaccurate. The values of equilibrium moisture content were also found using numbers of observation equal to (N-1) and (N-2) by discarding the last one or two observations in order to improve the correlation and the values of the equilibrium moisture content. The values of equilibrium moisture contents are given in **Table 1**. The calculated equilibrium moisture content decreased with the increase in the air temperature. Equilibrium moisture contents observed during the drying tests were found by drying the rapeseed to the equilibrium moisture content. The functional relationship between equilibrium moisture content and drying air temperature was obtained by the equation below:

$$M_e = 7.35 - 0.0865\,T, \quad r = -0.99 \quad \ldots\ldots\ldots\ldots (5)$$

The observed equilibrium moisture content decreased with an increase in the drying air temperature. The values of $2.28 \pm 0.025$ and $4.84 \pm 0.023$ were observed at 60

**Table 1** Equilibrium Moisture Content of Rapeseed

| Drying air temperature | Observed equilibrium moisture content | | Calculated equilibrium moisture content, % (d.b.) | | | |
|---|---|---|---|---|---|---|
| | | | Observations | | | |
| (°C) | % (d.b.) | | (N-1) | | (N-2) | |
| | mean ± SEM* | | mean ± SEM | | mean ± SEM | |
| 60 | 2.28 | 0.025 | 2.67 | 0.101 | 2.45 | 0.103 |
| 50 | 2.87 | 0.027 | 3.33 | 0.102 | 3.06 | 0.104 |
| 40 | 3.84 | 0.035 | 4.30 | 0.096 | 3.93 | 0.096 |
| 30 | 4.84 | 0.023 | 5.26 | 0.079 | 4.78 | 0.901 |

*SEM = Standard error of mean

and 30°C drying air temperature, respectively. The maximum standard error of 0.035 was at 40°C air temperature. The values of equilibrium moisture content observed during the experiments were less than the calculated values. This clearly shows that the straight line relationship between the drying rate and average moisture content does not represent the exact relation during the final stages of drying. At 60°C drying air temperature, the observed equilibrium moisture content was 2.28 ± 0.025 while the calculated equilibrium moisture content for (N-1) and (N-2) observation were 2.67 ± 0.1 and 2.45 ± 0.1% (d.b.), respectively. These values were improved fitting the data to (N-2) observations. The use of drying rate and average moisture content data to calculate the equilibrium moisture contents was not found satisfactory. This was also observed by Nellist (13).

### Variation of Drying Constants

The drying data were analysed in order to determine the moisture content, drying rate, average moisture content and moisture ratio. The computer program DRYING was used to fit the drying data to equation (1). The drying constants A and B and correlation coefficients obtained by regression are given in **Table 2**. Both drying constants varied with the drying parameters. The drying analysis showed that the drying air temperature was a more important factor than the initial moisture content and air flow rate. The constant A at all air flow rates decreased linearly while the constant B increased linearly with increase in drying air temperature at all initial moisture contents. The following functional relationships were developed between the drying constants and the moisture content, air temperature and air flow rate using multiple regression.

Table 2 Constant 'A' and 'B' of Oilseed Rape at Different Moisture Contents, Drying Air Temperatures and Airflow Rates

| Airflow $m^3 (s\,m^2)^{-1}$ | Moisture content % (d.b.) | Drying air temperature (°C) | Constant A | Constant B | Regression coefficient (r) |
|---|---|---|---|---|---|
| 0.53 | 24.98 | 60 | 0.5457 | 0.9081 | −0.99 |
| | | 50 | 0.6798 | 0.8682 | −0.98 |
| | | 40 | 0.6742 | 0.6963 | −0.99 |
| | | 30 | 0.7897 | 0.6357 | −0.99 |
| | 18.15 | 60 | 0.5351 | 0.8570 | −0.98 |
| | | 50 | 0.6237 | 0.8678 | −0.99 |
| | | 40 | 0.6649 | 0.6473 | −0.98 |
| | | 30 | 0.7381 | 0.6205 | −0.99 |
| | 13.77 | 60 | 0.6000 | 1.0157 | −0.99 |
| | | 50 | 0.7018 | 0.8851 | −0.98 |
| | | 40 | 0.7471 | 0.7890 | −0.99 |
| | | 30 | 0.9191 | 0.6855 | −0.99 |
| 0.33 | 24.98 | 60 | 0.6984 | 1.1119 | −0.99 |
| | | 50 | 0.7332 | 0.9368 | −0.99 |
| | | 40 | 0.7783 | 0.8328 | −0.99 |
| | | 30 | 0.9763 | 0.8478 | −0.99 |
| | 18.15 | 60 | 0.6437 | 1.0927 | −0.99 |
| | | 50 | 0.7592 | 0.9523 | −0.98 |
| | | 40 | 0.8279 | 0.9161 | −0.99 |
| | | 30 | 0.8554 | 0.7940 | −0.99 |
| | 13.77 | 60 | 0.6945 | 1.0932 | −0.99 |
| | | 50 | 0.8437 | 0.9743 | −0.98 |
| | | 40 | 0.8995 | 0.8882 | −0.98 |
| | | 30 | 0.8392 | 0.6999 | −0.98 |
| 0.21 | 24.98 | 60 | 0.6879 | 0.9724 | −0.99 |
| | | 50 | 0.8284 | 0.9306 | −0.98 |
| | | 40 | 0.8660 | 0.7496 | −0.98 |
| | | 30 | 0.9629 | 0.7060 | −0.99 |
| | 18.15 | 60 | 0.7196 | 0.9933 | −0.99 |
| | | 50 | 0.7954 | 0.9311 | −0.99 |
| | | 40 | 0.9391 | 0.8442 | −0.99 |
| | | 30 | 0.9220 | 0.7062 | −0.98 |
| | 13.77 | 60 | 0.7744 | 1.0266 | −0.99 |
| | | 50 | 0.8340 | 0.9424 | −0.99 |
| | | 40 | 0.8325 | 0.7296 | −0.99 |
| | | 30 | 1.0049 | 0.6845 | −0.98 |

$$A = 1.3532 - 0.00301\,M - 0.00751\,T - 0.5112\,G, \quad R^2 = 85.9 \quad (6)$$

$$B = 0.5086 - 0.00151\,M + 0.0103\,T - 0.2440\,G, \quad R^2 = 78.3 \quad (7)$$

for

$$13.77 \leqslant M \leqslant 24.98\%(d.b.)$$
$$30 \leqslant T \leqslant 60 \quad C$$
$$0.21 \leqslant G \leqslant 0.53\ m^3 (s\,m^2)^{-1}$$

The variation of constants A and B with moisture content, drying air temperature and airflow rate can be analyzed by comparing the constants and their signs in equations (6) and (7). The generalized thin-layer drying equation of rapeseed was obtained by substituting the relationships for the constants A and B and equilibrium moisture content in equation (1). The equation is simple and can easily be accommodated in the modelling of the drying processes.

## Conclusions

The drying of rapeseed has been observed to lie within the falling rate zone. The drying rate is increased with increase in airflow rate and initial moisture content. The effect of airflow rate and initial moisture content is diminished as

drying proceeds.

The moisture content and drying rate of rapeseed, both decrease with drying time at all values of drying air temperatures. The drying air temperature affects both the time required to dry the rapeseed to the equilibrium moisture content and the moisture content to which the rapeseed can be dried.

As drying proceeds, the initial moisture content has no effect on the equilibrium moisture content and it is, therefore, convenient to mix several batches of samples at different moisture contents for simultaneous drying.

The determination of the equilibrium moisture content assuming a straight line relationship between the drying rate and average moisture content has not predicted the results accurately during the final stages of drying.

The generalized thin-layer drying prediction equation for rapeseed was developed using the experimentally determined drying characteristics.

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# Rice Post-harvest Practices and Loss Estimates in Bangladesh

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## Abstract

The objectives of the study were to observe rice postharvest practices and estimate losses occuring in the country during harvesting through field transport operations.

The total rice loss estimates from harvesting to field transport varied between 2.4% and 3.9%. 'Aman' season observed the highest loss while 'Boro' season had the least. Pre-postharvest losses were 2.5% in 'Aman', 1.1% in 'Boro' and 2.0% in 'Aus' season. The shattering and lodging nature of local varieties increased pre-postharvest loss in 'Aman' and 'Aus' seasons. The HYVs were found more resistant to lodging and shattering. In field transport, head carrying had more loss than shoulder carrying.


## Introduction


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Rice is the staple food in Bangladesh where there are 11.5 million ha of cultivable land of which 89% is used for rice cultivation producing more tahn 20 million t of paddy (BBS, 1984). Rice in Bangladesh is grown and harvested during 'Boro', April to June; 'Aus', July to August; and 'Aman' November to December seasons. 'Aman' and early 'Boro' crops are harvested in dry lands while late 'Boro' and 'Aus' crops are harvested in wet and flooded fields. Yields of 'Boro', 'Aus', and 'Aman' paddy are 4.7, 4.8, and 10.6 million t per season, respectively. High yielding varieties (HYVs) cover 25% of the total rice growing area producing 40% of the total production (BBS, 1984).

Karim and Rashid (1979) reported that 96% of the farmers in Mymensingh district suffered rice postharvest losses during 'Boro' seasons. In another report they mentioned that about 3.0% paddy were lost during cutting and threshing in 1981 'Aus' season (Karim et al., 1982). Greeley (1981) conducted a study in Bangladesh and found that total physical losses in harvesting to drying operations did not exceed 7.0%. In a separate paper, Greeley and Rahman (1980) reported that losses from harvesting through threshing in 'Boro' and 'Aus' seasons were 4.8%. According to Haque et al (1984) loss figures obtained in harvesting to threshing operations varied from 0.9 to 5.9% in 'Aus' season indicating lower values for HYV and higher values for local varieties. Choudhury (1984) mentioned that preliminary result of rice postharvest loss assessment from harvesting milling did not exceed 15%.

The present study was conducted in Bangladesh to observe and gather information on existing postharvest operations at the village level and to estimate the extent and causes of losses. The postharvest operations studied were harvesting, field stacking, field transport, threshing, cleaning, winnowing, drying, parboiling, milling and storage.

## Paddy Harvesting to Field Transport Practices

The postharvest operations prac-

ticed at the village level in Bangladesh is shown in Fig. 1. Paddy from the field undergoes a series of operations before it is sold, consumed or used as seeds.

### Harvesting/Cutting

Manual harvesting of paddy using a sickle is the only prevailing practice followed by farmers in Bangladesh. The sickle varies in curvature, size, thickness, and weight depending upon the locality. The blade serration is inclined towards the wooden handle. During harvesting, the sickle is held by one hand and the bunch of stems, usually one hill in transplanted crop, is fed and held by the other. Rice plants are then cut about 10 to 30 cm above the ground. This operation is done in quick succession until the hand is full of the cut plant stalks. In transplanted rice, the crop is usually cut close to the ground for easy handling during threshing, and to obtain the maximum amount of straw for other uses as animal feeds, fuel, roofing materials or for sale. In deep water rice, the plants are cut at about the bends or knees where the panicles rise after lodging when the flood water receded. The rice plants cannot be harvested or cut at the base in this condition because of the long straw which grows as much as 5 m.

Wind and other natural factors causes some maturing crops to lodge in different directions making it difficult to harvest. Farmers in the northwest region physically lodge the Aman season crop by pressing the plants in one direction from one side of the field for easy harvesting. A bamboo, 4 m to 6 m long, with a string tied to lift it up is used. Starting from one end of the field, the farmer presses the bamboo near the base of the plants with one foot slightly forward and down causing the plant to lodge. He then lifts the bamboo with the tied string, steps forward and repeats the operation until he reaches the other end of the field with all the rice plants lodged in one direction. This is usually done during the early morning when the plants are soft with the overnight moisture.

In wet and shallow flooded fields the harvested stalks are accumulated, made into bigger bundles, and piled to the nearest levee. When the water is about knee to waist deep, farmers harvest the crop by 'feeling' and intuition. The bundled harvested stalks are either placed in a boat kept beside him, or allowed to float in the water. In flooded deep water rice where the farmers cannot stand in the field, the rice plants are harvested by riding on a boat. The harvested stalks are tied, placed in the boat

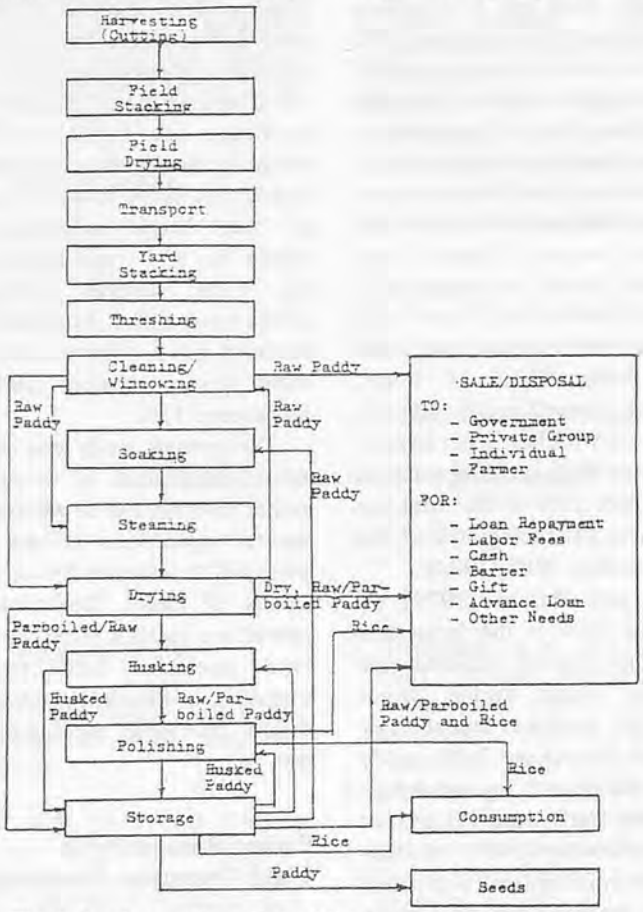


Fig. 1 Post-harvest operations at the farm and village level in Bangladesh (Arboleda, 1982).

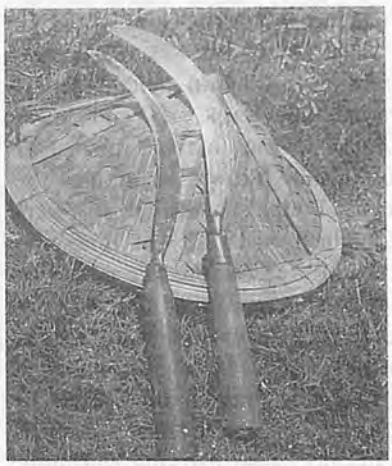

Fig. 2 Sickles.

Fig. 3 Crop cut close to the ground.

and transported to an elevated ground from where it is finally transported to the threshing yard.

Farmers usually harvest their crop at the optimum ripening stage. Sometimes, particularly in 'Boro' and 'Aus' seasons, they harvest their crop early because of uncertainty of rain and early flood, desire to prepare land early for the next season crop, or to supplement their basic needs because their rice stock from the previous harvest have been exhausted. In 'Aman' season, however, farmers have the tendency to harvest late with overmatured crops because of labour scarcity as harvesting coincides with it and is affected by land preparation and planting of dry season crops.

**Field Stacking/Bundling/Drying**

After cutting, paddy stalks are left on the ground, tied with same stalks to form a bundle the size of which depends upon the choice of the harvester, paddy culture and threshing methods. If threshing is done by hand beating or by pedal thresher, bundles are made smaller containing 1 to 3 handsful and if it is done by ox-treading, these are made bigger containing 10 to 15 handsful of cut paddy stalks. In some areas, particularly in 'Aman' season, harvested stalks are dried for one or two days in the field before bundling but the practice is gradually decreasing. Bundles are then gathered in one spot for tying into bigger bundles for transport to the threshing yard. In the wet fields bundles are placed on the levees or other elevated grounds with the panicles positioned upward where the bundles are partially dried or allowed to drip excess water before transport.

**Field Transport**

Harvested stalks are transported from the field to the threshing yard mainly by head carry, shoulder carry and animal-pulled carts. Boats, rickshaws, waterways and combinations of two or more of the above depending upon the farmers' capability and situations existing in the field, are also used.

Head carry is generally practiced where paddy is threshed by oxen. Small bundles are tied into bigger ones, loaded on the head with the assistance of another farmer and transported to the threshing yard. The size of the bundles varies depending upon the carrying capacity of the farmer, distance of the field to the threshing yard and moisture content of the harvested stalks. Usually 10-15 bundles are carried at a time.

Shoulder carry, the most common method of field transport, is generally practiced where transplanted crop is grown. In this method, small bundles are tied into bigger ones by a rope, inserted and tied into the two ends of a bamboo pole, about 1.25 m long, and carried by the shoulder with the panicles hanging upside down. There is a rythmic movement of the hanging panicles in resonance with the pace of the farmer which may cause shattering. Some areas in the north-east, a container called 'sika' is used and placed at the ends of a bamboo poles in transporting the harvested stalks. The 'sika' is made of two strips of looped cane, about 2 m long each, with the ends tied to a circularly formed cane of about 25 to 35 cm diameter. The cane strips open outward making it easy to load the bundles.

In 'Aman' season when the climate is comparatively dry, animal-pulled carts where available, are used in transporting harvested paddy. Rickshaws and rickshaw vans are also used in some parts of the country.

In deep water rice areas where harvesting is done in flooded situation, farmers transport the harvested stalks in boats. Sometimes the bundles are allowed to float in water, tied with a rope one after another, and pulled up to the elevated ground where it is untied, taken out from the water and piled for final transport to the threshing yard by other means. Duff and Toquero (1975) reported that depending upon the number of times the harvested stalks are handled from the field to the threshing yard, shattering loss occured up to 7%.

