DYNAMICS OF POWER TRANSMISSION IN TRACTOR MOUNTED PADDY REAPER

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Dynamics of Power Transmission in Tractor Mounted Paddy Reaper"** 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 any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Dynamics of Power Transmission in Tractor Mounted Paddy Reaper"** is a record of original work done independently by Sri. Sushilendra, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Dedicated to

My Loving Parents

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SYMBOLS AND ABBREVIATIONS

Agric	-	Agricultural
AICRP	-	All India co-ordinated Research Project
AMA	-	Agricultural Mechanisation in Asia
CAAMS	-	Chinese Academic of Agricultural Mechanisation Sciences
CI	-	Cast Iron
CIAE	-	Central Institute of Agricultural Engineering
cm	-	Centimetre(s)
CMERI	-	Central Mechanical Engineering Research
D	-	Diameter
d.f	-	degree of freedom
dia.	-	Diameter
Dept.	-	Department
Engng.	-	Engineering
Engr.	-	Engineer
et al.	-	and others
FAO	-	Food and Agriculture Organization
Fig.	-	Figure
FIM	-	Farm Implements and Machinery
FPME	-	Farm Power Machinery and Energy
g	-	gram(s)
ha	-	hectare(s)
HG	-	High gear
hp	-	horse power
hr	-	hour
IARI	-	Indian Agricultural Research Institute
ICAR	-	Indian Council of Agricultural Research
i.e	-	that is
IRRI	-	International Rice Research Institute
ISI	-	Indian Standard Institute
J.	-	Journal
KAMCO	-	Kerala Agro-Machinery Co-operation
KAU	-	Kerala Agricultural University

KCAET	-	Kelappaji College of Agricultural Engineering and Technology
Kg	-	Kilogram
kmph	-	kilometer per hour
kw	-	kilo watt
L	-	Length
Lit.	-	Litre(s)
LG	-	low gear
Ltd.	-	limited
m	-	metre(s)
man-hr	-	man hour(s)
mc	-	moisture content
MF	-	Messey Ferguson
min.	-	minute(s)
mm	-	millimetre
MS	-	Mild Steel
M/s	-	Messers
PAU	-	Punjab Agricultural University
PP	-	Pages
PTO	-	Power Take Off
Pvt.	-	Private
RARS	-	Regional Agricultural Research Station
RNAM	-	Regional Network for Agricultural Machinery
rpm	-	revolutions per minute
Rs.	-	Rupees
S	-	Second(s)
Sci.	-	Sciences
Sec	-	second(s)
TNAU	-	Tamil Nadu Agricultural University
viz.	-	namely
W	-	Watt(s)
&	-	and
@	-	at the rate of
$^{\circ}$	-	degree
/	-	per
%	-	percentage
π	-	pie

Introduction

INTRODUCTION

Paddy is one of the important agricultural commodities in world trade eventhough it is less than five per cent of the total production of all agricultural commodities. The total world paddy production is estimated to be about 420 million tonnes. Asia is the major paddy producing continent with 91 per cent of the world's paddy production and India is the second largest paddy producing country in the world.

Since the introduction of high yielding varieties and use of other inputs like chemical fertilizers, herbicides, pesticides and better means of irrigation, India has been witnessing a progressive growth in paddy production. Paddy production is increased from 20.58 million tonnes in 1950-51 to 81.61 million tonnes in 1994-95. Productivity increased from 668 kg/ha to 2,487 kg/ha. In 1989-90, India was able to export paddy to a level of over 0.40 million tonnes. The growth since then increased gradually touching a record export of 0.75 million tonnes in 1991-92 (Farm Guide, 1986 and 1995).

It has been found that India's present productivity is only 75 per cent of that world's productivity of 3,320 kg/ha. It has been observed that India can produce additional 37.5 million tonnes of paddy if she attains the average productivity of Asia which is 3402 kg/ha.

One of the reasons for the low productivity is insufficient power availability on the farms and low level of mechanisation. In order to achieve the increase in the productivity, the power availability has to be increased from 0.54 hp/ha to 1 hp/ha (Michael and Ojha, 1978).

Agricultural production of Kerala has been lagging behind other states in India. The share of agricultural sector in the state's domestic product which was in the order of 59.0 per cent in 1960-61, declined to 49.5 per cent in 1970-71. This trend was continued and it's share was only 39.0 per cent in 1989-90 (Zachariah, 1995).

Paddy cultivation in Kerala is confronting a crisis today. The last two decades witnessed a steady decrease in area and production of paddy because of high production cost attributed by non-availability of labourers for farm operations and high wage rates. The area under paddy has been reduced from 0.74 m ha in 1983-84 to 0.50 m ha in 1994-95 (Farm Guide, 1985 and 1995). The total paddy production during past few years has been stagnating between 1.10 to 1.11 million tonnes.

In paddy cultivation, transplanting, harvesting and threshing are the three major labour intensive operations. Harvesting is an important operation which is laborious involving human drudgery and requires about 150-200 man hrs/ha. Traditionally, paddy is harvested by manual labour by using sickles. Due to the non-availability of labourers crop harvesting is often delayed which exposes the crop to vagaries of nature. Timely harvesting is utmost important as delayed harvesting leads to a considerable loss of grain and straw, owing to over maturity and hampers seed bed preparation and sowing operations for the next crop. This paucity of labour force has been forcing the farmers of Kerala to go for crops which are more remunerative and less labour intensive thus affecting the state's paddy production.

Mechanisation of harvesting could well be the answer to overcome these problems. As a consequence of this realization several types of paddy harvesters like, self-propelled type, power tiller operated and tractor mounted have been introduced and evaluated in Kerala recently. It has been found that, self-propelled harvester with 5 hp engine posses inadequate power output when the field is wet and soil is heavy.

Tractors and power tillers constitute the major items of agricultural machinery used for land preparation and other crop production operations. The average annual sale of tractors, in Kerala, during past few years has been increasing with 440 numbers in 1991-92 to 896 numbers in 1993 (Zachariah, 1995).

Visualising the great potential for tractors in Kerala and encouraged by the success of using tractors on hire basis, tractor mounted harvester has been introduced, to take care of labour scarcity in addition to increase in the annual use of tractors, in Kerala 1993. The tractor mounted harvester found suitable for harvesting paddy as it makes clean windrows with earheads on one side and plants laid perpendicular to the direction of travel for easy collection by manual labour (Sivaswami, 1993). Studies showed that the cost of operation and labour requirements for reaper were lower than the manual harvesting method. It has also been observed that, the quality of grain and straw was affected when harvesting fields with standing water, which is common in some parts of Kerala, as the swath was windrowed into the water. It was felt necessary, before recommending tractor mounted harvester to the farmers, to evaluate it's performance to determine the optimum operating parameters such as engine speed, forward speed of the machine, cutterbar linear speed and linear speed of conveyor.

Hence, the present work was taken up with the following objectives;

1. To establish the optimum relationship between the reciprocating cutterbar speed and tractor forward speed.

2. To analyse the correct conveyor speed in relation to the length of cutterbar and forward speed of tractor.

3. To develop a crop collecting attachment to the reaper.

4. To assess the economics of operation with manual harvesting.

Review of Literature

REVIEW OF LITERATURE

This chapter deals with the research works which were carried out, on paddy harvesting, different harvesting methods and types of paddy harvesters in India and abroad.

2.1 Harvesting

Harvesting is the operation of detaching, picking or cutting the crop from the undesired plant portion. Paddy harvesting involves cutting of the straw along with earhead to recover both paddy and straw.

Harvesting of paddy immediately after the cessation of the biological maturity ensures maximum yield. Too early a harvest results in more chaff and ill filled grains. Delayed harvesting results in low yield as the crop suffers various pre-harvest losses. Timely harvesting of crop ensures good grain quality and high market value.

It was found that paddy harvested a week before maturity exhibited the lowest level of average grain loss, 0.77 per cent, whereas the average grain losses at one week and two week after the maturity were 5.63 per cent and 8.64 per cent respectively with only 3.35 per cent loss at correct maturity (Ruiz, 1965).

According to Govindaswamy and Ghosh (1969) optimum harvesting time for early varieties is between 25 and 33 days after flowering and for medium and late varieties between 33 and 39 days after flowering.

The losses due to shedding and shattering of grains in the field can considerably be reduced by harvesting paddy as soon as it attains maturity, 30-35 days after flowering and at the moisture content at grain between 23 and 25 per cent (Michael and Ojha, 1978).

Pandey (1985) reported that in Ludhiana the shattering losses were high (10 per cent) when the harvesting was delayed. It is also established that early or late harvesting deteriorates the seed quality.

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

2.2 Cutting force requirements for paddy harvesting

Experiments have been done in U.S.A to evaluate the forces and energy in cutting of forage crops. The information available from these experiments was indirectly utilised for the studies on energy requirement for cutting of the single paddy stem.

The initial deformation of the stalk during cutting of forage crops accounts for about 25 per cent of the total cutting energy and plant fibres decrease in toughness from the base to the top of the plant (Fisher *et al.*, 1957). At the cutting speed of 2.54 cm/min the Alfalfa stem was flattened into two fibre sheets which subsequently failed separately. A blade bevel angle of 24 degree was reported to be the most efficient from the point of cutting and the force and energy values increase after the angle exceeds 30 degrees (Chancellor, 1958).

The effect of initial moisture content on the toughness of forage stalks was studied by Liljedahl *et al.*, 1961. The energy requirements for cutting was highest between 30 and 35 per cent initial moisture content of plants.

Trivedi (1965) during his studies on the harvesting and threshing of paddy found that the shear resistance per unit cross-sectional area of paddy increases with the distance of the section from the base of the plant. It was also found that the resistance to cutting is inversely proportional to the moisture content. Similar results were reported by Ingle (1965) during his studies on the analysis of power requirement of flywheel type chaff-cutter.

The losses incurred in harvesting were a function of variety, time, date and method of harvesting. The cutting strength of paddy stem is not constant throughout it's length but was found to increase along it's height and the force and energy required for cutting paddy stem varies inversely with it's initial moisture content and directly with it's cross sectional area. The cross sectional area has more pronounced effect on cutting force and energy. At 10 cm cutting height, the force and energy were minimum for the blade having 30 degree bevel angle. The effective cutting moisture content is 30-35 per cent and the stresses for cutting paddy stem varies from 40 to 99 kg per square cm for the cross-sectional area between 0.0389 and 0.0499 square cm (Rajput and Bhole, 1973).

The average cutting force during cutting portion of the stroke may be at least as great as the maximum inertia force of the knife. For a given mower the average cutting force is directly proportional to the feed rate. Both average and maximum cutting forces were found to increase with decrease in straw moisture content at the point of cut and increases with forward velocity and plant density. Higher shattering loss was observed at lower grain moisture contents. Percentage of shattering loss was found to decrease with increase in plant density but no definite trend was observed with forward velocity (Singh and Singh, 1978a).

The power requirement for harvesting wheat crop was computed by summing the power required to pull the reaper on wheat stubble field at no load and load conditions. The power requirement increased linearly with an increase in forward speed and same trend was observed for plant density. A forward speed of 1.5 kmph and plant density between 200 to 400 plants/square meter were found to be optimum for harvesting (Singh, 1981).

Rangaswamy (1981) during his studies on paddy harvester as an attachment to power tiller, found the followings.

a. The power required for cutting, conveying of paddy per hill was 0.128 hp.

b. The power required for traction of a power tiller mounted reaper was 2.22 hp.

c. The static shear stress and dynamic cutting stress of paddy found to be varied from 22.79 to 42.06 kg per square cm and 1.04 to 11.25 kg per square cm respectively.

The power requirements of a tractor front mounted vertical conveyor reaper-windrower were determined by Sidhu (1987). The tests were conducted at three levels of forward speeds *viz.*, 2.24, 2.68 and 3.24 km/hr, three levels of plant density *viz.*, 187, 329 and 396 tillers per square metre and at 8 cm and 16 cm cutting heights. He reported the following,

a. Total power requirement increased with an increase in the forward speed of machine.

b. Net and total power requirements increased with an increase in the plant density.

c. Net power, total power as well as net and total specific power requirements were increased with an increase in the conveyor index.

d. Net power, total power as well as net and total specific power requirements were less at higher cutting height (16 cm) than at the lower cutting height (8 cm).

