STUDIES ON TRACTOR MOUNTED PADDY REAPER

By

SUJATHA ELAVANA

THESIS

Submitted in partial fulfilment of
requirement for the degree of

Master of Technology
in
Agricultural Engineering

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

Department of Farm Power Machinery and Energy
Kelappaji College of Agricultural Engineering and Technology
Tavanur - 679 573
Malappuram

1993

DECLARATION

I hereby declare that this thesis entitled "Studies on Tractor Mounted Paddy Repaer" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Tavanur,

21st Jan., 1994.

SUJATHA ELAVANA

CERTIFICATE

Certified that this thesis entitled **"Studies on Tractor Mounted Paddy Reaper"** is a record of research work done independently by **Miss Sujatha Elavana** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Tavanur,

21st Jan., 1994.

Dr. M. Sivaswami
(Chairman, Advisory Committee)
Assistant Professor
Department of Farm Power,
Machinery and Energy
K.C.A.E.T., Tavanur

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Miss Sujatha Elavana**, a candidate for the degree of Master of Technology in Agricultural Engineering with major in Farm Power and Machinery, agree that the thesis entitled **"Studies on Tractor Mounted Paddy Reaper"** may be submitted by Miss Sujatha Elavana, in partial fulfilment of the requirement for the degree.

Dr. M. Sivaswami
Chairman, Advisory Committee,
Assistant Professor
Department of Farm Power Machinery and Energy
K.C.A.E.T., Tavanur
CHAIRMAN

Sri. Jippu Jacob
Associate Professor & Head
Department of Farm Power,
Machinery and Energy
K.C.A.E.T., Tavanur
(Member)

Dr. K. John Thomas
Dean i/c
K.C.A.E.T., Tavanur
(Member)

Sri. M.R. Sankaranarayanan
Assistant Professor (Agric.Engng)
College of Horticulture
Vellanikkara, Thrissur
(Member)

11/2/94

External Examiner

Dedicated to

My Loving Parents

ACKNOWLEDGEMENTS

With deep sense of gratitude and due respect I express my heartfelt thanks to Dr. **M. Sivaswami**, Assistant Professor, Department of Farm Power Machinery and Energy, K.C.A.E.T., Tavanur and Chairman of my Advisory Committee for his valuable guidance, critical suggestions and immense help throughout the course of work and in preparation of this thesis report.

I am immensely grateful to Sri. Jippu Jacob, Associate Professor and Head, Department of Farm Power Machinery and Energy; Dr. K. John Thomas, Dean i/c, K.C.A.E.T., Tavanur and Sri. M.R. Sankaranarayanan, Assistant Professor (Agric.Engng.) College of Horticulture, Vellanikkara, members of the Advisory Committee for their sustained interest and advices extended to me to complete this endeavour.

It proves difficult to forget the valuable advices given by Prof. T.P. George, former Dean i/c, K.C.A.E.T., Tavanur during the course of my research work.

This work would not have been possible but for the sincere help and remarkable co-operation extended by Sri. K.T. Ramachandran, Sri. K. Aravindan and Sri. N. Narayanan, A.I.C.R.P. on FIM, K.C.A.E.T., Tavanur. I am short of words to acknowledge their help.

With extreme gratitude I remember the ICAR scheme for supplying me the workshop facilities.

I have no words to express my gratitude to the staff and students of K.C.A.E.T., Tavanur, for the help extended by them.

I am thankful to the Kerala Agricultural University for awarding me the research fellowship for the post graduate studies.

At this moment I thankfully acknowledge the blessings of my loving parents and their stable support throughout the work.

It is a pleasure to express my thanks to the staff, Peagles, Mannuthy for the efficient typing and prompt service for the preparation of this report.

My sincere thanks remains with all who have helped me in one way or other for the completion of this researh work.

Tavanur

SUJATHA ELAVANA

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

Agric.	-	Agricultural
AICRP	-	All India Co-ordinated Research Programme
AMA	-	Agricultural Mechanization in Asia
CAAMS	-	Chinese Academy of Agricultural Mechanization Sciences
CI	-	Cast iron
C.I.A.E.	-	Central Institute of Agricultural Engineering
cm	-	centimetre(s)
C.M.E.R.I.	-	Central Mechanical Engineering Research Institute
D	-	diameter
dia.	-	diameter
Dept.	-	Department
Engng.	-	Engineering
Engr.	-	Engineer
et al.	-	and others
F.A.O.	-	Food and Agriculture Organisation
fig.	-	figure(s)
FIM	-	Farm Implements and Machinery
FPME	-	Farm Power Machinery and Energy
g	-	gram(s)
ha	-	hectare(s)
hp	-	horse power

hr	-	hour(s)
I.A.R.I.	-	Indian Agricultural Research Institute
I.C.A.R.	-	Indian Council of Agricultural Research
i.e	-	that is
IRRI	-	International Rice Research Institute
I.S.I.	-	Indian Standard Institutions
J.	-	Journal
KAMCO	-	Kerala Agro-Machineries Co-Operation
K.A.U.	-	Kerala Agricultural University
K.C.A.E.T.	-	Kelappaji College of Agricultural Engineering and Technology
kg	-	kilogram
kmph	-	kilometre per hour
K.S.D.C.	-	Kerala Soaps, Detergents and Chemicals
kw	-	kilowatt
L	-	length
lit	-	litre(s)
Ltd.	-	Limited
m	-	metre(s)
man-h	-	man hour(s)
mc	-	moisture content
MF	-	Massey Ferguson
min	-	minute(s)
mm	-	millimetre(s)
MS	-	Mild steel

M/s	-	Messers
No.	-	Number(s)
P.A.U.	-	Punjab Agricultural University
pp	-	page
PTO	-	Power Take Off
Pvt.	-	Private
R.A.R.S.	-	Regional Agricultural Research Station
RNAM	-	Regional Network for Agricultural Machinery
rpm	-	revolutions per minute
Rs.	-	rupees
s	-	second(s)
Sci.	-	Sciences
sec	-	second(s)
sq.m.	-	square metre
T.N.A.U.	-	Tamil Nadu Agricultural University
Viz.	-	namely
w	-	watt(s)
&	-	and
@	-	at the rate of
°	-	degree
	-	per
	-	percentage

Introduction

INTRODUCTION

India is the second largest paddy producing country in the world. In 1992 the total paddy production in India was 75 million tonnes (Venkateswarlu, 1993) and the population was 843.9 million (Farm Guide, 1993). With the explosion of population the demand for food grain is increasing day by day.

It has been observed in Kerala that the area and production of paddy cultivation is decreasing steadily for the last few decades. In 1983-84, the area under the paddy was 0.74 million hectares which has been reduced to 0.56 million hectares in 1990-91. Correspondingly the paddy production has also reduced from 1.2 million tonnes to 1.09 million tonnes (Farm Guide, 1986, 1993).

The main reason for this situation is that the paddy cultivation has become uneconomical owing to the high production cost. Labour wages are comparatively higher in the state and labour shortage is often felt especially during the harvesting periods. The new generation lacks the skill and efficiency and they are shun to accept the drudgery and physical exertion of farm works. Hence farms are compelled to change to plantation crops like coconut where labour requirement is comparatively low.

According to a world wide survey, the optimum power needed for improved agriculture is 1.0 hp per ha. The present power availability in India is only 0.4 hp per ha (Michael and Ojha, 1978). In Kerala it is still less.

The present status of agricultural mechanization in Kerala is still in the infant stage. To get the sufficient yield from every unit of land and from every unit cost of investment it is necessary to promote the power input and the use of agricultural machineries in different vicinities.

In paddy cultivation transplanting, harvesting and threshing are the three major operations consuming maximum labourers. Harvesting is one of the critical operations in paddy cultivation which is laborious involving lot of manhours and human drudgery. Harvesting by human labour by using sickles is the most common method adopted in India. Acute shortage of labourers during harvesting periods leads to the loss of grain and straw due to over maturity and by natural calamities like rain. In double cropping areas, the timely harvesting of the first crop is a must for early land preparation to have the second crop within the season. The cost of harvesting can also be reduced if the human labour is partially replaced.

Improper harvesting and threshing usually result in losses upto 5 per cent of the crop, therefore better cultivation technique alone are not sufficient to solve the food problem and this necessitates the introduction of proper harvesting and threshing equipments (Ghosh _et al_., 1990).

Considering all the above factors several types of paddy harvesters utilizing bullock power, power tiller and tractor have been developed and tested in several parts of the country.

In Kerala the IRRI 1 m vertical conveyor reaper-windrower was evaluated. The results revealed the need of a lot of modifications before the introduction in Kerala. The harvester with a 5-hp diesel engine possesses inadequate power output when the field is wet and the soil is heavy. The harvesters operated with tractor or power tiller will find an important role as it reduces the cost of harvesting considerably.

Now most of the area under paddy in Kerala are puddled with tractors and hence the harvesters as an attachment will improve the annual utilization of tractors.

The selection of a suitable tractor operated paddy reaper, evaluation of the performance and carrying out the modifications are necessary before introducing these types of machines in Kerala.

The general objective of the research work is to technically evaluate the performance of a tractor operated paddy reaper in Kerala.

The specific objectives are as follows:

1. Detailed studies on the important components of the reaper.

2. Detailed studies on the hitching and power transmission system.

3. Detailed studies on the efficiency and safety.

4. To incorporate improvements in the machine, if required on the basis of field trials.

5. To assess economics of operation with manual harvesting.

Review of Literature

REVIEW OF LITERATURE

A brief review on paddy harvesting, different harvesting methods, types of paddy harvesters and their components are presented in this chapter.

2.1 Harvesting

Harvesting is an important operation in any crop production process. It is done with the view to recover the desired part of the plant to meet the needs of man and animal kingdom such as food, feed, fuel and fibre. In paddy cultivation, harvesting is the operation of cutting the straw along with the earhead in order to recover the paddy and straw.

According to Ghosh (1969) the optimum harvesting time for early varieties of paddy (120 days duration) is between 25 and 33 days after flowering and for medium and late varieties (over 125 days) between 33 and 39 days.

The effect of moisture content on harvesting was studied by Araullo et al. (1976). According to sahay if paddy is harvested at about 24 per cent moisture content and the grain is dried mechanically in stages by three or four passes of hot air, then minimum milling losses were observed. The losses due to shedding and shattering of grains in the field can considerably be reduced by harvesting paddy when the moisture content is between 23 and 25 per cent (Michael et al., 1978).

Pandey (1985) reported that in Ludhiyana the shattering losses were high (10 per cent) when the harvesting was delayed. It is also established that the harvesting of crop before physiological maturity leads to reduction in yield. Tomar (1985) reported that the harvesting should be done at about 30-35 days after 50 per cent of flowering. At this stage the moisture content in the grains should be around 16 to 20 per cent. Early or late harvesting deteriorates the seed quality.

The above mentioned reviews point out the importance of timely harvesting.

2.2 Harvesting methods

The different harvesting methods, their advantages and disadvantages, their suitability to Kerala conditions and their economics in introduction are reviewed here.

The description about different harvesting methods and equipments in India was given by Shanmugham (1981).

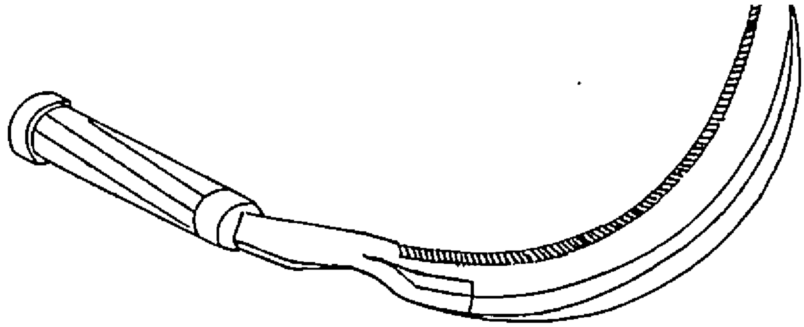
Depending upon source of power, harvesting can be manual, animal or power operated.

2.2.1 Manual harvesting

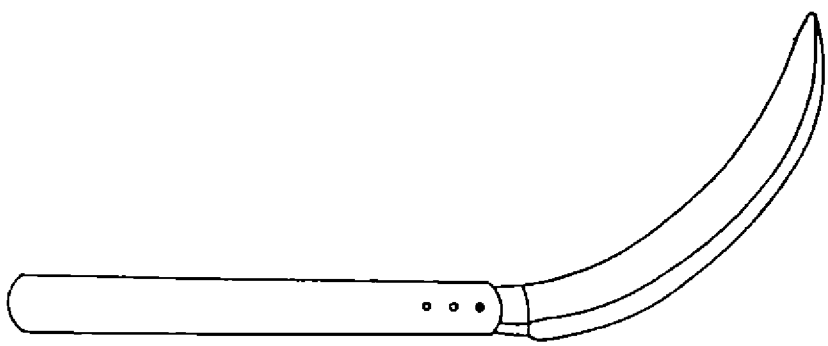
The harvesting of paddy crop is traditionally done by manual methods by majority of farmers. About 150 to 200 man-hours are required for harvesting one hectare of paddy. Manual harvesting is done either by hand sickle or by hand dropper, both by man and woman labourer. There are two main types of sickles, plain and serrated. Sickles with serrated edges do not require the repeated sharpening as needed by plain edged sickles. They are also light in weight and require less cutting force as compared to plain edged sickles. The output of labourers is increased by using serrated sickle than plain edged sickle (Michael et al., 1978).

Manually operated push type harvester usually known as hand dropper was developed and used in Japan. It consists of a pair of serrated blades mounted at an angle of 30 degrees to each other, with a mechanism to retain harvested plant and a lever to drop them. The capacity was about 0.2 ha per day. In India it was not very successful (Michael et al., 1978).

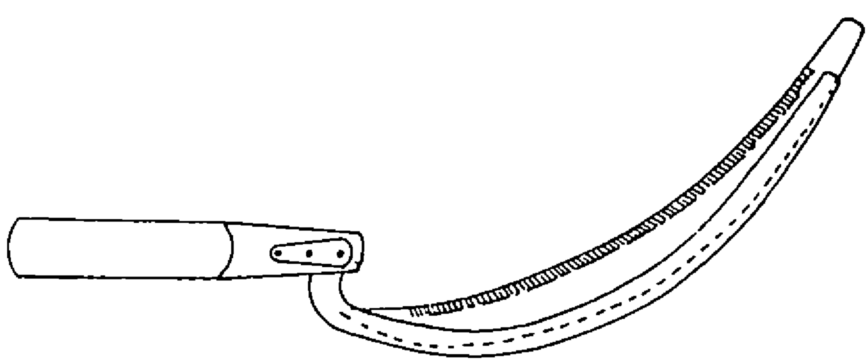
Pandey (1981) compiled the information about all types of local sickles used in India. The design of sickles is based on the principles of cutting viz. friction and shear.



VAIBHAV SICKLE



MAHARASHTRA SICKLE



NAVEEN SICKLE

FIG.1 IMPROVED SICKLES FOR HARVESTING CEREAL CROPS

It is assumed that the cutting takes place by friction when a knife edge slips around the stalk. The cutting force along the edge is in two components, normal and tangential to the edge. The normal force helps the penetration of the edge into stalk and the tangential force in movement of the edge along the stalk until the cutting is completed (Pandey, 1988).

To increase the efficiency of operation and to reduce the drudgery, new types of sickles were developed. Three types of improved sickles for harvesting cereal crops are shown in Fig.1. They are not becoming popular in Kerala because no sufficient extension work is carried out. Specification of Naveen sickle is given in Appendix I.

Yadav (1990) gave details about different harvesting tools, machineries and equipments available in India.

Due to the shortcomings of engaging only the human labourers for harvesting operation animal drawn, power tiller operated and tractor operated harvesters were developed.

2.2.2 Animal drawn reaper

In England McComick and Hussey started developing horse drawn reapers during 1830's. They also fabricated horse drawn grain binders (Smith *et al.*, 1977).

A bullock operated harvester having 1.05 m cutterbar and which would be operated by an average pair of bullocks was developed. Power required by different components at no load and power requirement for harvesting the crop were analysed (Singh et al., 1973).

In Ludhiyana, the P.A.U. animal drawn paddy reaper was developed during 1964 and was found to give satisfactory results (Fig.2), Appendix-III. This machine was similar to McComick reaper in design with reduced weight. The major drawback of this model was the high draft requirement. To overcome this problem more than one pair of bullocks were used. In 1966-67 the P.A.U. animal pulled engine driven reaper was developed so as to operate easily with a single pair of bullocks (Fig.3), Appendix-IV. The quality of windrow formed was not found good (Yadav, 1988).

In 1968, similar work was started at New Delhi. The only difference was the introduction of horizontal endless belt conveyor windrower behind the cutterbar. This provision was made to windrow the harvested crop to a side to ensure immediate removal and clearing of swath for the subsequent runs of the machine (Yadav, 1988). Bhatnagar (1969) studied field performance of the animal drawn engine driven reaper. Similar work was also carried out at Jabalpur during 1970 and at Pantnagar during 1981 (Singh et al., 1987).

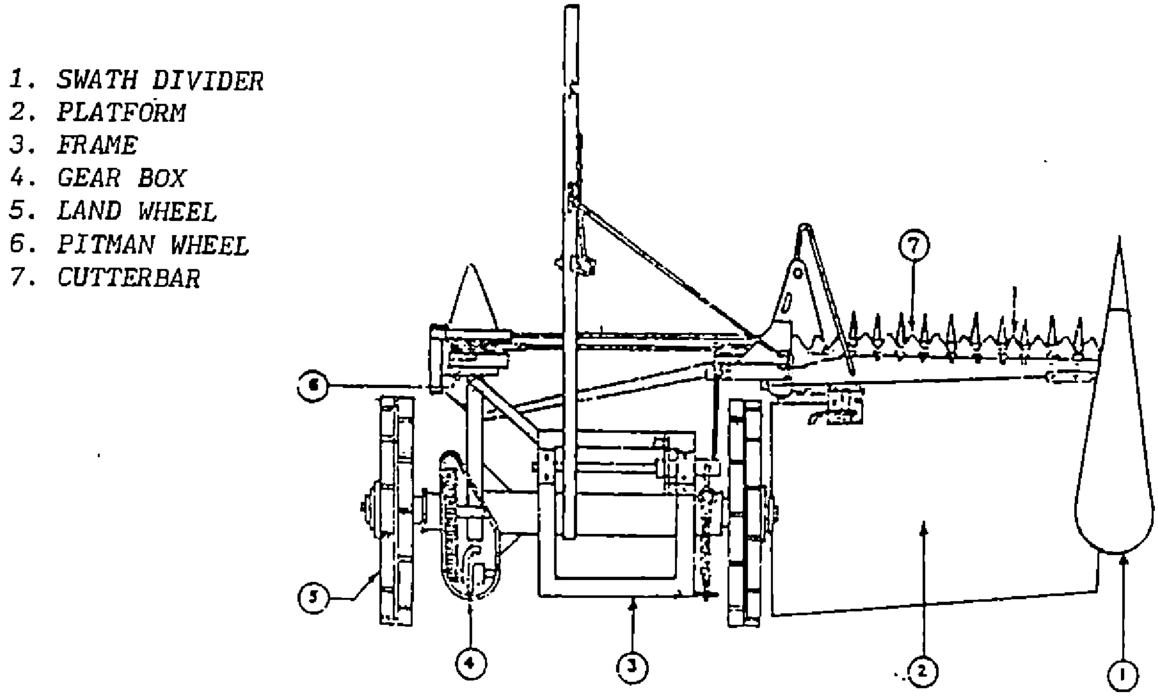


FIG.2 P.A.U. ANIMAL DRAWN REAPER

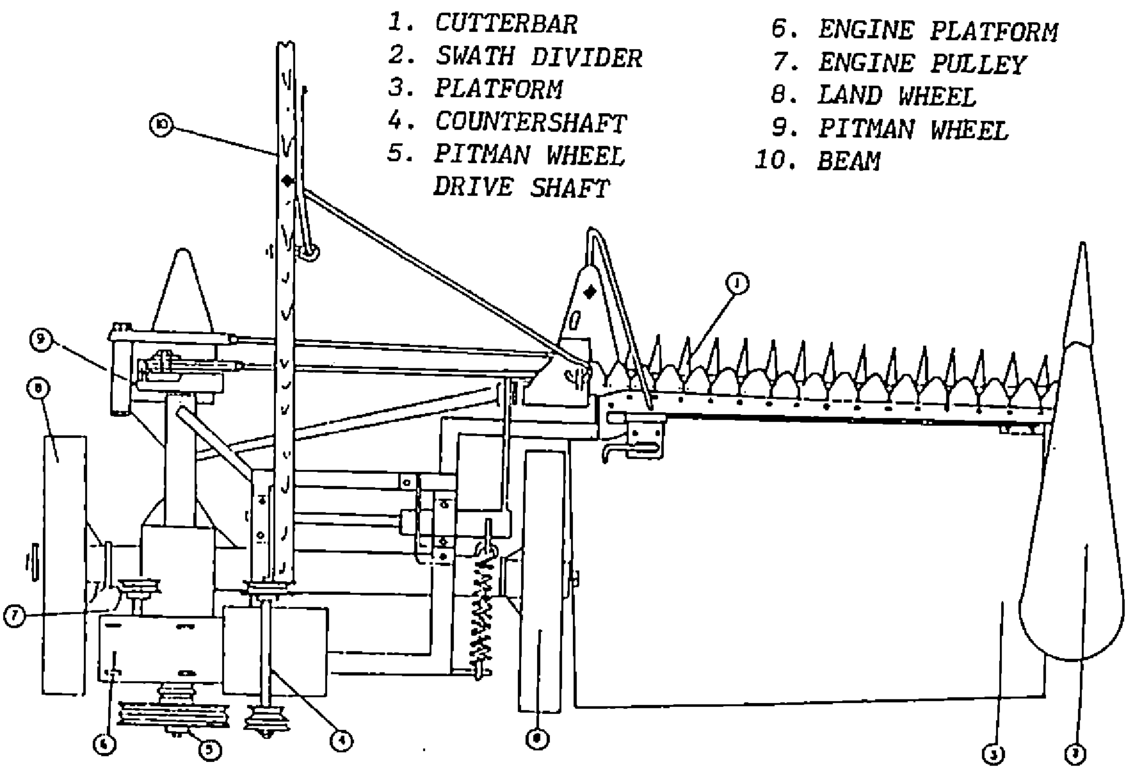


FIG.3 P.A.U. ANIMAL DRAWN ENGINE OPERATED REAPER

Efforts were taken to develop animal drawn reapers in Austria, China and many other countries. The Austrian reaper with single wheel was a single animal operated machine with a conventional cutter bar. The Chinese design animal drawn reaper had a cutterbar for cutting plants, a reel for gathering of harvested crop and a crop board for collecting harvested crop. It also had a provision of hook through which animals were harnessed by chain or rope (Yadav, 1988).