Fig. 4 Paddy carried on the head.

**Loss Assessment Procedure**

A total of 35 villages from 5 project areas were selected for the loss assessment study conducted during 1983 'Aman', 1984 'Boro' and 'Aus' harvest seasons. The selection was based on accessibility, co-operation of the farmers and representativeness of the village in the cropping pattern and post-harvest practices of the district. Six replications were made for each operation studied in each village. Losses were calculated by dividing the weight of lost grain collected, by the paddy yield obtained after threshing the bundles or area studied. All grain weights were converted into standard 14% MC (wet basis) before loss calculations were made. Detailed methods and procedures contained in the postharvest rice loss assessment manual, prepared for the study by Arboleda et al, (1983) was used.

## Summary of the Methods

**Harvesting**

Loss assessment in harvesting was done on a measured 50 $m^2$ (5 x 10 area. Five $m^2$ (5 x 1) in one end was used for measuring

pre-harvest loss and another 5 $m^2$ (5 x 1) selected randomly from 45 $m^2$ (5 x 9) was used to measure combined pre-postharvest loss. In both cases, grains that fell on the ground were manually collected. The whole 50 $m^2$ was then harvested and threshed to get the obtained yield.

### Field Stacking/Bundling/Drying

Harvested stalks were placed on canvas sheets spread in the field. Bundling of harvested stalks from small to bigger bundles in preparation for transport to the threshing yard was also done on the canvas. Shattered grains collected on canvas were considered as loss.

### Transporting

Grains that shattered during loading and transport were collected and considered as transport loss. Canvas-catches were designed and constructed for both head and shoulder carry to collect shattered grains during transporting.

Table 1 Percent Loss Estimates in Harvesting to Field Transport Operation by Rice Variety and Season

| Postharvest operation | Variety | Aman | Boro | Aus | Weighted average |
|---|---|---|---|---|---|
| Pre-postharvest | High yielding | 0.8 | 0.9 | 1.0 | 0.9 |
| | Pajam | 1.8 | – | – | 1.8 |
| | Local braodcast | 4.1** | – | 4.4** | 4.2 |
| | Local transplant | 2.8 | 1.4 | 1.2 | 2.3 |
| | Weighted average | 2.5 | 1.1 | 2.0 | 2.2 |
| Field stacking/ bundling/ drying | High yielding | 0.6 | 0.7 | 0.5 | 0.6 |
| | Pajam | 1.0 | 1.1** | – | 1.0 |
| | Local braodcast | 0.9 | – | 0.9** | 0.9 |
| | Local transplant | 0.8 | 0.6 | 0.4 | 0.6 |
| | Weighted average | 0.8 | 0.7 | 0.6 | 0.7 |
| Field transport | High yielding | 0.2 | 0.6 | 0.4 | 0.5 |
| | Pajam | 0.8** | 1.1** | – | 0.9 |
| | Local braodcast | 0.6 | – | 0.8** | 0.7 |
| | Local transplant | 0.6 | 0.3 | 0.6 | 0.5 |
| | Weighted average | 0.6 | 0.6 | 0.6 | 0.6 |

Table 2 Percent Loss Estimates in Harvesting to Field Transport Operations by Method and Season

| Postharvest operation | Method | Aman | Boro | Aus | Weighted average |
|---|---|---|---|---|---|
| Harvesting | Preharvest[1] | 0.5 | 0.3 | 0.3 | 0.4 |
| | Pre-postharvest | 2.5 | 1.1 | 2.0 | 2.2 |
| Field stacking | | 0.8 | 0.7 | 0.6 | 0.7 |
| Field transport | Head carry | 0.7 | 0.9** | 0.9 | 0.8 |
| | Shoulder carry | 0.3 | 0.4 | 0.4 | 0.4 |
| | Others[2] | 1.4** | 0.7 | – | 1.3 |
| | Weighted average | 0.6 | 0.6 | 0.6 | 0.6 |
| Total (sum of average) | | 3.9 | 2.4 | 3.2 | 3.5 |

[1]. Not included in total; [2]. Boat transport in deepwater rice field.

## Results and Discussions

### Varietal Effect on Loss

In pre-postharvest operation, estimated loss in four varietal groupings varied significantly in 'Aman' and 'Aus' seasons (Table 1). High loss observed in local broadcast varieties during 'Aman' and 'Aus' seasons could be due to the shattering characteristics of the variety, uneven lodging of the plants with the panicles in disarray, and the tendency to harvest an overmature crop ('Aman' season). This could also be the reason for high loss observed in local transplant varieties during 'Aman' season compared with other seasons. Consistently lower loss estimate (less than 7.0%) in HYVs as shown by three seasons result indicate its less shattering characteristic.

The estimated loss in field stacking/bundling/drying was less than 1% and did not vary significantly among four varietal groupings during 'Aman' season.

In field transport, significant variations were observed in loss estimates with comparatively high loss values obtained during 'Aman' and 'Boro' and local broadcast during 'Aus' season. Although significant variations in loss levels existed, the values obtained were low.

It can be noted that there is a progressive reduction in the percentage loss obtained in each varietal grouping from harvesting to transport operations. This result indicates the extent of handling the paddy panicles (jarring and jerking), frictions imparted to the grains during post-harvest operations, and the variability of force required to separate the grains from the panicle as influenced by varietal shattering characteristics and maturity. Overmatured and high varietal shattering characteristics result in high loss. The varietal and seasonal effects on the losses incurred from harvesting to transport operations are shown in the loss aggregate (Table 1).

### Effect of Methods on Loss

The consequence of delay in harvesting is shown by the higher quantity of shattered grains as preharvest loss during 'Aman' compared to 'Boro' and 'Aus' seasons (Table 2). In Nepal, the average harvesting loss reported by Kumer (1984) was 1.2% while in Malaysia, Mohamed (1981) claimed that preharvest loss in standing crop was 0.4 and 1.4% in cutting and handling, respectively.

Although the loss values obtained in field transport were low

and varied with variety (Table 1), differences were also observed in the methods of transport (Table 2). Shoulder carry seems to shatter the grain more because of the rythmic swaying of the hanging panicles with the pace of the man. The result, however, showed that even if the values obtained were less than 1%, the grain loss in shoulder carry was less by about half of those obtained from head carry in all seasons studied. It was observed that the main loss occured during head loading of the bundles in the field. Transport of harvested panicles by boat in deep water areas results in higher loss (1.4%) probably because of the very high grain moisture content. The filled grain, heavy with moisture, easily separate with the slight movement or jarring of the panicles. In general, the loss values obtained in transport operation were low. In Nepal, Kumer (1984) claimed that transportation loss was 0.8% while in Indonesia, Gaiser (1981) reported that transport loss was 1.3%. They did not mention, however, whether these values were field or distribution losses.

### Large and Small Farmers

Separating the loss data between large and small farmers in the different villages studied, the results obtained were slightly higher with the large farmers but statistical t-test showed that the loss differences between two groups of farmers were insignificant (Table 3).

Total loss estimates in the operations from harvesting through field transport were 3.9%, 2.4% and 3.2% for 'Aman', 'Boro' and 'Aus' seasons, respectively, with a weighted average of 3.5%. In terms of actual grain loss, this was equivalent to 0.7 million t of paddy for three seasons calculated from the estimated production of 20.1 million t.

Table 3 Percent Loss Estimates in Harvesting to Field Transport Operations by Farm Size and Season

| Postharvest operations | Farm size | Aman | Boro | Aus |
|---|---|---|---|---|
| Pre-postharvest | Small | 2.1 | 1.1 | 1.6 |
| | Large | 2.9 | 1.3 | 2.5 |
| Field stacking/bundling/drying | Small | 0.8 | 0.7 | 0.6 |
| | Large | 0.8 | 0.8 | 0.6 |
| Field transport | Small | 0.6 | 0.5 | 0.5 |
| | Large | 0.6 | 0.6 | 0.5 |

## Conclusion and Recommendation

Common postharvest practices exist in the country with variations evolving with the methods in some areas to cope with the existing localized conditions. HYVs shattered least but local broadcast varieties shattered most, 'Aman' season harvesting loss was observed high because the crop was often harvested late or over-matured.

Increased food availability in the postharvest sector can be achieved if the government can provide necessary input, training and incentive for the farmers to plant HYVs because these not only increases yield but also reduce postharvest losses. A study should be conducted on the appropriate time of 'Aman' season harvesting to minimize shattering loss.

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# Field Performance of Tractors in Pakistan

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## Abstract

Field data was collected for various tractors operating on 41 different sites in Pakistan for tillage operations in order to evaluate their tractive performance. On an average, the tractors' drive tyres were found to be over-inflated by about 1.5 times compared to the average recommended inflation pressure. The average forward speed of the tractors during tillage operations was observed to be 1.44 m/sec as against the recommended speed of 1.56 m/sec to 2.69 m/sec for such operations. All the tractors tested were under-ballasted. The average calculated actual weight to optimum weight ratio was 0.31. The average wastage of tractor power was estimated to be about 70%. The calculated tractive efficiency was only 52% of optimum tractive efficiency. Assuming that all the tractors were operating around the average recommended speed of 2 m/sec, the average actual weight to optimum weight ratio was calculated to be 0.43. The average power wastage under these conditions was about 57%.

## Introduction

At present tractors have a vital role in agriculture, everywhere in the world, both in developed and developing countries. The yearly increase in tractor population in the world indicates the importance and need of the tractor in today's agriculture. The tractor population in the world in 1973 was 16,462,834 and increased to 22,916,527 in 1983, i.e., an increase of 39% in 10 years (FAO, 1984). In Asia, which is mostly comprised of agricultural countries, the tractor population was 1,018,095 and 4,086,589 in the years 1973 and 1983, respectively, an increase of 301%. Like other countries in the world, the tractor population increased considerably in Pakistan during 1973-83, an increase of 351% (FAO, 1976; FAO, 1984).

It is, therefore, evident that tractors have a prime importance in today's agriculture and their population is increasing day by day. Hence it is necessary to aim for efficient utilization of tractor power at farms. Particularly during the present time when a farmer has to spend a reasonable portion of his investment for fuel and the tractor itself, it is crucial to make sure that tractors are operated at an optimum level. Utilizing maximum possible available power of tractor at high efficiency will ensure reduced operational costs.

One of the possible ways to improve the tractive performance of a tractor is to reduce power losses at the soil-tyre interface. Gee-Clough (1982) stated that in order to optimize the output of a wheeled tractor performing a draught operation in any dryland soil condition there has to be a proper matching of tractor power, weight, speed and draught force (or wheel slip). Zoz (1970), Reece (1970), Wismer and Luth (1973), Brixius and Zoz (1976), Domier and Willans (1977) etc, all tried to develop certain relationship between the above mentioned parameters for optimum performance. Dwyer (1978) used average values from field tests on tractive performance of tractor drive tyres to derive a curve of the form

$$W/P = 1.79/V \qquad (1)$$

This curve was also verified by Gee-Clough (1982). Where W is the weight on the drive axle (kN), P is the power available at the drive axle (kW) and V is the forward speed of the tractor (m/sec). Freitag (1965), using dimensional analysis, found that various parameters affecting the performance of a wheel were functions of a single dimensionless term which he called 'mobility number' and defined as $M = Cbd/W \times \sqrt{\delta/h}$. Where M is the mobility number, C is cone index (kPa), b is tyre width (m), d is tyre diameter (m), W is weight on the tyre (kN), $\delta$ is tyre deflection under load on a hard surface (m) and h is tyre section height (m). Later on Turnage (1972) suggested the following mobility number, modified to include the effect of tyre width to diameter ratio.

$$M = Cbd/W \times \sqrt{\delta/h}/[1+b/(2d)]. \qquad (2)$$

Gee-Clough et al (1978) described maximum coefficient of

traction of rolling resistance and rate constant in terms of the mobility number as follows.

$$(C_t)_{max} = 0.796 - 0.92/M \quad (3)$$

$$k(C_t)_{max} = 4.838 + 0.061\,M \quad (4)$$

$$C_r = 0.049 + 0.287/M \quad (5)$$

In addition, the following relationship was found to hold good in almost all field conditions in their experiments:

$$C_t = (C_t)_{max}\,[1 - Exp(-kS)] \quad (6)$$

Where $C_t$ is coefficient of traction, $(C_t)_{max}$ is maximum value of coefficient of traction, $C_r$ is coefficient of rolling resistance, k is rate constant and S is wheel slip. They recommended average wheel slip of 10% for maximum efficiency. Gee-Glough et al (1982) also showed that

$$\eta/\eta_{opt} = W/W_{opt} \times C_t/(C_t)_{opt} \quad (7)$$

Where $\eta$ is actual tractive efficiency, $\eta_{opt}$ is optimum tractive efficiency, $W_{opt}$ is the weight required on the rear axle for optimum performance (kN) and $(C_t)_{opt}$ is coefficient of traction under optimum conditions.

Inspite of the work done, as stated above, to improve a tractor's performance by proper matching of power, weight, speed and slip; a great deal of work remains to be done to demonstrate to farmers the losses caused by improper matching of the above-mentioned factors and, particularly, emphasizing the use of tractors with the correct amount of ballast necessary for optimum performance. The situation is even worse in developing countries like Pakistan where illiterate farmers hardly have any knowledge about proper ballasting. High inflation pressure, under ballasting, loss of considerable tractor power and high percentage of wheel slip are common practices there (Farooq et al, 1983; Khalid, 1985).

## Objective

The main objective of the study was to determine the following parameters under actual conditions in Pakistan:

(1) How tractors are typically ballasted as compared to the optimum ballasting requirements;

(2) Tractor power wasted due to improper matching of weight, power, speed and slip in Pakistan; and

(3) Difference between actual tractive efficiency and maximum possible tractive efficiency on tractors.

## Methodology

The study was conducted at 41 different farms in 11 districts of the North-Western Frontier and Punjab provinces of Pakistan. The selection of farms and tractors/implements was unbiased and made at random from the sales record of tractor/implements distributors. All the tractors tested were 2-wheel drive type. The study was confined to tillage operations in dry land conditions only. The most popular tillage implement used with a tractor in Pakistan is a cultivator, a version of the Massey Ferguson tiller model MF-38 (Fig. 1) and was, therefore, found in most of the farms where tests were conducted. Most of the implements were being used for seed bed preparation of sugarcane, cotton, maize, vegetables or fodder. At every site data on the following were recorded.

1. Inflation pressure in tractor rear tyre using a tyre pressure gauge.
2. Cone penetrometer resistance using a soil resistance tester model SR-2, made by Kiya Seisakusho Ltd, Japan.
3. Tractor forward speed using a measuring tape and stop watch.
4. Wheel slip by counting wheel revolutions to travel a certain distance under load and at no load.
5. Weight on the tractor rear axle with implement raised, using a self developed load cell (Fig. 2).
6. Tractor PTO horse power as quoted by the manufacturer.
7. Tractor tyre dimensions as quoted by the manufacturer.

Fig. 1 A tractor with MF-38 tiller.

Fig. 2 Load-cell developed for weight measurement.

In addition, it was assumed that the axle power would be equal to the quoted PTO horse power of the tractor and as most of the farmers were using a tine tiller, a light draught implement, the static weight on the rear axle with implement raised was used in all calculations instead of dynamic weight.

## Results

### Tyre Inflation Pressure

As illustrated in Table 2, the average rear tyre inflation pressure was about 147 kPa with a maxi-

mum of 333 kPa and a minimum of 69 kPa against the average recommended pressure of 96 kPa. In all the cases except one, actual tyre pressure in the rear wheels was more than the recommended tyre pressure for field work. In four cases, i.e., site Nos. 22, 29, 31 and 35, the actual tyre pressure was more than twice the recommended tyre pressure; while in one case, i.e., at site No. 18, the actual tyre pressure was more than three times the recommended tyre pressure. It is, therefore, evident that the farmers need to be guided about proper tyre inflation pressure, particularly in the drive tyres, as over inflation itself causes a decrease in tractive performance. The tractor distributors should make sure while delivering/servicing a tractor that the tyres are inflated to the correct pressure.

### Wheel Ballast

At the present time only one tractor manufacturer in Pakistan supplies front end weights with a tractor as a standard feature. Even the farmers who had front end weights with their tractors were not using those while ploughing because they thought that the weights were necessary only when the tractor is pulling a load on roads.

Among all the tractors tested, not a single tractor was using rear wheel ballast of any type. At present no tractor manufacturer in the country offers rear wheel weights for ballasting and most of the farmers do not have any knowledge about water ballasting.

### Tractor Operating Speed

The actual forward speeds at which the tractors were operating in the field were measured and are given in **Table 1**. At a few sites (site nos. 2, 5, 32, 37, 38 and 39), the speed was too slow either due to excessive slippage, selection of wrong gear/throttle setting or due to the condition of the top soil surface, i.e., presence of furrows, ridges, etc in the field. The average forward speed for the data collected was 1.44 m/sec with maximum 2.38 m/sec and minimum 0.67 m/sec. A suitable forward speed for such tillage operations ranges from 1.56 m/sec to 2.69 m/sec (Kepner et al; 1978). Therefore, depending on circumstances, there was still room for increasing the tractor forward speed slightly in every case, as this will reduce the weight requirement on drive axle for the same power output. Hence an attempt was made to analyse the situation, as shown in **Table 1**, assuming that all the tractors were operating at 2 m/sec (a typical average recommended speed for tillage work) and keeping all the other parameters unchanged. The benefits achieved are discussed in the following sections.