2.3 Harvesting methods

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

2.3.1 Manual harvesting

The harvesting of paddy crop is traditionally done by human hands with the help of sickle. Sickle has been the most common harvesting tool used by majority of farmers for ages due to it's easy construction, low cost and simplicity in operation. Yoshida (1961) studied the different Indian sickles and found them belonging to shear type in which shearing force predominates the frictional cutting force at the cutting edge. He analysed the forces acting on the cutting edges of sickles theoretically and determined the various dimensions.

Manual harvesting involves slicing and tearing actions that result in plant structure failure due to compression, tension or shear. Sickles with serrated edge are light in weight and require less cutting force and are found to need no repeated sharpening (Michael and Ojha, 1978).

The force requirements for harvesting different crops were found to be less in the case of hand sickles having I.S.I. standards (Singh and Singh, 1978b). It was also found that materials which were used for sickle construction do not have significant difference in the force requirements for harvesting if edges are equally sharp.

Pandey (1981) compiled the information about all types of local sickles used in India. An improved, Naveen sickle was designed, incorporating best features of various sickles and utilizing the principle of frictional cutting. The Naveen sickle required minimum time to harvest the crop. An equation giving the relationship of the labour requirement with respect to the crop yield per ha for the sickle was also developed.

2.3.2 Animal operated reapers

Horse drawn reapers were widely used in America and European countries after their invention by Cyrus McCormik in 1830. The reaper saved nearly three fourth of the labour requirement. Some mowers were designed with a two speed gear box, the higher speed was used for cutting the grass and lower one for cutting dry stalks. He has also mentioned that corresponding to a forward travel of 3 kmph the knife bar was reciprocated about 30 times per revolution of the main driving wheel with an output of 0.2 ha/hr (Kamafoiski and Karwowski, 1976).

Verma and Bhatnagar (1970) made considerable efforts to develop bullock-drawn reapers suitable for Indian conditions. This machine was similar to the McCormik reaper in design but weight was reduced. Because of high draft and more labour requirement, this design could not become popular. To solve this problem of high draft, an auxillary engine was introduced to operate cutterbar whereas the machine was pulled by a pair of animals. This design also did not become popular as the quality of windrow was not good.

During 1968, at New Delhi the research work on animal drawn reaper was started. This research effort was similar to the work done at Ludhiana, excepting the introduction of horizontally operated belt conveyor windrower behind the cutterbar. This provision was made to windrow the harvested crop to a side (Khanna, 1980).

Singh (1981) carried out work on design and development of animal drawn reaper at Pantnagar. The relationship between power requirement and plant density at different speeds of operation were studied. The power required for harvesting increased with the increase in plant density and speed of operation. The research work on animal drawn reaper was further continued by introducing an auxillary engine in the design incorporating a vertical conveyor windrower in the system.

Due to one or other limitations not even a single design could become popular in any country. Seeing the pressing needs of animal drawn reapers in the country for cereals, the design and development work was initiated at Bhopal. This was light weight machine, required less draft as compared to earlier designs. The crop harvested by this machine was delivered in uniform bunches behind the cutterbar. The special feature of this machine was transformation of low soil thrust developed from the traction wheel into higher force for cutting crops through crank and lever mechanism. The field capacity was 0.12-0.14 ha/hr. The harvesting losses were less than 5 per cent with Rs.135/ha was the cost of harvesting with the machine (Yadav, 1988).

Animals which were a major source of draught power for ploughing and other land preparations in Kerala are becoming scarce and expensive. With the limitations in the usage of animals, such as size and capacity, the necessity for the introduction of power operated reapers in Kerala was emerged.

2.3.3 Power operated harvesters

Depending upon source of power, paddy harvesters are classified into three major types such as self-propelled, power tiller operated and tractor mounted harvesters.

2.3.3.1 Self-propelled reaper windrower

The Chinese Academy of Agricultural Mechanisation Sciences (CAAMS) in collaboration with IRRI improved the original Chinese reaper to suit agricultural and industrial conditions of developing countries. It was light, less expensive and easy to fabricate with shop tools. The design eliminated the lugged V-belts and simplified the conveyor drive and cutterbar mechanism. A self-propelled harvesting machine with 4.5 hp engine for paddy was developed by CMERI, Durgapur (Devnani, 1980).

Under CIAE-IRRI industrial extension project, Coimbatore, a self-propelled reaper based on the design of vertical conveyor reaper available from IRRI was developed in collaboration with manufacturers using 6 hp diesel engine.

Several demonstrations were organised resulting in reasonable sales of the reaper (Datt, 1987).

Satoh reaper binder (a self propelled 0.5 m wide walking type) was evaluated for harvesting wheat and paddy crops at Bhopal. The result indicated the high cost of operation, varying from Rs.189 to Rs.272/ha and the labour requirements were in the range of 50 to 60 man-hrs/ha. It was concluded that machine cannot be adopted by farmers unless it has low cost of operation, high output and low price (Devnani, 1988b).

In Kerala, the self propelled one metre vertical conveyor reaper was tested at farmers fields as well as at research stations from 1989 onwards. Several successful demonstrations were conducted in Kerala after incorporating modifications. With a pair of side clutches to facilitate easy steering in muddy fields, a new model was developed. The average field capacity was 0.14 ha per hour (KAU, 1991; Sivaswami, 1991). This unit was found suitable for paddy harvesting in dry and water logged fields.

Kubota Power Reaper (AR 120) has been developed by M/s KAMCO in Kerala. It was a self propelled paddy reaper windrower based on Kubota reapers of Japan. This was reported to be suitable for paddy and wheat harvesting (Indian Express, 1994).

2.3.3.2 Power tiller operated reapers

Attempts were made at Udaipur, Coimbatore and Durgapur to develop power tiller operated canvass conveyor type reapers. The performance was found satisfactory, when operated in well prepared paddy crop. This machine was selected for evaluation at different countries under Regional Network of Agricultural Machinery (RNAM) programme during 1978-80 (Devnani, 1980).

Devnani and Howson analysed the suitable size of harvester for crops on Indian farms during 1981. They concluded that 1.6 m will be an appropriate width of cut for a machine to be operated with a power tiller and 2.2 m with tractor. Accordingly the design and development of a power tiller operated vertical conveyor reaper was started and the first prototype was fabricated during 1981 by Bhopal.

A harvester as an attachment to power tiller with 5.4 hp Lambardini engine as it's prime mover was developed at Coimbatore. It was field tested for sorghum harvesting. The optimum engine speed, forward speed of machine and cutterbar speed were 1150 rpm, 2.5 km/hr and 0.80 m/s respectively. The operational cost of the machine for harvesting sorghum crop and forage crop were Rs.157.15/ha and Rs.127.85/ha respectively (Chinnaswamy, 1983).

Amjad and David (1983) evaluated the performance of power tiller operated vertical conveyor reaper for paddy and reported that the optimum machine performance was obtained with fast cutterbar speed and high gear. This not only minimized the harvesting losses but also maximized the work rate. The field capacity was 0.47 ha/hr with 76 per cent field efficiency.

Rahman (1985) modified the Chinese vertical conveyor reaper having one metre width and attached to a power tiller. Modifications of the header unit, star wheels, cutterbar knife mechanism, drive main, lifting mechanism and chain type conveyor were made.

An efficient and easy to operate mechanical paddy harvester has been developed at Philippines. The gasoline powered harvester was found efficient and cost effective. The stripper rotar of the machine, fitted with slotted teeth combs, the grains from the straw moved in an upward direction and fed into a container. When the container gets filled, it is quickly changed and harvesting can be continued. This machine could harvest 0.5 tonnes/hr. The speed of operation was 4 kmph and it's weight was 240 kg. It required only six people for operating in shifts. The approximate cost of machine was Rs.55000 without the engine (The Hindu, 1995).

Field evaluation of paddy harvestor of 1.6 m cutting width, operated by Mitsubishi power tiller, was carried out at Tavanur. The average field capacity was 0.20 ha/hr. The total harvesting loss due to machine harvesting was 2.43 per cent. The savings of 186 man-hrs/ha and Rs.1277/ha were achieved by the introduction of power tiller operated harvestor. The required improvements and modifications were carried out and it was found suitable for harvesting paddy both in wet as well as in dry fields except for the fully lodged crops (Selvan, 1995).

2.3.3.3 Tractor mounted reapers

In India, during 1968-69 the tractor pulled P.T.O. operated self raking harvestor was developed and evaluated for wheat harvesting. The machine could harvest an area of 3 to 4 ha/day with a saving of about Rs.555/ha and of 75 man-hr/ha (Verma and Garg, 1970).

During 1969-70, the tractor front mounted unit using cutterbar, reel and canvass conveyor was developed at Ludhiana. The field capacity was 0.29 ha/hr. The machine was able to cut the crop and drop it in the form of windrow for easier collection. Limited units were marketed in 1970-71 (Verma and Garg, 1971).

During 1974-79, work continued on the development of tractor rear mounted reaper binder with side delivery of crop bundles. This machine was evaluated at Ludhiana and at Bhopal. The performance of the machine was reported satisfactory (Devnani, 1980).

A tractor mounted reaper with a gathering arrangement was also developed at New Delhi during early seventies. It became famous as 'pusa reaper' but could not be commercialized. The machine cut and dropped the crop in bunches in the field for manual gathering (Devnani, 1980).

The prototype of the tractor mounted reaper-binder was tested and evaluated at Ludhiana. The overall working of the machine was found to be satisfactory. The machine was tested for paddy, oat and wheat. The machine was operated by a 35 hp tractor giving an output of 2.5 ha/day. The total harvesting loss of wheat was found to be around 7.00 per cent and 3.14 per cent during the harvesting seasons of 1974 and 1976 respectively (Chauhan and Kalkat, 1976).

Singh *et al.* (1984) conducted evaluation of three locally manufactured tractor mounted reapers in Pakistan. They reported that the average field capacity was 0.4 ha/hr with 4 per cent grain loss. The labour input for mechanical reaper was 5 man hr/ha as compared to 84 man hr/ha for manual harvesting. The reapers were operated at 2.68 to 3.28 km/hr.

A tractor front mounted vertical conveyor reaper windrower was evaluated in the field for its performance at different forward speeds, conveyor indices, crop densities and cutting height (Sidhu, 1987). He reported the followings:

a. Total harvesting losses increased and tillers angle of the windrow with respect to forward direction of travel decreased with an increase in the forward speed of machine.

b. Reaping loss decreased and windrow loss increased, with an increase in the crop density.

c. Tillers angle of the windrow with respect to forward direction of travel of machine increased with an increase in the crop density at the highest forward speed and an opposite trend was observed at lowest speed of machine.

d. Reaping loss decreased and windrow loss increased with an increase in the conveyor index.

e. Reaping, windrow and total harvesting loss was more at higher cutting height 16 cm than that at 8 cm.

A forward speed of 2.68 km/hr, 1.60 conveyor index and lower cutting height of 8 cm were recommend for wheat harvesting.

Bukhari *et al.* (1991) conducted field investigation to study the grain losses by a mechanical reaper and manual harvesting for wheat crop. They reported that the total grain losses were 41.0 to 48.4 kg/ha for machine harvesting and 84.9 to 139.6 kg/ha for manual harvesting.

A tractor mounted 2.2 m wide vertical conveyor reaper for harvesting paddy was field tested at Tavanur. Modifications on various components to achieve efficient power transmission, hitching, lifting and lowering of reaper and prevention of winding of paddy straw were carried out. Field evaluation revealed that with the field capacity of 0.38 ha/hr an amount of Rs.900/ha and 130 man-hr/ha could be saved in harvesting (Sujatha, 1993; Sivaswami, 1993).

Chauhan *et al.* (1994) conducted studies on the adoption behaviour of farmers for the tractor front mounted vertical conveyor reaper for harvesting wheat crop. They reported that none of the farmers were satisfied with the after sales services provided by manufacturers. The users were not satisfied with the functional performance of the reaper due to frequent break downs and failures observed in the reapers which included breakage of blades, guards, welding etc. These types of failures of parts were due to bunds laid in the field and poor materials used in the reaper.