In 1980's an animal drawn reaper was developed at Bhopal as an attachment to a tool frame with two transport wheels. Power transmission from the friction wheel was done through a set of sprocket, chain and bevel gears. Rotary motion was converted into reciprocating motion by introducing a lever mechanism which helped in improving the force developed by the friction wheel for cutting. Because of this feature of the machine the draft requirement was reduced. The machine consisted of many components such as cutterbar assembly, side gauge wheel, crop board, inner and outer shoe and crop board actuating lever. For positioning of the lodged and bent crops and for gathering of the cut crop, a fixed bat type reel had been provided in the machine. As and when needed, drive to the cutterbar and reel as well as to the crop board was cut off by lifting the friction wheel with the help of pedal operated levers (Yadav, 1988).

We find that considerable effort has been made at various places for the development of animal drawn reapers. But because of one or the other limitations not a single design could become popular in our country. In Kerala use of animals for agricultural operations is reducing day by day and the size and draft capacity of the animals are also limited to use any heavy equipment like reaper. Only a power operated harvester will solve the harvesting problems in Kerala.

2.2.3 Power operated harvesters

Power operated paddy harvesters are classified into three major types such as self propelled, power tiller operated and tractor mounted harvesters.

2.2.3.1 Self propelled reaper windrower

The first vertical windrowing reaper in China was developed in 1976. Its early prototype had a cutting width of 1.85-m with a rear windrowing mechanism mounted with a two wheel walking tractor. The operation was blocked by the change in the direction of the conveyed crop through 90 degrees and hence it did not get popularized. The machine was modified as a side windrowing reaper. A new series of reapers was introduced in 1977 with cutting width of 0.7, 1.0, 1.3, 1.6, 1.9 and 2.5 m.

The following improvements in the design were incorporated with reapers during 1979-80.

(i) The clearance between the ledger plate and the knife section was improved.

(ii) Wrapping of straw around the starwheel was prevented.

(iii) The susceptibility of the frame to deformation was rectified.

The Chinese Academy of Agricultural Mechanization Sciences (CAAMS) and IRRI collaborated to improve the original Chinese reaper so as to better suit agricultural and industrial conditions of developing countries in South and South East Asia.

In 1980, three Chinese engineers worked at IRRI in Philippines to develop a simplified reaper. It was light, less expensive and easy to fabricate with shop tools. The materials and components were easily available to small scale manufacturers in Philippines and other developing countries. The design eliminated the lugged V-belts and simplified the power take off, conveyor drive and cutter bar mechanisms.

Another self propelled harvesting machine for paddy was also developed by CMERI, Durgapur. Its power requirement was 4-5 hp (Devnani, 1980).

The CAAMS-IRRI reaper was having a cutterbar of width 1.0 m and field capacity 2.4 ha per day with 3 hp petrol engine (Bockhop et al., 1986).

Under CIAE-IRRI Industrial Extension Project at Coimbatore, the IRRI reaper was again modified to suit the local conditions with the incorporation of light weight diesel engine. Training was given to the manufacturers on the technique of production of these reapers. The unit consisted of reciprocating cutterbar of 1 m width , crop divider, starwheel, horizontal conveyor taking the crops in vertical position, 5-hp Lombardini diesel engine, speed reduction unit and a pair of pneumatic or cage wheels. The IRRI designed 1 m self propelled paddy reaper-windrower was popularized among the farmers from 1985 onwards (Devnani, 1988).

Another series of reapers were designed in 1984 with cutting width of 1.2, 1.5 and 1.8 m. A trade co-operation of small reaper manufacturers appeared in China comprising nine factories each having yearly output of 2000 to 5000 machines (Ling, 1986).

In Kerala, the 1 m vertical conveyor reaper was tested at farmers fields as well as at research stations from 1987 onwards. Several successful demonstrations were conducted in Kerala. It was found necessary to provide side clutches to facilitate easy turning in muddy fields. Hence a new model with side clutch was designed and fabricated and the field trials are in progress. The average field capacity is 0.14 ha/hr (KAU Research report, 1987-90, 1990-91; Sivaswami, 1990, 1991, 1992). This unit is exclusively used for harvesting paddy and is found suitable for both dry and wet paddy fields. It will be used only for a few days in a year. But if a power tiller operated or tractor operated paddy reaper is developed, the annual use of tiller or tractor will also be increased. So the owners of tiller or tractor will readily accept the reaper attachment. A self propelled reaper binder of 10 hp with a cutting width of 1.24 m was developed at Hissar (Devnani, 1988).

KAMCO, Angamali has taken up manufacture of self propelled paddy reaper windrower in limited numbers. This design was based on the Kubota reapers of Japan.

Joy (1993) reported the development of a self propelled paddy reaper in Aluva.

The improved IRRI 1 m paddy reaper was extensively field tested in various field conditions (Sivaswami, 1993). The unit also had the advantage of using it as a mini tiller after interchange with special rotavator.

2.2.3.2 Power tiller operated reapers

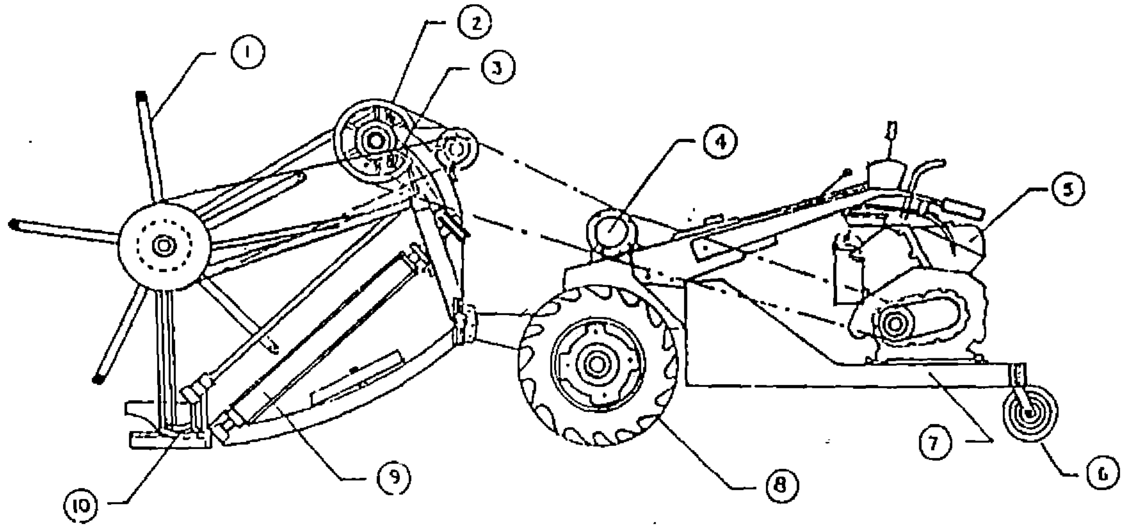
A side mounted power tiller operated harvester was developed at Udaipur during 1970. Attempts were made at Coimbatore and Durgapur to develop power tiller operated paddy reaper during 1971-74. Power tiller operated paddy harvester reaper which was fabricated at Coimbatore (Fig.4), Appendix V was selected for evaluation at different countries for its regional acceptance by RNAM during 1978-80 (Devnani, 1988).

Another model of a power tiller operated reaper windrower was developed during 1970-72 at Ludhiyana (Fig.5), Appendix VI. The engine of the tiller was shifted to the rear to achieve proper balancing (Devnani, 1980).

Chauhan (1973) reported that a prototype of power tiller front mounted reaper was developed and tested at Ludhiyana. Harvesting losses were observed and their causes were identified.

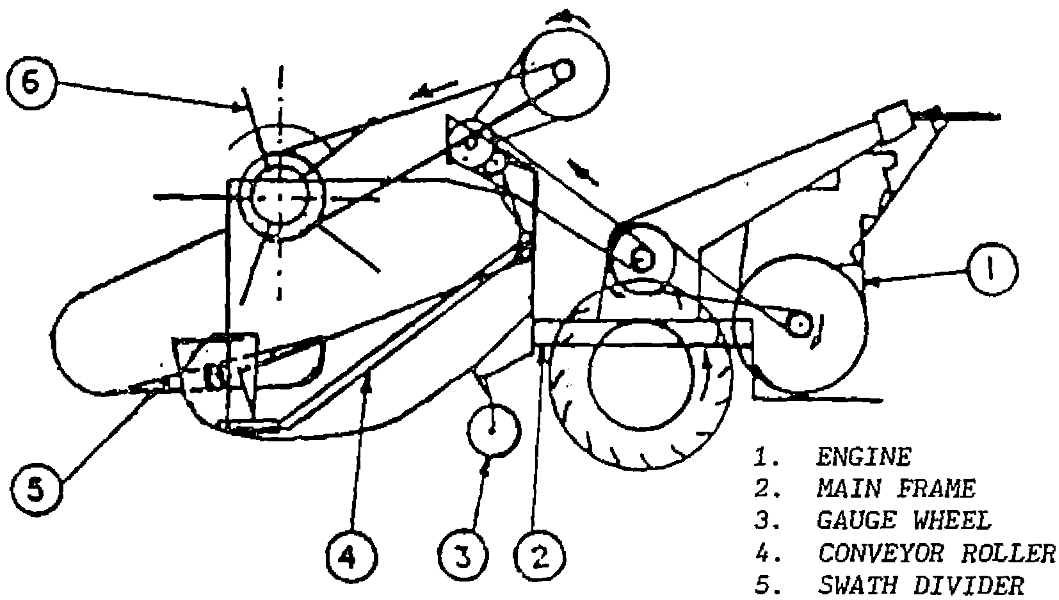
The design and development of a power tiller operated vertical conveyor reaper was started at Bhopal and the first prototype was fabricated during 1981.

Visualizing the great potentiality of the power tiller operated vertical conveyor reaper windrower, research work on development and evaluation was undertaken at Ludhiyana. The



1. REEL ASSEMBLY
2. MAIN SHAFT
3. MAIN FRAME
4. CLUTCH PULLEY
5. ENGINE
6. TAIL WHEEL
7. ENGINE CHASIS
8. GROUND WHEEL
9. CONVEYOR
10. CUTTERBAR

FIG.4 T.N.A.U. PADDY HARVESTER



1. ENGINE
2. MAIN FRAME
3. GAUGE WHEEL
4. CONVEYOR ROLLER
5. SWATH DIVIDER
6. REEL

FIG.5 POWER TILLER OPERATED REAPER

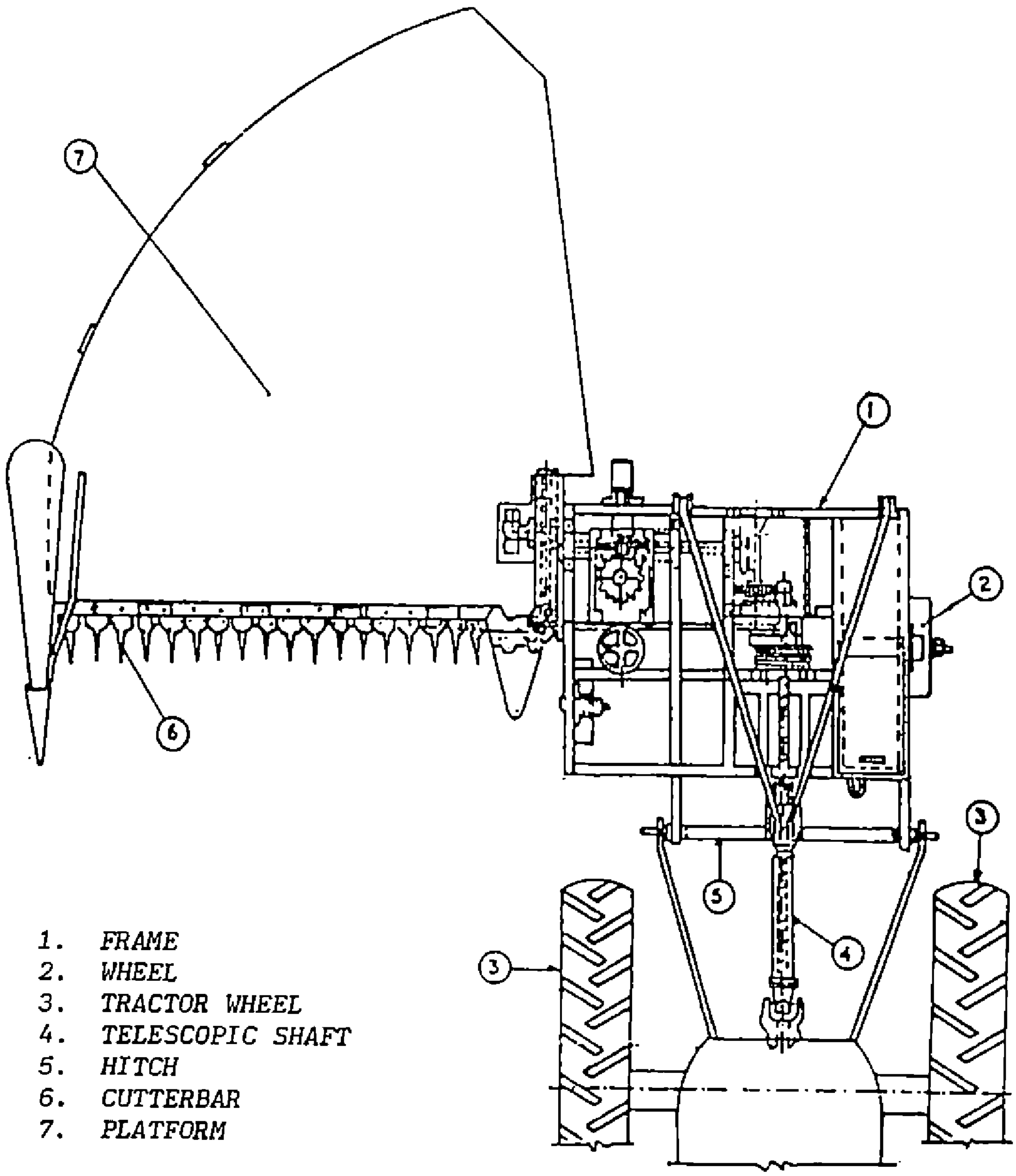
reaper having a cutting width of 1.6 m was developed in 1983 based on the IRRI design (Devnani, 1988).

2.2.3.3 Tractor mounted reapers

Tractors have occupied a major position in Indian agriculture and have already changed the agricultural scenario in the rural area. At present a total of 1.04 million number of various model tractors are used in India (Sahay, 1992). More than 70 per cent of land preparation for paddy in Kerala is carried out by tractors alone although the introduction of tractor is recent one. The use of tractors is restricted only for dry ploughing with cultivators, wet puddling with cage wheels and planks and for transporting with trailors. No other systems are used with tractors in Kerala.

During 1968-69 the tractor rear mounted PTO operated self raking type reaper was developed at Ludhiyana (Fig.6), Appendix XI. This machine was operated with a 30 hp tractor at a speed of 3 kmph. The field capacity was 0.37 ha/hr. The area to be manually harvested before starting the machine harvesting was found to be very high. The tractor rear mounted reaper binder was developed and evaluated mainly for harvesting wheat (Chauhan, 1976).

During 1960-70, the tractor front mounted reaper using cutterbar, reel and canvas conveyor was developed at



1. *FRAME*
2. *WHEEL*
3. *TRACTOR WHEEL*
4. *TELESCOPIC SHAFT*
5. *HITCH*
6. *CUTTERBAR*
7. *PLATFORM*

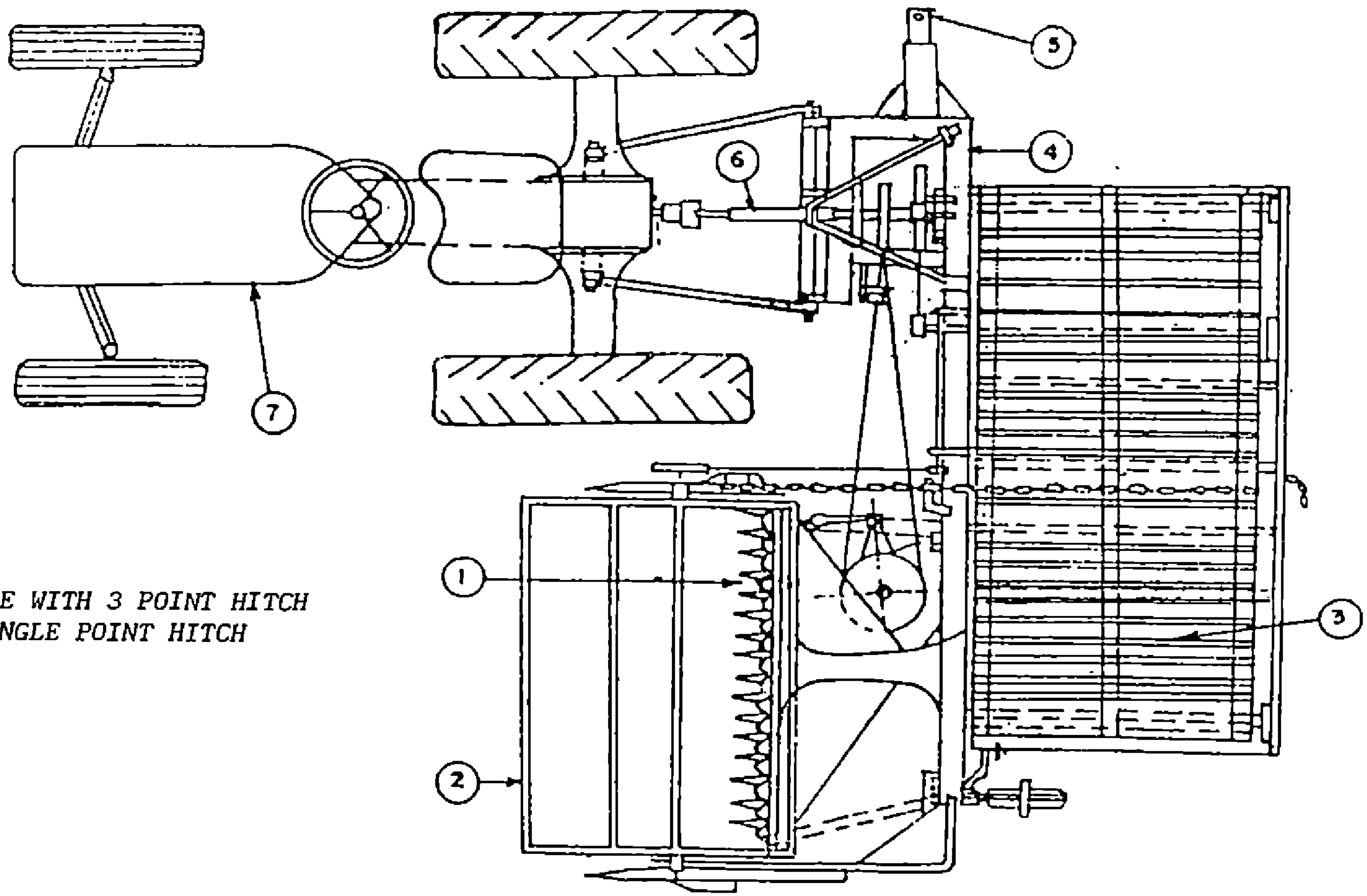
FIG.6 TRACTOR REAR MOUNTED SELF RAKING TYPE REAPER

Ludhiyana. The field capacity was 0.29 ha/hr. Limited units were marketed around 1971-72. The work was continued on the development of the machine during 1974-79 and was evaluated at Ludhiyana and Bhopal. Development of a tractor operated cereal harvester was reported by C.M.E.R.I., Durgapur.

The tractor testing and training stations at Hissar and Budhni conducted testing and evaluation of reapers and reaper binders. The tractor mounted PTO driven cereal reaper binder with 1.65 m cutterbar was developed. The field capacity of the machine was 0.28 ha/hr with grain loss in the range of 2.0 to 2.3 per cent. A tractor mounted reaper was also developed at I.A.R.I., New Delhi. It was known as 'Pusa reaper'.

During 1978 at Ludhiyana, tractor mounted reaper binder was developed (Fig.7), Appendix-XIII. The cutterbar had a width of 3.27 m and a field capacity of 0.2 to 0.3 ha/hr. The weight of bundles was 3 to 6 kg. At Bhopal a tractor operated reaper with a cutting width of 2.05 m was developed (Devnani, 1988).

A tractor front mounted PTO operated self raking type reaper was evaluated for its performance at Ludhiyana (Verma et al., 1970, 1971). The design, development and field evaluation of a tractor front mounted vertical conveyor



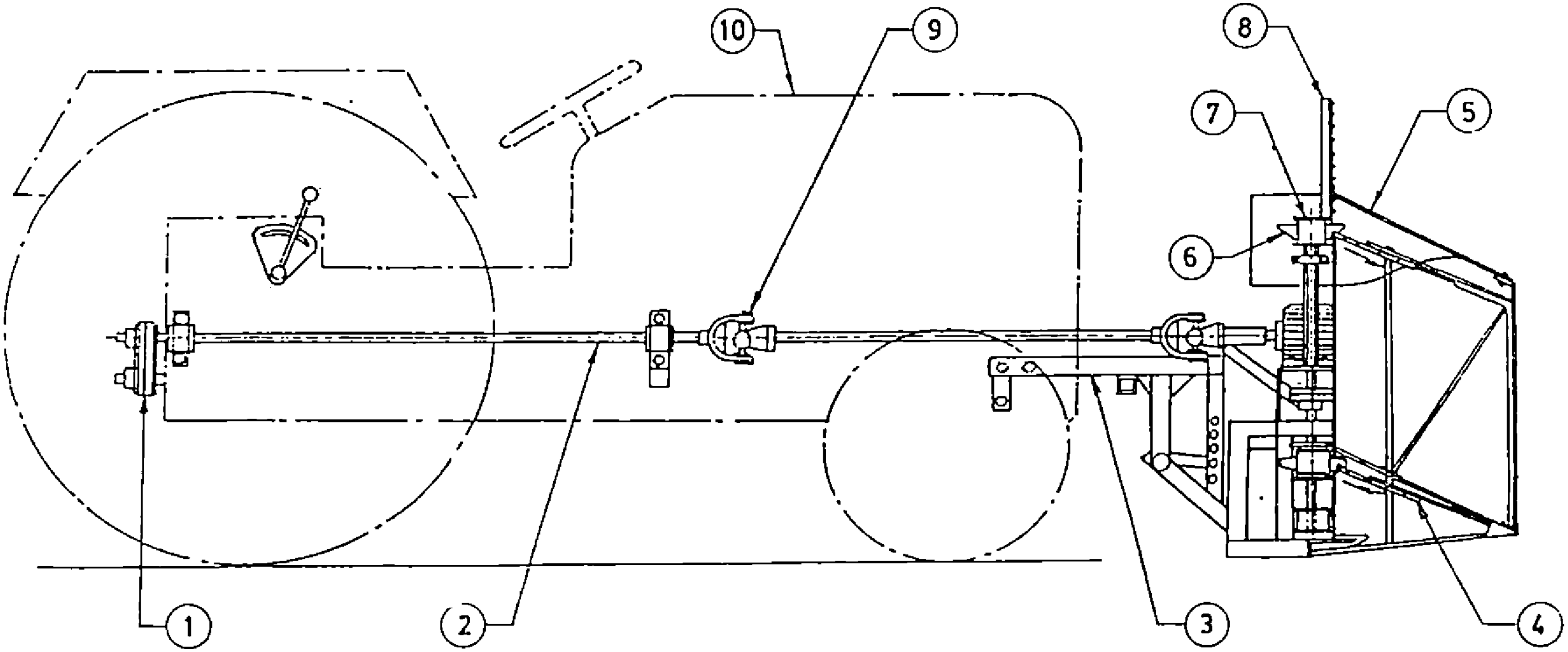
1. CUTTERBAR
2. REEL
3. CONVEYOR
4. MAIN FRAME WITH 3 POINT HITCH
5. OFFSET SINGLE POINT HITCH
6. PTO SHAFT
7. TRACTOR

FIG.7 TRACTOR MOUNTED REAPER BINDER

reaper-windrower was conducted at Ludhiyana. They had studied about the popularization, performance, production status and usage in Punjab (Garg _et al_., 1983, 84, 86, 91).