Table 1 Under-ballasting and Power Wastage

| No | $V_{ac}$ | $W_{ac}$ | $P_{ac}$ | $\frac{W_{ac}}{P_{ac}}$ | At actual speed | | | | At 2 m/sec speed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $W_{op}$ | $\frac{W_{ac}}{W_{op}}$ | $P_{use}$ | $P_{wst}$ | $W_{op}$ | $\frac{W_{ac}}{W_{op}}$ | $P_{use}$ | $P_{wst}$ |
| | m/s | kN | kW | | kN | | KW | % | kN | | kW | % |
| 1 | 1.00 | 11.79 | 32.30 | 0.37 | 57.82 | 0.20 | 4.50 | 86.06 | 28.91 | 0.41 | 9.00 | 72.12 |
| 2 | 0.96 | 10.57 | 32.30 | 0.33 | 60.23 | 0.18 | 6.40 | 80.19 | 28.91 | 0.37 | 13.33 | 58.73 |
| 3 | 1.18 | 12.05 | 32.30 | 0.37 | 49.00 | 0.25 | 8.22 | 74.54 | 28.91 | 0.42 | 13.94 | 56.85 |
| 4 | 1.06 | 11.85 | 33.94 | 0.35 | 57.31 | 0.21 | 8.42 | 75.20 | 30.38 | 0.39 | 15.88 | 53.21 |
| 5 | 0.85 | 12.24 | 35.06 | 0.35 | 73.83 | 0.17 | 7.03 | 79.96 | 31.38 | 0.39 | 16.53 | 52.85 |
| 6 | 1.08 | 12.74 | 35.06 | 0.36 | 58.11 | 0.22 | 9.66 | 72.45 | 31.38 | 0.41 | 17.89 | 48.99 |
| 7 | 1.09 | 12.14 | 35.06 | 0.35 | 57.58 | 0.21 | 8.95 | 74.47 | 31.38 | 0.39 | 16.42 | 53.16 |
| 8 | 2.38 | 12.25 | 33.94 | 0.36 | 25.53 | 0.48 | 14.86 | 56.22 | 30.38 | 0.40 | 12.49 | 63.21 |
| 9 | 1.78 | 12.60 | 33.94 | 0.37 | 34.13 | 0.37 | 12.22 | 64.00 | 30.38 | 0.41 | 13.73 | 59.55 |
| 10 | 1.76 | 12.78 | 35.06 | 0.36 | 35.66 | 0.36 | 13.10 | 62.62 | 31.38 | 0.41 | 14.89 | 57.53 |
| 11 | 1.08 | 12.05 | 35.06 | 0.34 | 58.11 | 0.21 | 8.37 | 76.13 | 31.38 | 0.38 | 15.50 | 55.80 |
| 12 | 1.77 | 12.24 | 35.06 | 0.35 | 35.46 | 0.35 | 8.19 | 76.64 | 31.38 | 0.39 | 9.25 | 73.61 |
| 13 | 1.44 | 12.24 | 33.94 | 0.36 | 42.19 | 0.29 | 6.71 | 80.22 | 30.38 | 0.40 | 9.33 | 72.52 |
| 14 | 1.49 | 12.15 | 35.06 | 0.35 | 42.12 | 0.29 | 9.29 | 73.50 | 31.38 | 0.39 | 12.47 | 64.43 |
| 15 | 1.42 | 12.31 | 35.06 | 0.35 | 44.20 | 0.28 | 6.02 | 82.84 | 31.38 | 0.39 | 8.47 | 75.83 |
| 16 | 1.93 | 12.26 | 33.94 | 0.36 | 31.48 | 0.39 | 7.95 | 76.57 | 30.38 | 0.40 | 8.24 | 75.72 |
| 17 | 1.06 | 13.85 | 35.58 | 0.39 | 60.08 | 0.23 | 9.56 | 73.14 | 31.84 | 0.43 | 18.03 | 49.32 |
| 18 | 1.80 | 13.23 | 35.58 | 0.37 | 35.38 | 0.37 | 8.85 | 75.12 | 31.84 | 0.42 | 9.84 | 72.35 |
| 19 | 1.36 | 13.72 | 35.58 | 0.39 | 46.83 | 0.29 | 9.16 | 74.27 | 31.84 | 0.43 | 13.46 | 62.16 |
| 20 | 1.76 | 13.70 | 35.58 | 0.39 | 36.19 | 0.38 | 10.58 | 70.27 | 31.84 | 0.43 | 12.02 | 66.22 |
| 21 | 1.39 | 13.72 | 35.58 | 0.39 | 45.82 | 0.30 | 9.69 | 72.78 | 31.84 | 0.43 | 13.94 | 60.83 |
| 22 | 1.20 | 13.91 | 35.58 | 0.39 | 53.07 | 0.26 | 10.75 | 69.80 | 31.84 | 0.44 | 17.91 | 49.66 |
| 23 | 1.11 | 10.40 | 30.59 | 0.34 | 49.33 | 0.21 | 7.13 | 76.69 | 27.38 | 0.38 | 12.85 | 58.00 |
| 24 | 1.97 | 12.83 | 30.59 | 0.42 | 27.79 | 0.46 | 11.83 | 61.32 | 27.38 | 0.47 | 12.01 | 60.73 |
| 25 | 2.07 | 12.24 | 30.59 | 0.40 | 26.45 | 0.46 | 16.65 | 45.55 | 27.38 | 0.45 | 16.09 | 47.40 |
| 26 | 1.73 | 15.48 | 32.83 | 0.47 | 33.96 | 0.46 | 13.70 | 58.27 | 29.37 | 0.53 | 15.83 | 51.76 |
| 27 | 1.84 | 17.64 | 44.76 | 0.39 | 43.54 | 0.41 | 18.57 | 58.51 | 40.06 | 0.44 | 20.19 | 54.90 |
| 28 | 1.72 | 16.56 | 49.24 | 0.34 | 51.24 | 0.32 | 13.08 | 73.43 | 44.07 | 0.38 | 15.21 | 69.10 |
| 29 | 1.52 | 15.48 | 45.42 | 0.34 | 53.49 | 0.29 | 14.79 | 67.43 | 40.65 | 0.38 | 19.47 | 57.14 |
| 30 | 1.65 | 16.16 | 41.78 | 0.39 | 45.32 | 0.36 | 13.85 | 66.85 | 37.39 | 0.43 | 16.79 | 59.82 |
| 31 | 1.91 | 16.26 | 41.78 | 0.39 | 39.16 | 0.42 | 21.17 | 49.34 | 37.39 | 0.43 | 22.16 | 46.95 |
| 32 | 0.67 | 19.58 | 44.76 | 0.44 | 119.58 | 0.16 | 6.94 | 84.50 | 40.06 | 0.49 | 20.71 | 53.74 |
| 33 | 1.70 | 23.02 | 39.36 | 0.58 | 41.44 | 0.56 | 20.97 | 46.73 | 35.23 | 0.65 | 24.67 | 37.33 |
| 34 | 1.89 | 13.23 | 33.94 | 0.39 | 32.14 | 0.41 | 14.07 | 58.56 | 30.38 | 0.44 | 14.88 | 56.15 |
| 35 | 1.63 | 21.55 | 46.25 | 0.47 | 50.79 | 0.42 | 22.50 | 51.36 | 41.39 | 0.52 | 27.60 | 40.32 |
| 36 | 1.02 | 19.60 | 45.42 | 0.43 | 79.71 | 0.25 | 13.43 | 70.43 | 40.65 | 0.48 | 26.33 | 42.03 |
| 37 | 0.94 | 15.19 | 32.82 | 0.46 | 62.50 | 0.24 | 9.41 | 71.34 | 29.37 | 0.52 | 20.01 | 39.03 |
| 38 | 0.93 | 13.70 | 35.06 | 0.39 | 67.48 | 0.20 | 9.08 | 74.10 | 31.38 | 0.44 | 19.53 | 44.31 |
| 39 | 0.96 | 17.64 | 49.24 | 0.36 | 91.81 | 0.19 | 10.45 | 78.78 | 44.07 | 0.40 | 21.77 | 55.78 |
| 40 | 1.05 | 13.00 | 35.06 | 0.37 | 59.77 | 0.22 | 9.24 | 73.65 | 31.38 | 0.41 | 17.60 | 49.81 |
| 41 | 1.74 | 17.53 | 44.76 | 0.39 | 46.05 | 0.38 | 18.84 | 57.91 | 40.06 | 0.44 | 21.66 | 51.62 |
| | 2.38 | Max | | 0.58 | | 0.56 | | 86.06 | | 0.65 | | 75.83 |
| | 0.67 | Min | | 0.33 | | 0.16 | | 45.55 | | 0.37 | | 37.33 |
| | 1.44 | Ave | | 0.38 | | 0.31 | | 69.55 | | 0.43 | | 56.84 |
| | 0.41 | S.D. | | 0.05 | | 0.10 | | 10.13 | | 0.05 | | 9.88 |
| | 0.28 | C.V. | | 0.13 | | 0.32 | | 0.15 | | 0.12 | | 0.17 |

$V_{ac}$ = actual forward speed measured in meters per seconds.
$W_{ac}$ = actual weight on rear axle measured in kilo Newtons.
$P_{ac}$ = axle power in kilo watts as quoted by manufacturer (PTO HP).
$W_{op}$ = optimum weight required on rear axle = 1.79 $P_{ac}/V_{ac}$.
$P_{use}$ = power used for operation = PULL × $V_{ac}$. (PULL = $C_t^{ac} \times W_{ac}$).
$P_{wst}$ = power wasted = $(P_{ac} - P_{use})/P_{ac} \times 100$.

### Drive Axle Load

The power available at the tractor rear axle and the actual static weight measured on the rear axle are shown in **Table 1**. The optimum weight required on the rear axle to efficiently transmit the power available at the rear axle at the actual forward speed has

been calculated using the equation W/p = 1.79/V. The average actual weight on the rear axle was only 31% of the weight required for optimum performance, with a maximum value of 56% and minimum of 16%. These figures clearly indicate that all the tractors tested were considerably under-ballasted. This is quite evident from **Fig. 3**. In this figure, the curve represents the standard equation given by Dwyer (1978), i.e., W/P = 1.79V; while the points below the curve indicate the observed values on the test sites.

From the ballasting values in **Table 1** and **Fig. 3**, it is clear that in some cases, particularly the ones where the forward speed was too slow, the extra weight required for optimum performance is tremendous and not practically feasible.

Therefore, the whole situation was again analysed to estimate the additional ballast required on the rear axle if the tractors were assumed operating at 2 m/sec speed. As shown in **Table 1**, under these assumed conditions, the average actual weight to optimum weight ratio was improved, i.e., the actual weight on the drive axle was calculated to be 43% of the optimum weight. The maximum value was 65% and a minimum of 37%. This is shown in **Fig. 4**.

The correct total weight needed on the rear axle for each individual case may be calculated using the equation W/P = 1.79/V for a known forward speed and axle power (axle power may be assumed equal to PTO power). This weight minus the weight already there on the rear axle with the implement raised, will give the extra ballast that will have to be added on to the rear axle for optimum performance. The rear tyres fitted to the tractor should be able to take this total weight safely at low inflation pressure. The hydraulic lever should then be set at a position that results in approximately 10% rear wheel slip. This will ensure the operation at maximum possible tractive efficiency. At the same time, the farmers will have to be guided about the use of water ballasting techniques and rear wheel weights as and when necessary. The tractor manufacturers should offer front end and rear wheel weights as a standard feature with their tractors.

### Power Wastage

The tractor power actually used during operation was estimated, as shown in **Table 1**, by calculating the mobility number and coefficient of traction using Equations 2, 3, 4 and 6. Using the coefficient of traction and the weight acting on the rear axle, the pull delivered by the tractor was calculated and multiplied by the actual forward speed to estimate the power delivered. As an average, Pakistani farmers under actual operating conditions were wasting about 70% of their tractor's power, with a maximum value of 86% and a minimum of 45%.

As shown in **Table 1**, the situation was slightly improved when the tractors were assumed operating at a speed of 2 m/sec. But even in this case the average calculated power wastage was about 57% with maximum and minimum values of 76% and 37%, respectively.

It is quite evident from **Table 1** that the same operations can be performed by a properly ballasted tractor having approximately half the power of the present tractors.

Tractor manufacturers, extension workers and other allied agencies should educate, guide and convince the farmers, through personal as well as mass contact media, about proper inflation pressure, operating speed, optimum ballasting, etc. This will ensure reduced tractor power losses.

### Wheel Slip

Wheel slip data for each test are given in **Table 2**. The average wheel slip observed was 22.37% with maximum 43.72% and minimum 7.55%. Although in a few cases wheel slip was very close to the optimum slip value, i.e., 10%; yet optimum tractive efficiency could not be achieved in those cases because not only slip but weight,

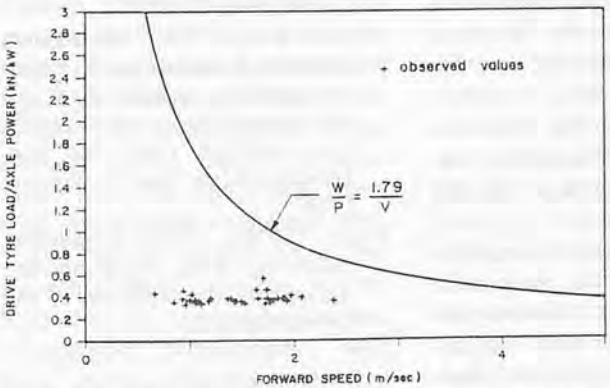


Fig. 3 Actual under-ballasting of tractors compared to standard ballasting requirements.

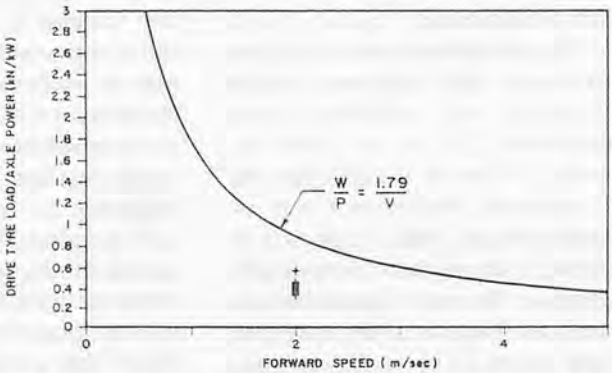


Fig. 4 Calculated under-ballasting of tractors at recommended speed.