A study was conducted to evaluate the performance and to assess the technical problems in vertical conveyor reapers being manufactured in the state of Punjab. The field capacity of the machines for wheat and paddy varied between 0.24 to 0.30 ha/hr and 0.23 to 0.33 ha/hr respectively. The total losses ranged from 0.23-2.08 per cent and 0.11 to 0.90

per cent for wheat and paddy respectively. No major break down or defect was observed in the machines (Manes *et al.*, 1995).

Modifications and improvements of components and sub-assemblies of the tractor mounted 2.2 m reaper windrower were carried out at Tavanur to harvest paddy in wet lands of Kerala. Studies were conducted on reaper with MF 245 tractor to harvest paddy in different field conditions. The tractor front wheel reaction has an increase of 56.7 per cent while the rear wheel reaction indicated a reduction of 8.9 per cent when fitted with the reaper (Sivaswami, 1995).

The studies undertaken on tractor operated cereal harvesters had resulted in the development of harvesters for wheat and paddy crop, in Northern India. In Kerala also, several field tests and successful field demonstrations of tractor operated harvester were conducted for harvesting paddy. But so far no efforts have been made to determine the optimum operating parameters of paddy harvester. Hence the present work is undertaken to determine the optimum values of important operating parameters of tractor front mounted harvester for Kerala conditions.

Materials and Methods

MATERIALS AND METHODS

Studies were conducted on the dynamics of power transmission in tractor front mounted paddy reaper windrower to determine the optimum relationship between forward speed of tractor, reciprocating speed of cutterbar and linear speed of conveyor belts under Kerala conditions. In this chapter, the test procedure followed for conducting laboratory and field studies to determine the optimum relationship, feasibility studies on providing additional facilities to improve the performance under wet conditions, economic analysis and comparison with traditional method of harvesting are described.

3.1 Selection of suitable machine harvesting method for Kerala conditions

Adoption of efficient harvesting machinery for paddy, which is one of the most important crops of Kerala, is a pressing need of the day. The harvesting of paddy is mostly done by human hands with the help of sickle, which is laborious and involves drudgery. It takes about 150 to 200 man-hrs to harvest one ha of paddy crop. Due to the labour scarcity at the time of harvesting, the entire operation continues for weeks together resulting in loss of grains to the extent of 5 to 10 per cent. Mechanisation of paddy harvesting is the most suitable way of solving this problem.

The direct combining helps in reducing the weather hazards to the standing crops by harvesting at slightly higher moisture. It involves least labour but because of high cost of harvester and loss of straw, which is used as cattle feed and fetches a good price of Rs.1000 to 1200/ha, this method is not prevalent in the country.

The other appropriate method would be binding and stacking. The field evaluation of reaper binders indicated that the cost of twine for binding the bundles is more than manual gathering and tying in conventional method. The cost of a reaper-binder of tractor operated or self propelled is quite high as it uses precission - built binding mechanism.

The use of reaper windrower type for harvesting the paddy crop, manual collection of windrows and stationary threshing of grain crop will be the most appropriate method from socio-economic conditions in Kerala. Hence reaper-windrower has been selected as suitable machine for paddy harvesting.

Reaper normally refers to a machine used for harvesting the grain crop. Windrower is normally used for harvesting fodder crop. The windrower cuts the crop and leaves the crop in a windrow for curing and drying in the field. Reaper windrower term is used in this machine to clarify and emphasize that the machine cuts the grain crop and lay the crop in the form of a windrow with the panicles on one side.

The tractors are used for an extensive range of operations comprising tilling, puddling, levelling the fields and hauling operations. Last few years has witnessed the considerable increase in the average annual sales of tractors in Kerala. Visualising the potentiality of tractors in Kerala, the tractor was selected as the prime mover for operating the reaper windrower.

3.2 Selection of reaper width

Studies indicated that the length of cutterbar should be very large to utilise the full power of the tractor. If the length of cutter bar is greater than 3 meters it would pose the design restriction, because for discharging the harvested crop from such a wide length, the conveyor belts speed has to be increased proportionally for efficient operation which can cause greater shattering losses. Greater length of cutterbar would increase cost of machine, affects manouvreability and movement on narrow field roads. Considering above points, a cutting width of 2.2 m was selected and a 2.2 m tractor operated reaper windrower and power transmission assembly was got fabricated from M/s Bharat Industrial Corporation, Punjab and was assembled with MF 245 tractor.

3.3 Specification of tractor front mounted reaper windrower

Type of machine	:	Tractor front mounted vertical conveyor reaper windrower
Power source	:	MF-245 tractor, 45 hp
Suitable crop	:	Paddy and wheat
Suitable crop height	:	500-1000 mm
Height of the unit	:	2340 mm
Length of the unit	:	3900 mm
Width of the unit	:	2200 mm
Cutting width	:	2100 mm
Minimum cutting height	:	100 mm
Machine weight	:	185 kg
Weight of rear frame	:	19 kg
Weight of front frame	:	52 kg
Weight of intermediate shaft and universal joint	:	34 kg
Number of crop row dividers	:	7
Number of star wheels	:	7
Drive to star wheels	:	through lugged conveyor belts
Number of knife sections	:	28
Number of knife guards	:	29
Stroke length	:	75.0 mm
Pitch of the knife sections	:	75.0 mm
Crank radius	:	37.5 cm
Number of conveyor belts	:	2
Spacing between belts	:	95 mm

Lugs spacing	:	130 mm
Angle of star wheel to horizontal	:	20 degrees
Arrangement for changing cutterbar and conveyor speed	:	Through PTO pulley and engine speed
Arrangement for changing forward speed of machine	:	Through engine throttle and forward gears
Arrangement for raising and lowering of machine	:	Tractor hydraulic with wire rope system
Number of persons required		
1. For operating	:	1
2. For collecting and binding of crops	:	2
3. Manual harvesting for field preparation for tractor mounted paddy reaper	:	2
Reaper windrower price	:	Rs.25000
Field capacity	:	0.38 ha/hr

3.4 Main components of a reaper windrower

The main parts of the reaper windrower are cutterbar, lifting and gathering mechanisms and lugged belt conveyor.

3.4.1 Cutterbar assembly

Cutterbar assembly consist of cutterbar, knife sections and knife guards.

Cutterbar frame - It is a metal bar having a length of 2.2 m on which 28 knife sections are mounted by rivets.

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

Knife guard - A set of 29 knife guards are fitted on the block at the bottom of main board. The guard protects the knife and acts as a stationary shearing edge for the moving knife section. The guard also divides the standing crops and guides them to knife sections. Lip is the top portion of the guard which along with ledger plate holds the crop during cutting. Finger is the projecting part of the guard which protects the knife from damage when reaper comes across any obstruction.

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

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.

Pitman - It is the rod connecting the crank of the reaper to the cutterbar. The crank and pitman converts the rotary motion from the auxillary gear box into reciprocating motion and transmits to the knife. The drive to the knives is provided by the slider crank mechanism. The plane of the knife is off set to the centre of the crank.

3.4.2 Lifting and gathering unit

The gathering system performs the jobs of dividing the crop rows, lifting of the plants, guiding them towards cutterbar, lifting up after they are cut and directing towards the conveying platform.

Crop row dividers - The total width of cutter bar is 2.2 m. There are seven crop row dividers at a spacing of 30 cm. They are provided to divide and guide the plants to cutting and conveying unit. The dividers are fitted at the bottom of main board in front of cutterbar assembly. They are mounted at an angle of 20 degrees to the horizontal. The shape of the divider is triangle in plan and a shoe is attached in the front. To each crop row divider (except one at the left most end) a star wheel is attached below the shield of divider. The shield covers the star wheel exposing only the fingers of star wheel at one side.

Star wheel - The star wheels are designed to gather the crop and feed it to the cutting mechanism. Star wheels also perform the functions of holding the crop during cutting and then feeding the cut crop to the conveying unit. They get the drive for it's rotary motion from the lugs provided on the top conveyor belt.

Pressure springs - Pressure springs and star wheel together hold the cut crop in vertical platform during conveying. To each of the crop row dividers except one at the left most end, two pressure springs are attached. The pressure springs ensure a smooth flow of crops along the crop board during conveying to the discharge plate by the pair of conveyor belts.

Conveyor belts - 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. The power required to drive the conveyor flat belts is received from the gear box through V-belts and V-pulleys.

Discharge plate - It is designed to discharge the cut crop 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 in the ground.

Main board - It holds the cutterbar assembly, crop row divider assemblies, conveyor belts, four pulleys for conveyor belts, gear box, crank and pitman. The crop 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 a pair of 'A' frames connected to the tractor and is lifted and lowered by wire ropes attached to hydraulic system of tractor.

3.5 Power transmission system in tractor front mounted reaper windrower

The power transmission system is shown in Fig.1. In a tractor front mounted reaper windrower, the power to the gear box of reaper is transmitted from PTO shaft through a long intermediate shaft running beneath the tractor body to the front. With the help of universal joint and telescopic shaft it is connected to the input shaft of gear box of reaper. Drive from the tractor PTO is taken with the help of V-belts and pulleys to intermediate shaft. The intermediate shaft is taken beneath the tractor body through a couple of bearing brackets. The gear box as shown in Fig.2, consists of a set of bevel gears. The bevel gear on input shaft has 10 teeth and another one on output shaft, which is in vertical position, has 16 teeth. A pair of universal joints and extensible splines are provided to facilitate the power transmission when the reaper is working at different heights from the ground. The details of components of power transmission assembly are given in Table 1.

Scale 1:26

1. A frame
2. Crop board
3. Star wheel
4. Shield
5. Shoe
6. Discharge plate
7. Conveyor belt pulley
8. Conveyor belt
9. Centre pulley
10. Lugs
11. Lower link
12. Universal joints
13. Intermediate shaft
14. Wire rope
15. Attachment to prevent the rubbing of wire rope
16. 'V' pulley over which wire rope passes
17. Intermediate shaft pulley
18. PTO pulley
19. Rear frame
20. Front mounting frame