The harvesting of crop with the reaper involves a combination of various unit operations in a particular sequence. The unit operations involved are dividing the crop rows, lifting up the plants, guiding the plant towards the cutterbar, holding them during cutting, lif ing the cut crop up and directing the plants towards the vertical conveyor belt and conveying to the ground. The cut crop was well laid out in windrow in the field for easier picking and collection of the crop (Devnani, 1988). A tractor operated sorghum harvester (Fig.8) was developed in Tamilnadu during 1991-92 based with tractor front mounted reapers (Asokan _et al_., 1993). The specifications of different harvesting machines developed in our country are given in appendices III, IV, V, VI, VII, VIII, IX, X, XI, XII & XIII.

The studies undertaken on tractor operated cereal harvesters had resulted in the development of wheat harvesters in North India. The unit was also used for harvesting paddy in limited extent. But no work was undertaken to develop any tractor operated paddy reapers suited to the various crop and field condition and the various cultural practices followed in paddy cultivation in Kerala.



1. PTO SHAFT PULLEY
2. DRIVE SHAFT
3. MOUNTING FRAME
4. STARWHEEL
5. CROP DIVIDER
6. LUGS
7. CONVEYOR
8. VERTICAL CROP SUPPORT
9. UNIVERSAL JOINT
10. TRACTOR

FIG.8 TRACTOR OPERATED SORGHUM HARVESTER

Materials and Methods

MATERIALS AND METHODS

In this chapter the various considerations involved while selecting the tractor operated paddy reaper-windrower and its components, the laboratory and field trials carried out to evaluate the reaper-windrower, the modifications undertaken to improve the efficiency of the unit and the economic analysis to study the feasibility in Kerala are being discussed.

3.1 Selection of the reaper

The self propelled 1 m IRRI vertical conveyor reaper-windrower had been successfully demonstrated in Kerala and other parts of the country for reaping paddy. The reciprocating cutterbar and the vertical conveyor belts are found to work satisfactorily in varying field conditions in Kerala. The vertical conveyor reaper-windrower mounted with tractors are widely used in Punjab for harvesting wheat crop only. The manufacturers of promising types of tractor operated vertical conveyor reaper were contacted and a 2.2 m tractor operated reaper-windrower with reciprocating cutterbar assembly, crop row dividers with star wheels, pressure springs, vertical conveyor belts fitted with lugs, crop board, pulleys, gear box and power transmission assembly was got fabricated from M/s Bharat Industrial Corporation, Punjab with a view of modifying and testing for paddy harvesting in Kerala.

3.1.1 Study of components of the reaper

3.1.1.1 Cutterbar assembly

The important part in any harvester is the cutterbar assembly. The reciprocating type cutterbar assembly comprises of the cutterbar, knife sections, knife guards, wearing plates, knife clips and pitman.

(i) Cutterbar - It is a metalbar having a length of 210 cm on which 28 knife sections are mounted.

(ii) Knife section - It is a flat steel plate of triangular shape with two serrated cutting edges (Fig.9). A set of 28 knife sections are riveted on the cutterbar without any gap between the knife sections. The centre to centre distance is 75 mm. The knife sections and the ledger plates together effect the scissor-like cutting action.

Knife guard - The guards protect the knife and act as a stationary shearing edge for the moving knife section. The Guard also divides the plants and guides them into knife sections. Each knife section starts

Scale 1:1.25

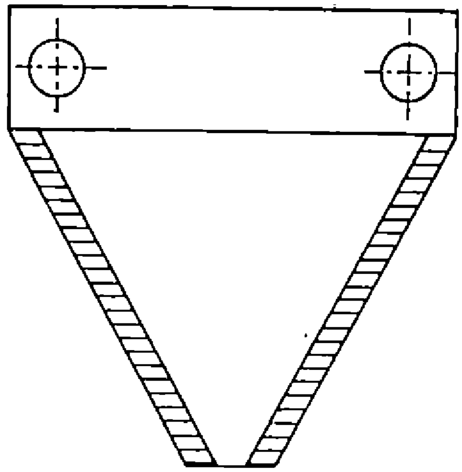
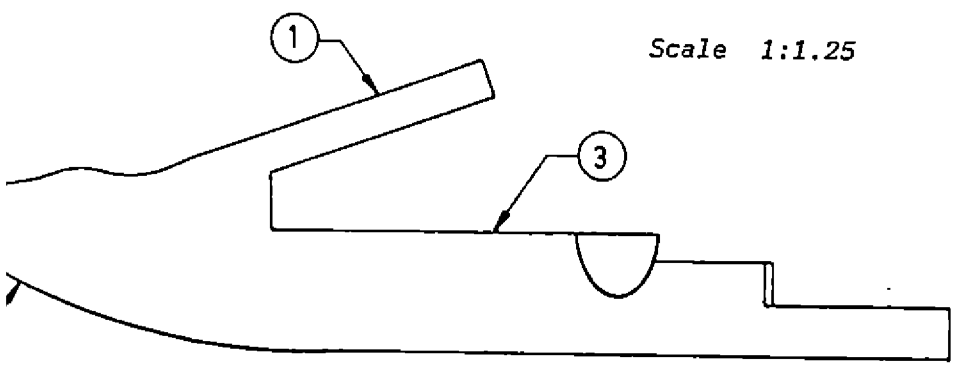
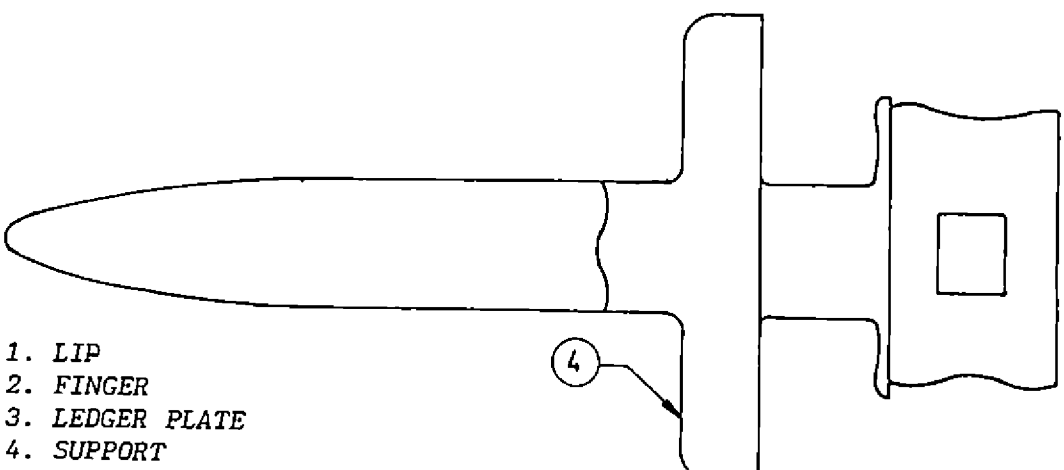


FIG.9 KNIFE SECTION

Scale 1:1.25



SIDE VIEW



1. LIP
2. FINGER
3. LEDGER PLATE
4. SUPPORT

TOP VIEW

FIG.10 KNIFE GUARD

the reciprocating motion from the centre of the guard and reach the centre of the adjecent guard on each stroke of 75 mm and returns back to the original position at the next stroke. Lip is the top portion of the guard which along with ledger plate holds the crop during cutting. The ledger plate is a hardened and polished metal plate riveted over the finger of the guard which perform the cutting action during the movement of knife section. The details of knife guard is shown in Fig.10. Finger is the projecting part of the guard which protects the knife from damage when the reaper comes across any obstruction.

(iv) Wearing plate - It is a hardened steel plate rectangular in shape attached to the reaper bar to form a bearing surface for the back of the knife during the reciprocating movement.

(v) Knife clip - It is an irregular piece of metal which holds the knife sections down against the ledger plates. It prevents lifting of knife section during operation.

(vi) Pitman - It is the rod connecting the crank of the reaper to the cutterbar. The crank and pitman convert the rotary motion from auxiliary gearbox into reciprocating motion and the pitman transmits the reciprocating motion to the knife. The drive to the knives is provided by the slider crank mechanism. The plane of the knife is offset to the centre of the crank. The length of connecting rod must be at least ten times larger than the crank radius.

The knife segment pushes the stalk against the finger liner (ledger plate), presses it in the gap between them and shears it. Since the cut crop rest against the finger liner and lip of the guard, the danger of bending of the stalk is reduced and thereby the reliability of cutting increases. Serrations prevent the slipping of the stalks from the knife while they are pushed towards the ledger plates and then they are gripped between them during cutting.

If the serrations of the knife have a pitch close to the diameter of the stalks, then the stalk become wedged in the space between serrations. This may choke the cutterbar and result in great power demand for cutting. To avoid this, the pitch of the serrations is made two to three times smaller than the diameter of the stalk. In cereal crops the stalk diameter is about 2 to 4 mm and hence the pitch of serrations of knives of reapers is between 1.0 and 1.2 mm.

The smaller the rake angle and greater the sharpness, the greater is the cutting ability of the knife. Wear resistance is a measure of the rate at which the knife blunts. Knives of smaller rake angles and sharp cutting edges become blunted more rapidly.

For high quality cutting, the cutting resistance must be less than the resistance for bending. The resistance for bending increases with the reduction of the clearance between the cutting pair and decreases with the increase of the height at which cutters are mounted. When the clearance is more, then the resistance of the stalks for bending may become less than the resistance for cutting. Then the stalk bends and is subjected to a stretching action between the knife and the ledger plate. This problem increases when the cutters are mounted at greater height. Clogging of the cutting pair with shreds of the plant not only lowers the quality of cutting but also increases the power requirement for the operation of the knife. The clearance between knife and ledger plate should normally be fixed at 0.3 mm to get best results.

3.1.1.2 Crop conveying assembly

(i) Crop row dividers

There are eight crop row dividers spaced at a distance of 30 cm. They are provided to divide the whole crop that can be cut by the reaper unit once into seven equal portions and guide them to the conveying unit. The crop row dividers are fitted at the bottom of the main board in front of the cutter bar assembly. They are mounted at an angle of 20 degree to the horizontal. The front ends of the crop row dividers are slightly bent above the ground so as to avoid hitting against the field bunds during operation. The shape of the crop row divider is triangle in plan and a shoe is attached in the front. To each crop row divider (except the one at the left most end) a starwheel is attached below the shield of crop row divider. Fig.11 shows the arrangement of crop row dividers with starwheels. The shield acts as a cover to the starwheel exposing only the fingers at one side. The crop row dividers with starwheels and pressure springs are designed to perform the functions of lifting, gathering and guiding the crop towards the cutterbar.

(ii) Starwheels

The starwheels are designed to gather the crop and to feed it to the cutting mechanism. Starwheels also perform the functions of holding the crop during cutting and then feeding the cutcrop to the conveying unit. They get the drive for its rotation action from the lugs provided on the moving conveyor belts.

The velocity component of the starwheel which is responsible for guiding the crop = $V_s \cos\alpha$

where,

V_s = the perpheral velocity of the starwheel along its plane

α = the angle of inclination of the starwheel to the horizontal

= the angle of inclination of the crop divider to the horizontal

α depends upon the position and length of crop row divider

The velocity component of starwheel $V_s \cos\alpha$ should be greater than the forward velocity of the machine in order to have the gathering action of crop towards the cutterbar by the starwheel. The minimum recommended value of speed ratio between $V_s \cos\alpha$ and forward speed is 1.026 for its proper functioning. If the ratio between the speed of lugged conveyor belt and the forward speed of machine is lower than unity it will result in pushing of crop away from the cutterbar without cutting results in uncut loss. If the ratio is higher shattering losses will be increased.

(iii) Pressure springs

Pressure springs and starwheels together hold the cutcrop in vertical position during conveying. To each crop row divider (except the one at the left most end), two

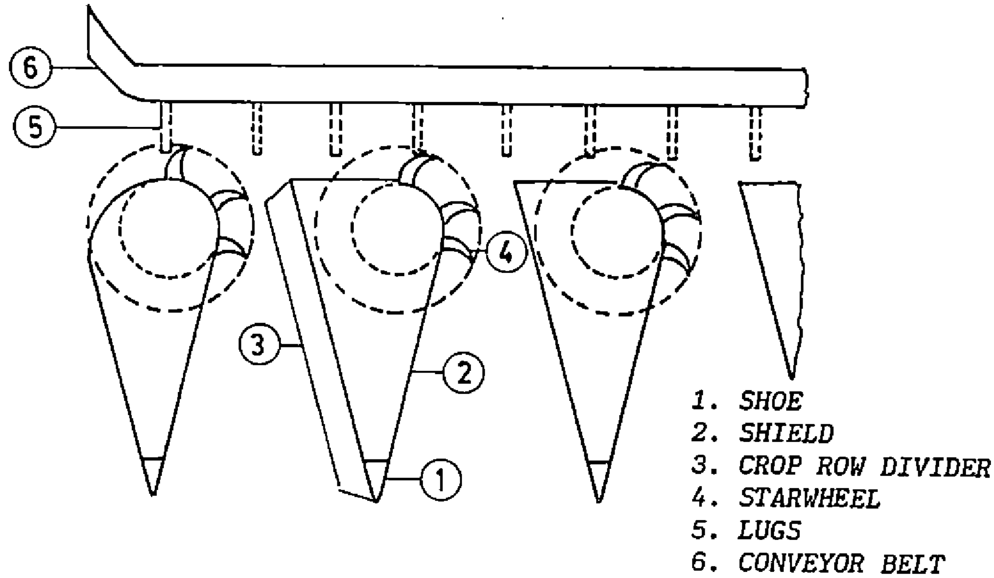


FIG.11 CROP ROW DIVIDERS WITH STARWHEELS

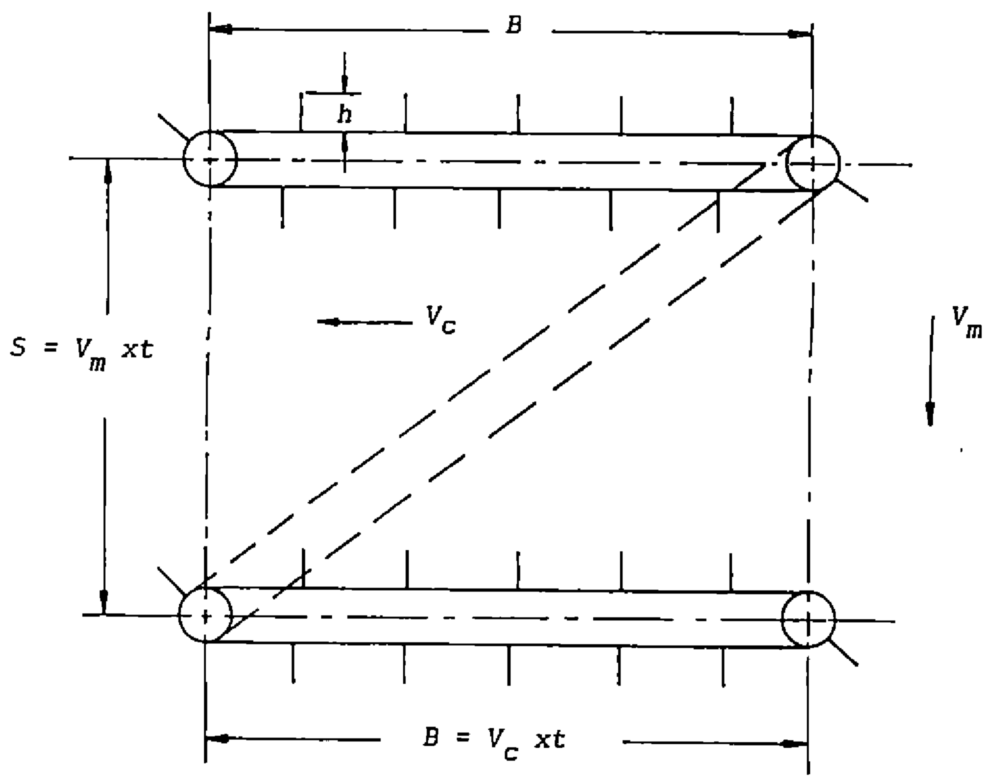


FIG.12 RELATION BETWEEN MOVEMENT OF CONVEYOR BELT AND MACHINE FORWARD TRAVEL

pressure springs are attached. The pressure springs also ensure a smooth flow of crops along the main board during conveying to the discharge plate.

(iv) Conveyor belts

The harvested crop from the cutterbar is delivered to the vertical main board and is held by the pressure springs. There are two conveyor flat belts of 6 cm width with lugs fixed at every 13 cm. The spacing between the belts is 9.5 cm. The bottom belt is having lugs of triangular shape and the top belt is having lugs of rectangular shape. The power required to drive the conveyor flat belts is received from the gear box through V-belts and V-pulleys.

The cut stalks are loaded on the conveyor in vertical position, and are moved in a direction perpendicular to the direction of motion of the tractor and are delivered in windrows at the right side. The speed of conveyor belt, for machine speed of 1 m/s is about 1.5 to 1.6 m/s. Fig. 12 shows the relation between the movement of conveyor belt and the tractor forward travel. The lug height, which is the projected length from the belt, is determined based on the assumption that the entire cut crop is to be moved out of the machine at the outermost end.

The bunches of the crop can be continuously conveyed without any blockage only when the conveyed output per unit time is greater than or equal to the cut crop.

that is,

$$Q\ con \geq Q\ cut$$

$$\rho_2 \times h \times B \geq \rho_1 \times B \times V_m \times t$$

$$\rho_2 \times h \times B \geq \rho_1 \times B^2 \times V_m/V_c$$

then

$$h \geq \frac{B.V_m}{q.V_c}$$

where

h = height of lugs

B = cutting width

V_m = travelling speed

t = time

V_c = Speed of conveyor belt

ρ_1 = density of plant in the field

ρ_2 = density of cut crop on the vertical platform

q = gathered cut crop parameter, $\frac{\rho_2}{\rho_1}$

(v) Discharge plate

It is designed to discharge the cut crops carried by the conveyors in a neat windrow. The discharge plate slightly projects from the line of conveyor belt so that the cut crops strike the discharge plate and then are laid in windrows on the ground.

(vi) Main board

It is the basic structure which holds the cutterbar assembly, crop divider assembly, conveyor belts, four pulleys for the conveyor belts, gear box, crank and pitman. The vertical plate (crop board) of main board helps the harvested crop to stand vertically and to convey them to the right side with the help of conveyor belts. The main board is hitched to the specially fabricated front hitch frame connected to the tractor. For lifting and lowering, the main board is attached, through a pair of 'A' frames and wire ropes, to the hydraulic system of the tractor.

3.1.1.3 Hitching and lifting assembly

The mounting of paddy reaper with tractor is based on following considerations:

(i) Lifting capacity of the hydraulic system.

(ii) Loading capacity of tyres both front and rear.

(iii) Height of hitch and resulting effect on front wheel.

(iv) Power requirement of the harvesting machine and compatibility with the tractor considering power, pull, forward speed and PTO speed.

(v) Height of cut.

The hitching and lifting assembly consists of

(i) Front hitch frame

A suitable mounting frame (Fig.13) is designed and fabricated to suit the MF 245 tractor available at the Department of FPME, K.C.A.E.T., Tavanur. The frame is made up of channel sections to withstand the load and vibration. It is rigidly fitted at the front end of the tractor with easy fasteners. Plates I and II show the right and left views of front mounting frame along with MF 245 tractor.

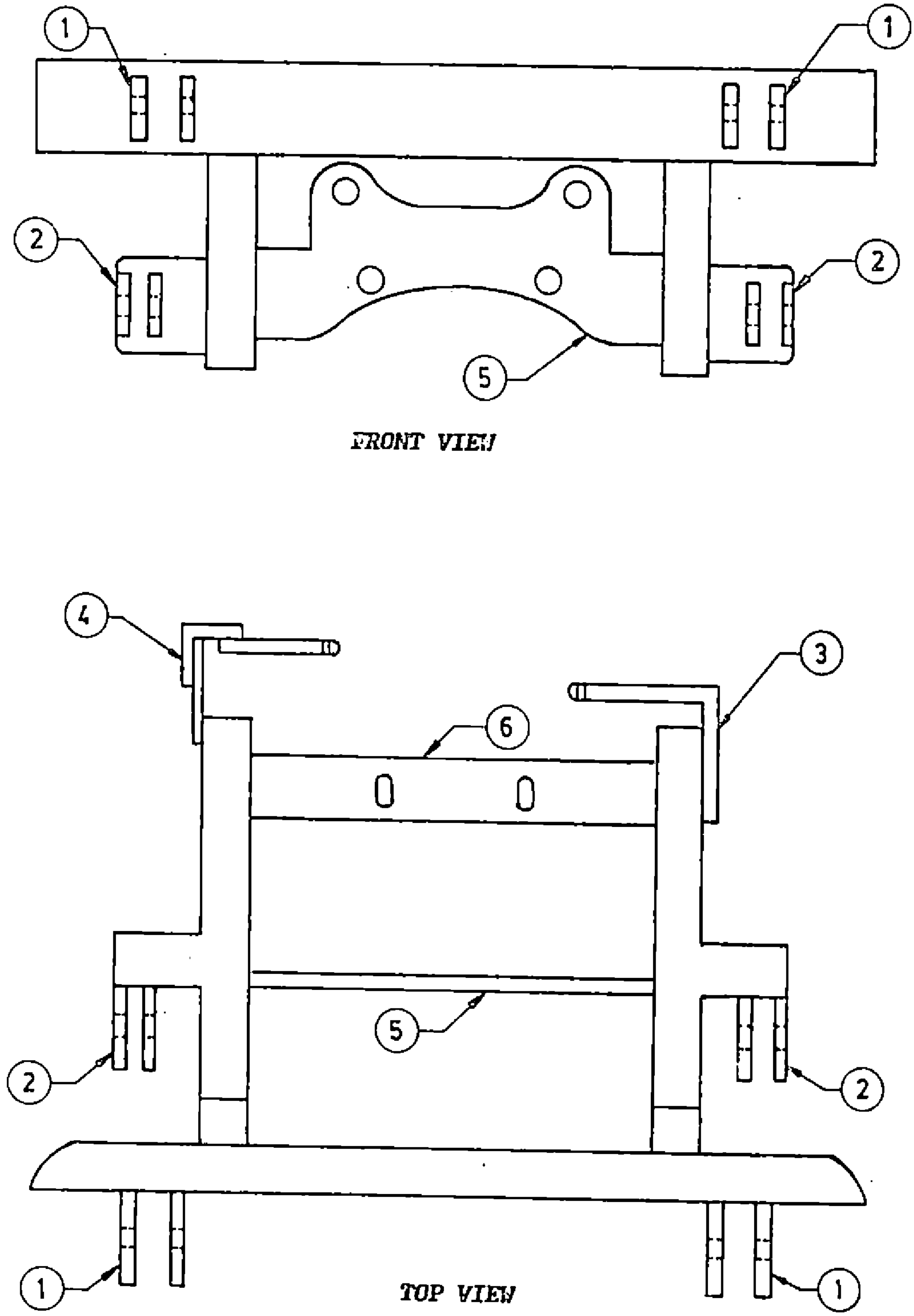
(ii) Combination frame

It comprises the rear frame, a pair of 'A' frames and a pair of wire ropes.