Table 2 Over-inflation and Loss of Tractive Efficiency

| No | Cone index kPa # | Wheel Slip % # | Tractor model | Implement | Rear type size | Type pressure kPa # | Over-inf. ## | $W_{ac}/W_{op}$ ## | $C_t$ ## | $(C_t)_{op}$ ## | $\eta/\eta_{op}$ ## |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 309.18 | 10.48 | MF-135 | Cultivator | 12.4-28 | 132.39 | 1.38 | 0.20 | 0.38 | 0.21 | 0.37 |
| 2 | 357.08 | 28.53 | MF-135 | Cultivator | 12.4-28 | 176.52 | 1.84 | 0.18 | 0.63 | 0.24 | 0.46 |
| 3 | 653.19 | 19.13 | MF-135 | Cultivator | 12.4-28 | 147.10 | 1.53 | 0.25 | 0.58 | 0.34 | 0.42 |
| 4 | 517.11 | 32.74 | MF-240 | Cultivator | 12.4-28 | 147.10 | 1.53 | 0.21 | 0.67 | 0.31 | 0.45 |
| 5 | 395.54 | 41.15 | MF-240 | Cultivator | 12.4-28 | 147.10 | 1.53 | 0.17 | 0.68 | 0.21 | 0.53 |
| 6 | 632.78 | 38.99 | MF-240 | Cultivator | 12.4-28 | 98.07 | 1.02 | 0.22 | 0.70 | 0.32 | 0.47 |
| 7 | 438.18 | 38.04 | MF-240 | Cultivator | 12.4-28 | 127.49 | 1.33 | 0.21 | 0.68 | 0.29 | 0.50 |
| 8 | 424.57 | 16.33 | MF-240 | Cultivator | 12.4-28 | 107.87 | 1.12 | 0.48 | 0.51 | 0.35 | 0.70 |
| 9 | 531.63 | 17.87 | FM-240 | Cultivator | 12.4-28 | 127.49 | 1.33 | 0.37 | 0.54 | 0.35 | 0.58 |
| 10 | 535.25 | 20.93 | MF-240 | Cultivator | 12.4-28 | 137.29 | 1.43 | 0.36 | 0.58 | 0.34 | 0.61 |
| 11 | 625.97 | 25.89 | MF-240 | Cultivator | 12.4-28 | 152.00 | 1.58 | 0.21 | 0.64 | 0.32 | 0.41 |
| 12 | 589.69 | 9.23 | MF-240 | Cultivator | 12.4-28 | 152.00 | 1.58 | 0.35 | 0.38 | 0.35 | 0.37 |
| 13 | 748.45 | 8.88 | MF-240 | Cultivator | 12.4-28 | 147.10 | 1.53 | 0.29 | 0.38 | 0.35 | 0.31 |
| 14 | 517.11 | 15.77 | MF-240 | Cultivator | 12.4-28 | 147.10 | 1.53 | 0.29 | 0.51 | 0.33 | 0.44 |
| 15 | 816.49 | 7.55 | MF-240 | Cultivator | 12.4-28 | 127.49 | 1.33 | 0.28 | 0.34 | 0.35 | 0.27 |
| 16 | 571.54 | 7.86 | MF-240 | Cultivator | 12.4-28 | 152.00 | 1.58 | 0.39 | 0.34 | 0.35 | 0.37 |
| 17 | 430.02 | 34.13 | FIAT-480 | Cultivator | 12.4-28 | 176.52 | 1.84 | 0.23 | 0.65 | 0.28 | 0.54 |
| 18 | 707.62 | 8.82 | FIAT-480 | Cultivator | 12.4-28 | 333.43 | 3.47 | 0.37 | 0.37 | 0.36 | 0.39 |
| 19 | 748.45 | 13.68 | FIAT-480 | Cultivator | 12.4-28 | 112.78 | 1.17 | 0.29 | 0.49 | 0.35 | 0.41 |
| 20 | 816.49 | 11.08 | FIAT-480 | Cultivator | 12.4-28 | 166.71 | 1.73 | 0.38 | 0.44 | 0.36 | 0.46 |
| 21 | 616.90 | 15.26 | FIAT-480 | Cultivator | 12.4-28 | 112.78 | 1.17 | 0.30 | 0.51 | 0.34 | 0.45 |
| 22 | 647.75 | 27.02 | FIAT-480 | Cultivator | 12.4-28 | 245.17 | 2.55 | 0.26 | 0.64 | 0.33 | 0.51 |
| 23 | 816.49 | 20.19 | FORD-3600 | Cultivator | 12.4-28 | 127.49 | 1.33 | 0.21 | 0.62 | 0.35 | 0.37 |
| 24 | 571.54 | 13.17 | FORD-3600 | Cultivator | 12.4-28 | 127.49 | 1.33 | 0.46 | 0.47 | 0.36 | 0.60 |
| 25 | 412.33 | 34.05 | FORD-3600 | Cultivator | 12.4-28 | 137.29 | 1.43 | 0.46 | 0.66 | 0.35 | 0.88 |
| 26 | 421.85 | 16.92 | FORD-3600 | Cultivator | 13.6-28 | 147.10 | 1.53 | 0.46 | 0.51 | 0.34 | 0.68 |
| 27 | 560.66 | 19.00 | MF-165 | Cultivator | 16.9-30 | 147.10 | 1.53 | 0.41 | 0.57 | 0.36 | 0.64 |
| 28 | 517.11 | 12.44 | MF-265 | Cultivator | 16.9-30 | 127.49 | 1.33 | 0.32 | 0.46 | 0.35 | 0.43 |
| 29 | 510.55 | 24.03 | FIAT-640 | Cultivator | 16.9-30 | 196.13 | 2.04 | 0.29 | 0.63 | 0.35 | 0.53 |
| 30 | 270.80 | 18.18 | FORD-4600 | Cultivator | 16.9-30 | 107.87 | 1.12 | 0.36 | 0.52 | 0.31 | 0.59 |
| 31 | 666.80 | 29.42 | FORD-4610 | Cultivator | 16.9-30 | 196.13 | 2.04 | 0.42 | 0.68 | 0.37 | 0.76 |
| 32 | 816.49 | 15.77 | IMT-558 | Cultivator | 14.9-28 | 122.58 | 1.28 | 0.16 | 0.53 | 0.31 | 0.28 |
| 33 | 210.11 | 24.20 | BELARUS50 | Cultivator | 18.3-30 | 147.10 | 1.53 | 0.56 | 0.54 | 0.31 | 0.96 |
| 34 | 653.19 | 18.41 | MF-240 | Disc harrow | 12.4-28 | 137.29 | 1.43 | 0.41 | 0.56 | 0.36 | 0.64 |
| 35 | 567.91 | 30.05 | MF-265 | Disc harrow | 14.9-28 | 205.94 | 2.14 | 0.42 | 0.64 | 0.34 | 0.79 |
| 36 | 507.58 | 33.74 | FIAT-640 | Disc plough | 16.9-30 | 98.07 | 1.02 | 0.25 | 0.67 | 0.32 | 0.52 |
| 37 | 653.19 | 28.85 | FORD-3610 | MB plough | 13.6-28 | 152.00 | 1.58 | 0.24 | 0.66 | 0.33 | 0.48 |
| 38 | 680.41 | 43.72 | MF-240 | MB plough | 12.4-28 | 127.49 | 1.33 | 0.20 | 0.71 | 0.32 | 0.46 |
| 39 | 611.46 | 22.42 | MF-265 | Chisel plough | 16.9-30 | 68.65 | 0.71 | 0.19 | 0.62 | 0.32 | 0.37 |
| 40 | 438.18 | 40.27 | MF-240 | Chisel plough | 12.4-28 | 127.49 | 1.33 | 0.22 | 0.68 | 0.28 | 0.52 |
| 41 | 560.66 | 23.04 | MF-165 | Chisel plough | 16.9-30 | 147.10 | 1.53 | 0.38 | 0.62 | 0.36 | 0.66 |
| | 816.49 | 43.72 | | Maximum | | 333.43 | 3.47 | 0.56 | | | 0.96 |
| | 210.11 | 7.55 | | Minimum | | 68.65 | 0.71 | 0.16 | | | 0.27 |
| | 562.88 | 22.37 | | Average | | 146.86 | 1.53 | 0.31 | | | 0.52 |
| | 148.93 | 10.21 | | Std. deviation | | 43.41 | 0.45 | 0.10 | | | 0.15 |
| | 0.26 | 0.46 | | Coef. of variance | | 0.30 | 0.29 | 0.32 | | | 0.29 |

# measured values ## calculated values Recommended pressure = 96.1 kPa.
OVER Inf = ratio between actual & recommended rear type inflation pressure.
$W_{ac}/W_{op}$ = ratio between actual weight & optimum weight on rear axle.
$C_t$ & $(C_t)_{op}$ = coefficient of traction at actual & optimum conditions respectively. Calculated using equations 2, 3, 4 and 6.
$\eta/\eta_{op}$ = ratio between actual and optimum tractive efficiency = $W_{ac}/W_{op} \times C_t/(C_t)_{op}$.

power and speed also have to be properly matched.

### Tractive Efficiency

The ratio between actual tractive efficiency and optimum tractive efficiency was calculated using equations 2, 3, 4, 6, 7 and assuming $\delta/h$ equal to 0.20. The slip at optimum performance was assumed to be 10%. As shown in **Table 2**, very little of the available power at the drive axle of tractors used in Pakistan was converted into useful work at the drawbar. The reasons were under-ballasting, low forward speeds, excessive wheel slip or a combination of all. The average ratio between actual tractive efficiency and optimum tractive efficiency at all the sites tested was estimated to be 0.52 with a maximum of 0.96 and a minimum of 0.27. **Fig. 5** shows the consequences of improper ballasting in terms of loss of tractive efficiency.

The tractor manufacturers, after careful study, should work with extension workers to demonstrate to the farmers how they can improve the performance of their tractors by proper matching of power, weight, speed and slip in dryland conditions. These demonstrations will help to improve the tractive efficiency of the tractors.

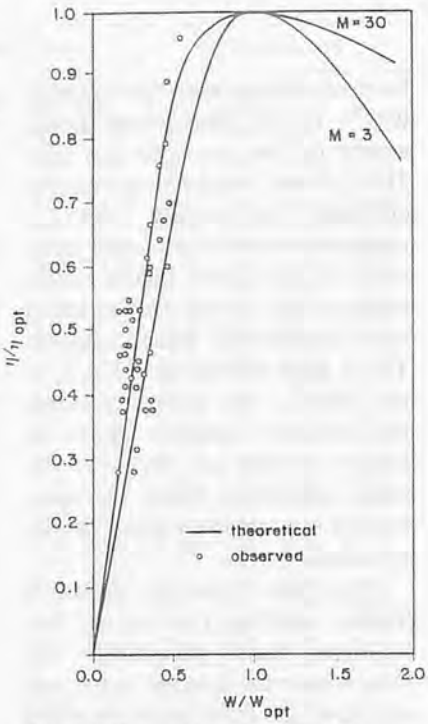


Fig. 5 Efficiency loss due to under-ballasting.

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*(Continued on page 74)*

# Matrix Method for Measuring Forces in Three Dimensions

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## Introduction

For optimal design of the tillage tools, the analysis of 3-dimensional forces and moments operating in the soil-tool interaction system is of utmost importance. Different techniques and modes of analysis have been used to obtain the information necessary to make such assessment and evaluation. Some of the techniques used provided information on all force components and moments about the three orthogonal axes, while others did not. Original work (Payne, 1956; Tannar, 1960) incorporated suspending the tool from a series of single dynamometers to measure the horizontal and vertical forces on the tool, later on Hendrick and Buchele (1963) used a dynamometer made of steel tubing fitted with strain gauges to measure horizontal force, vertical force and moments. Many research workers have also used more advanced and complicated dynamometers with force transducers to obtain detailed data on forces and moments (Chisholm, 1970; Luth, 1974). Although the aforesaid techniques and attempts towards the measurements of 3-dimensional forces and moments acting on tillage tool are heraldic, yet these techniques are quite complicated and clumsy using more extra hardware for installation and mounting of the dynamometer and comparatively difficult to handle in field conditions. The present research study is oriented and intended to measure the 3-dimensional forces acting on the tillage tools. For the purpose of this study an extended octagonal ring transducer was used. This transducer responds and works properly, when it is assumed that the soil failure is symmetrical. In this case, the lateral force and moments about the horizontal and vertical axes will be zero, i.e., the extended octagonal ring transducer is capable of providing information on forces in the horizontal and vertical directions and moments about the lateral axis. Further rationale for using this dynamometer in the present study was that, it is a compact unit with manageable protruding cable, it does not require extra hardware for installation, can be easily integrated and coupled with the tillage tool, and is easy to handle and economical.

## Methodology

An extended octagonal ring transducer was calibrated for static forces in two orthogonal directions and moment about the third by applying weights. The transducer was then attached to a narrow tine and to a small mole plow. The narrow tine and mole plow were drawn through the simulated soil and force measurements were taken.

## Equipment

The equipment and instrumentation used for the purpose of this study included: extended octagonal ring transducer (Fig. 1 for strain gauge positions), narrow tine, small mole plow, simulated soil tank, implement carrier, tension dynamo-

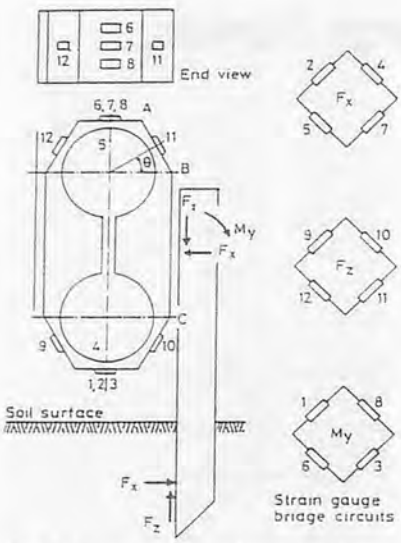


Fig. 1 Forces acting on dynamometer with cultivation tine attached and strain gauge bridge circuits.

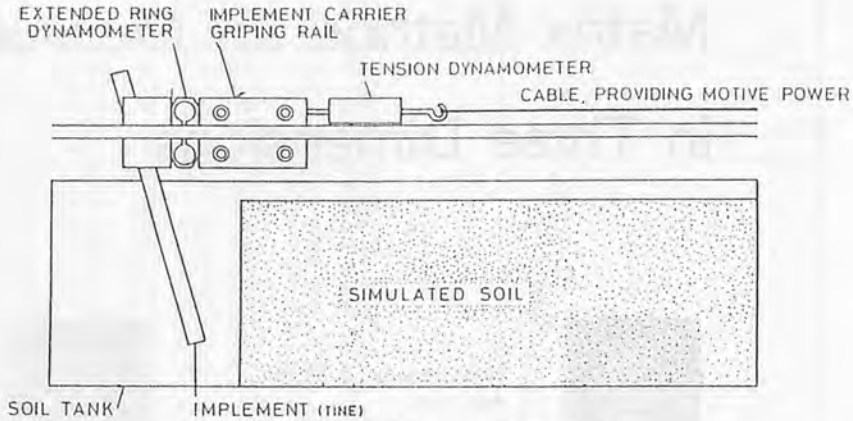


Fig. 2 Arrangement showing dynamometer transfered to test rig.

meter (Fig. 2), multichannel amplifier, stablized voltage supply, digital voltmeter, ultra violet (UV) recorder, and power source.

## Experimental Procedure

The transducer was placed in two positions and weights were applied at points a-e (Fig. 2). The signal from the amplifier was monitored by the digital voltmeter (Tables 1 and 2). As the experiment progressed the recording apparatus became more unstable to the point where errors of ± 10mV had to be assigned. Due to instability of the recording apparatus, zeroing of the bridge constants was found to be increasingly difficult. This, however, need not be the problem and has been dealt within data processing. The outputs were not tested for repeatability, but by loading and subsequently unloading, the hysteresis was found to be zero or negligible. The tension dynamometer was also calibrated in this way. The UV recorder was not calibrated, but was assumed to have been calibrated accurately by the manufacturer. The dynamometers were then transferred to the test rig (Fig. 2), and were coupled with the tine and mole plow in turn. The outputs from the transducer was led to the UV recorder via the multichannel amplifier. In the case of the tine, the data was recorded of the tension dynamometer output, the horizontal draught forces, vertical forces, and moment acting on the tine. The measurement of forces on the tine was made for tine at 3 different rake angles. Also, in the case of the mole plow, recordings of the horizontal force, vertical force and the moment on the mole plow leg and mole plow foot were made. The rolling resistance of the implement carrier as given by the tension dynamometer operating with no implement attached was also measured. The output traces from the UV recorder were analyzed using a planimeter for unstable traces and direct measurement for more stable ones (Table 6).

## Treatment of Results

### Nomenclature

The terminology and symbols devised and adopted for the analysis, handling and treatment of transducer calibration results as

Table 1 Results for Calibration of Vertical Loads

| Load N | Outputs d = 0.1 m | | | Output at d = O | | | Output at d=−0.1 m | | |
|---|---|---|---|---|---|---|---|---|---|
| | $O_1$ (mV) | $O_2$ (mV) | $O_3$ (mV) | $O_1$ (mV) | $O_2$ (mV) | $O_3$ (mV) | $O_1$ (mV) | $O_2$ (mV) | $O_3$ (mV) |
| 98.0 | – | – | 21 | – | 73 | – | – | – | – |
| 196.2 | – | 147 | 39 | 0 | 144 | 3 | 1 | 142 | 48 |
| 294.0 | – | – | 56 | – | 217 | – | – | – | – |
| 392.0 | – | 294 | 75 | 2 | 288 | 4 | 3 | 284 | 102 |
| 490.0 | – | – | 95 | – | 362 | – | – | – | – |
| 588.0 | 5 | 442 | 110 | 5 | 436 | 5 | 4 | 428 | 149 |
| 686.0 | – | – | 131 | – | 507 | – | – | – | – |
| 784.0 | 12 | 589 | 149 | 7 | 580 | 6 | 7 | 569 | 197 |
| 883 | – | – | 170 | – | 653 | – | – | – | – |
| 981.0 | 14 | 736 | 190 | 10 | 725 | 7 | 9 | 713 | 246 |
| Error: | ± 3 | ± 3 | ± 3 | ± 3 | ± 2 | ± 1 | ± 3 | ± 2 | ± 4 |

Table 2 Results for Calibration of Horizontal Loads

| Load N | Output at d = 0.5 m | | | Output at d = 0.3 m | | | Tension dynamometer calibration output |
|---|---|---|---|---|---|---|---|
| | $O_1$ | $O_2$ | $O_3$ | $O_1$ | $O_2$ | $O_3$ | |
| 98.0 | 57 | – | – | 54 | 6 | – | 64 |
| 196.2 | 117 | 20 | 249 | 114 | 10 | 145 | – |
| 294.0 | 175 | – | – | 175 | 13 | – | 190 |
| 392.0 | 239 | 25 | 506 | 233 | 17 | 311 | 253 |
| 490.0 | 301 | – | – | 294 | 20 | – | 317 |
| 588.0 | 357 | 48 | 768 | 354 | 25 | 480 | 380 |
| 696.0 | 418 | – | – | 416 | 30 | – | 443 |
| 784.0 | 478 | 58 | 1 025 | 470 | 35 | 620 | 507 |
| 883.0 | 538 | – | – | 530 | 39 | – | 570 |
| 981.0 | 600 | 75 | 1 256 | 590 | 43 | 785 | 634 |
| Error | ± 5 | ± 10 | ± 10 | ± 8 | ± 5 | ± 10 | ± 1 |

well as test rig results are defined as follows:

The names channel 1, 2, 3 refer to the hardware associated with 4 strain gauges positioned on the extended ring transducer to record strains resulting from horizontal, vertical, and moments, respectively.

Channel 4, likewise, refers to the tension dynamometer output or alternatively the output from the foot of the mole plow. $O_1, O_2, O_3, O_4$ refer to the outputs (potentials) from channels 1, 2, 3, 4, respectively, (unit: volt, unless otherwise stated). $I_1, I_2, I_3, I_4$, refer to the mechanical inputs of these channels (units N or Nm unless otherwise stated). $X_{ab}$, refers to the sensitivity of channels 'a' to load 'b'—thus for example $O_1 = X_{13}I_3$, where a pure moment only is being applied, d- refers to the perpendicular distance from the point of application of the load to the centre of the dynamometer, the point about which moments are taken. ($X_{ab}$, $a \neq b$) refer to the cross sensitivities of the channels.