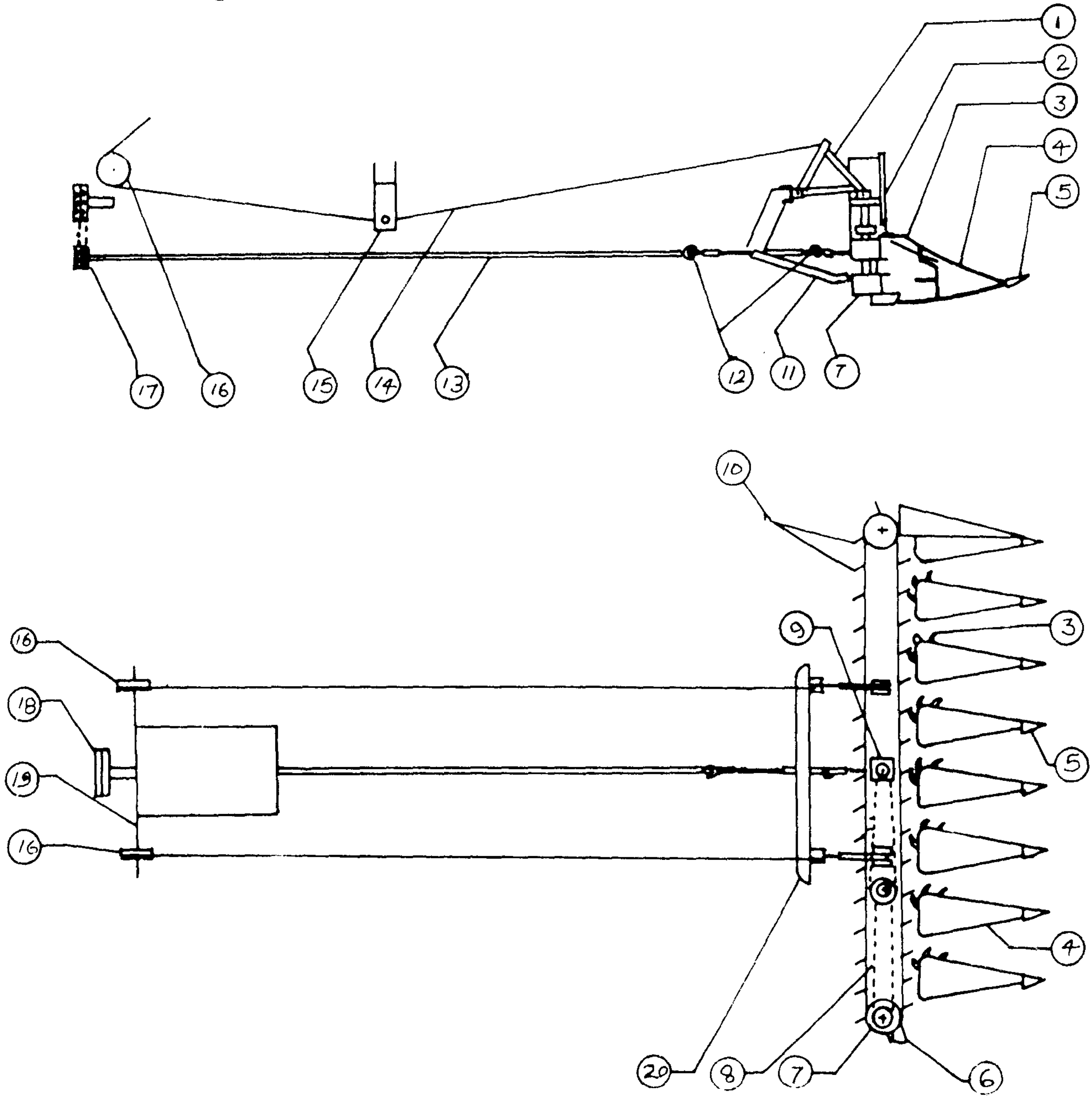


FIG.1 POWER TRANSMISSION SYSTEM IN TRACTOR FRONT MOUNTED REAPER WINDROWER

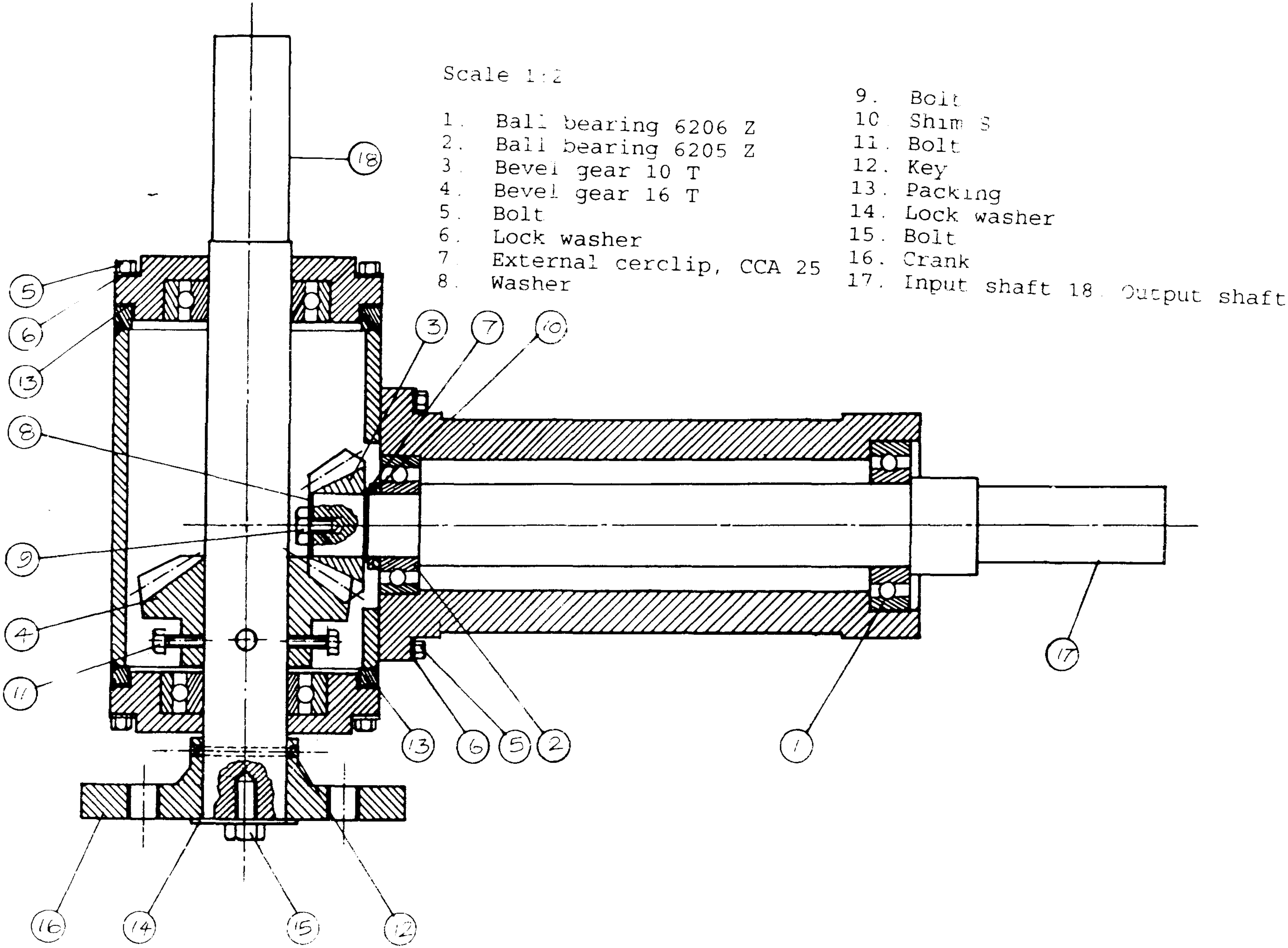


FIG.2 SECTIONAL VIEW OF REAPER GEARBOX

Table 1. Power transmission assembly components

Sl. No.	Main parts	Specification (mm)	Material of construction	Quantity
1.	PTO pulley	177.8D, 190.3D 203.2D	CI	3
2.	Main shaft pulley	100 D	CI	1
3.	V belts	B 31	fibre impregnated rubber	2
4.	Bearing	335	-	2
5.	Bearing brackets	-	MS	2
6.	Intermediate shaft	50D, 2200L	MS	1
7.	Universal joints	-	MS	2
8.	Bearing	6205Z, 6206Z	-	1
9.	Input gear	Bevel 10 teeth	-	1
10.	Output gear	Bevel 16 teeth	-	1
11.	Bearing	6305Z	-	2
12.	Gear box	-	MS	1
13.	Crank	-	MS	1
14.	Circlip	-	-	2

The power from input shaft of gear box, which is in horizontal position, is transmitted to output shaft in vertical direction. This output shaft transmit the power to the shaft driving the lugged flat conveyor belts, through a set of V-pulleys and belts as well as the cutterbar through a crank and pit man. The top lugged conveyor belt drives the star wheels on the crop row dividers. The forward movement of reaper windrower is achieved by the forward travel of the tractor. When the PTO lever is engaged, a portion of engine power is transmitted to the PTO shaft to give it rotary motion. The different components of reaper-windrower starts operating as explained earlier. As the tractor moves forward, the crop row dividers enter the standing crop, the star wheels guides the crops towards cutting blade and with pressure springs and conveyor belts it conveys the crops to right extreme end. At the end, crop is discharged and is laid on the ground in the form of a windrow. Reaper windrower is lowered or raised by hydraulic system of the tractor with the help of parallel bar linkage and wire rope pulley lifting system.

Pneumatic tyres and cage wheels are provided to suit ground conditions at the time of harvesting. Cage wheels are normally used for improving the traction in puddled soil condition of paddy field as the mobility of tractor fitted with pneumatic tyres is affected by the wet conditions. The conventional cage wheels normally used in Kerala will cut the soil while moving. The use of ordinary cage wheels for harvester would not be preferred as the width of tractor with the cage wheels was found to be more than the width of cut.

A pair of special cage wheels with characteristics of increased floation in wet lands without any excessive sinkage or cutting of soil was designed and got fabricated from M/s KAICO, Palakkad. The dimensions of cage wheels were decided considering the width of reaper windrower to avoid running of cage wheels over windrowed crop.

3.6 Requirements of tractor front mounted reaper windrower

Following are the requirements of tractor front mounted reaper windrow to have satisfactory harvesting.

(i) The crops should be conveyed in the vertical position and the panicles should not have any contact with the moving parts of the machine to have the minimum shattering loss.

(ii) The conveying of crop in the vertical position should be under control and crop should be laid on the ground in a clear windrow maintaining the swath perpendicular to the direction of travel to have ease in manual collection and tying.

(iii) The machine size should permit to have the better manouvreability in the field.

(iv) The power from the tractor should be sufficient for traction, cutting the crop at desired height and for windrowing the cut crop at desired pattern. Lifting capacity of the hydraulic system should be sufficient to ensure easy raising and lowering of the machine.

It is evident that, there is a definite relationship between the forward speed of the machine, linear speed of cutterbar and conveyor belt speed for obtaining better performance. Fig.3 shows the relation between movement of conveyor belt and machine forward travel. The speed of conveyor belt pulley (Vc) with respect to tractor forward speed (Vm) is very important. The power for the rotation of starwheels is taken from the conveyor flat belt. Star wheel helps in lifting, gathering and guiding the crops towards the cutterbar and holds the cut crop in vertical position and directs the plants towards conveyor belt. The speed of starwheels and conveyor belt are very important for the proper operation of the reaper windrower. If the speed of conveyor belt is too great, the cut crop bunches will be roughly ejected instead of being smoothly conveyed, resulting in uneven windrows and grain losses. If the conveyor speed is too low, the conveyor will fail to handle the entire cut crop.

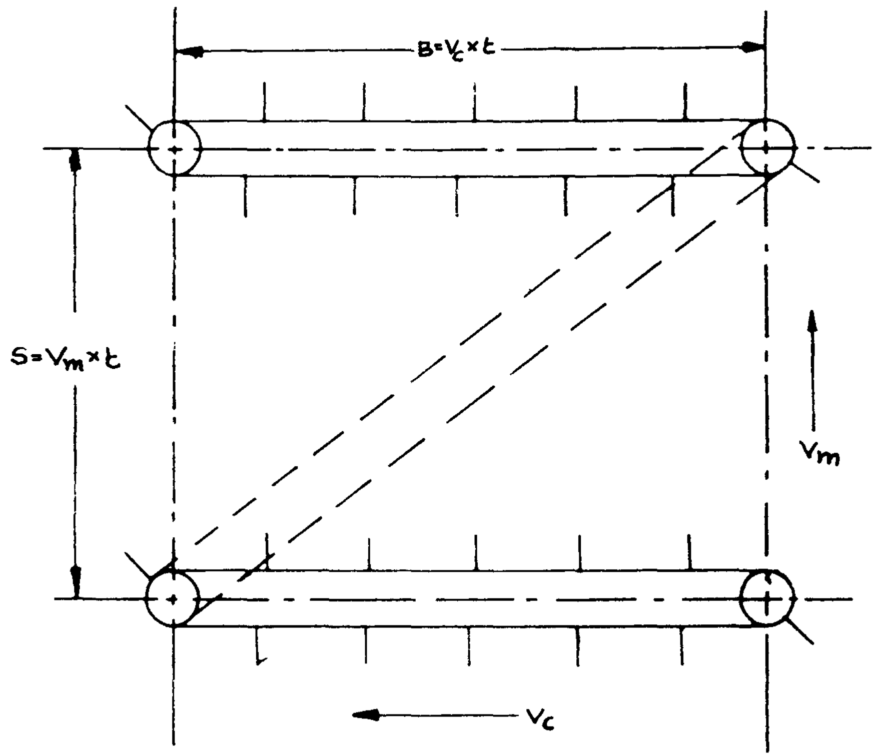


FIG.3 RELATIONSHIP BETWEEN THE FORWARD SPEED OF REAPER AND CONVEYOR BELT SPEED

This will result in pushing the crop away from the cutterbar. Similarly the cutterbar speed is also a function of the forward speed of the machine. If the ratio is higher, the shattering loss is likely to be higher because of either by detachment of individual grains or a part or whole of an earhead by rubbing of the earheads and plants and vibration imparted by cutting force. It is noted from the previous studies that cutting force requirements and shattering losses increases with an increases in the ratio of cutterbar linear speed to forward speed.