The rear frame (Fig.14) is mounted at the tractor rear housing. It carries the rear end of the intermediate shaft to transmit power from the PTO pulley through V belts to the reaper. The details of the rear frame is shown in plate III.

The wire rope assembly is provided to lift the reaper unit while in transport, crossing the bunds, reverse travel of tractor and while taking turns at the corners of fields. The required height of cut of paddy crop is achieved by this

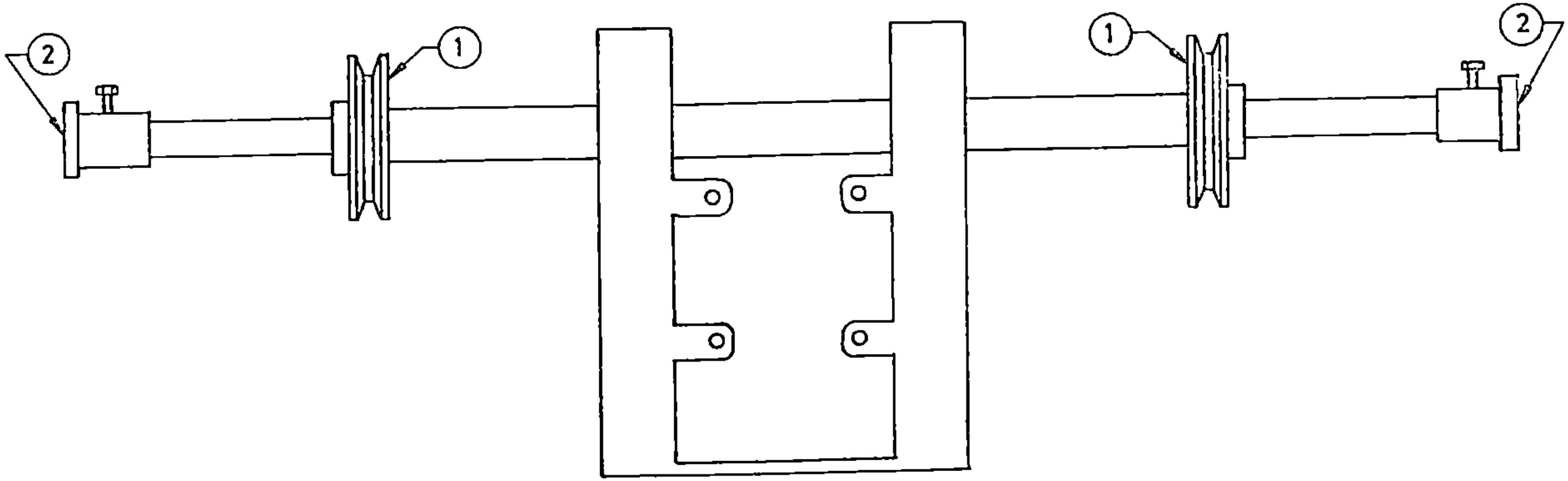
Scale 1:7



1. UPPER LINK
2. LOWER LINK
3. LEFT ANGLE (w.r.t. the operator)
4. RIGHT ANGLE (w.r.t. the operator
5. FRONT FRAME PLATE
6. SUPPORT FOR FRONT BEARING BRACKET OF INTERMEDIATE SHAFT

FIG.13 FRONT HITCH FRAME

Scale 1:6.5



1. V PULLEY
2. SUPPORT TO PREVENT BENDING OF EXTENDED SHAFT

FIG.14 REAR FRAME

Plate I Right view of front mounting frame

Plate II Left view of front mounting frame

245

assembly. The wire ropes of are used to transmit the hydraulic power from the hydraulic link of the tractor to the reaper. From the hydraulic link holder the wire ropes passed through, the V pulleys mounted on the extended shafts of rear frame, then below the foot rests and connected to the 'A' frames which are connected to the reaper unit. There are two wire ropes, one from the left hydraulic link holder to the left 'A' frame and the other from the right hydraulic link holder to the right 'A' frame.

To avoid bending of the extended shafts of rear frame due to the load of the reaper a pair of supports (Fig.15) are fabricated and provided at the tractor rear housing.

The specially fabricated supp[illegible] rollers are provided below the foot rests for allowing the wire ropes to pass below the levers of brakes and clutch (Fig.16).

3.1.1.4 Power transmission assembly

As the reaper-windrower is a tractor front mounted unit, the forward movement is achieved by the forward travel of the tractor. The power operating the cutterbar assembly and conveying assembly is obtained from the PTO shaft of the tractor through a pair of V-pulleys, an intermediate shaft and a pair of universal joints to the auxiliary gear box. The power transmission system of the reaper is shown in Fig.17.

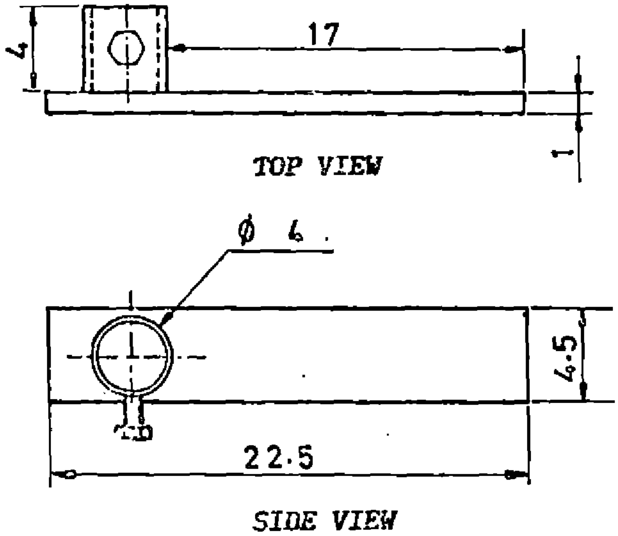


FIG.15 ATTACHMENT TO PREVENT BENDING OF THE EXTENDED SHAFT OF THE REAR FRAME

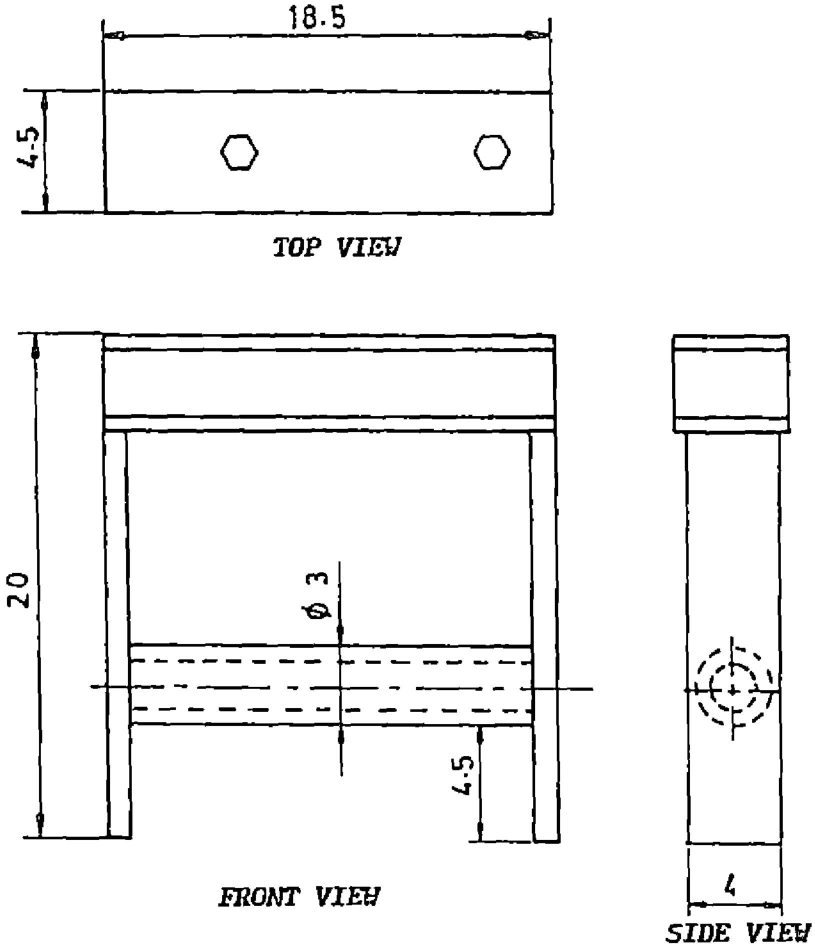


FIG.16 ATTACHMENT TO PREVENT RUBBING OF THE WIRE ROPE

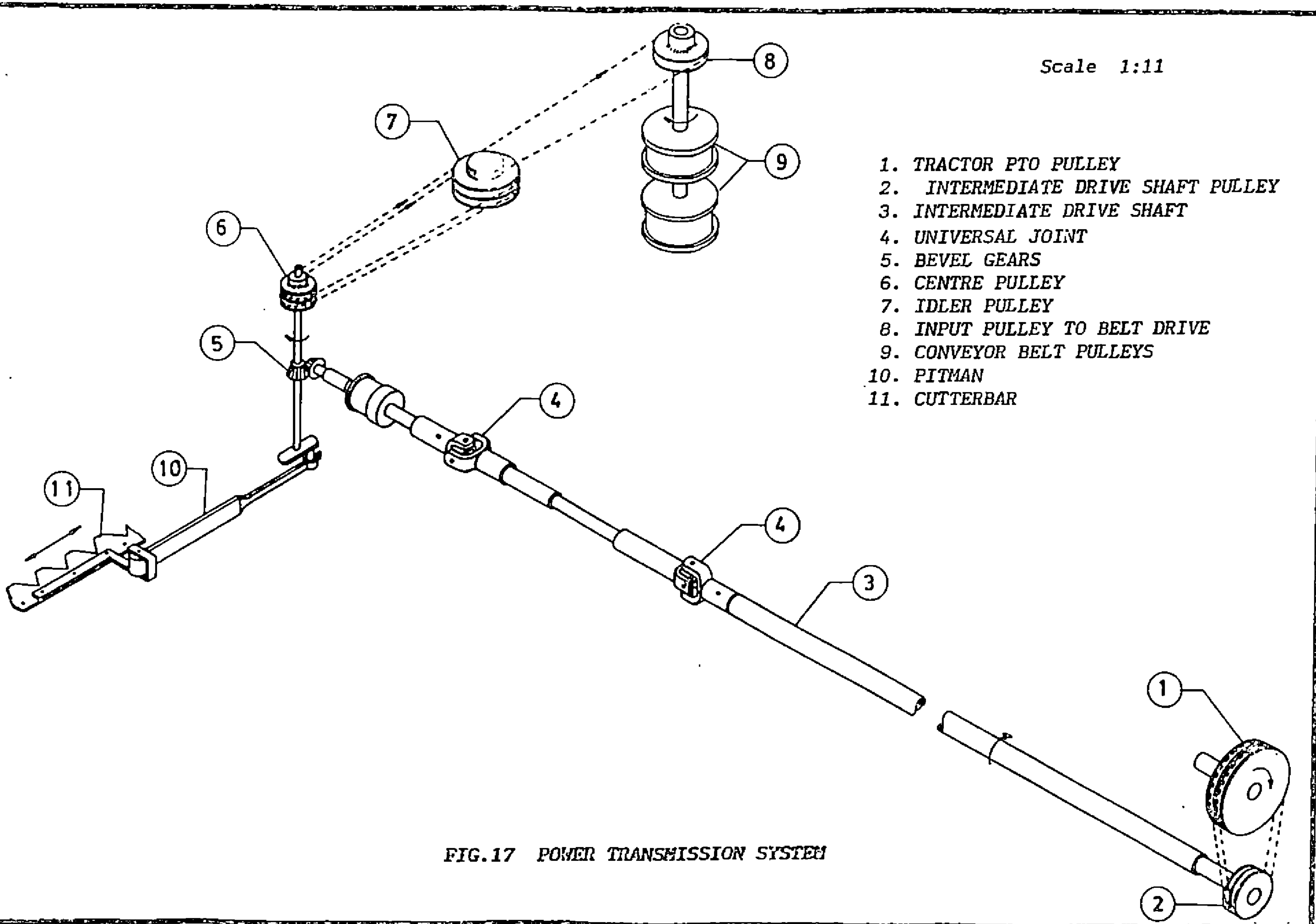


FIG.17 POWER TRANSMISSION SYSTEM

When the PTO lever is engaged, a portion of engine power is transferred to the PTO shaft to give it rotory motion. The power is transferred from the PTO shaft to the intermediate shaft through the drive pulley on the PTO shaft to the driven pulley on the intermediate shaft through two numbers of V-belts. The intermediate shaft is taken beneath the tractor body through a couple of bearing brackets. The front end of the shaft is inserted in a plain hollowshaft end of a universal joint. The other end of this universal joint is a splined hollow shaft in which the splined solidshaft of the other universal joint is inserted. The other end of this universal joint is a plain hollow shaft in which the input shaft of the auxiliary gear box is inserted. The pair of universal joints and the extensible splines are provided to facilitate the power transmission when the reaper is working at different heights from the ground levels.

The other end of this input shaft is connected to the auxiliary gear box and through a set of bevel gears. The power from the input shaft in horizontal direction is transmitted to output shaft in vertical direction. The output shaft is extended to the top and bottom of the gear box.

From the top end of this shaft, through a V-pulley and an intermediate pulley power is transmitted to another pulley mounted on a shaft at the right end of reaper. The two conveyor belt pulleys are mounted on the same shaft, below the V-pulley. Thus power transmitted is received by the belt pulleys to drive the pair of conveyor belts.

From the bottom end of the vertical shaft of the auxiliary gear box power is transmitted to the pitman through a crank mechanism to provide necessary reciprocating motion to the cutterbar.

3.1.2 Method of fitting

The method adopted for mounting the reaper-windrower on MF 245 tractor is discussed below.

The front hitch frame is attached to the tractor by fitting the left angle of the frame to left side of tractor, the right angle to right side and the plate of frame at the front using studs, bolts and nuts.

The autohitch assembly and the three point hitch links are removed. The PTO shaft cover is removed and the rear frame is fitted around the PTO shaft. Then the pulleys provided for rope system are mounted on the extended shafts.

The bearing brackets carrying the intermediate shaft are fitted on the space provided for them in the front hitch frame and rear frame. The intermediate shaft is checked for frame through the front legs of 'A' frames. The wire ropes from the top of 'A' frames are stretched below the foot rests, through the pulleys on the extended shafts and the rope ends are connected to the tractor hydraulic link holders by U-clamps. The wire ropes are fully stretched when the machine is in the lift position. Then the input shaft of the reaper is connected to the universal joints. The pair of lower links are connected between the front hitch frame and the reaper. Figure 18 gives the side view and top view of the tractor front mounted paddy reaper. Tractor mounted paddy reaper during field operation is shown in pate IV.

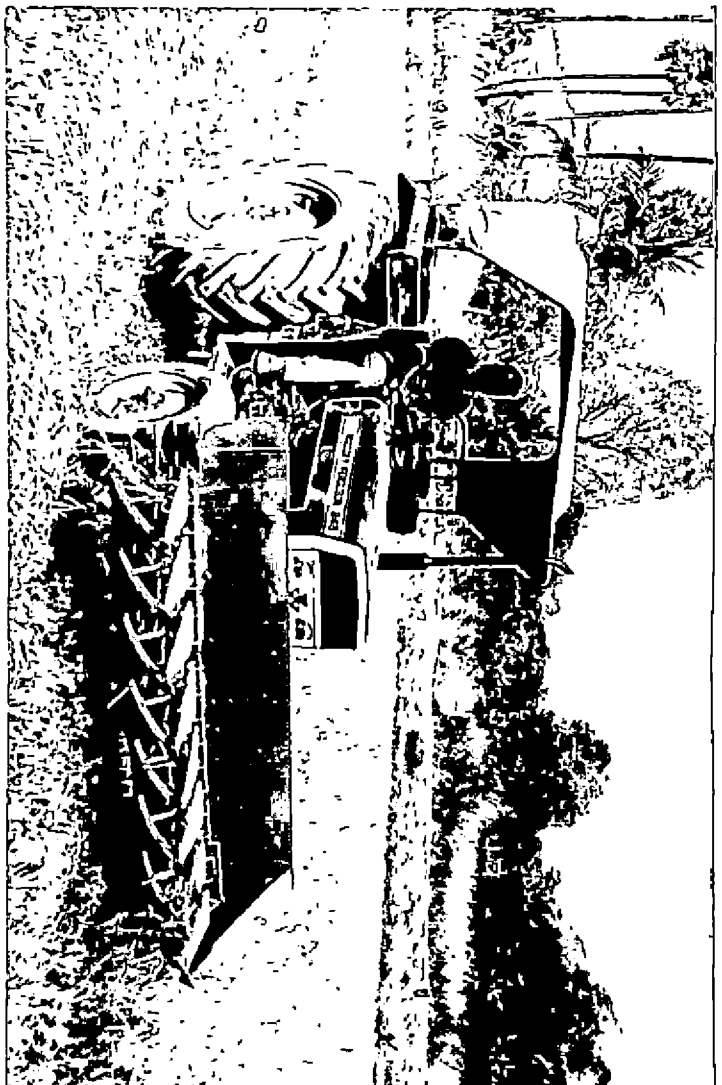
3.1.3 Preliminary trials

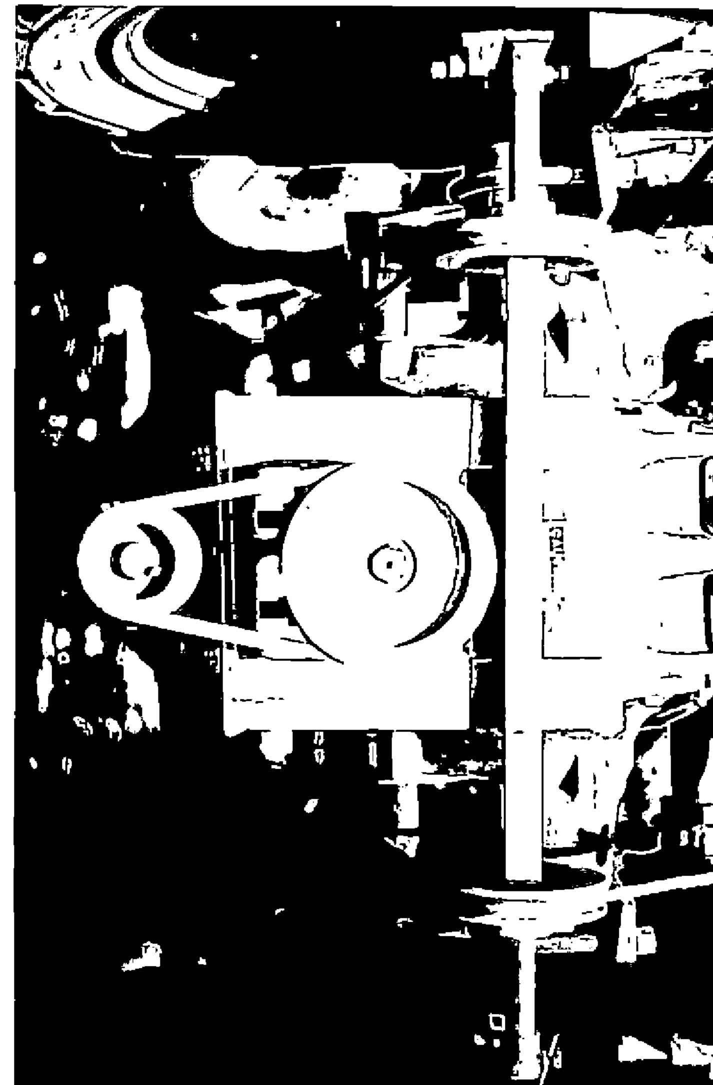
When the tractor is started and engaged the PTO lever is engaged the reaper assembly starts functioning. It can be raised and lowered by operating the hydraulic system of tractor. The harvesting of crop take place only when the tractor moves forward and the PTO lever is engaged.