## Calibration Results

To evaluate and assess the response of the transducer, the gradient curves for the known inputs were constructed. The procedure for constructing and obtaining the gradient curves is explained below:

i) The values for $X_{12}$, $X_{22}$, $X_{32}$ were obtained from graphing the results in **Table 1**, for load and $O_1, O_2, O_3$ at d = O directly.

ii) The difference of $O_a$ (d = 0.1 m) and $O_a$ (d = O) and of $O_a$ (d = –0.1 m) and $O_a$ (d = O) is the output due to the moment exerted by the loads at d = 0.1 m and d = –0.1 m. The values of $O_a$ (d = O) were lifted from the graphs obtained in (i) above in order to minimize the errors, plotting this difference v/s moment the lines of gradient $X_{13}$, $X_{23}$ and $X_{33}$ (a = 1, 2, 3,) were obtained.

iii) For calibration of horizontal forces, it should be noted that the difference $O_a$ (d = 0.5 m) – $O_a$ (d = 0.3 m) is due solely to the change in moment, the load being constant. Thus, it is evident that the component of $O_a$ at d = 0.5 m due to the moment of the load is

$$\frac{1 + 0.3}{0.5 - 0.3} = 2.5 \text{ times the difference.}$$

Thus the component of $O_a$ (d = 0.5 m) due to moment = 2.5 [$O_a$ (d = 0.5) – $O_a$ (d = 0.3)], plotting this value against the moment yielded another set of values for $X_{13}, X_{23}, X_{33}$.

iv) The component of $O_a$ due to

Table 3 $F_Z$ Response- output of Channels 1, 2 and 3 Due to Vertical Loading Only

| Load (N) | 98.0 | 196.2 | 294.0 | 392.0 | 490.0 | 588.0 | 686.0 | 780.0 | 883.1 | 981.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| $O_1$ (mV) | – | 0±3 | – | 2±3 | – | 5±3 | – | 7±3 | – | 10±3 |
| $O_2$ (mV) | 73±3 | 144±2 | 217±2 | 288±2 | 362±2 | 436±2 | 507±2 | 580±2 | 653±2 | 725±2 |
| $O_3$ (mV) | – | 3±1 | – | 4±1 | – | 5±1 | – | 6±1 | – | 7±1 |

Table 4 $F_X$ Response- output of Channels 1, 2 and 3 Due to Horizontal Loading Only

| Load (N) | 98.0 | 196.2 | 294.0 | 392.0 | 490.0 | 588.0 | 686.0 | 780.0 | 883.0 | 981.0 | Error |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel-1 (mV) | 55 | 112 | 168 | 320 | 290 | 344 | 403 | 460 | 518 | 578 | ±25 |
| Channel-2 (mV) | – | 4 | – | 7 | – | –2 | – | –5 | – | –3 | ±20 |
| Channel-3 (mV) | – | 0 | – | 20 | – | 48 | – | 55 | – | 56 | ±30 |

Calculated as:

* $O_a$(d = 0.5) – 2.5 [$O_a$(d = 0.5) – $O_a$(d = 0.3)]

2.5 [ $O_a$(d = 0.5) – $O_a$(d = 0.3) ] as defined by best fit line through points.

Table 5 Moment, $M_y$ Response

| *** Moment Nm | Channel-1 | Channel-2 | Channel-3 | ** Moment Nm | Channel-1 | Channel-2 | Channel-3 | * Moment Nm | Channel-1 | Channel-2 | Channel-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 49.0 | 7.5 | – | – | –98.1 | –1 | –12 | 239 | 9.8 | – | – | 18 |
| 98.1 | 7.5 | 25 | 260 | –83.3 | – | – | – | 19.6 | – | 3 | 36 |
| 147.0 | 0 | – | – | –78.4 | –½ | –11 | 191 | 29.4 | – | – | 53 |
| 196.0 | 15 | 20 | 487 | –68.6 | – | – | – | 39.2 | – | 6 | 71 |
| 245.0 | 17.5 | – | – | –58.8 | –1 | –8 | 144 | 49.0 | – | – | 91 |
| 294.0 | 7.5 | 50 | 720 | –49.0 | – | – | – | 58.8 | 0 | 6 | 105 |
| 343.0 | 5 | – | – | –39.2 | 0 | –4 | 98 | 68.6 | – | – | 126 |
| 392.0 | 20 | 58 | 1 112 | –29.4 | – | – | – | 78.4 | 4.5 | 9 | 143 |
| 441.5 | 20 | – | – | –19.6 | 1–6 | –2±4 | 45+5 | 83.3 | – | – | 165 |
| 490.5 | 25±20 | 80±20 | 1 177 | –9.8 | – | – | – | 98.1 | 4±6 | 11±5 | 183±4 |

Output of channels 1, 2 and 3 due to a moment only. The moment is considered as that which would normally operate on a tine being pulled through the soil. Moment is calculated as under:

$O_a$ (d = 0.1) – $O_a$ (d = O)*

also $O_a$ (d = –0.1) – $O_a$ (d = O)**

and 2.5 [$O_a$ (d = 0.5) - $O_a$ (d = 0.3)] ***

the load applied is then $O_a$ (d = 0.5) – 2.5 [$O_a$ (d = 0.5) – $O_a$ (d = 0.3)] plotting these values of outputs against loads gave curves with gradients $X_{11}$, $X_{21}$, $X_{31}$. The results of these calculations are given in **Tables 3, 4 and 5** and are presented graphically in **Figs. 4, 5, 6,** respectively.

v) The response curve for the tension dynamometer was plotted from the results (**Table 2, Fig. 7**).

### Test Rig Results

The results of UV plotter traces for the forces on the tine and mole plow are given in **Table 6**. The problem is now one of relating these results but by means of calibration curves and to the forces on the tool. Since the output of channel 1, $O_1$ is a result of the outputs due to horizontal, vertical and moment forces, so it can be stated that:

$$O_1 = X_{11}\, I_1 + X_{12}\, I_2 + X_{13}\, I_3 \text{ and likewise for } O_2 \text{ and } O_3$$

$$O_2 = X_{21}\, I_1 + X_{22}\, I_2 + X_{23}\, I_3$$

$$O_3 = X_{31}\, I_1 + X_{32}\, I_2 + X_{33}\, I_3$$

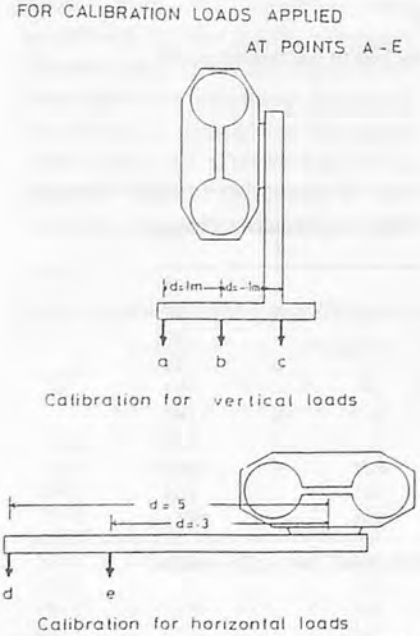


Fig. 3 Calibration of extended octagonal ring transducer in horizontal and vertical positions.

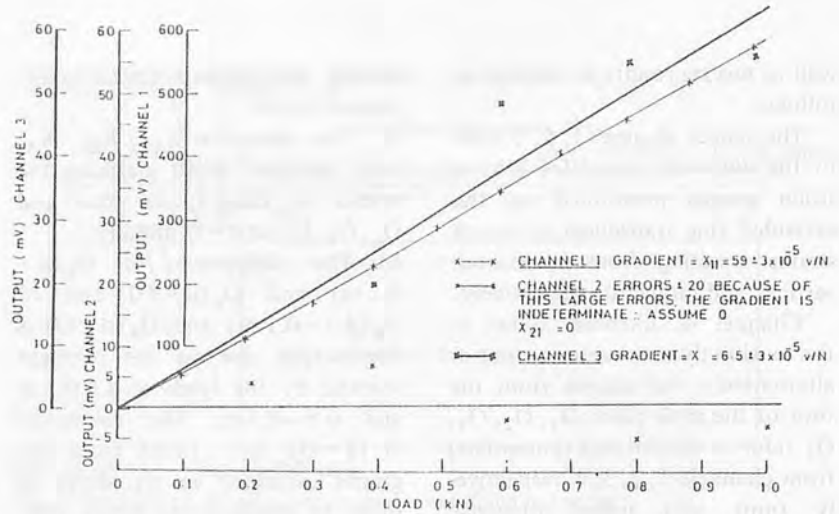


Fig. 4 Extended octagonal ring dynamometer calibration response to horizontal forces. (Fx).

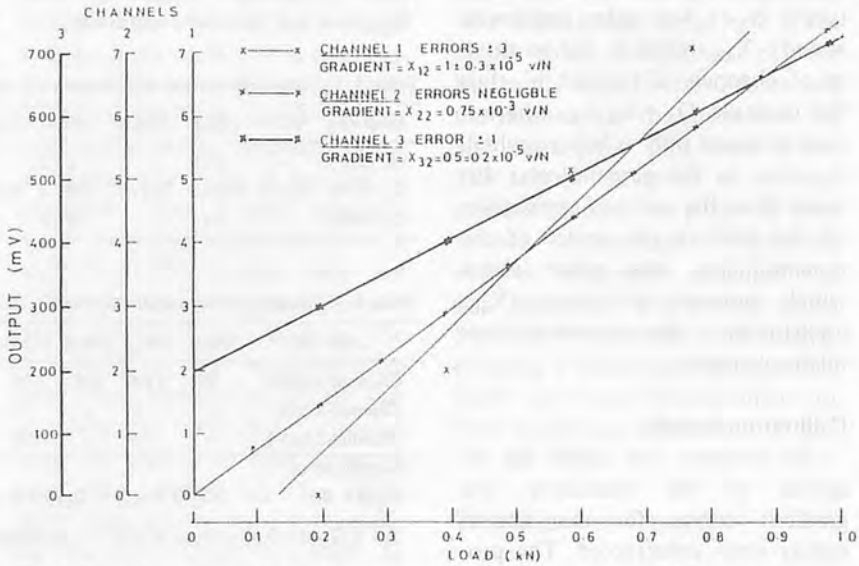


Fig. 5 Extended octagonal ring dynamometer calibration response to vertical load (Fz).

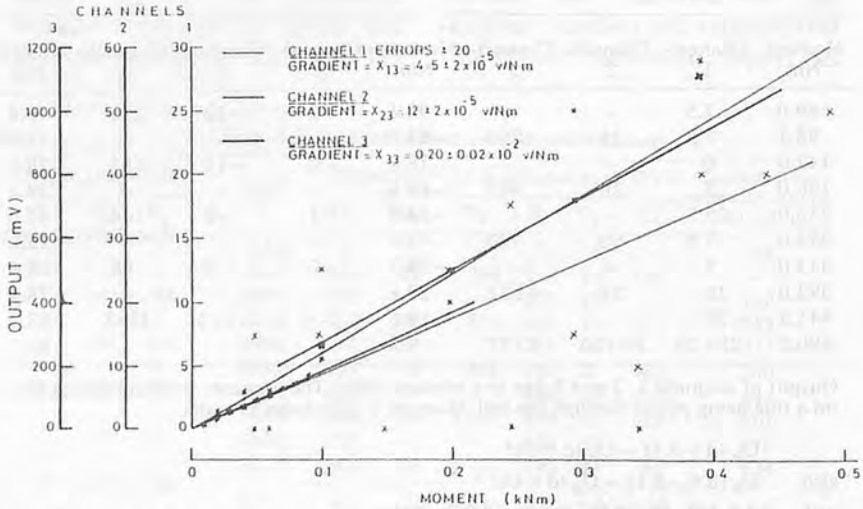


Fig. 6 Extended octagonal ring dynamometer calibration response to moment (My).

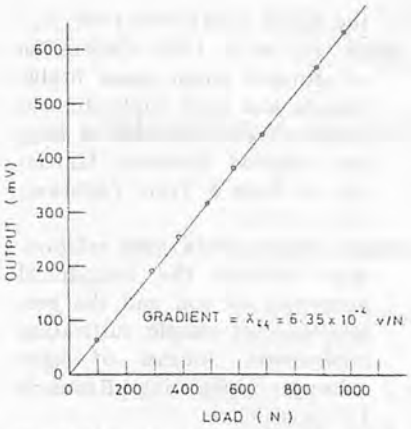


Fig. 7 Calibration for tension dynamometer.

The above expressions can be put into the matrix notation, viz:

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \end{bmatrix} = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \times \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

Or $\underline{O} = \underline{X}\,\underline{I}$

The solution is $\underline{I} = (\underline{X})^{-1}\,\underline{O}$

The solution was greatly simplified and obtained by restricting the values of X to the constants. For $X_{aa}$, the calibration curves show that $X_{aa}$ is very nearly constant for a = 1, 2, 3. Hence, the constant values for X were obtained from the calibration curves shown in **Figs. 4-7**, to obtain the values of $I_1, I_2, I_3$ from the testing results. thus it can be written as:

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \end{bmatrix} = \begin{bmatrix} 59\pm3 \times 10^{-6} & 0 & 6.5\pm3 \times 10^{-6} \\ 1.0\pm3 \times 10^{-6} & 75 \times 10^{-6} & 0.5\pm2 \times 10^{-6} \\ 4.5\pm2 \times 10^{-6} & 12\pm2\times10^{-6} & 200\pm20 \times 10^{-6} \end{bmatrix} \times \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

Taking the inverse of this matrix the above expression can be written as:

$$\begin{bmatrix} O_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 16.19 & 0.13 & -0.699 \\ -.276 & 13.33 & -0.030 \\ -.461 & -0.852 & 4.56 \end{bmatrix} \times \begin{bmatrix} O_1 \\ O_2 \\ O_3 \end{bmatrix} \times 10^2$$

For $I_4$, it was computed using the following equation:

$$I_4\, X_{44} = O_4 \text{ hence, } I_4 = (X_{44})^{-1} \times O_4$$

The value of $X_{44}$ was picked from the calibration curve. The values of $O_{1\text{-}4}$ are shown in **Table 6** for each test run, using these output results, the values for $I_{1\text{-}4}$ were obtained from the equation (1), Example test 1,

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 16.19 & 0.13 & -0.699 \\ -.276 & 13.33 & -.030 \\ -0.461 & -0.852 & 4.56 \end{bmatrix} \times \begin{bmatrix} .110 \\ .03 \\ .13 \end{bmatrix} \quad \begin{matrix} I_1 = 169.5 \text{ N} \\ I_2 = 36.6 \text{ N} \\ I_3 = 51.8 \text{ Nm} \end{matrix}$$

$$I_4 = (X_{44})^{-1} \times O_4 = 1\,575 \times .296 = 446 \text{ N } I_4 = 466 \text{ N}$$

Similarly, the values $I_{2\text{-}4}$ for different test runs, i.e., tests 2-4 were also computed and obtained by relating the outputs of the corresponding tests in the matrix equation (1) mentioned above. The summary of these results is given in **Table 7**.

Test 5 was also performed to determine the rolling resistance of the implement carrier. The value of rolling resistance so recorded is also given in **Table 7**.

Table 6 Output Results from U.V. Plotter Traces for Different Test Runs for the Tine at 3 Positions and Mole Plow in Simulated Soil Tank

| Output | Test 1 rake angle 67° depth 0.10-2 m | Test 2 rake angle 90° depth 0.17 m | Test 3 rake angle 112° depth 0.135 m | Test 4 mole plow |
|---|---|---|---|---|
| $O_1$ | 0.11 ±.01 V | 0.14 ±.01 V | 0.125±.01 V | 0.34±.02 V |
| $O_2$ | 0.03 ±.002 V | 0.014±.001 V | −.0.024±.002 V | 0.19±.01 V |
| $O_3$ | 0.13 ±.01 V | 0.2 ±.02 V | 0.125±.01 V | 0.47±.03 V |
| $O_4$ | 0.296±.03 V | 0.35 ±.002 V | 0.278±.01 V | 0.73±.02 V |

Test 5 : For rolling resistance of implement carrier itself. A test run was made with no implement attached. The output for this test is given as: $O_4$ = 0.01 V.

Table 7 Summary of Results for Different Test Runs

| Force components | Test 1 | Test 2 | Test 3 | Test 4 |
|---|---|---|---|---|
| $I_1$ ($F_X$) | 169.5±30 N | 213.0±40 N | 193.4±40 N | 520.4±60 N |
| $I_2$ ($F_Z$) | 36.6±2 N | 14.2±2 N | −35.9±2 N | 242.6±20 N |
| $I_3$ ($M_Y$) | 51.8±10 N | 83.7±15 Nm | 53.4±10 Nm | 182.8±40 Nm |
| $I_4$ (tention dynamometer output) | 466 ±30 N | 551±20 N | 438±15 N | 1 150±00 |

Test 5, Rolling resistance = 16±5 N

## Discussions

It is evident from the **Figs. 4-7** that within the range of the applied loads, the transducer worked well, the linearity was good, and the hysteresis was minimal. All the errors could have been substantially reduced if the repeatability tests were carried out.

$I_1$ and $I_4$ should differ by only the rolling resistance of 16N, but the results in **Table 7** show that $I_1$ and $I_4$ differ from each other by a factor of 2.5. This suggests that large error has been made somewhere that either $I_4$ is too large or $I_1$ is too small. This error most pro-

bably arose out of an error in noting the amplification used for channel 4 during calibration.

If one considers the forces per unit depth of tine as:

| | O = 67° | O = 90° | O = 112° |
|---|---|---|---|
| $I_2$ | 358.8 $Nm^{-1}$ | 83.5 $Nm^{-1}$ | −265.9 $Nm^{-1}$ |
| $I_3$ | 507.8 N | 492.3 N | 395.5 N |
| $I_4$ | 4 568 $Nm^{-1}$ | 3 241 $Nm^{-1}$ | 3 244 $Nm^{-1}$ |

The above results are in themselves surprising, as one would expect $I_4$, the draught force to rise with increasing the rake angle. However, this perhaps ought to have taken rather an indication that the draught force rise is a more complex function of depth. So in actual field conditions, without further information on the properties of soil, it is not possible to predict this function and comparision could not be really made.