3.7 Dynamics of power transmission in tractor front mounted paddy reaper

Functional performance of the reaper should be considered optimum when the harvesting loss and power requirements turn out to be minimum for a desired field capacity, harvesting pattern and windrowing pattern. The windrowing should be such that it facilitates easier collection of crop with lesser labour requirement and minimum windrow losses. Main objective of the study was to suggest values of the operational parameters for the optimum performance of the reaper for various field conditions. Harvesting pattern, windrowing pattern, harvesting losses and power requirements were taken as broad criteria for deciding optimum cutterbar speed, conveyor belt speed, engine speed and forward speed of the reaper.

The tractor front mounted reaper windrower was operated at different forward speeds, conveyor and cutterbar speeds to determine the optimum relation between them. The change in the forward speed of the reaper was achieved by changing the position of engine throttle and using different forward gears. MF 245 tractor has eight forward and two reverse gears, comprising four forward and one reverse gear with high and low range epicyclic gear. Four forward gears in low range and one gear (first gear) in high range were selected for field testing of reaper. The high forward speed of reaper, beyond first gear in a high range, posed problems in fields for harvesting.

3.7.1 Finding of relationship between engine speed and reaper parameters

The power for operating different components of reaper is taken from engine through PTO shaft. The change in the cutterbar speed and conveyor belt speed were achieved by using different diameter pulleys on the PTO shaft. The pulley with 17.78 cm diameter (PTO pulley No.I), 19.03 cm diameter (PTO pulley No.II) and 20.32 cm diameter (PTO pulley No.III) were selected for this purpose. All the three pulleys with the internal splines to match PTO shaft of the tractor were fabricated. The PTO shaft is fitted with PTO pulley No.I and unit was operated in field at the selected gears for different engine speed, ranging from 1000 to 2000 rpm at 100 rpm interval at three field conditions. The optimum engine speed, cutterbar speed and conveyor belt speed were determined based on harvesting pattern, windrowing pattern, harvesting loss and power requirement for cutting and conveying. The same procedure was repeated for other two PTO pulleys.

3.7.2 Finding of optimum forward speed, cutterbar index and conveyor index

After finding the optimum engine speed, the unit was field tested again to know the actual field capacity and field efficiency of tractor mounted reaper for selected gears at optimum engine speed for each PTO pulleys. The decisions with regards to the optimum cutterbar index, which is the ratio between the linear speed of cutterbar to the forward speed of machine as well as the conveyor index, which is the ratio between the linear speed at conveyor belt to the forward speed of machine, were made based on the field capacity, field efficiency, total harvesting losses, power requirement, harvesting and windrowing pattern.

The optimum value of conveyor belt speed of tractor front mounted 2.2 m wide reaper was compared with that power tiller operated 1.6 m wide reaper and self propelled 1 m wide reaper to know the variations in the conveyor speeds with respect to the length of cutterhar.

The procedure adopted for the computation of force and power requirements, determination of harvesting losses and quality windrowing at various forward speeds and engine speeds are discussed in the following pages. There is no systematic data available about the effect of forward speed, engine speed, cutterbar speed and conveyor speed on harvesting losses and power requirements. Thus, the present study was taken up to optimise the above variables for Kerala conditions.

3.8 Computation of force requirements

Pitman is the rod connecting the crank of the reaper to the cutterbar. The crank converts the rotary motion from auxillary gear box 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 displacement 'X' of the knife is given by

$$X = r \cos wt + r \frac{\lambda}{4} \cos 2 \; wt - r \frac{\lambda}{4} + \lambda h \sin wt \qquad \text{----- (1)}$$

where,

t = time of crank rotation in sec

w = crank angular velocity in radians/sec

$\lambda = r/l = \dfrac{\text{Crank radius}}{\text{length of pitman}}$

Velocity of knife is given by,

$$V_k = \frac{dx}{dt} = rw\ (\sin wt + \lambda/2 \sin 2\ wt - E \cos wt) \quad \text{------ (2)}$$

and acceleration of knife is given by

$$j_k = \frac{d^2x}{dt^2} = rw^2\ (\text{Cos}\ wt + \lambda \cos 2\ wt + E \sin wt) \quad \text{---- (3)}$$

Since λ and E are very low, the terms in equation 2 and 3 containing them may be neglected. The maximum velocities of knife occurs at 90 degree and 270 degrees. Maximum acceleration occurs at wt = 0, 180 and 360 degrees.

3.8.1 Force and power requirement for cutterbar assembly

The force 'p' resisting cutterbar movement is the sum of all the forces acting on the cutterbar.

$$P = P_{av} + P_j + F$$

Where

P_{av} is the average crop resistive force to cutting, kgf

P_j is the inertia force of the cutterbar, kgf

F is the frictional force, kgf

P_{av} - From literature it has been found that the maximum dynamic force required to cut one paddy stem is 0.10 kgf. The estimation of power required for cutting is as follows.

Average number of hills/m^2 = 45

Average number of plants/hill = 4

Average number of plants/m^2 = 180

Area covered by tractor front mounted reaper windrower in one second.

Total cutting width of machine X distance travelled by machine in one sec.

The total number of plants for the above area can be found out by knowing plant density per square metre.

Total force required for cutting at the given plant density = Number of plants x 0.1 kgf

Force required for cutting per stroke = $\frac{\text{Number of plants x 0.1}}{\text{strokes per sec}}$ kgf

P_j - The inertia force of cutterbar is governed by the mass m_k of the knife and its acceleration j_k, that is,

$$P_j = m_k \cdot j_k$$

where

$j_x = r\ w^2 \cos wt$

$w = \frac{2\pi N}{60}$, radians

N = revolutions of crank per min

r = crank radius cm

we have

$P_j = \frac{Wk}{g} r\ w^2 \cos wt$

where

W_k = weight of knife bar, kg

g = acceleration due to gravity, m/sec^2

The maximum value of $Pj_{max} = \frac{Wk}{g} w^2 r$ corresponds to the initial and final points of the knife path and $P_j = 0$ at $x = r$.

The friction force, F, acting on the knife as it slides over the finger bar consists of the friction force F_1 due to the weight of the knife itself, and the force F_2 due to the action of the connecting rod.

$F = F_1 + F_2$

where

$F_1 = W_k . f$

f is the coefficient of friction

$f = 0.25$ to 0.3

The force F_2 is caused by the normal component of the force exerted by the connecting rod on the knife.

$$F_2 = \frac{(P_{av} + P_j + W_k f)}{1 - \tan B} \tan B \,.f$$

where B is the angle subtended by the connecting rod with horizontal.

$$L \sin B = S + r \operatorname{Sin} Q$$

$$B = \operatorname{Sin}^{-1} \frac{S + r \operatorname{Sin} Q}{L}$$

where

L, is the length of connecting rod, cm

r, is the crank radius, cm

Q, is the crank angle, degrees

S, is the vertical distance between the centre line of crank and joint on a knife head, cm

The force P (kgf), resisting the motion of the knife, is given by,

$$P = P_{av} + P_j + F_1 + F_2$$

Power (hp) required to overcome friction force, F_1 and inertia force (both depends on the weight of cutterbar)

$$= \frac{(\text{Inertia force} + F_1) \times \text{cutterbar speed}}{75}$$

Increase in power (hp) due to cutting of plants and F_2,

$$= \frac{(P_{av} + F_2) \times \text{cutterbar speed}}{75}$$

The total (hp) power required for cutting

= Power for inertia and F_1 + Power increased due to cutting and F_2

3.8.2 Power required for conveyor assembly

The power for operating the reaper unit is taken from PTO shaft of the tractor. The power required to operate the conveyor assembly without crop was measured with wattmeter using a motor. The power from 7.5 hp motor was given to the intermediate shaft of the reaper instead from the PTO pulley. Suitable pulleys were used on the motor shaft to maintain the speed of intermediate shaft at same values for different PTO pulleys.

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. The power required by the reaper without the conveyor belt and pulleys (P_c) was noted.

Power requirement for operating conveyor assembly, hp

$$= P_t - P_c$$

Torque of the conveyor belt pulley is given by

$$T = \frac{hp \times 4500}{2\pi N}, \quad kg\ cm$$

Taking above torque as mean torque, the power required for operating the conveyor assembly at different pulley speeds was found out. The same procedure was repeated for other pulleys.

Power (hp) required for conveying cut crops is given by,

$$= \frac{\text{Total number of plants to be conveyed in one second} \times \text{Weight of single paddy plant} \times \text{Conveyor belt speed (m/s)}}{75}$$

The total power (hp) required for conveying is given by,

= Power required to operate conveyor assembly without crop + Power required for conveying cut crop in one sec

Then, the total power required for cutting and conveying is given by, hp

= Power required for cutting + Power required for conveying

$$\text{Specific power} = \frac{\text{Total power requirement for cutting and conveying}}{\text{Length of cutterbar}}$$

$$= \frac{hp}{m}$$

3.9 Harvesting losses

Pre harvest loss

Pre harvest loss is defined as the weight of grains fallen on the ground. Paddy grains and earhead, fallen on the ground were collected from selected samples from one square metre area spot. The grains so collected and weighed are denoted as W_{q0}. The frame of one square metre was used for collecting the shattered grains and earheads.

One square meter area on each plot were harvested at five places by traditional method using sickles. The total weight of harvested crop and weed were noted from each sample area. It was the total biomass per square metre. Then it was manually threshed. The weight of straw and grain were separately measured to know the straw grain ratios. The moisture content of grain and straw were measured using crop moisture meter. The number of tillers per square metre was noted. The grains on the field were collected which were harvested using sickle. The average weight (W_1) was noted. Then grain loss was calculated as below:

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

where,

Y_g = The weight of grain from 1 square meter area

The operating speed, cutting width and cutting height from ground level were noted. After running the tractor in field for a known distance in each test, the time taken by the tractor to cover the same distance was noted using a stop watch. The shattered grains left on five randomly selected one square metre area in each run were collected. The grains so collected and weighed are denoted as W_{g1} The shattering loss was calculated as below.

$$\text{Percentage of shattering loss} = \frac{W_{g1} - W_{go}}{Y_g} \times 100$$

The uncut loss was calculated. For this the uncut crop left in the five randomly selected one square metre area in each run, was manually harvested and weighed. Let the average of grain be W_{g2}.

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

The cutterbar loss is the sum of uncut loss and shattering loss and the same was calculated by following method:

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

where,

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

Windrower loss

A 12 m long gunny bag sheet was placed along side of the crop to be harvested. After reaping with machine, the crop windrowed on the sheet was taken away. The shattered grains, fallen on the sheet were, collected and weighed from one square metre area randomly selected at five places for each run. The distance of windrowed crop from the cutterbar block and quality of windrow were observed for the different forward speed and conveyor belt speed.

3.10 Windrowing quality

Quality of windrowing is very important from the crop collection point of view. At the delivery end of the reaper windrower, crop is acted upon by the forward speed of the tractor and the conveyor speed which decides the quality of windrowing. If the earheads of stalks remain in the same direction, labour requirement for tying the crop may be minimised. The ideal windrowing is such that the harvesting crop is laid perpendicular to the direction of machine travel, with ears away from the machine (Devnani, 1988a). The tiller angle, with respect to the direction of machine travel, between 80 to 90 degrees and the distance of throw of tillers, from discharge plate end, upto 15 cm were taken as acceptable limit for deciding quality of windrowing.

3.11 Statistical analysis

The independent variable under the present study was forward speed of reaper and the total power requirement and harvesting losses were the dependent variables. A set equations showing relationship between the forward speed of reaper with total power requirement and harvesting losses at optimum speeds were developed by using regression technique and the correlation coefficients for the above were also calculated. The test of significance of correlation coefficients were done using student t-distribution to know the relation between forward speed, total power requirements and harvesting losses.