Sufficient length of splined shaft is added to the universal joints to prevent any loss of link between the

Plate III View of rear-frame, V pulleys and wire rope assembly

Plate IV Tractor mounted paddy reaper windrower during field operation





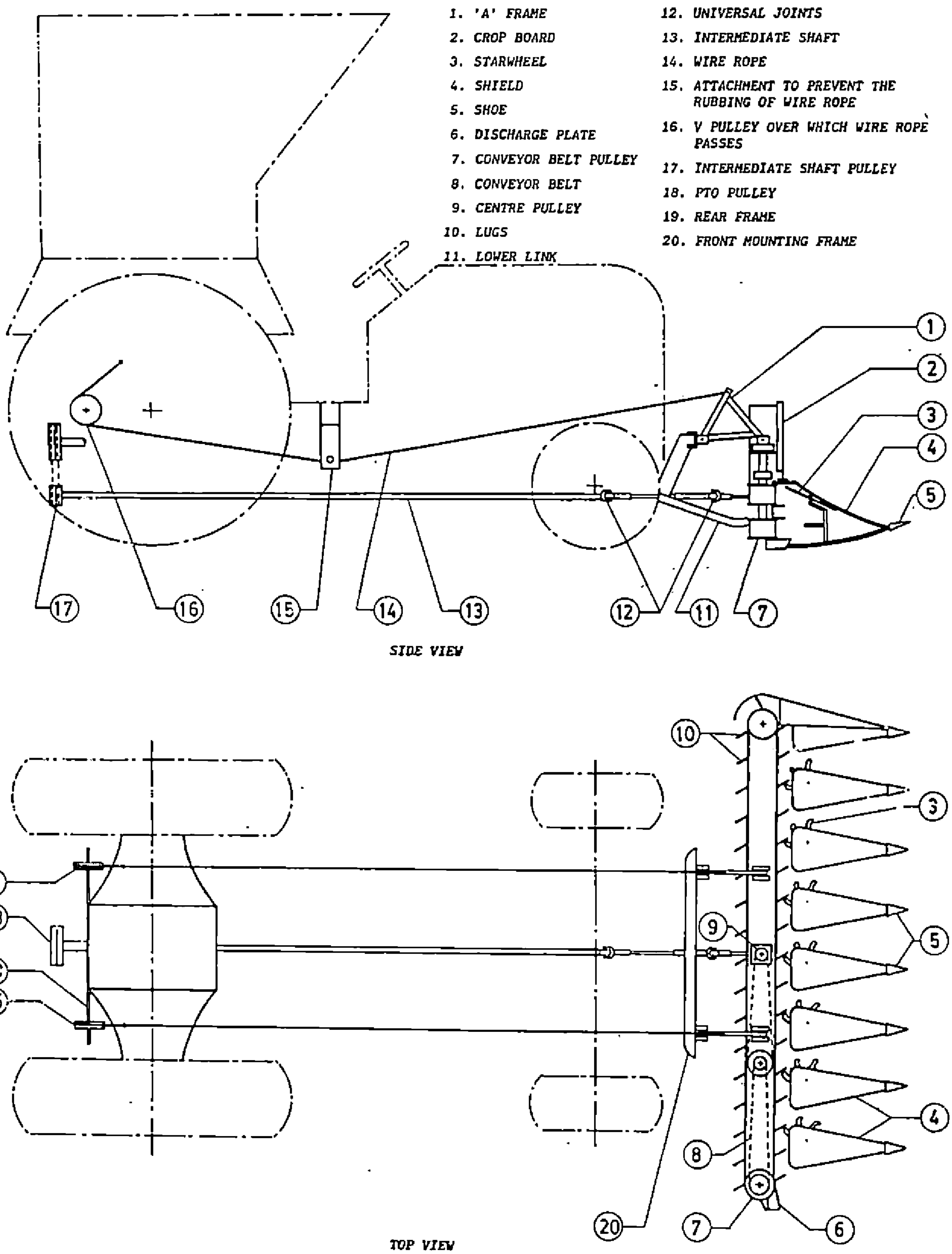


FIG.18 TRACTOR FRONT MOUNTED PADDY REAPER

intermediate shaft and the universal joint when the reaper assembly is lifted to get maximum clearance during transport.

The tractor mounted paddy reaper windrower is having many components, consisting of fabricated as well as purchased and assembled units. In the preliminary trials, performance of individual components were determined. The vibration, noise, balance, driver's safety, steering controls and visibility were checked.

Step I

After hitching the reaper assembly to the tractor, only the tractor was operated for five hours to identify any defects in the hitching. The studs, bolts and nuts were rechecked for their rigidness.

Step II

The reaper assembly was fitted with tractor and only the hydraulic links were operated. The observations were noted about the lifting and lowering of the reaper and the modifications required for proper functioning of the lifting assembly were carried out. The tractor was operated in all the forward and reverse gears and at the same time the lifting assembly was checked.

Step III

Double V-belts were used to connect the PTO pulley with the intermediate shaft pulley. Both the conveyor belts were disconnected. By engaging the PTO lever while the tractor had already started, only the cutter bar was operated. Observations were made on its performance.

Step IV

The conveyor belts were connected and the pin joining the crank and the pitman was removed to disconnect the cutter bar assembly. In the starting position of the tractor, by engaging the PTO lever, the functioning of the conveyor belt, crop divider with starwheels were noted. The required modifications and adaptations were carried out.

Step V

In the final stage of preliminary trials the cutter bar assembly, the crop conveying assembly, the hitching and lifting assembly as well as the power transmission assembly were properly connected after carrying out all the modifications. In the starting position of the tractor by engaging the PTO lever and using hydraulic control levers, all the above assemblies were operated. Observations were taken on the combined effect of individual components. After carrying out the necessary modifications, adjustments and replacements the unit was operated at different engine speeds in the starting position of tractor to check any failure.

Step VI

After ensuring satisfactory results, the tractor mounted reaper-windrower was moved forward in low gears when all the sub-assemblies were put in use. Observations were also made on driver's comfort and manoeuvrability.

3.2 Field trials

The tractor mounted reaper windrower was found satisfactory in the preliminary trials. A number of field trials were conducted to observe the defects of assemblies and the problems arising under different field and crop conditions.

The trials were carried out in three stages.

Stage A: Optimum conditions for a tractor operated reaper is the field of square or rectangular shape with dry soil, matured dry paddy of height around 60 to 100 cm without lodging and without considerable weeds. Field trials were carried out in the field having above condition. The problems faced by the reaper unit was systematically noted and rectified.

Stage B: Keeping all the above field condition the same as stage A the unit was operated in a green and wet paddy crop instead of matured and dry crop. The required adjustments were carried to achieve satisfactory performance.

Stage C: The tractor mounted paddy reaper windrower was tested in a field having stagnant water upto 10 cm. The trials were carried out and problems faced were noted.

A number of field trials were conducted to detect the defects during field trials in varying crop and field condition. After the rectifications were carried out, field trials were conducted to study the performance.

3.2.1 Evaluation of paddy reaper windrower in field

The field trials were conducted in fields of Instructional Farm, K.C.A.E.T., Tavanur. The slope, area, topography and type of the fields were noted. The moisture content of the soil was measured using the oven drying method. Frequency and size of bunds were noted. Variety, appearance and maturity of crop and type and extent of weeds were also observed. Number of grain per earhead was also measured.

Preharvest loss (Wgo) was noted from five 1 m^2 sample area in each plot. Then the five 1 [illegible] ch plot were harvested by traditional method using sickles. The total weight of the harvested crop and weed were noted from each sample area. It was the total biomass per m^2. Then it was manually threshed. The weight of straw and grain were separately measured. The weight of grain is the average yield (Yg). From the weight of straw and grain, straw grain ratio was calculated. Tripple beam balance was used for the weight measurement of straw, grain and soil. The moisture content of the grain was measured using crop moisture meter. The number of tillers per 1 m^2 was noted from the field. The grains left were collected from the fields which were harvested using sickle. The average weight (W_1) was noted. Then sickle loss was calculated as below:

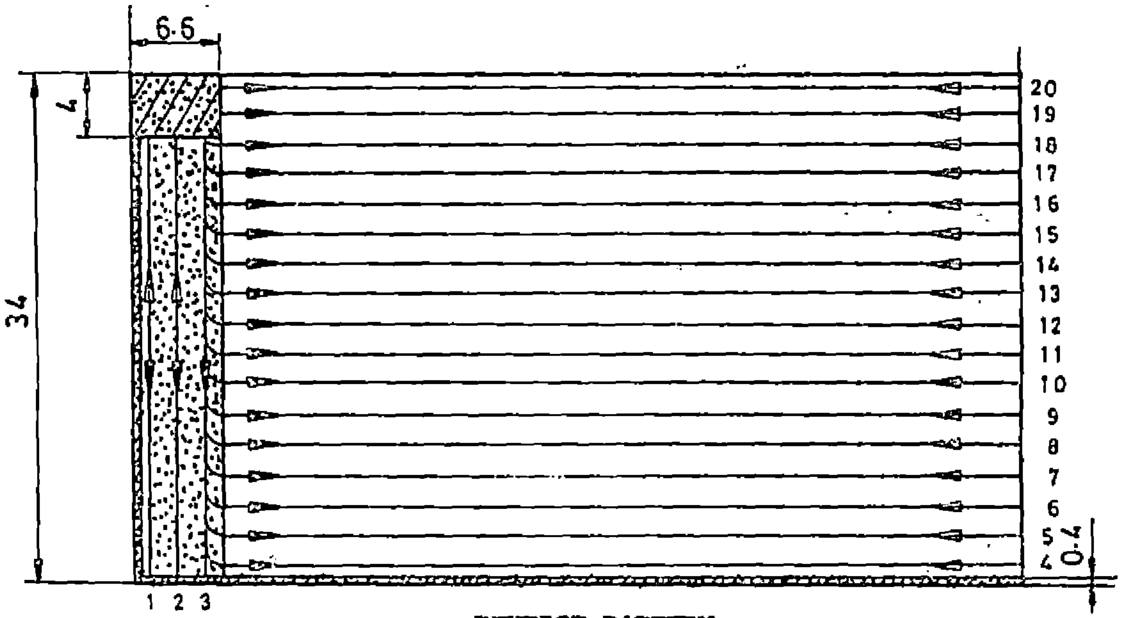
$$\text{Percentage sickle loss} = \frac{W_1 - W_{go}}{Y_g} \times 100$$

Since the side bunds of the plots were high there was no space for the placement of harvested crop as windrows while using tractor operated paddy reaper. Hence plants were harvested to a width of 40 cm from the bund by using sickle. Precautions were taken to harvest the crop only when the tractor is moving straight.

Plants in the area at the starting point of the plot which is equal to 3 times the area occupied by the tractor is manually harvested. This is for providing space for easy turning of the tractor with reaper. Two harvesting patterns were adopted which are shown in Fig.19.

The first pattern is known as reverse method. In this method, manual harvesting is required only at the sides of two boundaries as shown in Fig.19a. From the starting point, tractor with reaper moves in cutting run (1) along the shorter side upto the end of that side. From that end, tractor moves in reverse run with the reaper in lifted position to the starting point. Then tractor takes the next cutting run (2) and return on reverse to the starting point. Then takes the next cutting run (3). The crop which is harvested by the first three runs is removed for easier turning of tractor for further operations. From the end of run (3), tractor with reaper moves in run (4) at perpendicular to the previous direction which is along the longer side as shown in Fig.19a. At the end of this run, tractor is again reversed to return to the starting point of run (4). Then a number of cutting runs are conducted parallel to run (4) until the whole field is covered. At the end of each run, tractor takes the reverse movement with reaper in the lifted position to the starting point of that run.

The second harvesting pattern is known as circuitous method. For the placement of harvested crop as windrows, a strip of 40 cm width is harvested manually at all the four



a. REVERSE PATTERN

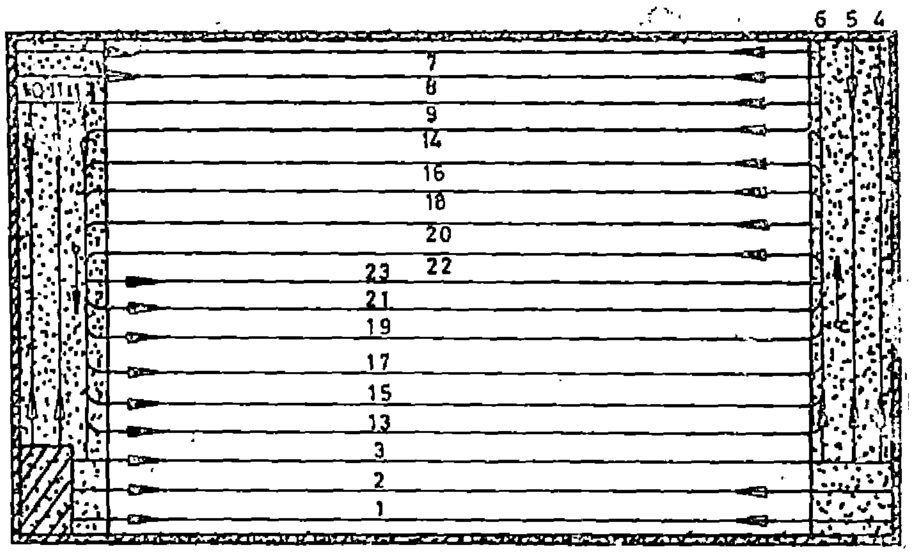
MANUAL HARVESTING, CROP TO BE REMOVED

TRACTOR HARVESTING, CROP TO BE REMOVED

REAPER IN CUTTING RUN, FORWARD TRAVEL

REAPER IN IDLE RUN, REVERSE TRAVEL

REAPER IN IDLE RUN, FORWARD TRAVEL



b. CIRCUITOUS PATTERN

All dimensions in m

G.19 HARVESTING PATTERN FOR TRACTOR FRONT MOUNTED PADDY REAPER-WINDROWER boundaries. From the starting point, tractor with reaper moves in the cutting run (1) along the longer side as shown in Fig.19b. At the end of this run tractor returns in the reverse direction with reaper in lifted position. Next is the cutting run (2) and then the tractor returns and starts the run (3). At the end of this run, tractor moves along the next side perpendicular to the direction for run (3). The runs 4, 5 and 6 are completed like the previous set of runs 1, 2 and 3. Likewise runs 7, 8 and 9 as well as runs 10, 11 and 12 are completed at the remaining boundaries. The crop which is harvested in these 12 runs is removed for easier turning of tractor for the remaining harvesting. Tractor runs in the round and round pattern and the cutting is carried out only at the two longer sides. Along the two shorter sides, tractor moves with reaper in lifted position.

The operating speed, cutting width and cutting height from ground level were noted. After completing harvesting, the shattered grains left on five randomly selected 1 m^2 area in each plot were collected. Let the average weight be W_{gl}, and the shattering loss was calculated as below:

$$\text{Percentage shattering loss} = \frac{(W_{gl}-W_{go})}{Y_g} \times 100$$

Then uncut loss was calculated. For that the uncut crop left in the five randomly selected 1 m^2 area in each plot, was manually harvested. Threshing was done manually. Let the average weight of grains be W_{g2}.

$$\text{Percentage uncut loss} = \frac{(W_{g2} - W_{go})}{Y_g} \times 100$$

Then cutterbar loss which is the sum of uncut loss and shattering loss was calculated.

$$\text{Percentage cutterbar loss} = \frac{(W_{gt} - W_{go})}{Y_g} \times 100$$

where,

$$W_{gt} = W_{g1} + W_{g2}$$

3.3 Power requirement

The power for operating the reaper unit is fully supplied from PTO shaft of the tractor. It is necessary to understand the power requirement to operate the individual sub-assemblies of the reaper without any crop.

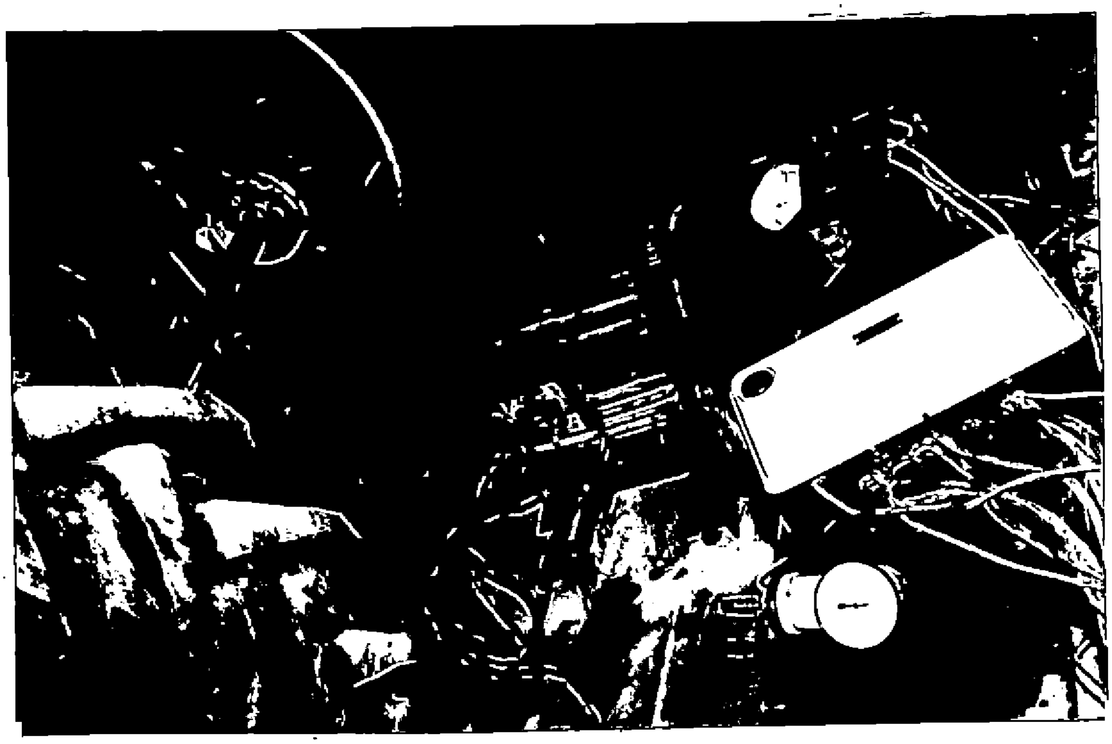
The engine rpm, pto rpm, centre pulley rpm and the belt pulley shaft rpm were noted using tachometer. The strokes/min of cutterbar were calculated.

The approximate power requirement for running a vertical conveyor reaper is less than 10 hp. The power from a 7.5 hp motor was given to the intermediate shaft of the reaper instead from the PTO pulley. The rpm of the intermediate shaft was maintained at the same value as that of the field operation by selecting suitable pulley for motor. The power requirements were measured using a wattmeter. The arrangement was as shown in Plate V.

The total power requirement (P_t) to operate all the sub-assemblies in idle condition was noted. Then the belt connecting the centre pulley and conveyor belt pulley of the reaper was dismantled, thus stoped the power transmission to conveyor belts. Then power carried by the reaper without the conveyor belt and pulleys (P_c) was noted. After that the connection to pitman was removed. So the power transmission to cutterbar and conveyor belt was stopped. The power requirement (P_u) was noted. Then the universal joint was detached. At that time the power was consumed only for driving the shaft and running the motor and the value (P_s) was noted. Then the belts connecting the motor pulley and mainshaft pulley were removed. Then the power requirement was only for running the motor and the reading (P_o) was noted. The same procedure was reversed by connecting the sub-assemblies and the readings were noted.

The readings obtained in watt were converted into hp. From the readings power requirement of each sub-assembly was calculated.

Plate V Arrangement for measurement of power requirement of subassemblies of reaper unit



Power requirement of motor at no load	=	P_o
Power requirement of intermediate shaft	=	$P_s - P_o$
Power requirement of universal joints + gear box	=	$P_u - P_s$
Power requirement of cutterbar	=	$P_c - P_u$
Power requirement of conveyor belts	=	$P_t - P_c$

3.4. Stability studies

Tractors are designed mostly to use implements mounted at the three point linkage or to be hitched at the drawbar. When the three point hitch is used, some portion of weight from the front wheel and weight from implement are transferred to the rear wheels. This is to prevent the tractor rear wheels from lifting and thus increasing the traction. But when the tractor is fitted with a front mounted reaper windrower, the weight transfer to the rearwheels may not take place. To study the effect of weight transfer before and after mounting the reaper windrower at the front end of tractor, stability study was carried out.

By keeping the four wheels of the tractor on the weighing platform, the total weight of the tractor was measured. By keeping the front half of wheel base at the platform, the weight on the front axle was measured. By keeping the rear half of wheel base on platform, the weight on rear axle was noted.

Similarly by keeping the exact right half and the exact left half of tractor on the weighing platform, the tractor's right half weight and left half weight were noted. Similarly weights were taken for tractor with reaper. The weights were taken using an electronic weighing balance available at K.S.D.C., Kuttippuram. The weights of reaper alone, rear frame, front frame, intermediate shaft with universal joints and the total weight were taken. These weights were compared in the study of weight transfer and stability.

3.5 Economic studies

Introduction of any farm machinery should be for its economic feasibility. The cost of harvesting of paddy is already high. The tractor operated reaper should reduce the cost of cutting compared to existing method. Hence the harvesting cost of paddy by tractor mounted reaper windrower was compared with the manual method.

The data about man-h required for harvesting 1 ha and the labour charges were collected from the Instructional Farm, K.C.A.E.T. From the data, cost of manual harvesting for one hectare was calculated. The harvesting cost of tractor operated reaper was also calculated. The two costs were compared.

Break even analysis for manual harvesting and harvesting by reaper was also carried out.

Results and Discussion

RESULTS AND DISCUSSION

The results of work carried out on the tractor front mounted vertical conveyor reaper windrower to make it suitable for field conditions of Kerala, the fabrication of accessories, modification of individual components, laboratory and field trials, evaluation of the reaper, extensive testing of the reaper and other relevant studies are discussed in this chapter.

4.1 Selection of the reaper

The 2.2 m reaper windrower was got fabricated from Punjab and was assembled with MF 245 tractor.

(i) The front hitch frame as per the Fig.13 was designed and fabricated. By four bolts from the tractor body and four bolts from the front plate of the tractor, the front hitch frame was fixed with the tractor. This frame also facilitates in receiving one of the bearing brackets of the intermediate shaft. The weight of the front hitch frame is 52 kg. The two lower links also hinge the front hitch frame with the reaper. The front hitch frame also facilitates lifting of reaper through a pair of 'A' frames and wire ropes connected with hydraulic links of the tractor.

(ii) The rear frame as per the Fig.14 was also designed and fabricated. The extended shafts carry V-pulleys through which wire ropes pass to the hydraulic links. The weight of the rear frame is 19 kg. Due to the weight of the reaper when operated by hydraulic links through ropes, the extended shafts started bending. To avoid this, supports were fabricated and provided at the shafts with the tractor rear housing for easy resting on the tractor (Fig.15). To eliminate rubbing of wire ropes at the foot rest at brake and clutch pedal, two roller U-clamp supports (Fig.16) were fabricated and assembled. The rear frame had also provision to receive the rear bearing bracket of the intermediate shaft.

(iii) The intermediate shaft, V-pulley and the universal joints weigh 34 kg. When the reaper unit was lifted upto 15 cm lift, the splined shaft was found to have connection to the input shaft of gear box. But beyond 15 cm lift due to shortness of the splined shaft, it started slipping away from the input shaft of the gear box. This necessitated an increase in the length of splined shaft. The length of the splined shaft with universal joints was increased to 70 cm. The intermediate shaft was alligned through the two bearing brackets and was made free to rotate. This eliminated the power loss during operation of the shaft.

(iv) The lifting and lowering of the reaper unit is achieved by the operation of the hydraulic lever. The length of the wire rope was so adjusted to allow the reaper to lower just 5 cm above the ground level.

The hitching and lifting assembly and the power transmission system were found to operate satisfactorily after these modifications. After careful study of each and every components, they were assembled properly. Then it was operated for in the laboratory to find out the faults and the following rectification works were carried out.