It will be noticed that even in the controlled environment of the simulated soil bin, not inconsiderable errors are present (Table 6), so in field experiments, it would be important to repeat the trials a number of times to obtain average values.

## Conclusion

The gradient matrix method can be conveniently and effectively used to predict and compute the 3-dimensional forces acting on tillage tools.

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# Influence of Storage Time on Quality of Mung Beans Stored in Different Packing Systems

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## Abstract

Mung dal (*Phaseolus aureus*) stored in jute bags (JUB) absorbed more moisture compared to that stored in polythene (PLY) and polythene impregnated jute bags (PIB) during a storage period of 120 days. Dispersion capacity of the dal grains stored in PLY remained the same after 20 min of cooking even after 120 days of storage while that in JUB and PIB increased appreciably producing more dilute dal of lesser consistency after 90 days. The total protein content which was about 25% remained almost the same whereas soluble protein and nitrogen solubility index drastically decreased, especially in JUB. Such changes were very slow for the product stored in PLY during 120 days of storage. The loss in dry solids, though not significant, is maximum in JUB and was noticed only after 90 days.



Note: This paper was presented in a conference organised by the Association of Food Scientist and Technologist (India) in 1985 held at Central Food & Technological Research Institute, Mysore 570013, India.

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## Introduction

Pulse is a very important food item and forms a significant source of protein for the people of India. Pulse is taken mostly in the form of dal (dispersed phase of pulse) as well as in the form of soup. The varietal difference in its cooking quality and the relationship between the cooking quality and chemical constituents (Narasimha and Desikachar, 1978) have already been evaluated. Packaging is very important because of the widespread use of pulses among the consumers. Good packaging also protects dal from deterioration during storage and serves in maintaining good quality of dal in a long term. Modern biotechnology lays more emphasis on the unit packaging system in preference to bulk packaging. Bulk packaging manifests in rapid deterioration in food quality by promoting the growth of molds and various microorganisms (Mahadevaiah et al, 1977). The present investigation has been carried out in order to determine some of the biochemical and physico-chemical properties showing the performance of the packaging unit which can maintain good nutritional qualities of mung dal in long term storage.

## Experimental Procedure

Mung dal collected from market was the subject of study. It was stored in polythene (400 $\mu$), polythene impregnated-jute (PIB) and jute bag (JUB) for 120 days. The parameters used in the study are moisture content, cooking quality, grain weight and protein content.

i) Moisture content of the samples were determined by keeping 25 g of sample in an oven (130°±2°C) for 1 h. The sam-

ples were cooled in a desiccator and weighed (AOAC, 1970).

ii) Cooking quality of dal was evaluated according to the method followed by Halick and Kelly for rice samples. A 2-g of dal sample was cooked with 15 ml of warm (80°C) water in a boiling water bath for 20 min. The water was drained off and the cooked grains were weighed to determine the water uptake at that instant.

iii) Dry weight of grain was determined by weighing 100 stored sound grains kept separately for moisture equilibriation and expressing the value on dry basis.

iv) Total protein content of dal sample was estimated according to the method of standard kjeldhal method.

Soluble protein content was estimated by taking a 0.2 g of dried sample. It was boiled in 25 ml of distilled water and 0.25 ml of concentrated glacial acetic acid for 5 min, cooled and allowed to stand for 4 h and then filtered. The precipitate was washed with 1% acetic acid and the filtrate was treated exactly in the same way as that of total protein estimation, in order to determine the amount of nitrogen present in the filtrate. The nitrogen solubility index (NSI) was determined using the formula:

$$NSI = \frac{\%\ \text{soluble nitrogen}}{\%\ \text{total nitrogen of sample}} \times 100$$

(Hulse, et al. 1981)

## Results and Discussion

### Moisture Content (MC)

The dal grains stored in each type of PLY, PIB and JUB bags absorbed moisture from the atmosphere with an increase of storage period (Table 1). However, the increase was highest (18.21%) in JUB and least (16.05%) in case of PLY after 120 days of storage. This indicates that the moisture exchange between the space above the stored material in PLY and the environment was insignificant. The shelf-life of the stored product remained almost intact up to 90 days (MC-15.2%) whereas that of PIB and JUB deteriorated only after 60 days (MC = 14.01% and 16.50%, respectively). Dal stored in PIB and JUB were heavily infested with a dirty appearance and undesirable texture and become unacceptable to the consumers.

Table 1 Variation in Moisture Content of *Mung Dal* Stored in Different Packaging Systems

| Days of storage | Moisture content, % (d.b.) | | |
|---|---|---|---|
| | Polythene bag | Polythene impregnated jute bag | Jute bag |
| 0 | 12.66 | 12.66 | 12.66 |
| 30 | 14.20 | 13.36 | 13.89 |
| 60 | 14.65 | 14.01 | 16.50 |
| 90 | 15.21 | 16.87 | 17.45 |
| 120 | 16.05 | 17.50 | 18.21 |

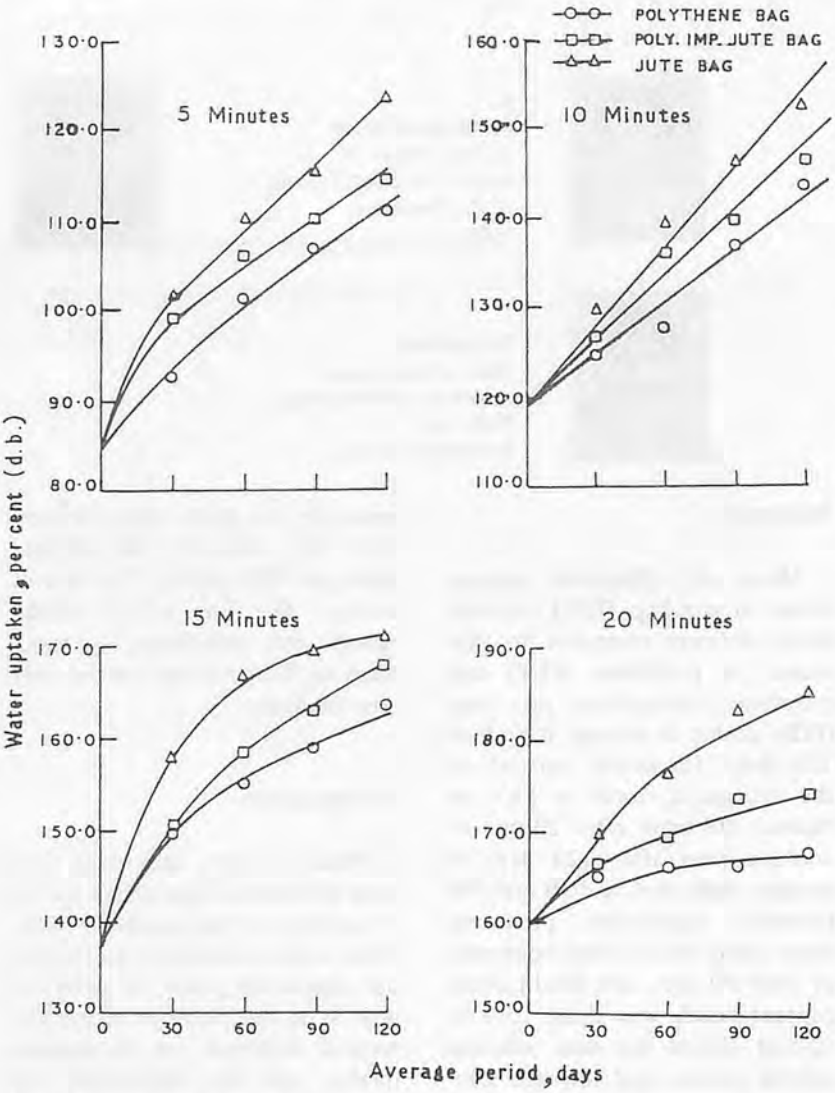


Fig. 1 Water-uptake of mung dal stored in different packaging systems.

Table 2 Influence of Storage Time on Total and Soluble Protein of Mung Dal Stored in Different Packaging Systems

| Number of days | Total protein, % (d.b.) | | | Soluble protein, % (d.b.) | | |
|---|---|---|---|---|---|---|
| | PLY | PIB | JUB | PLY | PIB | JUB |
| 0 | 25.03 | 25.03 | 25.03 | 5.85 | 5.85 | 5.85 |
| 30 | 25.60 | 24.85 | 28.77 | 5.31 | 5.23 | 5.25 |
| 60 | 24.81 | 25.25 | 29.64 | 5.00 | 4.42 | 4.94 |
| 90 | 24.70 | 27.17 | 24.99 | 4.69 | 2.72 | 1.98 |
| 120 | 24.80 | 27.52 | 23.45 | 4.06 | 1.375 | 0.75 |

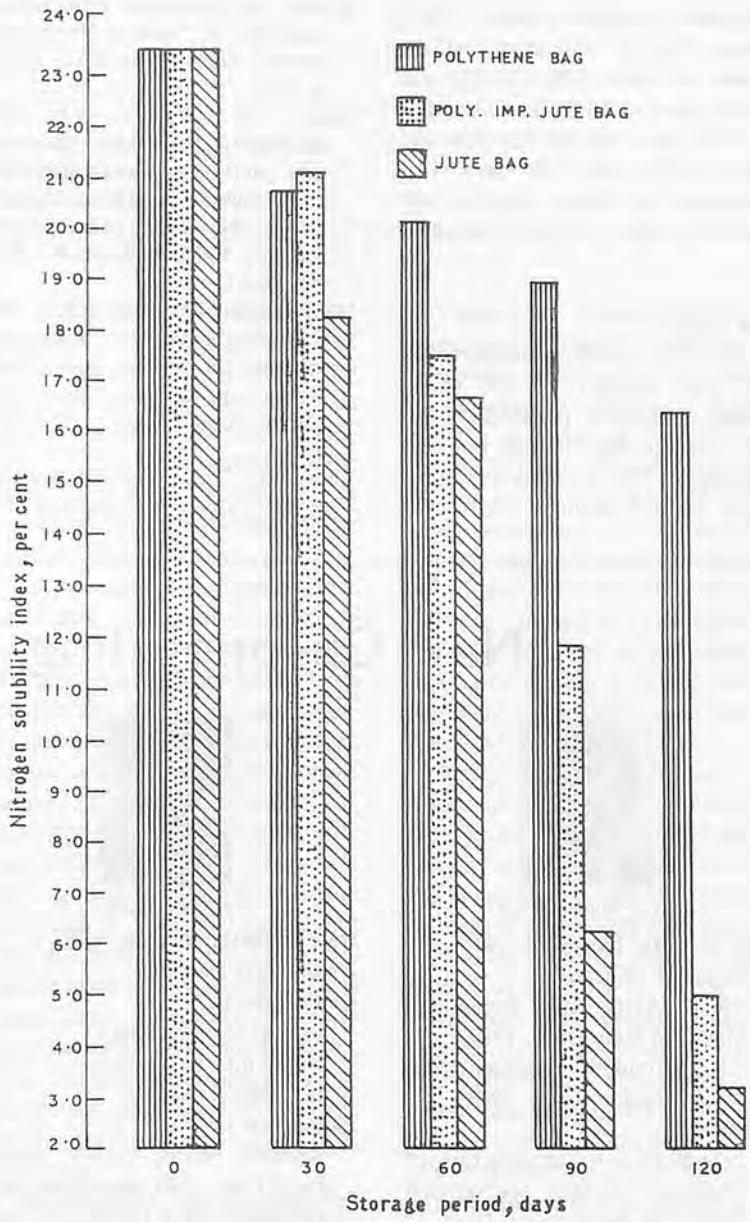


Fig. 2 Influence of storage period on nitrogen solubility index (NSI) of mung dal stored in different packaging systems.

## Cooking Quality

The cooking of dal was done in two phases. In the initial phase of cooking, the dal grains absorbed water and expanded in volume, hence the weight increased. But the grains were dispersed at a particular cooking time and the dispersed dal-water was actually liked and taken by the consumers (Narasimha and Desikachar, 1978). In the present investigation the dispersion capacity of dal was measured in terms of water-uptake values (Fig. 1) for 20 min in all types of bags. This shows that the dispersion of a definite quantity of dal after 20 min of cooking is most desirable with the material stored in PLY (166.48%). The dal stored in JUB (183.17% after 90 days) showed more dilute dispersed stage of less consistency dal and may not be liked by the consumers.

It is interesting to note that the diametrical expansion of *papad* made from blended material (green gram and black gram-flours with cereal) showed an increasing trend with storage period (Shrupalekar and Venkatesh, 1975). This indicates an improved effect of ageing on the stored blended material necessary for *papad* preparation. But in the case of mung dal the increased water-uptake and dispersion values of the grain stored in PIB, and particularly in JUB, is not an index of quality improvement of the food material stored. Rather it was due to the fact that JUB was heavily attacked by insects and microbes during the later part of storage period. A constant dispersion capacity (160-170 g water/g) of dal stored in PLY for 120 days and after 20 min of cooking showed that PLY is the most suitable packaging system to retain the initial quality of the dal (Fig. 1).

## Protein Content

Pulse proteins are very important in the sense that the whole protein is taken in the form of food and the gruel is not thrown away as it is done in the case of rice. The total protein of dal (25%) was found to be almost the same in PLY, slightly changed in PIB and still more in JUB during a storage period of 120 days (Table 2). The soluble protein (5.85%), on the other hand, drastically decreased in PIB, (2.72%) and JUB, (1.98%) during 60 to 90 days of storage, although little change was observed

in product stored in PLY (4.69%). The decrease in soluble protein as well as that of enzyme activities in soluble and insoluble portions of the cereals was observed by Primo et al, 1970. Similar results were found to be true in its changes in nitrogen solubility index (NSI) values (**Fig. 2**). The extent of decrease in initial NSI (23.5%) was much less (16.35%) for dal stored in PLY than that of PIB (5%) and JUB (3.2%) after 120 days. This indicates the better vitality and keeping quality of pulse stored in PLY.

### Net Weight

The dry matter as measured by net grain weight of 100 sound grains decreased (**Table 3**) along with storage time though not very significant. The decrease was maximum in JUB perhaps due to the higher rate of microbial and insect infestation in dal which invaded the solid matters from the dal grains.

Table 3 Influence of Storage Period on Net Weight of Mung Dal Stored in Different Packaging Systems

| Number of days | Net weight, g | | |
|---|---|---|---|
| | PLY | PIB | JUB |
| 0 | 1.12 | 1.12 | 1.12 |
| 30 | 1.10 | 1.08 | 1.09 |
| 60 | 1.03 | 1.03 | 1.00 |
| 90 | 0.98 | 0.92 | 0.91 |
| 120 | 0.91 | 0.85 | – |

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# An Improved Traditional Method of Parboiling Paddy

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## Abstract

In the improved parboiling technique, paddy after soaking in water for 24 to 48 h in a cement tank is steamed in a quick steamer where steam is introuced to pre-soaked paddy while moving through a perforated pipe and discharged immediately to the drying yard by a strong air stream. When compared with the steaming in cylindrical kettles which is the most popular method practised in Sri Lanka, this technique requires less steam and labour and also produces parboiled rice with less discolouration.

## Introduction

Parboiling, which involves hydration to saturate starch granules, heat treatment to gelatinize the starch and drying to reduce moisture absorbed, is a common practice in Sri Lanka. It reduces breakage and also obtains higher returns during processing. About 70% of the population in the country consumes rice in parboiled form. Parboiling operation is accomplished in traditional ways due to high investment cost of modern methods.

The common method of parboiling in most of the private rice mills is soaking the paddy in ambient temperature water for 24 h for short grain type and 48 h for long grain type, steaming in a metal tank or cylindrical kettles followed by drying in the sun. In a few rice mills, especially in the public sector, paddy is hot soaked at 70°C water for 2.5 to 3 h, steamed in cylindrical kettles and dried either in the sun or using driers.

In the system of steaming in a metal tank, paddy after soaking, is fed onto the sieve which is fixed in the tank about 300 mm above from the bottom. Water, available below the sieve, is heated by using a husk blower and the steam generated is passed through the grain bed gelatinizing hydrated starch. The main drawbacks of this method are gelatinization is not uniform as the grain bed is over 900 mm height over the sieve and also discolouration of grain is very high as it takes longer time to discharge paddy for drying after steaming. However, some millers, especially new investors and small scale rice millers, use this method due to low investment cost.

In the second system, a cylindrical kettle with a perforated pipe at the centre which is connected to the boiler is used for steaming. As small quantities are steamed in these kettles, this method produces uniformly parboiled rice with less discolouration than the latter method.

Vellanki et al has developed a continuous process of steaming of hot-soaked paddy which is similar to steaming in cylindrical kettles but the diameter of the kettle is about 150 mm. Paddy after hot soaking at 70°C for 2.5 to 3 h in a large metal tank is fed into the steamer and discharged continuously into the drier. However, this system is not picked up by the industry due to involvement of hot soaking. Also, this system produces under-parboiled paddy when cold-soaked paddy is fed.

Parboiled rice with less discolouration fetches high prices in the market. Hence, millers adopt several methods to produce less discoloured parboiled rice and few of them are dissolving washing soda to soaking water during parboiling, mixing wheat flour or dolomite to brown rice after dehusking during milling, etc. A study carried out by Adhikarinayake and Jayatillake found that when paddy is parboiled by the traditional method, cooling has an effect on grain discolouration and it improves the whiteness of the grain.