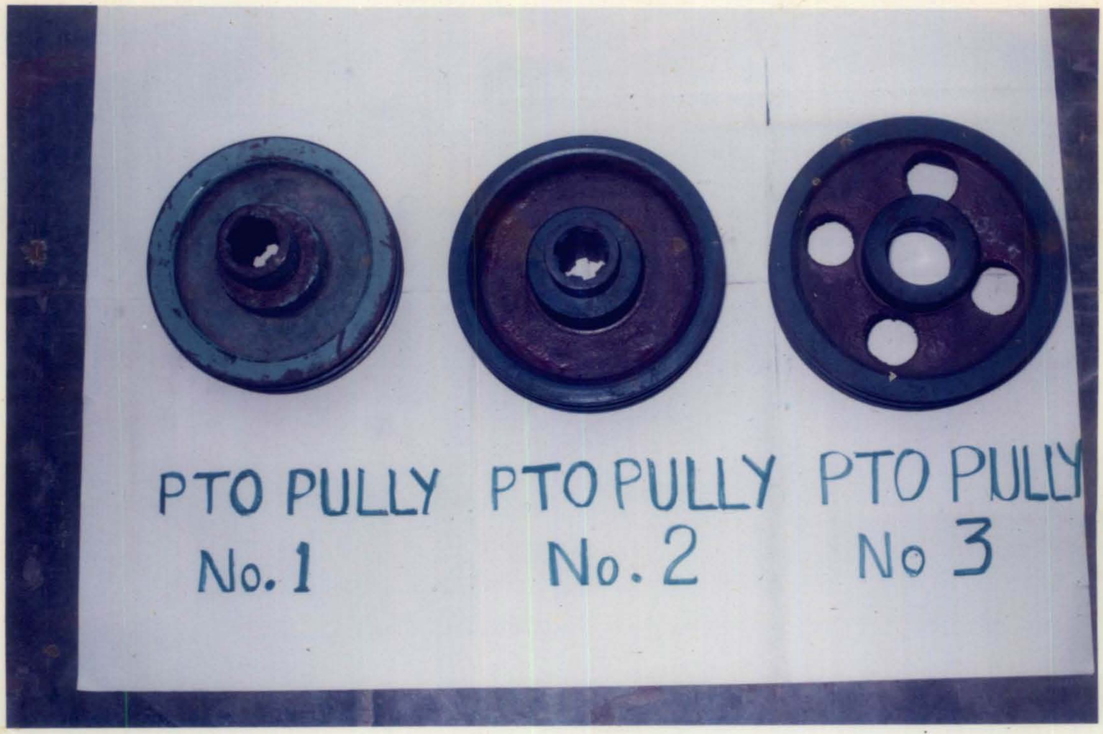
3.12 Preliminary trials

The preliminary trials of the tractor front mounted reaper windrower were taken up in the laboratory. The tractor mounted reaper windrower has many components. The cutter bar assembly and the crop conveying assembly, the hitching and lifting assembly as well as power transmission assembly were properly connected and then the unit was operated in the laboratory. The performance of individual components were observed. Again the machine was taken on the road and was operated to find out any defects in components and vibration. The tractor was operated at all gears to make the above observations.

The performance evaluation of reaper were carried out in laboratory. The independent variables were engine speed, linear speed of cutterbar and conveyor belt. Engine speed was changed by means of engine throttle. The three PTO pulleys were used to change the cutterbar and conveyor belt speeds. PTO pulley No.I having 17.78 cm diameter. PTO pulley No.II having 19.03 cm diameter and PTO pulley No.III having 20.32 cm diameter. were used for this purpose. The PTO speed and conveyor belt pulley speed were measured with the help of tachometer. By knowing the speed of crank, the speed of cutterbar was calculated. A set of readings of engine speed, PTO speed, cutterbar speed and conveyor belt speed were taken for all PTO pulleys. Plate I shows the three PTO pulleys used for changing the conveyor and cutterbar speeds.

Plate I Three PTO pulleys used for changing cutterbar and conveyor belt speeds

Plate II Tractor mounted paddy reaper in operation in wet lands


PTO PULLY
No. 1
PTO PULLY
No. 2
PTO PULLY
No 3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3.13 Evaluation of paddy reaper windrower in field

The field trials were conducted in fields of Instructional Farm KCAET, Tavanur. The slope, area, topography and other details of the fields were noted. The moisture content of soil was measured by using oven dry method. Frequency and size of bunds were noted. Variety, appearance and maturity of crop and the type and extent of weeds were also observed. Number of grains per earhead was also noted. The relation between different operating parameters of tractor front mounted reaper windrower was determined by operating the unit at different forward speed, conveyor belt speed and cutterbar speed. The Plate II shows the tractor mounted paddy reaper in operation.

3.14 Economic studies

The main aim of introduction of farm machinery is to increase the land productivity, labour productivity and to reduce cost of cultivation. The tractor front mounted paddy reaper will reduce the cost of harvesting compared to the manual harvesting methods. The harvesting cost of paddy by tractor operated reaper was compared with the manual method. Economic studies were conducted as per ISI (1979).

The data on manual harvesting and the labour charges were collected from the Instructional Farm KCAET, Tavanur. With the data, cost of manual harvesting for one ha was calculated.

The cost of harvesting by tractor operated reaper was analysed. The costs were compared with manual harvesting. Break even analysis for manual harvesting and harvesting by reaper was also carried out.

3.15 Crop collecting attachment to the reaper

It has been observed during previous field trials on tractor front mounted reaper windrower that, the quality of grain and straw was affected by the standing water in the fields, which is common in Kerala, as the swath was conveyed into the standing water. It was felt necessary to provide a simple crop collection unit to the reaper windrower to collect the crop from conveyor to avoid falling of crops in the standing water.

Considering power availability, manouvreability and crop heights of different paddy varieties the width of conveyor belt roller was decided. Normally height of paddy crop varies between 60-110 cm and reaper cuts the crop at a height of 10-12 cm from the base of the crop. The basic principle involved in the operation of collection unit is to collect the crop from conveyor belt of the reaper on a flat conveyor belt before it get windrowed on the wet field and conveying the crop into a rectangular box.

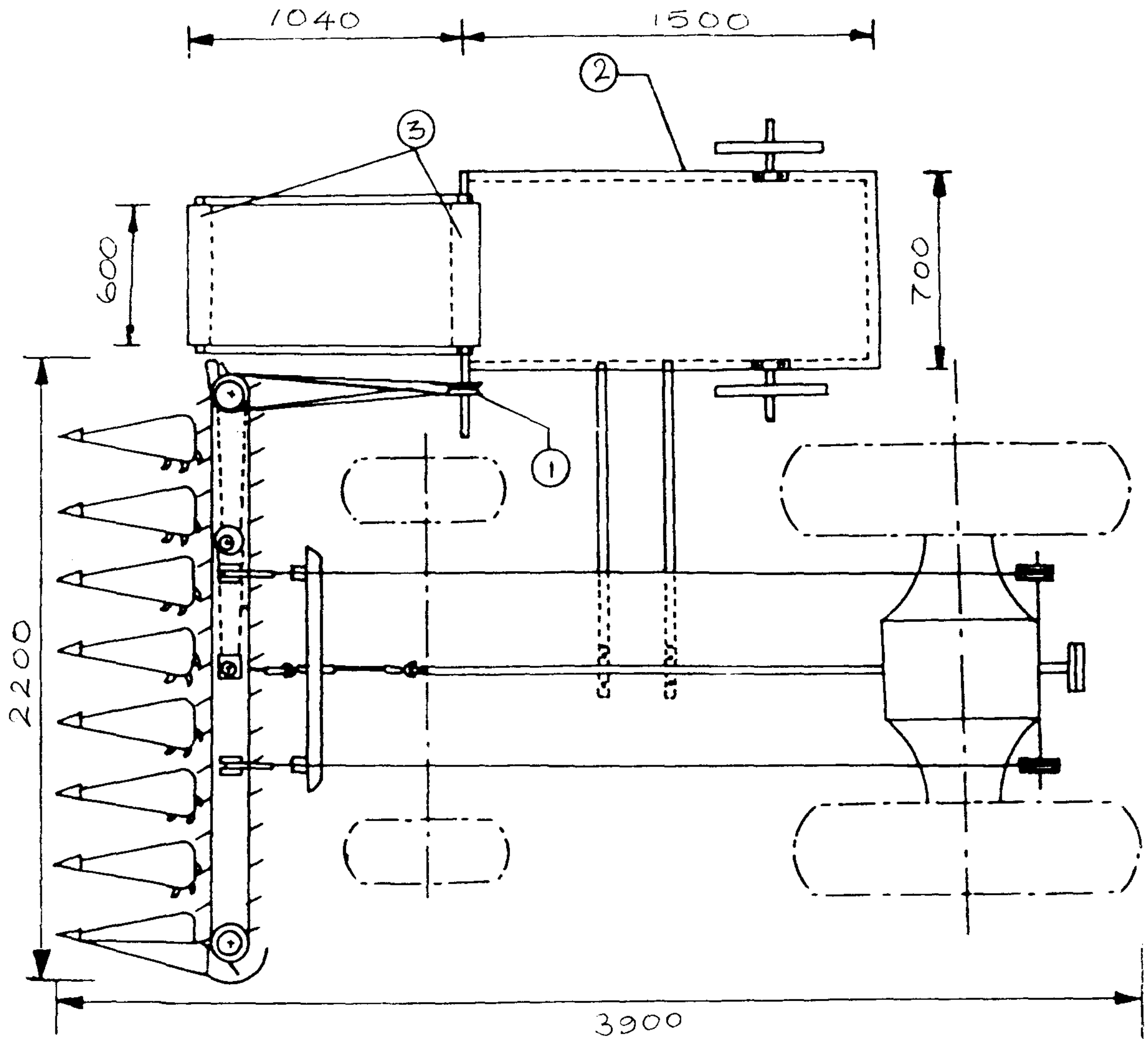
3.15.1 Components of crop collection unit

The main parts of the simple collection unit are the two rollers, flat conveyor belt and collection box (Fig.4 and 5). Among the two rollers, one was provided at the discharge plate in the reaper, from where crop gets ejected, and another on the top of the collection box. These two rollers are made by using MS pipe of size 7.5 cm x 50 cm dimensions.

Conveyor belt of same width as that of rollers was provided over the rollers. The collection box of 1.5 m x 0.70 m x 0.35 m is made by using 2.54 cm diameter GI pipes for main frame and 5 mm rods for side supports. The bottom and sides of collection box are covered with gunny bags. Collection unit is provided with two rear wheels of the 40 cm diameter and one front wheel of 12 cm diameter with swivel bearings. The details of components of collection unit are given in Table 2. The purpose of using gunny bags and pipes for rollers is to make collection unit as light as possible to ensure the smooth moving of unit with tractor.