(i) Replacement of the ordinary bolts connecting knife guard and reaper bar by good quality carriage bolts with double lock nuts and spring washers. This helped in eliminating the rotation of knife guard about the bolt, as the knife guard was having a square section to receive the counter bolt. This also helped to tight the bolt more easily. The projection of the head of ordinary bolt was eliminated by the thin flat head of the carriage bolt.

(ii) The movement of cutterbar was not free. The ledger plates in some of the guards were not level and hence the knife section and ledger plates were subjected to wear and tear. Poorly maintained ledger plates cause rugged cutting and side draft. Each guard were inspected for wear, nicks, breakage, rust and bending and remedial measures were carried out. Correct alignment of guards were done. To get proper seating and alignment all the ledger plates were rivetted again. The height of the rivet head on the ledger plate was maintained so that the rivet head and ledger plate were in level. The clearance between ledger plates and knife sections was corrected by adjusting the clearance between the knife clips and the knife sections. Spacers were added or removed to increase or decrease clearance between the clip and the knife section. Thus the movement of cutterbar was made free and smooth.

(iii) Due to misalignment, all the starwheels were not free to receive drive from the conveyor belt. Proper setting of the crop divider and starwheel eliminated the defect. Thus the starwheel was made to rotate freely and resulted in better gathering of crop to feed to the cutting mechanism and to the conveying mechanism.

(iv) Replacement of the pin connecting the crank and pitman was to avoid break in the connection between crank and pitman.

(v) The auxillary gearbox was found to have defects in the gears and bearings settings. Proper setting and aligning of the bevel gears, bearings and the input and output shafts were carried out.

4.2 Field trials

A number of field trials were conducted at farms of K.C.A.E.T., Tavanur; R.A.R.S., Pattambi and at various farmer's fields to detect the defects in its operation and proper remedial measures were carried out to rectify them.

The windrowing was not proper and the crop was found to spread nonuniformly over the field. This was due to the defects in the discharge plate. The defects of discharge plate were rectified and its positioning was adjusted which results in easy and proper discharge of cut crop as neat windrows.

The conveying of cut crop along the cupboard was not proper. Proper arrangement of pressure springs helped the cut crop to be properly carried by the conveyor belt.

The problem of winding of straw around the hub of starwheel was noticed. It was found that the winding of straw was due to rotation of hub along with starwheel. The straw coming in contact with the hub easily wound around and made the starwheel impossible to rotate. Hence a steel cup was mounted on the starwheel shaft so as to cover the starwheel hub. As this cup was not rotating the straw was not having any possibility to wind around the hub. Table 1 gives the details of components of the reaper-windrower.

The reaper was field tested with fully matured and dry crop and no problem was faced. When the crop height is below 15.5 cm, only the bottom conveyor belt was to hold the crop and it was observed that a part of the cut crop used to slip from the grip of the single conveyor belt and fall horizontally during conveying. This needed frequent cleaning. When the crop is green but without moisture in the stalk then also no problem was faced. Only when the crop surface is moist and the reaper is dry, the stalk used to stick in the surface of crop divider, starwheel and the crop board and resistance to move along the conveyor belt is observed.

4.2.1 Evaluation of paddy reaper windrower in field

Critical evaluation of the tractor mounted reaper windrower was carried out at Instructional farm, K.C.A.E.T., Tavanur.

Table 1. Details of components of paddy reaper-windrower

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos)
I	Cutterbar assembly			
1.	Cutterbar	25x9x2200	MS	1
2.	Knife section	--	High grade steel	28
3.	Knife guard	--	CI	29
4.	Wearing plate	34x3x110	High grade steel	6
5.	Knife clip	--	CI	6
6.	Reaperbar	90x50x2400	MS	1
7.	Pitman	50x20x440	MS	1
8.	Guide	30x10x190	MS	1
9.	Rail	15x15x245	MS	1
10.	Carriage bolts	45 L, 8 D	MS	29
11.	Hexagonal nuts	8 D	MS	58
12.	Spring washers	8 D	--	58
II	Crop conveying assembly			
1.	Shield	--	MS	8
2.	Starwheel	280 D	Aluminium	7
3.	Bolts (connecting shield, starwheel & pipe frame)	13 D, 50 L	MS	8

Contd.

Table 1 (Contd.)

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos)
4.	Hexagonal nuts	13 D	MS	8
5.	Shoe	--	MS	8
6.	Bolts (connecting shoe, shield & pipe frame)	12 D, 40 L	MS	8
7.	Hexagonal nuts	12 D	MS	8
8.	Pipe frame	25 D	MS	
9.	Pressure spring	4 D, 270 L	Special alloy	13
10.	Conveyor	60x8x4340	Canvas reinforced rubber	2
11.	Lugs	50x2.5x60	Aluminium	72
12.	Conveyor belt pulley shaft	400 L, 23.5 D	MS	1
13.	Bearing	6205 Z	--	2
14.	V pulley (single groove)	B 100 D	CI	1
15.	Conveyor belt pulley	160 D, 85 L	CI	4
16.	Bolts (connecting lugs to conveyor belt	3 D, 15 L	MS	144
17.	Hexagonal nuts	8 D	MS	144
18.	Idler pulley shaft	23.5 D, 50 L	MS	1

Contd.

Table 1 (Contd.)

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos)
19.	Idler pulley (tripple groove V pulley)	B, 130 D	CI	1
20.	Bearing	6205 Z	--	2
21.	V pulley (double groove)	B, 90 D	CI	1
22.	U-clamp with threaded bolt end	--	MS	2
23.	Bearing	6205 Z	--	4
24.	V-belts	B 50	fiber impregnated rubber	3
25.	Circlip	--	--	2
26.	Bolts (connecting pipe frame to reaperbar)	12 D, 70 L	MS	16
27.	Hexagonal nuts	12 D	MS	16
28.	Spring washer	12 D	--	16
29.	Mainboard	680x2x2450	MS	1
30.	Sheet metal cover	350x2x620	MS	3
31.	Frame at the back of main board	350x95x1850	MS angle iron	1
III	Hitching and lifting assembly			
1.	Front hitch frame	--	MS angle iron & flat	1

Contd.

Table 1 (Contd.)

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos)
2.	Bolts	16 D	MS	4
3.	Nuts	16 D	MS	4
4.	Bolts	18 D	MS	4
5.	Nuts	18 D	MS	4
6.	'A' frame	--	MS	2
7.	Cotter with split pin	26 D, 90 L	MS	4
8.	Lower link	50x9x650	MS	2
9.	Cotter with split pin	26 D, 70 L	MS	4
10.	Rear frame	--	MS	1
11.	V pulley (single groove)	B, 150 D	CI	2
12.	Stud	15 D	MS	4
13.	Support to extended shaft	--	MS	2
14.	Hook	145 L	MS	2
15.	Nut	20 D	MS	2
16.	Wire rope	10 D, 3120 L	Carbon steel	2
17.	U-clamp	--	MS	8
18.	Roller support	--	MS	2

Contd.

Table 1 (Contd.)

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos)
IV	Power transmission assembly			
1.	PTO pulley	178 D	CI	1
2.	Main shaft pulley	100 D	CI	1
3.	V belts	B 31	fiber impregnated rubber	2
4.	Bearing	335	--	2
5.	Bearing brackets	--	MS	2
6.	Intermediate shaft	50 D, 2200 L	MS	1
7.	Universal joints	--	MS	2
8.	Input shaft	23.5 D, 50 L	MS	1
9.	Bearing	6205 Z, 6206 2Z	--	1 1
10.	Input gear	Bevel, 10 teeth	--	1
11.	Output gear	Bevel, 16 teeth	--	1
12.	Output shaft	23.5 D, 50 L	MS	1
13.	Bearing	6305 Z	--	2
14.	Gearbox	--	MS	1
15.	Crank	--	MS	1
16.	Circlip	--	--	2

The safety of the tractor with front mounted paddy reaper-windroweris checked. The attachment at the front does not affect the visibility from driver's seat. It is observed that there is not any change in sound level after attaching the reaper with the tractor. The turning radius needed for the tractor with reaper is slightly more than the tractor without reaper. The front mounted reaper reduces the jerking of the tractor front axle. This shows that these ergonomic factors are within the permissable limits.

The field selected was almost level and no bunds were present in each plot of 2040 sq. m. Hence the operation was very smooth for taking field trials. Since the land was dry the pneumatic tyres were used. The variety of paddy (Jyothi) is a high yielding, short duration and a dwarf variety. The crop was erect and not lodged. The details of the field and crop are given in Appendix-XXII. The tractor was operated in low second gear.

The results of the field trial by reverse harvesting pattern is given in Table 2. The actual cutting time, actual cutting distance, idle time and the total time taken for covering the plot were noted. The speed of actual cutting was 1.05 m/s. The time taken for actual cutting was 15 min 45 sec, the idle time was 17 min 18 sec and the total time for harvesting was 33 min 3 sec. The percentage of cutting time

Table 2. Performance of reaper in reverse harvesting pattern

Cutting			Idling
Distance (m)	Time (s)	Speed (m/s)	Time (s)
30	30	1.00	40
30	30	1.00	44
30	28	1.07	62
53	49	1.08	57
53	55	0.96	55
53	53	1.00	67
53	53	1.00	62
53	49	1.08	56
53	48	1.10	54
53	49	1.08	56
53	49	1.08	59
53	48	1.10	55
53	51	1.03	51
53	53	1.10	55
53	50	1.06	51
53	51	1.04	54
53	49	1.08	55
53	48	1.10	51
53	52	1.02	54
53	50	1.06	--
991	945		1038

Time taken for actual cutting = 945 s = 15 min 45 s

Idle time = 1038 s = 17 min 18 s

Total distance of cutting run = 991 m

Average speed of cutting $= \frac{991}{945} = 1.05$ m/s

Total time taken for harvesting = Cutting time + idle time

= 945 + 1038 = 1983 s

= 33 min 3 s

Percentage of time taken for actual cutting w.r.t. total time $= \frac{945}{1983} \times 100$

= 47.66

Area of the plot = 2040 sq.m.

Actual width of cut $= \frac{2040}{991} = 2.06$ m

Theoretical width of cut = 2.1 m

Theoretical field capacity $= \frac{991 \times 2.1 \times 3600}{1983 \times 10000}$

= 0.378 ha/hr

Actual field capacity $= \frac{2040 \times 3600}{1983 \times 10000}$

= 0.370 ha/hr

Field efficiency $= \frac{0.370}{0.378} = 97.9$ %

to total time was 47.66 and the percentage of idle time was 52.34. The percentage of actual cutting time to the total operating time should be 50 if the tractor is only used for forward cutting runs and reverse idle runs. But in actual field condition the reaper should take turns at the end of each strip for starting next strip and the percentage was reduced from 50 to 47.66.

For plot of 2040 sq.m., the total cutting distance was calculated to be 991 m for the reaper having effective width of 2.06 m compared to the theoretical width of cut of 2.10 m. The theoretical field capacity was calculated to be 0.378 ha/hr and the actual field capacity was found to be 0.370 ha/hr which amounted to a field efficiency of 97.9 per cent.

The results of the field trial by circuitous harvesting pattern are shown in Table 3. The actual cutting distance, the actual cutting time for each run and the idling time were noted for a plot of 2040 sq.m. The actual cutting speed for each run was calculated. The average speed of cutting was calculated to be 0.98 m/s and it was acceptable within the limits. The time taken for actual cutting was 16 min 35 sec, the idling time was 15 min 39 sec and the total operating time was 32 min 14 sec. The percentage of cutting time to total time was 51.45 and the percentage of idle time was 48.55.

Table 3. Performance of reaper in circuitous harvesting pattern

Cutting			Idling
Distance (m)	Time (s)	Speed (m/s)	Time (s)
56	54	1.04	90
56	90	0.62	86
56	60	0.93	70
27	36	0.75	96
27	24	1.13	46
27	25	1.08	49
53	60	0.88	63
53	51	1.04	99
53	55	0.96	74
20	22	0.91	50
20	25	0.80	60
20	25	1.15	40
46	40	1.00	14
46	46	0.89	14
46	52	0.92	13
46	50	1.15	12
46	40	1.15	12
46	40	1.15	11
46	40	1.15	12
46	40	1.15	10
46	40	1.15	10
46	40	1.15	8
46	40	1.15	--
974	995		939

Total distance of cutting run $= 974$ m

Time for actual cutting $= 995$ s $=$ 16 min 35 s

Average speed of cutting $= \frac{974}{995} = 0.98$ m/s

Idle time $= 939$ s $=$ 15 min 39 s

Total time taken for harvesting = Cutting time + idle time

$= 995 + 939 = 1934$ s

$=$ 32 min 14 s

percentage of time taken for actual cutting w.r.t. total time $= \frac{995}{1934} \times 100$

$= 51.45$

Area of the field $= 2040$ sq.m.

Actual width of cut $= \frac{2040}{974} = 2.09$ m

Theoretical width of cut $= 2.1$ m

Theoretical field capacity $= \frac{974 \times 2.1 \times 3600}{1934 \times 10000}$

$= 0.380$ ha/hr

Actual field capacity $= \frac{2040 \times 3600}{1934 \times 10000}$

$= 0.379$ ha/hr

Field efficiency $= \frac{0.379}{0.380} = 99.7$ %

Comparison between reverse pattern and circuitous pattern

Change in percentage idle time $= 52.34 - 48.55$

$= 3.79$

Percentage change in total time taken for harvesting $= \frac{1983-1934}{1983} \times 100$

$= 2.47$

Percentage change in idle time $= \frac{1038-939}{1038} \times 100$

$= 9.54$

For a plot of 2040 sq.m., the total cutting distance was 974 m. The effective width was estimated to be 2.09 m compared to theoretical width of 2.10 m. The theoretical field capacity was calculated to be 0.380 ha/hr whereas the actual field capacity was found to be 0.379 ha/hr which lead to a field efficiency of 99.7 per cent. This indicates that the method is very efficient.

The percentage of idle time in circuitous pattern was 3.79 per cent less than the reverse pattern. It was found that the circuitous pattern had a reduction of 2.47 per cent in total time taken for harvesting and 9.54 per cent in idle time compared to the reverse method. The circuitous pattern was established as the efficient cutting pattern for the tractor front mounted paddy reaper for the normal paddy field condition in Kerala.

The field efficiency also depends upon the operator's skill. The overlapping of cutting paths should be minimised to increase the field efficiency.

The results of the experiments conducted to find out the grain loss during harvesting by the reaper-windrower were given in tables 4, 5, 6, 7 and 8. The total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss (total loss) from five randomly selected $1m^2$ areas, from

Table 4. Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for plot No.I

		I	II	III	IV	V	Average
Total yield Y_g (g)		300	300	300	300	300	300
Pre harvest loss	Wg_o (g)	0.03	0.03	0.03	0.03	0.03	0.03
	$\frac{Wg_o}{Yg} \times 100$ (%)	0.01	0.01	0.01	0.01	0.01	0.01
Sickle loss	W_1 (g)	3	2.4	1.8	3	3	2.64
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	0.99	0.79	0.59	0.99	0.99	0.87
Uncut loss	Wg_1 (g)	1.2	0	0	0	0	0.24
	$\frac{Wg_1}{Yg} \times 100$ (%)	0.4	0	0	0	0	0.08
Shattering loss	Wg_2 (g)	4.2	4.5	5.1	5.7	9	5.7
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	1.39	1.49	1.69	1.89	2.99	1.89
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	5.4	4.5	5.1	5.7	9	5.94
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	1.79	1.49	1.69	1.89	2.99	1.97

Table 5. Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for plot No.II

		I	II	III	IV	V	Average
Total yield Y_g (g)		300	310	300	290	300	300
Pre harvest loss	Wg_o (g)	0	0	0	0	0	0
	$\frac{Wg_o}{Yg} \times 100$ (%)	0	0	0	0	0	0
Sickle loss	W_1 (g)	2.4	1.8	3	3	3	2.64
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	0.8	0.58	1.0	1.03	1.0	0.88
Uncut loss	Wg_1 (g)	0	0	1.2	0	0	0.24
	$\frac{Wg_1}{Yg} \times 100$ (%)	0	0	0.4	0	0	0.08
Shattering loss	Wg_2 (g)	5.7	9	5.7	5.4	5.4	6.24
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	1.9	2.9	1.9	1.86	1.8	2.07
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	5.7	9	6.9	5.4	5.4	6.48
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	1.9	2.9	2.3	1.86	1.8	2.15

Table 6. Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for plot No.III

		I	II	III	IV	V	Average
Total yield Y_g (g)		300	290	310	290	310	300
Pre harvest loss	Wg_o (g)	0.03	0	0.03	0	0.03	0.018
	$\frac{Wg_o}{Yg} \times 100$ (%)	0.01	0	0.01	0	0.01	0.006
Sickle loss	W_1 (g)	3	2.4	3	1.8	3	2.64
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	0.99	0.83	0.96	0.62	0.96	0.87
Uncut loss	Wg_1 (g)	0	1.2	0	0	0	0.24
	$\frac{Wg_1}{Yg} \times 100$ (%)	0	0.4	0	0	0	0.08
Shattering loss	Wg_2 (g)	9	8.7	6	9	5.7	7.68
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	2.99	3	1.93	3.1	1.83	2.57
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	9	9.9	6	9	5.7	7.92
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	2.99	3.41	1.93	3.1	1.82	2.65

Table 7. Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for plot No.IV

		I	II	III	IV	V	Average
Total yield Y_g (g)		300	300	300	310	290	300
Pre harvest loss	Wg_o (g)	0.03	0.03	0.03	0	0	0.018
	$\frac{Wg_o}{Yg} \times 100$ (%)	0.01	0.01	0.01	0	0	0.006
Sickle loss	W_1 (g)	3	2.4	1.8	2.7	3	2.58
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	0.99	0.79	0.59	0.87	1.03	0.85
Uncut loss	Wg_1 (g)	0	1.2	1.2	0	0	0.48
	$\frac{Wg_1}{Yg} \times 100$ (%)	0	0.4	0.4	0	0	0.16
Shattering loss	Wg_2 (g)	6	6	5.4	5.4	5.4	5.64
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	1.99	1.99	1.79	1.74	1.86	1.87
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	6	7.2	6.6	5.4	5.4	6.12
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	1.99	2.39	2.19	1.74	1.86	2.03

Table 8. Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for plot No.V

		I	II	III	IV	V	Average
Total yield Y_g (g)		290	310	290	290	310	298
Pre harvest loss	Wg_o (g)	0	0	0	0	0	0
	$\frac{Wg_o}{Yg} \times 100$ (%)	0	0	0	0	0	0
Sickle loss	W_1 (g)	3	3	2.4	2.7	1.8	2.58
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	1.03	0.97	0.83	0.93	0.58	0.87
Uncut loss	Wg_1 (g)	0	0	0	0	0	0
	$\frac{Wg_1}{Yg} \times 100$ (%)	0	0	0	0	0	0
Shattering loss	Wg_2 (g)	9	8.7	9	6	5.7	7.68
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	3.1	2.81	3.1	2.07	1.84	2.58
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	9	8.7	9	6	5.7	7.68
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	3.1	2.8	3.1	2.07	1.84	2.58

Table 9. Average values of total yield, preharvest loss, sickle loss, uncut loss, shattering loss and cutterbar loss for 1 m^2 area for 5 plots

		I	II	III	IV	V	Average
Total yield Y_g (g)		300	300	300	300	298	300
Pre harvest loss	Wg_o (g)	0.03	0	0.018	0.018	0	0.013
	$\frac{Wg_o}{Yg} \times 100$ (%)	0.01	0	0.006	0.006	0	0.004
Sickle loss	W_1 (g)	2.64	2.64	2.64	2.58	2.58	2.62
	$\frac{W_1 - Wg_o}{Yg} \times 100$ (%)	0.87	0.88	0.87	0.85	0.87	0.87
Uncut loss	Wg_1 (g)	0.24	0.24	0.24	0.48	0	0.24
	$\frac{Wg_1}{Yg} \times 100$ (%)	0.08	0.08	0.08	0.16	0	0.08
Shattering loss	Wg_2 (g)	5.7	6.24	7.68	5.64	7.68	6.59
	$\frac{Wg_2 - Wg_o}{Yg} \times 100$ (%)	1.89	2.07	2.57	1.87	2.58	2.2
Cutterbar loss (total loss)	$Wgt = Wg_1 + Wg_2$ (g)	5.94	6.48	7.92	6.12	7.68	6.83
	$\frac{Wgt - Wgo}{Yg} \times 100$ (%)	1.97	2.15	2.65	2.03	2.58	2.28

each of the five plots are given in these tables. The average values are given in Table 9.

The difference between total cutterbar loss and sickle loss is 1.41 per cent. When the yield is assumed as 3 tonnes/ha the difference between cutterbar loss and sickle loss is only 42.3 kg. At a cost Rs.4 per kg of paddy, the loss is Rs.169.20 per ha. The loss is nullified by the reduction in cost of harvesting.

4.3 Power requirement

The engine of MF 245 tractor is found to run at 2000 rpm, the tractor PTO is giving 700 rpm. The conveyor belt pulley is having 400 rpm and the speed of the conveyor belt is 202 m/min. The strokes of cutterbar is calculated to be 1573 strokes/min. Speed of main components is given in Table 10.

The power requirement for running different sub-assemblies of reaper was found out as discussed in 3.3 and is shown in Table 11. The power requirement of intermediate shaft is 0.185 hp, universal joint is 0.09 hp, cutterbar is 0.625 hp, conveyor belt is 2.595 hp and the total power requirement is 3.495 hp. Compared to cutterbar, conveyor belt consumes more power. This test was conducted in the laboratory without actual cutting of paddy. Hence the power requirement of cutterbar was only for reciprocating motion and

Table 10. Relative speed of main components of paddy reaper

Engine, rpm	=	2000
PTO, rpm	=	700
Conveyor belt pulley, rpm	=	400
Intermediate shaft, rpm	=	1258 rpm
Vertical shaft, rpm	=	786.25
Cutterbar, strokes/min	=	1573
Speed of belt pulley, m/min	=	202 m/min
Speed reduction of auxiliary gear box	=	1:0.625

Table 11. Power requirement of sub-assemblies

Sub-assemblies	Power requirement (hp)		
	I	II	Average
Motor at no load (P_o)	0.400	0.400	0.400
Motor + shaft (P_s)	0.584	0.584	0.584
Motor + shaft + universal joints (P_u)	0.675	0.674	0.675
Motor + shaft + universal joints + cutterbar (P_c)	1.300	1.300	1.300
Motor + shaft + universal joints + cutterbar + conveyor belts (P_t)	3.894	3.895	3.895
Intermediate shaft (P_s-P_o)	0.184	0.185	0.185
Universal joints (P_u-P_s)	0.091	0.089	0.090
Cutterbar (P_c-P_u)	0.625	0.626	0.625
Conveyor belts (P_t-P_c)	2.594	2.595	2.595
Total power requirement of reaper (P_t-P_o)	3.494	3.495	3.495

the crop resistance was absent. But the conveyor belt had to operate starwheels and hence the power requirement of conveyor belt is comparatively more. From the review the average cutting resistance of paddy crop is 60 kgf/m. Therefore the power requirement to overcome the cutting resistance at a forward speed of 1 m/s for 2.1 m wide reaper is only 1.68 hp. Thus the power requirement of harvesting operation is 5.175 hp. There is some more power required for conveying the cut crop. Even then the total power requirement will be very much below the PTO capacity of 15 hp. This reserve power available will undertake any unforseen requirement.