The main objective of this study was to steam cold-soaked paddy using a minimum amount of steam readucing steaming time and also discharge steamed paddy as soon as possible to drying yard incorporating cooling of the heated grain for

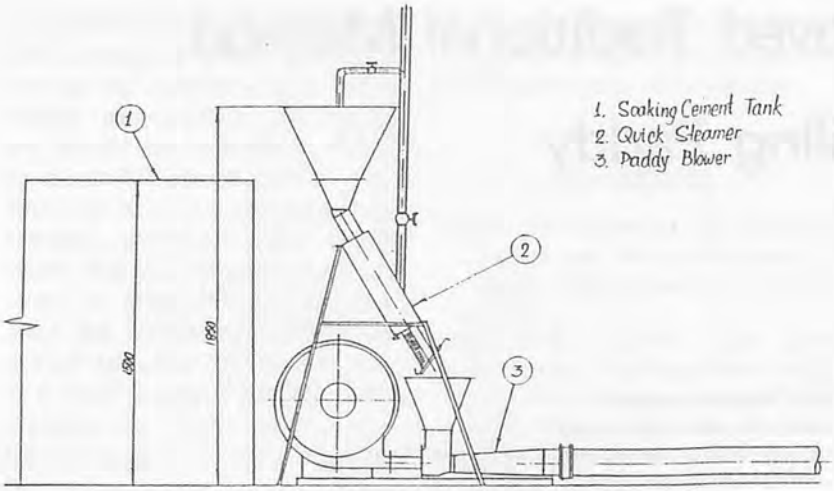


Fig. 1 Parboiling plant.

Fig. 2 Quick steamer.

the production of less discoloured parboiled rice at a low investment cost.

## Construction and Operational Features

The main components of the parboiling plant are cement tank for cold soaking, quick steamer for steaming and a paddy blower with venturi tube to transport paddy to the drying yard (Figs. 1 and 2).

### Quick Steamer

The quick steamer consists of a hopper for soaked paddy, steaming section and paddy outlet. Two steam lines are provided to the paddy hopper and steaming section. The steam pipe in the hopper is used to heat cold soaked paddy before entering the steaming section. A sliding door is provided at the bottom of the hopper to feed paddy in. The steaming section is made of two pipes of 125 and 75 mm diameter. The inner pipe has perforations. Steam is supplied into the space of two pipes while paddy is passed through the inner pipe. The outer surface of the steaming section is coated with asbestos powder to prevent heat losses. At the paddy outlet a sliding door is provided to control the paddy flow. At the lower side of the outlet pipe, perforations are made to drip condensed water off from paddy (Fig. 3).

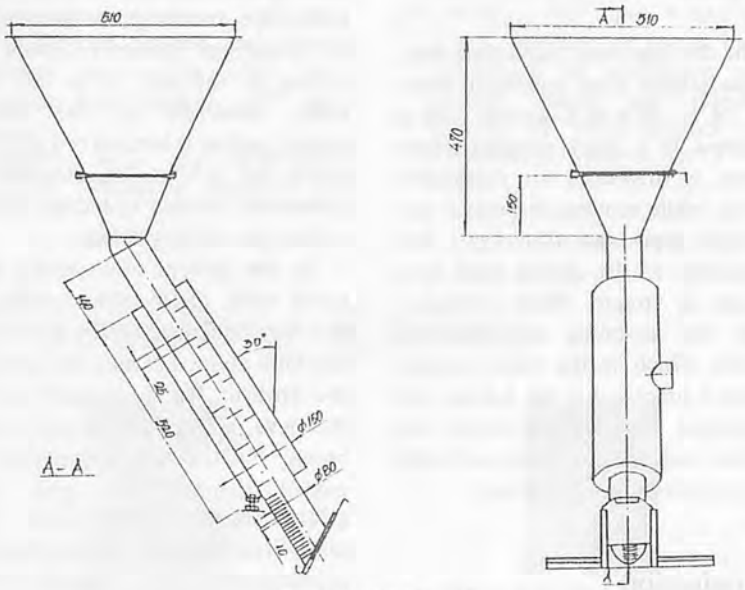


Fig. 3 Paddy blower.

### Paddy Blower

The paddy blower consists of a high pressure blower with 1.5 hp motor and a venturi tube with a hopper for steam paddy and number of pipes to deliver paddy to the drying yard. As these pipes are connected using coupling, the length of the delivery line could be altered.

Paddy, after soaking in the cement tank, is fed into the hopper of the quick steamer. Before feeding the paddy to the steamer both valves are opened to heat paddy and steamer until steam has escaped from the paddy outlet. Once steam appears, the sliding door at the paddy hopper of the steamer is opened fully and the flow is adjusted by the door fitted at the end of the steamer. Water condensed during steaming is separated from paddy and removed by the U trough fitted to the outlet of the steamer.

The steamed paddy is then fed into the hopper of the paddy

blower and transported to the drying yard by a strong air stream. As the paddy delivery line is comprised of a number of pipes joined together by couplings, paddy can be transported to any place of the drying yard (Fig. 4).

## Results and Discussions

Laboratory tests showed that all paddy grains steamed were gelatinized completely when the steamer was operated at a rate up to 1.5 t/h. Also, it was observed that paddy grains were not split open during steaming and no under-parboiled grains were found. Rice produced by this system has very light colour. This may be due to the fact that paddy, after steaming, was discharged immediately to the drying yard and cooled immediately by the air stream sent by the paddy blower. As paddy was discharged to the drying yard by the paddy blower, two workers could handle the whole parboiling operation.

When compared with the system of steaming in cylindrical kettles, which is the most popular and also from the millers point of view is the best method practised in the country. This system has a number of advantages: requires less amount of steam and investment for the boiler is reduced. In addition, as paddy is transported by a strong air stream this system requires less labour and also produces light colour parboiled rice. Further, gruel losses that occured during steaming was very low.

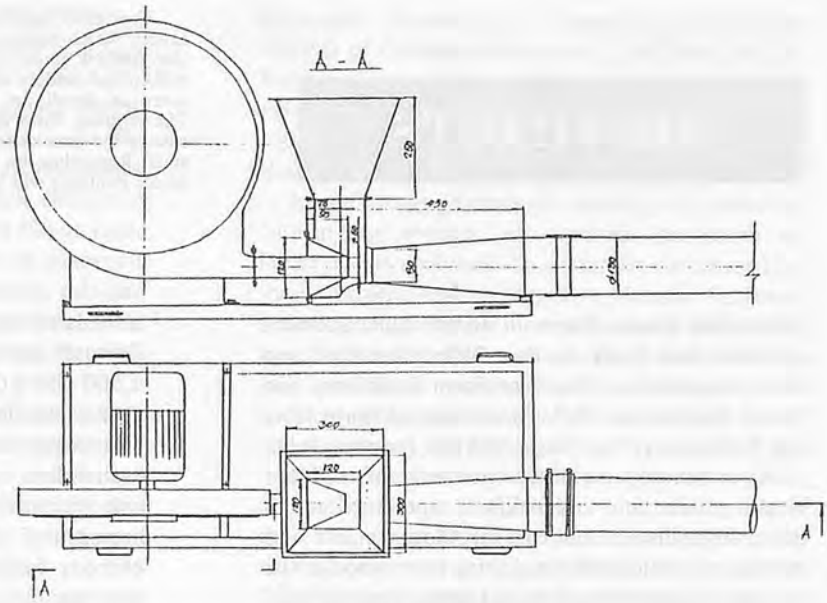


Fig. 4 View of parboiling plant.

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## ERRATA

AMA Vol. 20, No. 3, Summer 1989.

"Energy Consumption and Possible Savings in Tea Processing"

P. 73, in the abstract, the third sentence should read as, "Production in south India is mainly concentrated in the states of Kerala, Tamil Nadu and Karnataka"

Pp. 74-75, the titles for the figures 4 and 5 should be interchanged.

# 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.

*Monitoring Biogas Plants in Hills:* D.P. Darmora and Bachchan Singh, Jr. Res. Officer and Prof. and Head, respectively, Dept. of Farm Machinery and Power Engineering, G.P. Pant Univ. of Agriculture and Technology, Pant Nagar-263145, Nainital, India

A commonly observed problem of reduced biopas production under low temperature conditions, high installation cost of Biogas plants and scarcity of sufficient animal dung have stood in the way of adoptability of biogas technology in hills. This paper explores the possibilities of improving plant functioning in hills through plant design modification, raintaining digester temperature above ambient temperature and using suitable additives to stimulate gas production.

*Performance Study of Tinkabi Tractor in Tanzania:* T.E. Simalenga; D. Mafunda; N. Katibu, Dept. of Agric. Engg. and Land Planning, Sokoine Univ. of Agriculture, P.O. Box 3003, Morogoro, Tanzania

This study was undertaken in Morogoro, Tanzania to determine the suitability of the Tinkabi tractor (16Hp) as a potential source of power in small farm mechanization. Experiments done for three consecutive years (1984-1987) have shown that ploughing using Tinkabi tractor takes 29 hours per hectare as compared to 14 hours/ha when oxen 1.2 hours/ha when using a conventional 50 kW tractor.

Comparative results of work performance for Tinkabi, animal powered and engine powered systems are pressented and the question as to whether Tinkabi tractor is appropriate to a small scale holder farmer in Tanzania is discussed.

*Comparison of Draft Power in Zebu and Exotic x Zebu Crossbred Bullocks:* S.P. Agarwal, Prof.; V.K. Agarwal, Assoc. Prof.; O.P. Nangia, Prof., Dept. of Veterinary Physiology, Haryana Agric. Univ., Hisar-125004, India

Four Hariana and four crossbred (HF X Hariana and Jersey X Hariana) bullocks were hitched to a specially designed telescopic beam type bullock cart with a provision to attach a dynamometer to record the pull. The weight of the cart was 325 kg and two attendants weighing about 120 kg drove the cart. The cart was sequentially loaded with 0, 500, 1 000, 1 500 and 2 000 kg weight and hauled on tar roads over a circular path covering a distance of 3.8 km. The target was fixed to complete three rounds by each animal until the animal was exhausted and unable to continue. The speed of each animal and the average pull were recorded and the pull as per cent of body weight, draft, horse power and work done was calculated using standard formulas. In both cases, the speed progressively declined from 9 km/h with "no load" to 4 km/h with 2 000 kg load. Depending on load, the respective values for per cent pull, draft, horse power and work done were 5.5 to 21%, 21 to 88 kg, 0.6 to 1.5 H.P. and 1.6 to 4.1 x $10^5$ kg-m/h in crossbread bullocks against 4.5 to 20%, 19 to 89 kg, 0.6 to 1.7 and 1.2 to 4.1 x $10^5$ kg-m/h in Hariana bullocks. Some of these parameters showed curvi-linear relationship with payload in both groups of animals. The results indicate that the draftability of crossbred bullocks is as good as that of Hariana bullocks and that the maximum power and work output is at a payload of 1 000 kg on a wooden wheel cart as further increase of payload reduces the draft power of the animal.

*Design of Tandojam Sugarcane Planter:* Jan Muhammad Baloch, Asst. Prof.; Sheruddin Bukhari, Assoc. Prof.; Dept. of Farm Power and Machinery, Sind Agric. Univ. Tandojam, Pakistan

The sugarcane crop is one of the most important cash crops in Sind Province and its planted area continues to increase because of the many favourable conditions for sugarcane culture. Planting and harvesting of this crop are tedious jobs. Many planting machines, both bullock-drawn and tractor-drawn, have been designed and tested. The Tandojam sugarcane planter which is an appropriate technology for small holder mechanization was designed and tested. Its comparison with other sugarcane planters is shown in Table 6. This sugarcane planter is simple in construction, low in cost, durable, and gives better effective field capacity as compared with that of other sugarcane planters as it has only one furrow opener.

*Effect of Vegetable Cover, Mulching and Planting Time on Some Soil Physical Properties and Soil Loss in Pineapple Plots:* S.N. Asoegwu, Dept. of Agric. Engg., Federal University of Technology, P.M.B. 1526, Owerri, Nigeria

Studies were made on the effects of mulch materials – woodshaving (WS), rice husk (RH) and sawdust (SD) with a no mulch control (C) on some soil physical properties and soil loss in pineapple plots established during early rain (April), mid-rain (June) and late rain (August). Cumulative weed weight and soil loss were highest in June plantings while woodshaving controlled weeds much better and reduced soil loss than rice husk and sawdust. In April plantings, RH and SD produced significantly more leaf area than WS and C. But in June and August plantings, RH and WS had more leaf area than SD and C. Mulching reduced the proportion of sand and increased the proportion of silt and proportion of clay at 50% flowering. It also increased the proportion of soil moisture retention, soil pH and other properties. RH, SD and C increased soil bulk density at 2 months after planting (MAP). WS consistently had lower soil bulk density than other mulch and no mulch treatments. For the control plots, soil bulk density increased with MAP up to 6 MAP and decreased to 2 MAP values at 10 MAP.

*Growth and Productivity of Egusi-melon (Colocynthus citrullus L.) as Affected by Tillage Depth:* S.N. Asoegwu, Dept. of Agric. Engg., Federal University of Technology, P.M.B. 1526, Owerri, Nigeria

Field experiments were carried out on sandy loam soil during 1981-82 to determine the effects of tillage depths; 0, 10, 15, and 20 cm on the yield and yield components of egusi-melon on an Alfisol. The depths were achieved by adding dead weights on the loading frame of a tandem disc harrow in such a way that the weight was symmetrically distributed over the discs.

All measured root parameters were higher in the 15-20 cm tillage depth than in no-tillage-root length per unit area (56-72%), total root surface area (25-28%), mean root diameter (3.6-10.7%) and root length density (45.4-53.5%). While soil bulk density and penetration resistance decreased with depth of tillage, penetration resistance also decreased with days after sowing (DAS) and bulk density increased with DAS. Total porosity increased with tillage depth and decreased with DAS.

The number and weight of fruits and dry seed weight increased with tillage depth. These were increased by 69%, 60.5% and 62.2%, respectively, by 20 cm tillage depth over zero tillage. The ratio of dry seed weight to fresh fruit weight was about 2%.

*Economic Viability of Operating Custom-hire Services of Combine Harvesters in Pakistan:* Abdur Razzaq, Senior Subject Matter Specialist (Engg.), Adaptive Res. Farm, Sheikhupura; Ch. Bashir Ahmad Sabir, Director of Agriculture (Adaptive Research), Lahore, Pakistan

In the study, economic viability of operating custom-hire services of combine harvesters in Pakistan was analysed. An enterprise cooperated by three farmers and owning five Massery Ferguson self-propelled combine harvesters, model MF-3640, was studied. The firm was operating combines with full back-up of managerial and workshop facilities and had completed one year of harvesting of wheat and rice crops.

It was found that the enterprise earned negative net profit during the first year of operation. However, the rate of return in the succeeding years was so high that net profit of the amount equal to 55.25% of the capital investment would be generated in addition to pay back the loan, including interest within the installment period of six years. The study established that operating custom-hire service of combine harvesters in Pakistan was economically viable and its financing was a safe investment and debt servicing well ensured.

*Product Development of Manual Wheel Hoe Weeder for Ergonomical and Fabrication Considerations:* Gyanendra Singh, Head, Agro-Industrial Extension Div., Central Institute of Agric. Engg., Nabi Bagh, Berasia Road, Bhopal, India

The development of a wheel hoe weeder was undertaken with a view to fabricating it through small scale manufacturers. This group of manufacturers possesses limited fabrication facilities and thus improvement in the design was made such that the same was adopted easily. The major modifications were made in the design of wheel, handle and cutting blade components. The design has since been released for popularization amongst the farmers in 12 provinces by the Ministry of Agriculture, Government of India. More than 1 100 units have been supplied by the Central Institute of Agricultural Engineering, Bhopal alone for popularization amongst the local farmers. The cost of the weeder was less than US$10.00. It required 60-110 man-h/ha for weeding in black heavy soil and 25 man-h/ha in light soil.

*Puddling Type Floating Power Tiller for Small-scale Rice Farms:* H.T. Manaligod, Dept. of Agriculture, Bureau of Plant Industry, San Andres, Malate, Manila, Philippines; R.E. Stickney, Int. Rice Res. Inst., P.O. Box 933, Manila, Philippines

Puddling-type floating (P/F) power tillers have been developed and have gained acceptance by farmers with small waterlogged areas planted to rice in the Philippines. Modified existing P/F tiller designs to reduce problems related to poor maneuverability and control, and uneven field preparation (furrowing) were developed. The main features of the modified design, called the 'hydrotiller', are the twin pontoons that are used for flotation in order to minimize furrowing and the angled lugs on the puddling wheel inclined in such a way that the desired combination of traction, puddling, and lift is attained. A 1-m wide hydrotiller has a field capacity of 1.5-2.0 ha/day and sells for roughly P8000 (US$400), excluding the engine. The hydrotiller is now being fabricated by eight manufacturers in the Philippines. Farmer acceptance is increasing because the hydrotiller is considerably faster and more economical to use in waterlogged areas and even in normal field conditions than conventional alternatives (e.g., water buffalo and two-wheel hand tractor).

*Wheat Grain Losses Influenced by Timing and Date of Harvesting:* Sheruddin Bukhari, Assoc. Prof., Farm Power and Machinery; Khalil Ahmed Ibupoto, Lecturer, Farm Buildings and Structures; Ghulam Hyder Jamro, Asst. Prof., Dept of Agronomy; Ghulam Abbas Khorro, Director Farms, Sind Agriculture Univ., Tandojam, Pakistan

The grain losses affected by timing and delayed harvesting for different varieties of wheat were studied at Latif Experimental Farm, Sind Agriculture University, Tandojam during 1987. The agronomical parameters of the various wheat varieties like plant height, number of tillers and number of earheads per plant were not so much different from each other.