3.15.2 Attaching of collection unit to tractor mounted reaper windrower

The collection unit is attached at the right side of the tractor where the crop is conveyed and windrowed by using a



All dimensions are in mm

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1. 'V' belt pulley
2. Collection unit
3. Rollers

FIG.4 TOP VIEW OF TRACTOR FRONT MOUNTED REAPER WITH COLLECTION UNIT

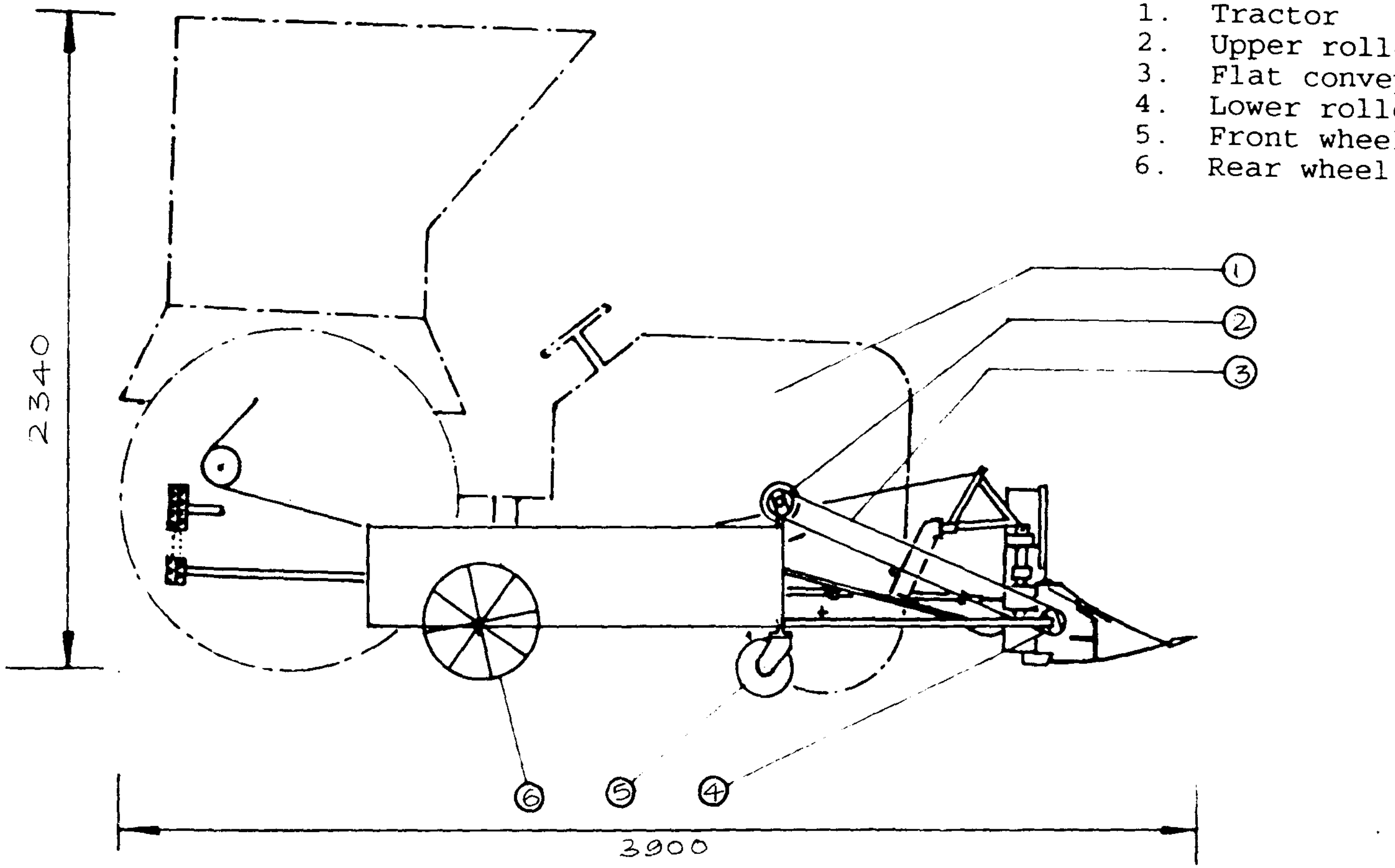

FIG.5 SIDE VIEW OF TRACTOR FRONT MOUNTED REAPER WITH COLLECTION UNIT

Table 2. Details of components of crop collection unit

Sl. No.	Main parts	Specification or size (mm)	Material of construction	Quantity (nos.)
1.	Collection box			
	a. Main frame	700x350x1500	GI pipe (25.4 dia)	1
	b. Side supports	5x350	MS Rods	8
	c. Cover	350x3800	Gunny bags (sacks)	1
	d. Wheels			3
	(i) Front wheel with swivel bearing	120D (with a total height of 200)	Rubber	1
	(ii) Rear wheel	400D	MS	2
II	Roller	75D, 500L	MS pipe	2
III	Bush bearing	25ID, 35 OD	MS	4
IV	Shaft	25D, 800L	MS	1
V	Pulley	101D	CI	1
VI	Flat conveyor belt	2310L	Canvass cloth	1

suitable frame. The frame is made from angle irons of size 50 mm x 50 mm x 3 mm. It consists of two main angle irons of length 70 cm, which are fitted to the rectangular plate with four bolts at the bottom of tractor.

The other two MS angle of same size and of 20 cm length are fitted to the main MS angle irons at an angle of 30 degrees by using two bolts and nuts. The crop collection unit is attached to the other end of angle irons by using suitable bolts and nuts to provide sufficient support and to ensure smooth moving of unit with tractor. Plate III and IV shows the parts of crop collection unit with tractor mounted reaper.

3.15.3 Power transmission system in tractor front mounted reaper windrower with collection unit

The power for the operation of conveyor belt in collection unit is taken from right conveyor belt pulley of the reaper. The single V-groove pulley of right conveyor belt was replaced with double V-groove pulley of the same size. One groove is used for driving conveyor belt of reaper and other groove is used for driving the conveyor belt of collection unit.

The top roller of collection unit is provided with a shaft of 2.5 cm diameter and 80 cm length. To the left extreme side of shaft is provided with a single V-groove pulley of 10.16 cm diameter. The position of this pulley can

Plate III Side view of crop collection unit with tractor mounted reaper

Plate IV Rear view of crop collection unit with tractor mounted reaper


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be adjusted to make it in align with the double V-pulley of the conveyor belt of reaper. As the PTO shaft is engaged while moving in forward direction, the cutterbar and conveyor assembly of reaper starts operating. The top roller in collection unit gets drive from right conveyor pulley and operates the flat conveyor belt of the collection unit.

As the tractor moves forward, reaper cuts the crop and conveys it to the right side for windrowing. The bottom roller collects the crop falling over on it and conveys the crop to collection box with the help of collection conveyer belt and top roller.

3.15.4 Preliminary trials

The crop collection unit was attached to tractor front mounted reaper windrower and was operated in the laboratory to know the performance of collection unit. The speeds of rollers and collection conveyor belt were recorded for all three PTO pulleys with the help of a tachometer, at optimum engine speeds. Then the unit was operated in the field and observations like turning radius and maneuverability were made.

3.15.5 Field trials

The field trials of tractor front mounted reaper windrower with collection unit were carried out at KCAET Instructional Farm, Tavanur to evaluate the performance and suitability of the collection unit.

Results and Discussion

RESULTS AND DISCUSSION

The results of the work carried out on the dynamics of power transmission in tractor mounted vertical conveyor reaper windrower to make it suitable for paddy harvesting under Kerala conditions are presented and discussed in this chapter. It included the results of laboratory and field studies conducted to decide the optimum operating parameters of reaper windrower, feasibility studies on providing collection unit to reaper windrower to improve its performance under wet conditions and other relevant studies.

4.1 Laboratory studies

A 2.2 m width reaper windrower was thoroughly examined before assembling it with tractor for its materials used, method of fabrication and alignment of its various working parts.

After carrying out the necessary improvements and adjustments on the individual components, the reaper was assembled to the MF 245 tractor with all accessories like power transmission unit with the help of rear and front frames. Then the unit was operated in the laboratory and the performance of individual components was observed. After ensuring the satisfactory operation of the unit, the performance evaluation of reaper windrower was carried out in laboratory.

Tractor front mounted reaper windrower was fitted with PTO pulley No.I on the PTO shaft and the readings like engine speed, PTO speed, central shaft speed (which supplies power to the cutterbar and conveyor belt pulley) and conveyor belt pulley speed were noted down. From central shaft speed, cutterbar strokes per min. and its reciprocating speed were calculated. The speeds of above mentioned components of reaper windrower were noted down for different engine speed, ranging from 1000 to 2000 rpm for every 100 rpm interval.

The values of the cutterbar and conveyor belt linear speeds to the engine speeds with PTO pulley No.I are given in Appendix-I. Since the speed of PTO depends on the engine speed, it has been found that the values of cutterbar and conveyor belt speed increased with an increase in the engine speed. The minimum values of cutterbar and conveyor belt linear speeds were observed at lowest engine speed i.e., at 1000 rpm and the maximum values of cutterbar and conveyor belt speeds were observed at an engine speed of 2000 rpm. For PTO pulley No.I, the maximum and minimum values of cutterbar linear speeds are 0.98 m/s and 1.91 m/s respectively and 1.46 m/s and 2.84 m/s are minimum and maximum conveyor belt speeds.

For PTO pulley No.II, the maximum values of cutterbar linear speed are 1.05 m/s and 2.05 m/s respectively, while the minimum and maximum values of conveyor belt linear speed are 1.54 m/s and 3.04 m/s respectively. For PTO pulley No.III, the minimum and maximum values of cutterbar speed are 1.13 m/s and 2.18 m/s respectively, while the minimum and maximum values of conveyor belt speed are 1.67 m/s and 3.24 m/s respectively (Appendix II and III).

It has been observed that the values of cutterbar speed and conveyor belt speed were increased with an increase in the diameter of PTO pulley for the same engine speed. The maximum values were recorded for PTO pulley No.III and the minimum values were observed for PTO pulley No.I at the same engine speed.

4.2 Field trials

A number of field trials were conducted on tractor front mounted reaper windrower at farms at KCAET, Tavanur to detect the defects in its operation and proper remedial measures were carried out to rectify the same.

The problem of winding of straw around the hub of star wheel was noticed. The straw coming in contact with the hub easily wound around and made starwheel impossible to rotate.

This problem was rectified by providing a steel cup on the starwheel shaft so as to cover the star wheel hub. As this cup was not rotating the straw was not having any possibility to wind around the hub.

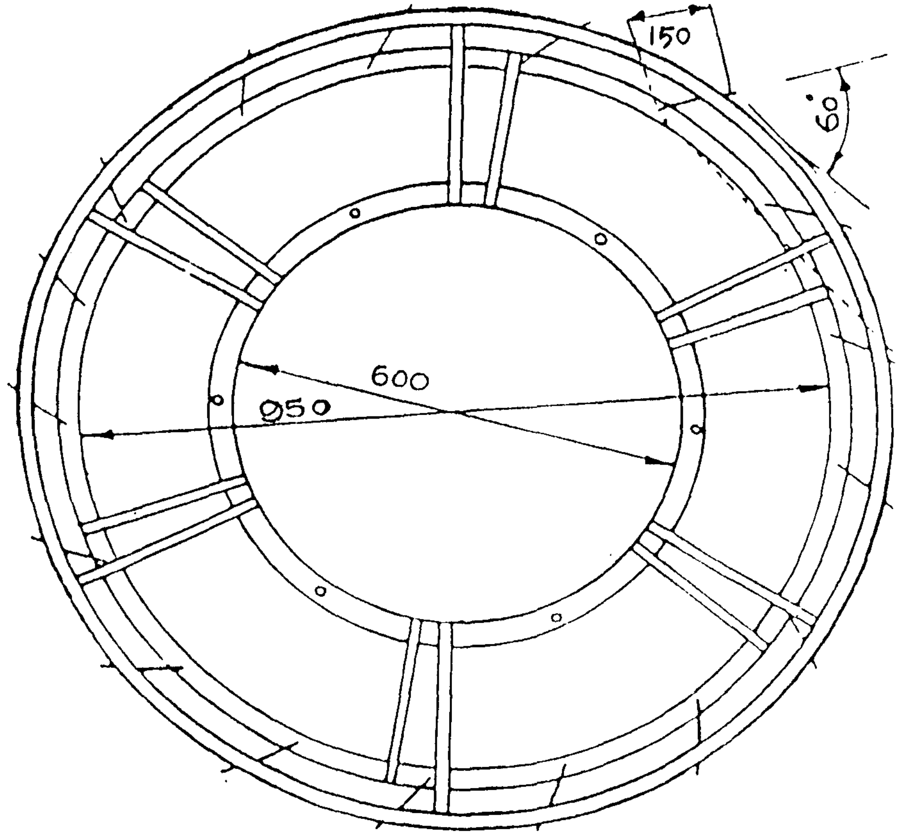
The conveying of cut crop along the crop board was not proper. Proper alignment of pressure springs helped the cut crop to be properly carried by the conveyor belt.

The windrowing was not proper and the crop was found to spread non uniformly over the field. This problem was rectified by proper positioning the discharge plate.