4.4 Stability analysis

The stability analysis by way of studying the changes in the wheel reaction as discussed in section 3.4 had carried out. Table 12 gives the changes in the weight on the front and rear axle of the tractor with and without the reaper. The total weight of tractor is 1680 kg and the weight of tractor with reaper is 1970. The difference is 290 kg which is equal to the total weight of reaper, its mountings, intermediate shaft and universal joints. The difference in right half weight as well as left half weight with and without the harvester is the same and is 145 kg. This is half of the total weight of reaper, its mountings, intermediate shaft and universal joints. This indicates that the additional weight

Table 12. Weight measurement of weight of important components of reaper, tractor with and without the reaper for studying weight transfer

	Without harvester (kg)	With harvester (kg)
Total weight of tractor	1680	1970
Weight on front	675	1050
Weight on rear	1005	920
Right half weight	830	975
Left half weight	850	995

Weight of reaper = 185 kg

Weight of rear frame = 19 kg

Weight of front hitch frame = 52 kg

Weight of intermediate shaft + universal joints = 34 kg

Total weight of the reaper, rear frame, front frame & intermediate shaft = 185 + 19 + 52 + 34

= 290 kg

of mounting the reaper with the tractor is shared by both the right and left wheels equally without altering its stability. But the case of weight on front and weight on rear axles is different. After mounting the harvester, weight at front increased to the extent of 375 kg. As the reaper is mounted at the front, a portion of weight from rear wheels transfers to the front wheels which is equal to 85 kg. Thus the increase in weight on the front wheel is the sum of total weight of reaper and the weight transferred from the rear axle.

4.5 Economic analysis

The economic studies were done by comparing the cost of manual harvesting and harvesting by reaper. The studies are given in Appendix-XXIII.

From the above analysis it is found that the cost of harvesting paddy per ha by manual method is around Rs.1625. This can be reduced to the range of Rs.350 to 410 depending upon the shape and size of field and the pattern of harvesting the area by using tractor front mounted paddy reaper-windrower. The use of tractor operated reaper for harvesting paddy alone saves 75 to 78 per cent of the cost of harvesting. This is in addition to the saving of grains which otherwise will go on loss due to delay in harvesting. The labour displaced from harvesting by the use of tractor mounted paddy reaper windrower will be used for threshing the crop in the same day even if mechanical thresher is not available in the locality. This will avoid loss in the field due to rain and shedding.

The cost of harvesting for one hectare is Rs.350 for reverse method and Rs.410 for circuitous method. Thus the cost is more for the circuitous method than the reverse method. This is due to the more manual labour requirement for cutting and clearing the boundaries in the circuitous pattern. But if the area of the plot is more this pattern is profitable than the other pattern since the idle time is less and the cost of manual labour requirement for clearing boundaries will be reduced.

Then break even analysis was carried out between manual harvesting and machine harvesting. The assumption in the economic studies is that the cost of harvesting is directly proportional to the time of harvesting. But in this analysis it is assumed that some expenditure incured for machine harvesting even if no harvesting is carried out. The analysis was carried out on two situations.

Situation (i): The tractor is used only with the reaper for harvesting and it is not used for any other operations. So the cost of harvesting consists of the fixed cost of tractor and reaper and the variable cost. Even if no area is harvested the cost of harvesting is the fixed cost of tractor and reaper. As the harvesting area increases the cost of operation increases due to the increase in the variable cost with the increase in duration of harvesting. The variable cost consists of the operating cost of tractor and reaper including the labour cost for manual harvesting and clearing which is required at the boundaries for clearing the field give pathway to the tractor mounted reaper.

Situation (ii): The tractor is used for harvesting and also for other purposes. So the cost of harvesting consists of the fixed cost of reaper and the variable cost. The variable cost consists of the fixed cost of tractor per hour and the cost of operation per hour. Even if no area is harvested the cost of harvesting is the fixed cost of reaper only. As the harvesting area increases the cost of operation increases due to the increase in the variable cost with the increase in duration of harvesting.

Figure 20 shows the break even analysis. Table 13 gives the calculations of the break even analysis. It was found that for the first situation 22.5 ha is the break even point and for the second situation 4.0 ha is the break even point.

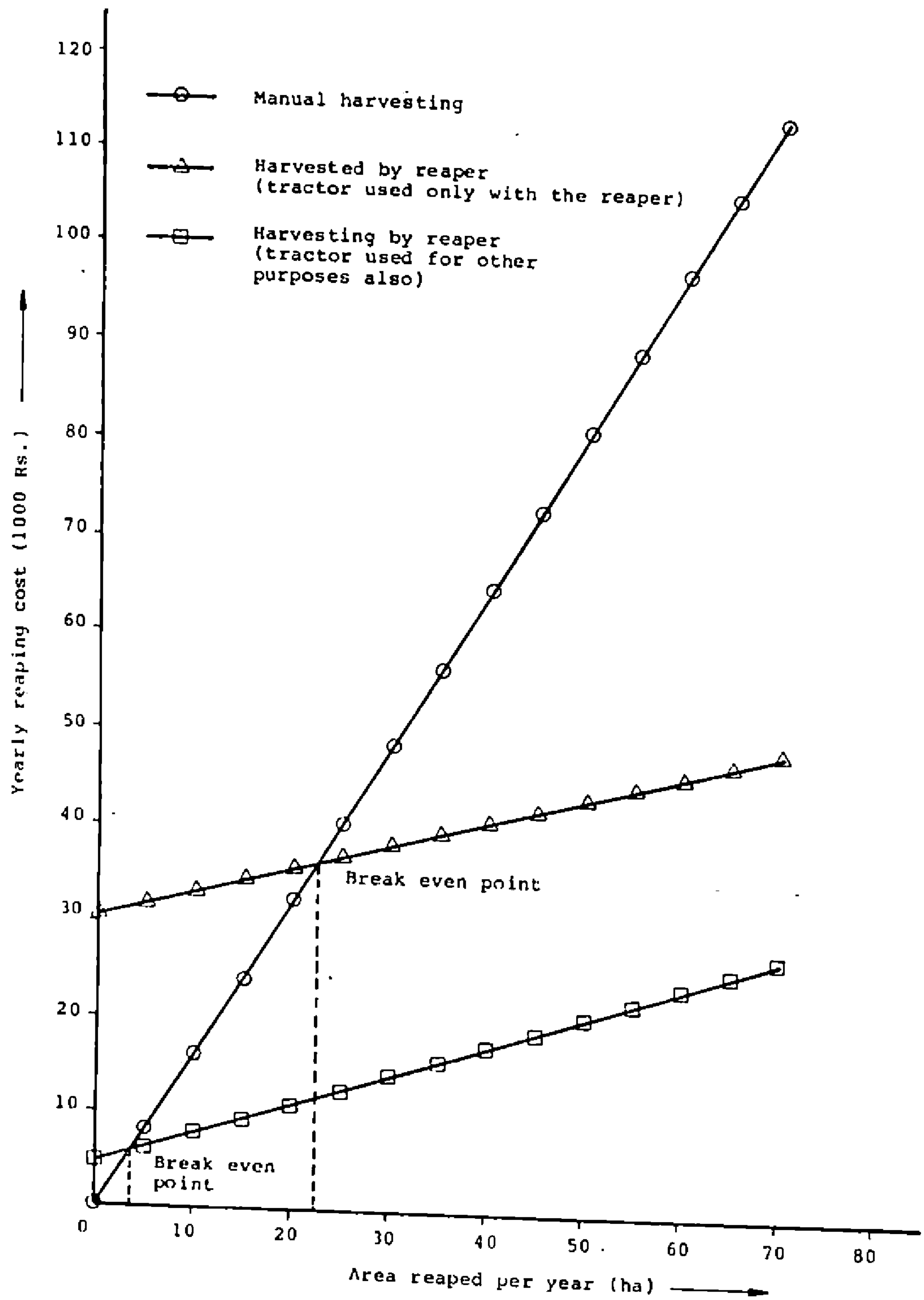


FIG.20 BREAK EVEN ANALYSIS OF COST OF HARVESTING

Table 13. Break even analysis of cost of harvesting

Area (ha)	Cost of manual harvesting (Rs)	Cost of harvesting by reaper (tractor is used only with reaper, and is not used for any other purposes) (Rs)	Cost of harvesting by reaper (tractor is used for other purposes also) (Rs)
0	0	30620.00	4150.00
5	8125	31890.38	5777.72
10	16250	33160.75	7405.44
15	24375	34431.13	9033.16
20	32500	35701.50	10660.88
25	40625	36971.88	12288.60
30	48750	39512.63	13916.32
35	56875	38242.25	15544.04
40	65000	40783.00	17171.76
45	73125	42053.38	18799.48
50	81250	43323.75	20427.20
55	89375	44594.13	22054.92
60	97500	45864.50	23682.64
65	105625	47134.88	25310.36
70	113750	48405.25	26938.08
75	121875	49675.63	28565.80
80	130000	50946.00	30193.52
85	138125	52216.38	31821.24

Sample calculation

(i) Manual harvesting

Cost of harvesting for 5 ha = 5 x 25 x 65

= Rs.8125

(ii) Harvesting by reaper

Labour requirement for manual harvesting at the boundaries and for collecting the cut crop is 11 woman hours per ha.

Manual labour cost = $11 \times \frac{65}{8}$

= Rs.89.375/ha

Average time required for machine harvesting = 2.7 hr

(a) Repaer harvesting:- (Tractor is used only for harvesting with the reaper)

Cost of harvesting

for 0 ha = fixed cost of tractor + fixed cost of reaper

= 26470 + 4150

= Rs. 30620

for 5 ha = fixed cost of tractor + fixed cost of reaper + variable cost + manual labour cost

= $26470+4150+5 \times 2.7 \times 61+5 \times 11 \times \frac{65}{8}$

= Rs.31890.38

(b) Reaper harvesting:- (Tractor used for other purposes also)

Cost of harvesting

for 0 ha = fixed cost of reaper

= Rs.4150

for 5 ha = fixed cost of reaper + cost of tractor for the area + manual labour cost

$$= 4150+5\times2.7\times87.47+5\times11\times \frac{65}{8}$$

= Rs. 5777.72

During the period of study the farmers who visited the college for collecting information about the reaper, expressed their opinion that if the tractor mounted reaper is available on hire basis they are ready to take it even at a cost of Rs.400 per hr. The reaper harvests 1 ha in 2.7 hr. Therefore the cost of harvesting per ha is Rs.1080. The cost of harvesting by using sickles is Rs.1625. Thus the farmers will get a profit of Rs.545/ha if they hire the reaper at a cost of Rs.400/hr. The farmer will be benefitted by timeliness also.

The reaper costs Rs.410/ha i.e. Rs.410 per 2.7 hr. Therefore the reaper costs only Rs.150/hr. Therefore by giving on hire basis at a cost of Rs.400/hr, the owner will get a profit of Rs.250/hr. The studies indicates that both the owners of the tractor mounted paddy reaper windrower who hire out for harvesting and the farmers who use the reaper on hire basis are getting a monetary benefit.

The total manual labour requirement of the reaper per ha is an operator for 2.7 hr and 11 man-h for cutting and collecting the cut crop at the boundaries. Therefore the total labour requiremend is 13.7 i.e. 14 man-h/ha. The conventional method requires 200 man-h/ha. Thus there is a saving of 186 man hours.

Summary

SUMMARY

The area and production of paddy, the major food crop in Kerala, is decreasing due to high production cost. The high labour requirement for this crop and the high wage rates for labourers in Kerala are the major reasons for the increased cost of cultivation and hence the return is not remunerative.

To reduce the cost of cultivation, introduction of appropriate farm mechinery is necessary atleast for the high labour intensive operations like transplanting, harvesting and threshing. Tractor is widely used for the land preparation in Kerala and the tractor mounted paddy reaper will be acceptable by farmers.

A suitable tractor front mounted paddy reaper-windrower was got fabricated. The important components such as cutterbar assembly, conveying assembly, hitching and lifting assembly and power transmission assembly were studied in detail and the defects were rectified to attain smooth operation.

Substitution of many small components like counterbolts to ordinary bolts in the knife guards, design and

fabrication of front hitch frame to suit MF 245 tractor, modification of supports to the extended shafts, lengthening of splined shaft and development of two roller support to prevent rubbing of wire ropes on foot rest were carried out. Steel cups were provided on the starwheel shafts to prevent wrapping of straw around the starwheel hub. The starwheels, pressure springs and discharge plate were correctly aligned to achieve proper conveying. Alignment and clearance of every element were adjusted to achieve perfect operation.

The reaper receives the power supply from the PTO shaft of the tractor, through the intermediate shaft to the auxillary gearbox of the reaper. From the gearbox through the pitman and guide, the cutterbar gets the reciprocating motion. The conveyor belts also get the drive from the auxiliary gearbox through pulleys and belts. The hydraulic links of the tractor are connected to the reaper through a pair of wire ropes and 'A' frames for lifting and lowering of the reaper. The forward movement of the reaper is achieved through the forward movement of the tractor.

As the tractor is moving forward and PTO shaft is engaged to operate the reaper the crop row dividers with the starwheels lift, gather, guide and hold the crop. The cutting is carried out by the scissor-like cutting action between reciprocating knife sections and stationary ledger plates.

The starwheels together with the pressure springs feed and hold the cutcrop to the conveyor belts having lugs and convey the cutcrop to right side through the discharge plate. The cutcrop is discharged at the right end of the reaper in the ground as a neat windrow.

After carrying out all the modifications extensive field trials were conducted at farms of K.C.A.E.T., Tavanur; R.A.R.S., Pattambi and at various farmer's fields and the defects during the long term field operations were rectified properly.

Field trials were conducted at K.C.A.E.T. farm, Tavanur to evaluate the performance of the reaper windrower. Two patterns of harvesting viz., reverse method and circuitous method were adopted and were compared. Total time taken to cover each plot, duration of harvesting run and duration of idle run were noted. The field efficiency was found to be 97.9 per cent and 99.7 per cent respectively for the two patterns. It was found that the circuitous pattern is better. The percentage of duration of idle run to cutting run in this method is 3.79 per cent less than that in reverse method. The average field capacity is 0.37 ha per hr.

Total yield, preharvest loss, sickle loss, uncut loss, shattering loss and total outerbar loss per sq m area were calculated from five randomly selected areas in each plot. The average values were 300 g, 0.004 per cent, 0.87 per cent, 0.08 per cent, 2.2 per cent and 2.28 per cent respectively. The losses occurred by the use of the reaper are slightly higher compared to manual harvesting which is compensated by the savings in the cost of harvesting.

While manual harvesting needs Rs.1625 per hectare the tractor operated reaper requires only Rs.400. An amount of Rs.1225 is saved per ha by introducing the reaper alone, which will reduce the cost of cultivation to a significant level. The break even point for the reaper is 4 ha when the tractor is also used for other operations and is increased to 22.5 ha when the tractor is used only for harvesting with reaper.

The power required to operate without any crop is 0.625 hp for cutterbar, 2.595 hp for conveyor belts, 0.09 hp for universal joints, 0.185 hp for the intermediate shaft and the total power requirement of the reaper assembly is 3.495 hp only.

The weight distribution of the tractor with and without the reaper on all the four wheels were studied. With reaper the tractor front exle had an increase of 375 kg and the rear axle had a decrease of 85 kg compared to the tractor without reaper. This was due to the weight of the reaper at the front axle and the weight transfer from rear wheels. The weights at the front and rear axles are equally shared between the right and left wheels without altering the stability.

From the studies it is well established that the tractor front mounted reaper-windrower which costs around Rs.20,000 is technically and economically suitable for harvesting paddy crop in Kerala. It is found that the owner of tractor mounted paddy reaper windrower who hire out the reaper at a cost of Rs.400/hr get a profit of Rs.250/hr whereas the farmer using the hired reaper get a savings of Rs.545/ha in addition to the timeliness. A saving of 186 man-h per ha is another achievement of the introduction of the tractor mounted paddy reaper.

References

REFERENCES

Araullo, E.V., Graham, M. and Padua. (1976). Rice Postharvest Technology. International Development Research Centre, Canada. pp. 83-105.

Asokan, D. and Shanmugham, A. (1993). Adaption of Vertical Reaper for Sorghum Harvesting. Annual Report 1991-92, TNAU, Coimbatore: 37-50.

Bhatnagar, A.P. (1969). Development of Animal drawn reaper with engine driven knife bar. Indian J. Agric. Sci. 39 (1): 105-112.

Bockhop, C.W., Duff, B., Fernandez, C.P., Juarez, F.S., Manaligod, H.T., Salazar, G.C. and Stickney, R.E. (1985). CAAMS-IRRI Mechanical Reaper: Experiences in the Philippines. Proceedings of International Conference on Agricultural Equipment for Developing Countries. Manila, Phillippines: 341.

Braunbeck, O.A. and Wilkinson, R.H. (1977). Elements of Agricultural Machinery Vol.2, FAO, Rome. pp.165.

Chauhan, A.M. (1973). Power tiller front mounted reaper. J. Agric. Engng. 10 (2): 65-68.

Chauhan, A.M. and Kalkat, H.S. (1976). Development and evaluation of a rear mounted reaper binder. J. Agric. Engng. 13 (2): 64-67.

Das, P.K. (1988). Design and balancing of reciprocating cutterbar. Proceedings of National Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Datt, P. (1988). Design considerations in mounting of drive systems in harvesting machines. Proceedings of National Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Devnani, R.S. (1980). Harvesting Equipment Developed in India, C.I.A.E., Bhopal.

Devnani, R.S. (1988a). Design considerations of gathering and lifting devices for harversters. Proceedings of National Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Devnani, R.S. (1988b). Harvesting systems and historical development of mechanical harvesters in India. Proceedings of National Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Devnani, R.S. and Nag, K.N. (1970). The power tiller harvester. J Agric. Engng. 7 (4): 61-63.

Farm Guide (1993). Farm Information Bureau. Government of Kerala.

Garg, I.K., Gupta, P.K. and Sharma, V.K. (1983). Design, development and field evaluation of a tractor front mounted vertical conveying reaper windrower. Annual Report AICRP on FIM Scheme, PAU, Ludhiyana: 8-25.

Garg, I.K., Gupta, P.K. and Sharma, V.K. (1984). Monitoring the popularization and performance of tractor front mounted vertical conveyor reaper windrower at farmers level. Annual Report AICRP on FIM Scheme, PAU, Ludhiyana: 71-83.

Garg, I.K., Gupta, P.K. and Sharma, V.K. (1986). Production status and usage of PAU tractor front mounted vertical conveyor reaper windrower in Punjab. Agric. Engng. Today 10 (5): 19-25.

Garg, I.K. and Sharma, V.K. (1991). Tractor operated vertical conveyor reaper windrower. Indian Farming 40 (11): 32-36.

Ghosh, A.K. and Govindaswamy, S. (1969). Time of harvest, moisture content and method of drying on milling quality of rice. Oryza 6: 54.

Ghosh, R.K. and Swain, S. (1990). Practical Agricultural Engineering. Naya Prakash, Culcutta-6, I Ed. pp. 153-156.

ISI (1967). Indian Standard Specification for Sickle. Indian Standard Institution, New Delhi.

ISI (1979). Indian Standard Guide for Estimating Cost of Farm Machinery Operation. Indian Standard Institution, New Delhi.

ISI (1985). Indian Standard Test Code for Cereal Harvesting Machines. Indian Standard Institution, New Delhi.

Joy, F.K.J. (1993). Harvesting made easier. Indian Express (22.9.93), Kochi: 8-9.

Kanafojski, C.Z. and Karwowski, T. (1976). Agricultural Machines Theory and Construction Vol2 Crop Harvesting Machines. Foreign Scientific Publications Department, Warsaw. pp. 48-120.

KAU. (1990). Research Report, 1987-90.

KAU. (1991). Research Report, 1990-91.

Klenin, N.I., Popov, I.F. and Sakun, V.A. (1985). Agricultural Machines. Amerind Publishing Co. Pvt. Ltd., New Delhi. pp. 294-333.

Ling, B. (1986). Wheat and paddy reapers in China - Small farm equipment for developing countries. Proceedings of International Conference on Agricultural Equipment for Developing Countries. Manila, Philippines: 329.

Michael, A.M. and Ojha, T.P. (1978). Principles of Agricultural Engineering Vol.1. Jain Brothers, New Delhi, 2nd Ed. pp. 278-297.

Pandey, M.M. (1981). Harvesting Handtools of India, CIAE, Bhopal.

Pandey, M.M. (1985). Introduction to harvesting machinery and their selection. Seminar on Utilization of FIM, Trainers Training Centre, C.I.A.E., Bhopal.

Pandey, M.M. (1988). Principles and design of a sickle. Proceedings of Natiional Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Sahay, J. (1992). Elements of Agricultural Engineering, Agro Book Agency, Patna, 3rd Ed. pp. 273-280.

Shanmugham, C.R. (1981). Farm Machinery and Energy Research in India, CIAE, Bhopal. pp. 240.

Singh, M.S., Singh, B. and Singh, K.N. (1977). Analysis of power requirement of a bullock operated harvester. J. Agric. Engng. 15 (2): 54-59.

Singh, M.S. and Singh, K.N. (1978). Force requirements of different sickles. J. Agric. Engng. 15 (1): 11-18.

Sivaswami, M. (1990). Evaluation of self propelled vertical conveyor reaper for paddy. AICRP on FIM Annual Report of K.C.A.E.T., Tavanur.

Sivaswami, M. (1991). Evaluation of one metre vertical conveyor reaper. AICRP on FIM Annual Report of K.C.A.E.T., Tavanur.

Sivaswàmi, M. (1992). Evaluation of one metre vertical conveyor reaper-IRRI model (5 hp Paddy Harvester). Proceedings of AICRP on FIM Annual Report, K.C.A.E.T., Tavanur.

Smith, H.P.A.E. and Wikes, L.H.M.S. (1977). Farm Machinery and Equipment. Tata Mc-Graw Hill Publishing Company Ltd., New Delhi, 6th Ed. pp. 286-324.

Tomar, J.B. (1985). Quality seed protection technologies for rice. Indian Farming 35 (3): 7-10.

Venkateswarlu, B. (1993). Rice. East Merits More Attention. The Hindu Survey of Indian Agriculture 1992: 22-27.

Verma, S.R. and Garg, R.L. (1970). Development and performance of a tractor mounted, PTO-operated self raking reaper. Agric. Engr. 15: 29-37.

Verma, S.R. and Garg, R.L. (1971). Design and development of tractor front mounted reaper. J. Agric. Engng. 8 (2): 55-59.