The grain losses among the wheat varieties were significantly influenced by various timing and date of harvesting. The minimum grain losses were recorded when the wheat was harvested from 8.00 AM to 12.00 noon and minimum grain losses were observed up to 10 days late harvesting than the normal date. It is concluded that grain losses increased with the delayed harvesting after ripening of the crop. The grain losses linearly increased with both late timing and date of late harvesting. Further, the grain moisture content was significantly influenced by the dates of harvesting and linearly decreased with delay in harvesting. Grain loss increased with a decrease in grain moisture. The grain moisture for normal harvesting and minimum grain loss was 14 to 15%.

*A New Design Concept for Animal-drawn Harvester:* B.G. Yadav, Res. Scholar, Div. of Agricultural and Food Engg., Asian Institute of Technology, Bangkok, Thailand

Animal-drawn cereal harvesters are extremely important in India in order to meet the harvesting needs of various crops. The earlier attempted designs on animal-drawn harvesters have limitations of ground traction and high draft requirements. In this paper attempt has been made to reduce the animal draft requirement. Also, the cutting force available at the cutter bar was increased by about 6-8 times.

*Design and Development of CIAE Bullock-drawn Reaper:* R.S.N. Yadav, Sr. Scientist, Central Institute of Agric. Engineering, Nabi Bagh, Berasia Road, Bhopal-462018; B.G. Yadav, Res. Scholar, Agric. and Food Engg. Div., GPO Box 2754, Bangkok, Thailand

An oxen-drawn harvester was the long felt need of the Indian farmers. CIAE Bhopal has designed and developed a simple and rugged oxen-drawn reaper for harvesting crops as cereals, pulses and oil seed. This is a light weight machine that requires less draft as compared to earlier designs of bullock-drawn reapers. The crops harvested by this machine is delivered in uniform bunches behind the cutter-bar. The special feature of this machine is tranformation of low soil thrust developed from the traction wheel into higher force for cutting crops through crank and lever mechanism at the cutter-bar. The field capacity is 0.12-0.14 ha/h. The harvesting losses are less than 5%, recoverable which consists of mainly loose stalks. The cost of harvesting crop by this machine is Rs 135.00/ha.

*Marketing of Agricultural Inputs:* B.K.S. Jain, Marketing, Management and Agro Consultants, 7 Neel Tarang, 208 Savarkar Marg, Bombay 400016, India

The article deals with the size and structure of the market in India for agricultural inputs, including agricultural machinery. Value-wise, the major components of engineering inputs are tractors, pumpsets and fuel for farm prime-movers. The write up covers sensitivity factors (market indicators), peculiarities of the rural market, farmer motivation, influencing agencies, problem areas, and the ASP-mix (advertising and sales promotion). ■■

## Algeria Challenges Sahara Desert to Meet Country's Food Needs

Racine, Wisconsin, U.S.A., July 1989. The Sahara Desert does not breed ideal farming conditions. Summer temperatures reach as high as 57 degrees Celsius (135 degrees Fahrenheit). Rainfall totals a meager 40 millimeters (1.6 inches) annually. And winds of up to 120 kilometers per hour (75 mph) reshape the sands on a daily basis. No familiar desert plants, including cacti, survive the beating.

But the Algerian government, with the assistance of international agricultural developer Western Agri-management International, S.A., a subsidiary of Western Agri-Management Company of Fort Collins, Colorado, U.S.A., has been fighting a good battle against the elements with a successful pilot irrigation project. As agreed upon the project was turned over to the government after its second year. Now in its third year, it is still defying the odds by delivering a healthy wheat crop in the Sahara.

This is especially important considering Algeria relies on wheat as a major food source, yet is forced to import nearly twice as much of the grain annually as it produces.

According to Michel Rogge, president of Western Agri-Management International, there is very little positive to say about the Sahara as crop land —other than that there are not too many insects or weeds. However, he maintains that developing the agricultural potential of this land is a smart move for the Algerian people.

"Algeria cannot claim the most positive of farming conditions. Aside from the country's northern regions near the Mediterranean Sea, it's very arid," Rogge says.

Algeria recognized the importance of developing agricultural capabilities in its current five-year development plan, introduced in 1985. With a full fifth of the country's export revenues being used to fund food imports, the plan cites agricultural and water resource development as a top priority in reducing the outlays. Algeria imports approximately 4 million tonnes of wheat each year.

In the 20 years following the country's independence from France in 1962, algeria emphasized industrial development to expand its economy. So in 1985, when it decided to focus on agricultural and water resources, it looked to the growing international consulting community for agricultural development assistance.

Agricultural Management Firm Hired:

The government chose Western Agri-Management International, with experience developing projects in Chile, Egypt, Jamaica, Paraguay, Saudi Arabia and Thailand. By adapting its techniques to the local climate, as well as economic and political problems in each country, Western has delivered solid results.

Western's mission in Algeria was to develop two pilot farms, each utilizing the center-pivot irrigation system. Under the plan, both farm — consisting of 20 25-hectare pivots and related support facilities — would be planned, built and productive in only one year.

Due to the area's unique climate, the farms are limited to producing wheat, sorghum and a sampling of barley on a rotating basis. Wheat is harvested in late spring, while the sorghum is harvested in late autumn. The Algerian people rely on sorghum for both food and animal feed.

Although some refundable financial support to help Western carry out the feasibility study was provided by the United States Trade and Development Program, the nearly U.S. $35 million project is being funded entirely by the Algerian government.

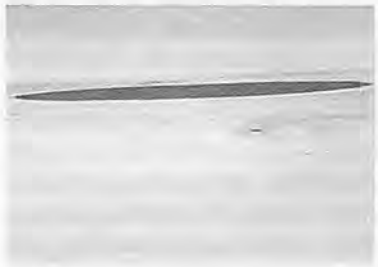
According to Western, the project's location some 900 km south of the country's capitol of Algiers created an immediate challenge. The company had to select suppliers that could service a remote development project under harsh conditions.

"We planned to use very high horsepower tractors and other large pieces of equipment — machines that many manufacturers would love to sell us," Rogge said. "But the size of the project demanded that the manufacturers have an African support network in place and a solid track record of work in developing countries." Case IH service and parts support for this project operates out of the company's Africa/Middle East headquarters in Le Plessis-Bellevill, France.

In the end, two primary suppliers were chosen: Case IH to supply the agricultural and construction equipment, and Lockwood Gering, NB, manufacturer of the 40 center-pivot irrigation systems.

According to Martin Patmore, agricultural product specialist in the Case IH International Business Group, Western's project also demanded a fast reaction from the Case IH distribution system.

"Their order included a veriety of 30 pieces of agricultural equipment,"



Patmore said. "And because the entire project had to be fully operational in only two years, our ability to quickly supply the equipment, spare parts and product training was critical."

The Case IH equipment supplied included: four Model 4694 four-wheel-drive tractors rated at 261 gross engine horsepower; four Model 2394 two-wheel-drive tractors rated at 197 gross engine horsepower; four Model 1660 Axial-Flow combines; four Model 6200 grain drills; two Model 14 subsoil chisel plows; two Model 5500 chisel-plows; four Model 770 offset disk harrows; four Model 496 tandem disk harrows and two Model 584E rough-terrain forklifts.

Desert Provides Special Obstacles:

Suppliers were not the only ones to face unusual challenges on the project. Western also focused on solving a number of problems not typically encountered in most development projects. The most significant included:

- Drilling 10 1000-m wells to draw irrigation water from below the desert surface. All water for the project was to be drawn from underground, using high-pressure, artesian aquifers. Eventually, seven more shallow wells at 183 m were drilled and fully equipped with pumps and an engine.
- Selecting seed varieties that mature quickly and provide tolerance to hgh winds, temperatures and water-salinity levels.
- Building two comfortable mini-communities — including sleeping, dining and recreational facilities — to sustain a staff of 20 persons per farm.
- Preventing harmful, wind-blown sand and locust invasion from destroying the wheat.

Once these challenges were overcome, Western proceeded with seeral center-pivot systems to test seed varieties and farming techiques. According to Rogge, the project should eventually yield approximately 6 tonnes of wheat per hectare — an excellent yield by any standards.

Although yields from a first-year (1986-87) 52-hectare test fell slightly short of this mark, the company has had an opportunity to adjust its production elements and in 1987-88 produced over 5 tonnes per hectare on the 17 circles planted.

The 1988-89 season was very important as the entire production was taken over by a full Algerian staff, according to Rogge. Yields on one farm averaged over 4 tonnes of wheat per hectare — a very encouraging result considering the new crew's relative lack of experiience. Rogge is confident that the project will eventually harvest 6 tonnes per hectare.

Rogge is hopeful that the Algerian project will establish itself beyond the testing stage into a major agricultural devlopment in 1989-1990. "The only way that Algberia can break its dependence on imported grain is to exploit the potential of its deserts," Rogge said. "We're confident that we've developed a system that will help Algeria meet the goals of its ambitioous five-year plan, which is supported by the newly appointed Minister of Agriculture Nourradine Kadra."

For its part, Western has submitted a follow-up proposal to the Algerian government that would extend the project from about 8,080 hectares to more than 200,000 hectares — one of the largest farms of its type in the world.

## A Machine for Post-harvest Bush Cleaning in the Humid Tropics

A machine designed to be a compromise between a tractorized rotary slasher and the conventional lawn mower was developed to meet the post-harvest bush clearing problems involved in zero-tillage farming for small

farmers in the tropics. The design concept emphasizes self propulsion and adequate robustness to enable it cut tall standing vegetation including straws and stovers. It features a blade tip exposing mechanism, whereby such vegetation can be slashed without being first bent over. Experiments carried out on a fabricated prototype of the machine show that it had a working rate of about 0.12 ha/h, a material cut rate of 183 kg/h, a fuel consumption of 4.5 l/h and corresponding field efficiency and estimated power requirement of 84.4% and 14.7kW, respectively. After some improvements in its cut material distribution and other minor operational inadequacies, the machine should ease the clearing of bush for zero-tillage farming system by small scale farmers.

Note: This abstract was written by M.O. Faborade, Dept. of Agric. Engg., Obafemi Awolowo Univ., Ile-Ife Nigeria.

## Hard Grains, Irrigation, Numerals and Script in the Rise of Civilizations

(Denmark)

*by Axel Steensberg*

The book is based upon a number of assertions, that is substantiated in its 10 chapters covering the six areas of the world where written script was independently invented: Babylonia, Egypt, Indus (Harappan culture), China (at the lower Hwangho river), Mesoamerica and Peru.

The first assertion is that numerals preceded script by many millennia. The second that urban agglomeration and class-specialization in the rise of big cities was based upon hard grains, first and foremost wheat, barley and maize, predominantly cultivated under dry or seasonal conditions by artificial irrigation and water control organised by public authorities, and measured, counted and stored in public granaries both as a means of subsistence and as an insurance against periods of dearth, famine and other unpredictable disasters.

The third assertions is that glyphic script emerged in connection with storage and redistribution of hard grains as a response recording an urgent need for labelling what was counted and registered to whom it belonged, and to whom it might be transported, lent, bartered or sold etc., and that consequently hard grain became means of evaluation quivalent to ready cash. Moreover in a later assertion it is argued that an organisational need for an expressive script transformed »glyphs« to »Hieroglyphs«, which though obscure for laymen, provided a means for the astrological computation of agricultural calendars, and for the prediction of disastrous events, the prevention of which would be of primary importance for rulers and societies.

Professor Steensberg has been trained in a wide area of studies reaching from the humanities to the sciences, with archacology —including the earliest systematical experimentations —history and cultural philosophy, ethnography, agricultural studies, geology and human geography. In 1986 he published »Man the Manipulator« as a conclusive work. But still, in his old age he has felt obliged to develop an old idea, inspired by reading. J. Evans' works on the Minoan culture of Crete, which he studied when in his yough he had emigrated from the life of a practical farmer to University training. He tries to sum up his studies in a kind of »Paleo-Geography« illuminated at the end of the book with a comparative diagram of the interdependent elements in the rise of literate civilisations of the six areas mentioned above.

In this diagram is included evidence of 1: Mean temperature, 2: Precipitation, 3: Geomorphology and soils, 4: Level above the Sea, 5: Vegetational-zone, 6: Type of irrigation, 7: Predominant species of hard grain, 8: Time of development, 9: Numerals, 10: Type of script, 11: Time of development, 12: Storage facilities, 13: Number of inhabitants in emerging cities, and 14: Means of transportation. This diagram is meant as a challenge to future researches in order to produce more exact figures.

Size: 23.5 × 15 cm, 147 pages, hard cover

Price: 250 DKK, excl. postage and handling.

Orders should be addressed to:

Grith Lerche
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Commission for Research on the History of Agricultural Implements and Field Structures
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DK-2800 Lyngby, Denmark

## Theory, Construction and Calcurations of Agricultural Machines-Volume 1 Russian Translation Series 66

(Netherlands)

*by E.S. Bosoi et al*

The theory, construction and calculations of machines and implements are discussed in relation to soil working, harvesting cereal crops, root crops and grasses and post harvest treatment of grains.

Great attention is paid to the theory of tillage tools and soil cutting with blades suited to different soilclimatic zones. The second edition (the first published in 1951) has been radically revised keeping in view the new course program and supplemented with material on the principles of designing farm machinery. The book is illustrated with examples of modern farm machines.

CONTENTS:

General information. Technological process of plowing. Plows for primary and special cultivation. Working tools of moldboard plows. Lifting and adjusting mechanisms of plows. Forces acting on the plow and their effects on plow balance. Draft of plows. Disk plows and disk harrows. Machines and implements for cultivation, grading and compacting of soil. Cultivators. Machines with powered working tools. Machines to combat wind erosion. Combined soil-working and sowing machines. General. Machines for sowing. Machines for application of fertilizers in the soil. Planting and transplanting machines.

Size: 24.5 × 16 cm, 325 pp, hard cover.

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c. "The AMA does not pay for articles published. However, the writers are given collectively 5 free copies (one copy air-mailed and 4 copies sent by surface/sea mail) of the AMA issue wherein their articles are published. In addition, a single writer is given 25 off-prints of the article and plural writers are given 35 off-prints (also sent by surface/sea mail)"

**Procedure**

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

**Format/Style Guidance**

a. Whether the article is a technical or popular contribution, lecture, research result, thesis or special report, the format must contain the following features :
   i) a brief and appropriate title ;
   ii) the writer(s) name, designation/title, office/organization ; and mailing address ;
   iii) an abstract following ii) above ;
   iv) body proper (text/discussion) ;
   v) conclusion/recommendation ; and a
   vi) bibliography
b. The pages must be numbered (Arabic numeral) successively at the top center. Tables, graphs and diagrams must likewise be numbered. Table numbers must precede table titles, e.g., "Table 1. Rate of Seeding per Hectare". Such table number and title must be typed at the top center of the table. On the other hand, graphs, diagrams, maps and photographs are considered figures in which case the captions must be indicated below the figure and preceded by number, e.g., "Figure 1. View of the Farm Buildings".
c. Tables and figures must be preceded by texts or discussions. Inclusion of such tables and figures not otherwise referred to in the text/discussion must be avoided.
d. Tables must be typed clearly without vertical lines or partitions. Horizontal lines must be drawn only to contain the sub-title heads of columns and at the bottom of the table.
e. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
f. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
g. Convert national currencies in US dollars and use the later consistently.
h. Round off numbers, if possible, to one or two decimal units, e.g., 45.5kg/ha instead of 45.4762kg/ha.
i. When numbers must start a sentence, such numbers must be written in words, e.g., Forty-five workers . . . , or Five tractors . . ." instead of 45 workers . . , or, 5 tractors.

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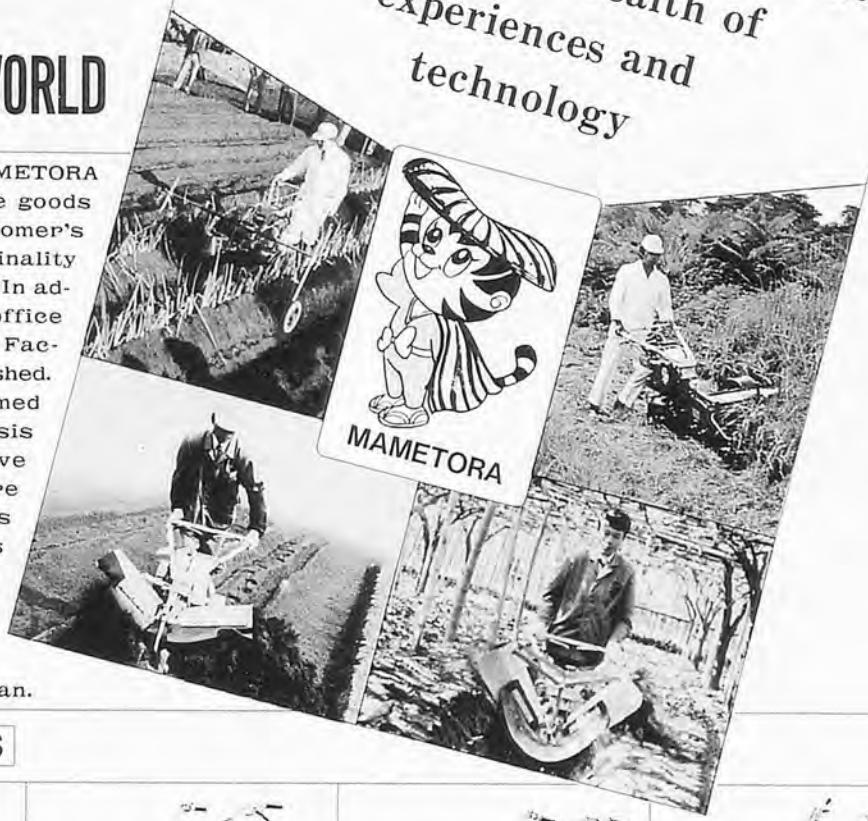


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