Yadav, B.G. (1991). A new design concept for animal drawn harvester. AMA 22 (4): 33-36.

Yadav, R.N.S. (1988). Design and development of bullock drawn reaper. Proceedings of Natiional Training Course on Farm Machinery Product Development for Manufacturing Phase II. C.I.A.E., Bhopal.

Yadav, R.N.S. (1990). Harvesting tools, machines and equipment. Proceedings of Training Course for Research on Agricultural Implements, Trainers Training Centre, C.I.A.E., Bhopal. 54-64.

Appendices

Appendix-I

Specifications of Naveen sickle (CIAE improved sickle)

1	Name of sickle	:	Naveen
2	Blade		
2.1	Length of blade (mm)	:	260
2.2	Length of cutting edge (mm) along with the edge	:	240
2.3	Maximum width & thickness (mm)	:	33 & 1.12
2.4	Radius of curvature & concavity (mm)	:	260 & 28
2.5	Cross section of blade	:	Rectangular
2.6	Type of cutting edge	:	Serrated
2.7	Number of teeth per cm	:	4.5
2.8	Height of teeth (mm)	:	1.7
2.9	Length of chord of cutting edge (mm)	:	225
2.10	Angle between handle and chord (degrees)	:	150
2.11	Material	:	Carbon steel
3	Handle		
3.1	Material & cross section	:	Wood & elliptical
3.2	Maximum diameter or thickness (mm)	:	40
3.3	Length (mm)	:	175
4	Weight of sickle, blade & handle (g)	:	257, 167 & 90
5	Joint of blade and handle	:	Blade riveted below the handle

Appendix-II

Technical specifications and test result of different designs of animal drawn reaper

Description	PAU, Ludhiyana design	IARI, Pusa design	CIAE, Bhopal design
Type	Animal drawn	Animal drawn engine operated 2-3 hp	Animal drawn
Provision of auxiliary engine	Yes	Yes	No engine is required
Overall length	2725 mm	--	1850 mm
Overall width	3725 mm	1800 mm	2100 mm
Overall height	1225 mm	--	1500 mm
Overall weight	330 kg	--	215 kg
Width of cut	1065 mm	1125 mm	900 mm
Type of cutterbar	Standard cutterbar 76.2 mm pitch	Standard cutterbar 76.2 mm pitch	Standard cutterbar 76.2 mm pitch
Output	0.15 ha/hr	0.25 ha/hr	0.12-0.14 ha/hr
Draft of the machine	130 kg on plain land 180 kg on irrigation bunds	--	85-100 kg
Number of persons to work with the machine	6	--	3

Appendix-III

P.A.U. Animal drawn reaper

Specifications

Nominal width of cut	: 1000 mm
Length of cutterbar	: 1060 mm
Ground wheel diameter	: 665 mm
Wheel track	: 1200 mm
Speed ratio between land wheel & pitman wheel	: 1:30
Number of strokes of cutterbar per revolution of drive wheel	: 60
Approximate weight	: 330 kg
Maximum cutting velocity of cutterbar at 1.6 kmph	: 93.56 m/min
at 2.4 kmph	: 143.56 m/min
Height of cut	: 90 mm
Cost of machine	: Rs.1200 (as reported during 1967)

Field performance data

Output of machine	: 0.2 to 0.3 ha/hr
Field efficiency	: 86 per cent
Average working pull on plain ground	: 110 kg
Average working pull while crossing field bunds	: 160 kg
Average losses	: 5 per cent Approx.
Labour requirement	: 50 man-h/ha
Cost of harvesting	: Rs.60 per ha (1968 estimates)

Developed at P.A.U., Ludhiyana

Appendix-IV

P.A.U. Animal drawn engine operated reaper

Specifications

Nominal width of cut	: 1250 mm
Length of cutterbar	: 1370 mm
Wheel diameter	: 625 mm
Wheel track	: 1200 mm
Speed of pitman shaft	: 408 rpm
Maximum cutting velocity of cutterbar	: 816 strokes/min
Engine make	: 2 hp Villiers petrol
Engine speed	: 3200 rpm
Height of cut	: 90-95 mm
Cost of machine	: Rs.3500 with engine (during 1967-68)

Field performance data

Output of machine	: 0.2 to 0.3 ha/hr
Field efficiency	: 82 per cent
Average working pull on level ground	: 129 kg
Average pull while corssing irrigation bunds	: 180 kg
Average grain loss	: 3.5 % (wheat m.c. 7% variety c-273)
Labour requirements	: 50 man-h/ha
Number of workers required	: 8

Developed at P.A.U., Ludhiyana

Appendix-V

Paddy harvester

Specifications

Dimensions of harvester		
Length	:	1600 mm
Width	:	1350 mm
Height	:	1300 mm
Dimensions with power tiller		
Length	:	3850 mm
Width	:	1350 mm
Height	:	1300 mm
Weight of harvester	:	228 kg
Power source	:	8-10 hp two wheel tractor
Cutterbar width	:	900 mm
Cutterbar speed	:	600 strokes/min
Length of stroke	:	80 mm
Width of conveyor	:	900 mm
Speed of belt conveyor	:	44.3 m/min
Diameter of the roller	:	60 mm
Speed of roller	:	235 rpm
Reel diameter	:	1050 mm
Number of bats	:	5
Speed of rotation	:	20 rpm

Clutch pulley speed	:	480 rpm
Main shaft speed	:	300 rpm

Field performance data

Field capacity of machine	:	0.055 ha/hr
Speed of operation	:	1.5 kmph
Height of cut	:	80 mm above ground
Field losses	:	1% of field (crop yield 5 to 6 tonnes/ha)
Minimum height of crop for harvesting	:	700 mm

Developed at T.N.A.U., Coimbatore

Appendix-VI

Power tiller operated reaper windrower

Specifications

Length of machine	:	2480 mm
Width	:	1300 mm
Height	:	1370 mm
Weight	:	588 kg
Length of cutterbar	:	1000 mm
Speed of cutterbar	:	130 m/min
Width of canvas conveyor	:	920 mm
Slope of conveyor	:	30°
Speed of conveyor	:	47 m/min
Length of conveyor roller	:	1000 mm
Reel speed	:	50 m/min
Number of bats	:	5
Speed of operation	:	2.5 kmph

Performance data

Field capacity	:	0.1 ha/hr
Forward speed	:	2.4 kmph
Grain loss	:	3-5%
Labour requirement	:	50 man h/ha

Developed at P.A.U., Ludhiyana

Appendix-VII

Power tiller harvester

Specifications

Width of cut	:	900 mm
Speed of cutterbar	:	430 rpm
Number of strokes	:	860 per min
Reel speed	:	30 rpm
Conveyor speed	:	240 rpm
Power unit	:	5 hp power tiller

Field performance data

Speed of operation	:	1.3 kmph
Field efficiency	:	50 per cent
Stubble height	:	95 mm

Developed at University of Udaipur, Udaipur

Appendix-VIII

Self propelled paddy harvester

Specifications

Width of cut	:	750 mm
Speed of operation	:	3 kmph
Power	:	4-5 hp

Field performance data

Capacity	:	1.0 ha/day

Developed at C.M.E.R.I., Durgapur

Appendix-IX

Reaper binder

Specifications

Length of cutterbar	: 1300 mm
Overall length of machine	: 1200 mm
Overall width of machine	: 2200 mm
Size of bundle	: 150 mm
Power requirements	: 10 hp through PTO
Type	: Fully mounted

Field performance data

Capacity	: 1.2-7.6 ha/day

Developed at C.M.E.R.I., Durgapur

Appendix-X

PUSA Reaper (Tractor operated)

Specifications

Width of cutterbar	:	1.5 m or 2.0 m
Number of persons required to operate	:	2
Cutterbar speed	:	800 strokes per min

Performance data

Field capacity	:	2 to 2.5 ha/day (8 working hours)

Developed at I.A.R.I., New Delhi

Appendix-XI

Tractor rear mounted self raking type reaper

Specifications

Length ot cutterbar	:	1500 mm
Length of machine	:	3280 mm
Width	:	3170 mm
Height	:	2600 mm
Weight	:	550 kg
Diameter of wheel (for adjusting height of cut)	:	240 mm
Speed reduction from main drive shaft to pitman drive	:	1.33:1
Main drive shaft to spider shaft reduction	:	50.46:1
Number of roller guides	:	4
Cutterbar speed	:	90.054 m/min
Spacing between knife guards	:	75 mm
Included angleof knife section	:	60°
P TO speed	:	540 rpm

Field performance data

Field capacity	:	0.37 ha/hr
Field losses	:	Upto 2.0% (with moisture content between 7 to 12% dry basis)

Speed of operation	:	3 kmph
Tractor size required	:	30 hp with PTO. shaft and 3 point linkage arrangement
Number of workers required	:	6

Developed at P.A.U., Ludhiyana

Appendix-XII

Tractor front mounted reaper windrower

Specifications

Size of cutterbar	:	1500 mm
Length of conveyor apron	:	1950 mm
Width of the conveyor	:	1000 mm
Slope of conveyor	:	18°
Length of machine	:	2600 mm
Width	:	2400 mm
Height	:	1900 mm
Maximum cutting velocity of cutterbar	:	100 m/min
Speed of conveyor	:	51.0 m/min
Conveyor roller diameter	:	65 mm
Diameter of reel	:	1000 mm
Number of bats	:	5
Size of bats	:	40 x 15 mm
Range of height of reel adjustments	:	120 mm

Field performance data

Output or capacity of the machine	:	0.29 ha/hr
Speed of operation	:	2 to 2.5 kmph
Field losses	:	2 to 6% (Crop moisture content 5.6% db db and yield 3.78 tonnes/ha

Developed at P.A.U., Ludhiyana

Appendix-XIII

Tractor rear mounted reaper binder

Specifications

Length of machine	:	2380 m
Width	:	3270 mm
Cutterbar width	;	1360 mm
Cutterbar speed	:	130 m/min
Convas conveyor length	:	1670 mm
Canvas Conveyor Width	:	1300 mm
Canvas conveyor speed	:	480 m/min
Reel width	:	1270 mm
Reel diameter	:	1100 mm
Reel speed	:	50 m/min
Twine used	:	Sisal twine

Field Performance data

Operating speed	:	1.5 to 2.4 kmph
Field capacity	:	0.2 to 0.3 ha/hr
Grain loss	:	3 per cent
Weight to bundles	:	3 to 6 kg (Approx.)

Developed at P.A.U., Ludhiyana.

Appendix-XIV

Mountings and drive systems of various reapers

Sl. No.	Harvesting system	Type of mounting	Power source and drive	Example
1.	Animal drawn reapers	Trailed	Bullock	Not used now
2.	Trailed combine	Trailed	Tractor PTO	Several companies made this types of machines. Makes like Mincopalis were imported in India in fifties
3.	Side mounted reapers	Semi-mounted	Tractor PTO	This design is one of the earliest and still used in soyabean reaper developed by C.I.A.E.
4.	Front mounted reapers	Mounted	Tractor PTO	Tractor front mounted vertical conveyor reaper of C.I.A.E.
5.	Side mounted combine harvesters	Semi-mounted	Tractor PTO	Vicon Combine Harvester
6.	Self propelled combine harvesters	Self propelled	Engine	Most of the modern combines used in India like ESPI John Deere Swaraj
7.	Self propelled reapers	Self propelled	Engine	Italian & Japanese designs are used even today. C.I.A.E. self propelled reaper

Appendix-XV

Specification of Hot air oven

Make	:	Sri Rudran Instruments Co.
Temperature	:	250°C
Rating	:	1800 W
Sl.No.	:	2360 10.91

Appendix-XVI

Specification of Tachometer

Make	:	Prestige Counting Instruments (P) Ltd., Bombay
RPM range	:	30-50000 rpm

Appendix-XVII

Specifications of Wattmeter

Make	:	Nippon Electrical Instruments Company, Bombay
Model	:	NTW 5-10 A 500 V
No.	:	3768 , 3 ph 3 wires
Maximum power range	:	0-4.2 kw

Appendix-XVIII

Specifications of moisturemeter

Name	:	Osaw Agro Moisturemeter
Make	:	The Oriental Science Apparatus Workshop
Accuracy	:	$\pm$ 0.2 per cent
Range	:	8 to 40 per cent

Appendix-XIX

Specifications of motor

Sl.No.	:	552
Hp	:	7.5
Rpm	:	1440
Volts	:	400/440
Phase	:	3

Appendix-XX

Specifications of reaper

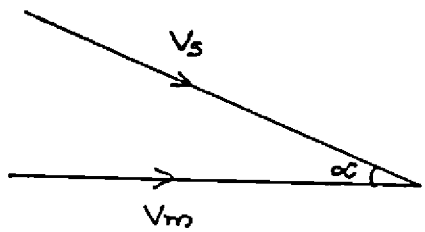
Suitability of crop	:	Paddy and wheat
Suitable crop height	:	50-100 cm
Cutting width	:	210 cm
Minimum cutting height	:	10 cm
Machine weight without mountings	:	185 kg
Weight of rear frame	:	19 kg
Weight of front frame	:	52 kg
Weight of intermediate shaft + universal joints	:	34 kg
Number of crop row dividers	:	8
Number of star wheels	:	7
Number of knife sections	:	28
Number of knife guards	:	29
Stroke length	:	75 mm
Number of pressure springs	:	13
Pitch of knife section	:	75 mm
Crank radius	:	37.5 mm
Width of conveyor belts	:	6 cm
Lug spacing	:	13 cm
Spacing between belts	:	95 mm
Angle of starwheel from horizontal	:	20°
Recommended forward speed	:	1 m/s

Speed of PTO	:	700 rpm
Engine rpm	:	2000
Time to harvest 1 ha	:	2.7 hr
Belt pulley rpm	:	400
Centre pulley rpm	:	625
Field capacity	:	0.37 ha/hr

Appendix-XXI

Design parameters for starwheel

The optimum inclination of starwheels, empirically arrived from field experiment is 20° with horizontal. The minimum required speed is calculated based on the following geometry.



where,

V_s = average starwheel velocity

V_m = machine forward velocity

α = angle of inclination of starwheel

Thus $$\frac{V_m}{V_s} = \cos\alpha$$

$$V_s = \frac{V_m}{\cos\alpha}$$

$$= \frac{V_m}{\cos 20}$$

$$V_s = 1.06\ V_1$$

Appendix-XXII

Field trial data

1. Field condition

a. Shape of the test field	:	Rectangular
b. Area of the test field	:	60 x 34 m^2
c. Topography of the field	:	Level
d. Type of the field	:	Dry land
e. Moisture content of soil	:	20 per cent dry basis
f. Frequency and size of bunds	:	Nil

2. Crop condition

a. Variety of paddy	:	Jyothi
b. Appearance	:	Straight (not lodged)
e. Moisture content	:	18 per cent dry basis
f. Straw grain ratio	:	1.5:1
g. Maturity of crop	:	100 days
h. Number of tillers/m^2	:	38
i. Total biomass of crop and weed	:	750 g/m^2
j. Number of grain per ear head	:	90
k. Extent of weeds	:	Negligible
l. Type of weeds present	:	not applicable

Appendix-XXIII

Economic studies

(i) Manual harvesting

An average of 25 woman days are required for only harvesting operation in an area of 1 ha.

The existing wage rate	=	Rs.65/woman day
The cost of harvesting per ha	=	25 x 65
	=	Rs.1625

(The value is also found to be correct when compared with the practice of giving paddy in kind as the wage for harvesting in the region. The share is nearly 1/7th of the total product)

(ii) Harvesting by tractor mounted reaper windrower

(A) Tractor:-

Initial cost of tractor (C)	=	Rs.170000
Fuel consumption	=	3 lit/hr
Fuel cost	=	Rs.7.5/lit
Oil cost	=	2/3 of fuel cost
Life of tractor (L)	=	10 years
Operating hours per annum (H)	=	1000
Salvage value (S)	=	10% of cost
	=	Rs.17000

Fixed cost

Annual depreciation $= \frac{C-S}{H} = \frac{170000-17000}{10}$

$=$ Rs.15300

Annual interest on investment

@ 10% of initial cost per annum $= \frac{C+S}{2} \times \frac{10}{100}$

$= \frac{170000 + 17000}{2} \times \frac{10}{100}$

$=$ Rs.9350

Insurance $=$ Rs.120

Taxes $=$ Nil

Housing cost @ 1% of initial cost $= 170000 \times \frac{1}{100}$

$=$ Rs.1700

Fixed cost per annum $= 15300+9350+120+1700$

$=$ Rs.26470

Variable cost

Repair and maintenance cost @ 5% of initial cost per annum $= 170000 \times \frac{5}{100}$

$=$ Rs.8500

Fuel cost per annum $= 10000 \times 3 \times 7.5$

$=$ Rs.22500

Oil cost per annum $= 2/3 \times 22500$

$=$ Rs.15000

Labour cost per annum	=	1000 x 15
	=	Rs.15000
Variable cost per annum	=	8500 + 22500 + 15000 + 15000
	=	Rs.61000
Total cost	=	Fixed cost + Variable cost
	=	26470 + 61000
	=	Rs.87470
Cost of operation of tractor per hr	=	$\frac{87470}{1000}$
	=	Rs.87.47

(B) Reaper:-

Initial cost of reaper (C)	=	Rs.20000
Life (L)	=	10 years
Operating hours (H)	=	480
Salvage value (S)	=	Rs.1000
Annual depreciation	=	$\frac{C-S}{L} = \frac{20000-1000}{10}$
	=	Rs.1900
Annual interest on investment @ 10% per annum	=	$\frac{C+S}{2} \times \frac{10}{100}$
	=	$\frac{20000 + 1000}{2} \times \frac{10}{100}$
	=	Rs.1050
Insurance	=	Nil

Housing @ 1% of initial cost = $20000 \times \frac{1}{100}$

= Rs.200

Repair and maintenance @ 5% of initial cost = $20000 \times \frac{5}{100}$

= Rs.1000

Total cost = 1900+1050+200+1000

= Rs.4150

Cost of operation of reaper per hr = $\frac{4150}{480}$

= Rs.8.65

Cost of operation of tractor mounted reaper per hr = 87.47 + 8.65

= Rs.96.12

Area of one plot = 2040 sq.m

Number of plots to be harvested to cover 1 ha = $\frac{10000}{2040}$

= 5

(a) Reverse harvesting pattern

Time required for harvesting one plot = 33 min 3 s

= 1983 s

Time required for harvesting 1 ha = $\frac{1983}{3600} \times 5$

= 2.75 hr

Cost of harvesting by tractor mounted reaper per ha = 96.12 x 2.75

= Rs.264.33

Area to be manually harvested for field preparation for the tractor mounted paddy reaper for one plot	=	3 times tractor standing area + 40 cm wide strip at the two right boundaries
	=	3x2.2x4+34x0.4+60x0.4
	=	64 sq.m.
Area to be manually harvested for 1 ha	=	64 x 5
	=	320 sq.m.
Labour requirement for harvesting the above specified area	=	$\frac{25 \times 8}{10000} \times 320$
	=	6.4 woman hours

5 woman are required to remove the cut crop within 10 minutes from the specified area for providing space for easy turning of tractor, for one plot.

Labour requirement for clearing	=	$\frac{5 \times 10}{60} \times 5$
	=	4.17 woman hours
Total labour requirement	=	6.4 + 4.17
	=	10.57 woman hours/ha
Cost of labour	=	$\frac{65}{8} \times 10.57$
	=	Rs.85.88
Total cost of harvesting by tractor mounted paddy reaper windrower including cost of land preparation for 1 ha	=	264.33 + 85.88
	=	Rs.350.21

(b) Circuitous harvesting pattern

Time required for harvesting one plot = 32 min 14 s

= 1934 s

Time required for harvesting one ha = $\frac{1934}{3600} \times 5$

= 2.69 hr

Cost of harvesting by tractor mounted reaper = 96.12 x 2.69

= Rs.258.56

Field preparations for harvesting by a tractor mounted paddy reaper for one plot requires manual harvesting for an area of 3 times the tractor standing area + 40 cm wide strip at four boundaries = 3 x 2.2 x 4 + 2 (34 x 0.4 + 60 x 0.4)

= 101.6 sq.m.

Manual harvesting area for 1 ha = 101.6 x 5

= 508 sq.m.

Labour requirement = $\frac{25 \times 8}{10000} \times 508$

= 10.16 woman hours

The area and the quantity of cut crop to be removed for clearing the area for easy turning tractor for the method II is double that of method I. Hence the labour requirement also become double.

Labour requirement = 4.17 x 2

= 8.34 woman hours

Total labour requirement	= 10.16 + 8.34
	= 18.5 woman hours
Cost of labour	= $18.5 \times \frac{65}{8}$
	= Rs.150.31
Total cost of harvesting by tractor mounted paddy reaper windrower including cost of land preparation for 1 ha	= 258.56 + 150.31
	= Rs.408.87
	= Rs.410

STUDIES ON TRACTOR MOUNTED PADDY REAPER

By

SUJATHA ELAVANA

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

Malappuram

1993

ABSTRACT

A tractor front mounted 2.2 m pully reaper-windrower was got fabricated from Punjab. Modifications were carried out to suit to Kerala conditions. Power is drawn from the PTO shaft of the tractor through the intermediate shaft to the auxillary gearbox of the reaper. From the gearbox power is transmitted to cutterbar and conveying assemblies. The reaper assembly is connected to the hydraulic link of the tractor through wire ropes and 'A' frames for lifting and lowering of the reaper. The crop is cut by the reciprocating knife and is conveyed through crop row dividers, starwheels, pressure springs and lugged conveyor belts and is discharged as a neat windrow.

The weight distribution of tractor with and without the reaper on all the four wheels were studied. It was found that in addition to the weight of the reaper at the front axle, a weight of 85 kg is transferred from the rear axle to the front axle when the reaper is mounted at the front of the tractor. The weight of the reaper is equally shared by the left and right wheels without affecting the stability.

The idle power requirement of the cutterbar, conveyor belts, universal joints, intermediate shaft and the total

power requirement are found to be 0.625 hp, 2.595 hp, 0.09 hp, 0.185 hp and 3.495 hp respectively.

The cost of the reaper is Rs.20,000. The average field capacity is found to be 0.37 ha/hr. The circuitous pattern of harvesting is found economical compared to the reverse pattern. The preharvest loss, sickle loss, uncut loss, shattering loss and total cutterbar loss were found to be 0.004 per cent, 0.87 per cent, 0.08 per cent, 2.2 per cent and 2.28 per cent respectively. Manual harvesting costs Rs.1625/ha whereas reaper needs only Rs.400/ha having a saving of Rs.1225/ha in addition to timeliness of work and saving in manual labour upto 186 man-h/ha.

It is established that the tractor front mounted paddy reaper-windrower is an appropriate agricultural machine which suites technically and economically to Kerala conditions and helps to reduce the cost of cultivation of paddy and is recommended for popularization.