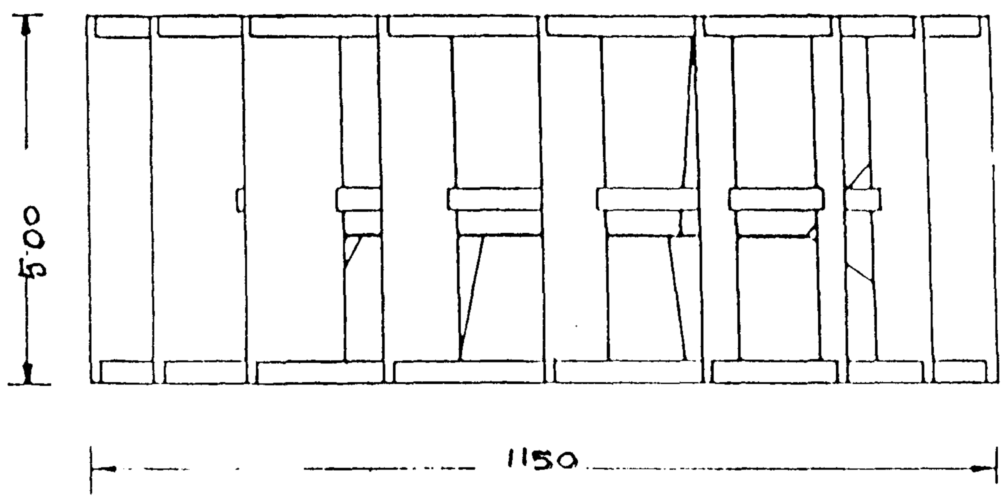
4.3 Special cage wheels

A pair of special cage wheels with characteristics of increased floation in wetlands without any excessive sinkage or cutting of soils was designed and got fabricated from M/s KAICO, Palakkad and was assembled with the tractor. The details of special cage wheel, *viz.* its dimensions and position of lugs, are shown in Fig.6. The total width of track of tractor front mounted reaper when fitted with special cage wheels was found to be 1.9 m which is less than the total width of reaper.

A plot of 50 m x 30 m was selected and tractor mounted paddy reaper fitted with special cage wheels was operated in the fields, with standing water to a depth of 5 cm to



ELEVATION



PLAN

SPECIAL CAGE WHEEL FOR PADDY REAPER

All dimensions are in mm

Scale 1:10

evaluate the performance of special cage wheels. Increased traction as well as increased floation without much sinkage or cutting of soil were achieved with these special cage wheels under wet conditions.

4.4 Evaluation of paddy reaper windrower

Critical evaluation of tractor front mounted reaper windrower was carried out to decide the optimum operating parameters in the field. The tractor was operated with pneumatic tyres and cage wheels for traction, depending upon the field conditions at the time of harvest. These trials were conducted at KCAET Instructional farm, Tavanur as per ISI (1985) and RNAM test codes. The unit was evaluated for paddy harvesting at different engine speeds and forward speeds. The evaluation studies were conducted on paddy crop, Red Triveni variety, having plant density of 160 plants per sq m. The moisture content of straw and grain at the time of harvesting were found to be 20 per cent and 18 per cent respectively. The yield of crop was found to be 300g per sq m. Number of plants handled by the reaper in unit time are given in the Appendix IV. The harvesting pattern, windrowing pattern and harvesting losses for all the operated conditions were observed. The total power and specific power requirement for cutting and conveying of paddy crop were computed. The data pertaining to the above were presented and discussed in the following paragraphs.

4.4.1 PTO pulley No.I

The tractor front mounted reaper windrower was fitted with PTO pulley No.I on the PTO shaft. Then the assembling of various components of tractor front mounted reaper windrower was made as per the requirements. Then the unit was field tested for harvesting of paddy crop. Four gears in low range and one gear (first gear) in high range were selected for the above purpose. The tractor mounted reaper windrower was operated at different engine speed varying from 1000 to 2000 rpm for the above gears.

It was found that at the engine speed of 1000 to 1400 rpm, the conveyor belt assembly was not conveying the cut crop due to the low linear speed of conveyor belts. The conveyor belt linear speed, at an engine speed of 1000, 1100, 1200, 1300 and 1400 rpm were 1.46 m/s, 1.58 m/s, 1.74 m/s, 1.90 m/s and 2.06 m/s respectively which was found to be insufficient to handle and convey the cut crops. Because of this the conveyor assembly was choked with crop and tractor had to be stopped frequently to clean the crop from conveyor assembly. The above operations were conducted at first gear in low range. The field testing of tractor front mounted reaper windrower at higher gears for the above engine speeds were not found possible as more choking of conveyor assembly with cut crop was noticed. This was due to increase in feeding rate of crops, as the forward speed is increased.

Then it was decided to conduct the field tests for higher engine speed varying from 1500 to 2000 rpm.

The tractor front mounted reaper windrower was operated at an engine speed of 1500 rpm. The variables like forward speed, uncut loss, cutterbar loss, windrowing loss, harvesting pattern and windrowing pattern were observed and noted down for selected gears. Then the power and specific power required for cutting and conveying were computed. The same procedure was followed for remaining engine speeds and experiment was continued upto an engine speed of 2000 rpm as the vibration, inconvenience faced in harvesting, problems of manOuvreability and harvesting losses were increased at rapid rate beyond this engine speed.

4.4.1.1 Total power and specific power requirement for harvesting

Total power required for cutting and conveying of paddy crop at different engine speed and forward speeds were computed following the procedure as explained in the previous chapter. The vallues for the PTO pulley No.I are provided in Appendix-V and VI.

It was found that the total values of inertia of cutterbar and the frictional force due to weight of cutterbar was increased with an increase in the engine speed. The minimum value of the inertia and frictional force, 1.33 hp, was observed at 1500 rpm and the maximum 2.85 hp at 2000 engine rpm. The increasing trend was due to the increase in cutterbar speed with engine speed. It was found that inertia and frictional force of cutterbar were main factor which influence the value of total power required for cutting. Increase in power due to cutting of crop was found to be low as compared to the inertia and frictional forces.

The maximum value of increase in power due to cutting of paddy crop and F_2, *viz.*, 0.34 hp, was observed at an engine speed of 1900 rpm at first gear in high range. The minimum value of the increase in power due to cutting and F_2, *viz.* 0.13 hp, was observed at an engine speed of 1500 rpm at first low gear. The tractor front mounted reaper was found not possible to operate at first high forward gear at an engine speed of 2000 rpm.

The maximum and minimum values of total power required and specific power requirement are presented in Table 3. The total power and specific power requirement were found to be increased with an increase in the forward speed of machine for the same engine speed. The maximum value of total power and specific power requirement, *viz.* 4.61 hp and 2.20 hp, were observed at an engine speed of 2000 rpm at fourth low gear and minimum values of total power and specific power

Table 3. Maximum and minimum power for harvesting with PTO pulley No.I

Forward gear	Forward speed (m/s)	Power for cutting (hp)	Power for conveying (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm					
LG-1	0.66	3.12	1.38	4.50	2.14
HG-4	1.70	3.17	1.44	4.61	2.20
Engine speed 1900 rpm					
LG-1	0.62	3.00	1.35	4.35	2.07
HG-1	2.40	3.08	1.46	4.54	2.16
Engine speed 1800 rpm					
LG-1	0.58	2.54	1.27	3.79	1.80
HG-1	2.33	2.62	1.37	3.96	1.89
Engine speed 1700 rpm					
LG-1	0.50	2.21	1.21	3.37	1.60
HG-1	2.20	2.29	1.30	3.50	1.70
Engine speed 1600 rpm					
LG-1	0.50	1.80	1.14	2.92	1.39
HG-1	2.10	1.87	1.21	3.06	1.46
Engine speed 1500 rpm					
LG-1	0.45	1.46	1.06	2.52	1.20
HG-1	1.90	1.52	1.15	2.67	1.27

requirement, *viz.* 2.52 hp and 1.20 hp, were observed at an engine speed of 1500 rpm at first low gear.

The total power requirement found to be increased with an increase in engine speed for the same gear. This trend was due to the increase in forward speed of machine with an increase in engine speed. The increasing trend of power requirement was because of more plant fed to the cutterbar at higher forward speeds. More the plant feed rate, more the number of plants to be cut per stroke and more the cut crop to be handled by conveyor assembly hence the more the values of power requirement. More plant feed rate at higher speeds caused the formation of bunch of stalks at the rear of knife sections prior to cutting. This required a larger force at the start of cutting.

Since the specific power depends on the total power requirement, the same trend was also observed with specific power engine engine speed relationship. From the analysis, the total power requirement and specific power were found to be low for 1500 engine rpm at all the operated gears.

4.4.1.2 Harvesting loss and harvesting pattern

The harvesting losses were collected for all engine speeds (from 1500 to 2000 rpm) at selected gears as per the procedure mentioned in the previous chapter and the values are presented in Appendix VII. The maximum and minimum values of total harvesting losses are presented in Table 4.

It was found that, the total harvesting losses were increased with an increase in forward speed of machine for the same engine speed. The maximum value of harvesting loss was observed at the highest gear and minimum value of harvesting loss was observed at lowest gear for the same engine speed. The maximum value of harvesting loss *viz.*, 3.00 per cent was observed at an engine speed of 2000 rpm at fourth gear and minimum value, 1.5 per cent was observed for at an engine speed of 1500 rpm at first gear.

The total harvesting losses were found to be increased with an increase in engine speed. In other words, harvesting losses increased with an increase in the forward speed. The reason for this increasing trend may be due to the increase in cutterbar speed and conveyor belt speed, which increased the impact to earheads through stems causing shattering. At higher forward speeds the cutterbard losses were increased due to the formation of a bunch of stalks at the rear of the knife. This increased impact of knife on the stem, hitting of crops to the crop board, rubbing among earheads and uncut losses.

The total cutterbar losses were found to vary from 1.05 per cent at 1500 rpm at first gear to 2.04 per cent at

Table 4. Maximum and minimum harvesting losses with PTO pulley No.I

Forward gear	Forward speed (m/s)	cutterbar loss (g/m²)	Windrow loss (g/m²)	Total loss (g/m²)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.66	5.25	2.25	7.50	2.50
LG-4	1.70	6.12	2.88	9.00	3.00
Engine speed 1900 rpm					
LG-1	0.62	4.78	2.17	6.95	2.32
HG-1	2.40	5.34	2.76	8.10	2.70
Engine speed 1800 rpm					
LG-1	0.58	4.49	1.93	6.42	2.14
HG-1	2.33	5.23	2.72	7.95	2.65
Engine speed 1700 rpm					
LG-1	0.55	4.30	1.85	6.15	2.05
HG-1	2.20	5.10	2.40	7.50	2.30
Engine speed 1600 rpm					
LG-1	0.50	3.82	1.64	5.46	1.82
HG-1	2.16	4.79	2.26	7.05	2.35
Engine speed 1500 rpm					
LG-1	0.45	3.15	1.35	4.50	1.50
HG-1	1.90	4.62	1.98	6.60	2.20

2000 rpm at fourth low gear. Windrowing losses were varied from 0.45 per cent to 0.96 per cent at the above operated conditions. The increase in windrowing loss was due to the speed of conveyor belts. At higher engine speed, the speed of conveyor belts found to be high. It was throwing the cut crop at quite some distance from the edge of discharge plate instead of conveying it neatly on to the ground. This was responsible for increase in windrowing loss as the cut crops were found to hitting on the field while windrowing. The same trend was observed for all selected gears. The minimum value of harvesting losses were observed for 1500 engine rpm at all the operated gears.

Harvesting pattern: For the higher engine speed, beyond 1700 rpm the linear speed of cutterbar was found to be high and this increased the multiple cutting of stem and stubbles. Because of this speed the cutterbar losses were found to be higher at the above engine speeds.

For the first three gears in low range, with engine speed, varying from 1500 to 1600 rpm, the total machine harvesting losses were found to be less than 2 per cent. This may be due to the low speeds of cutterbar and conveyor belt and forward travel. At higher gears, the uncut losses were increased as the forward speed of machine increased without the proportionate increase in the speed of cutterbar.

4.4.1.3 Windrowing pattern

As already discussed in previous chapters, vertical conveyor reaper windrower was designed to cut the crop, convey it in vertical position and to lay the conveyed crop on the ground in a clean windrow. The windrowing is such that the direction of tillers is laid perpendicular to the direction of machine travel, with ears away from the machine. The tractor front mounted reaper windrower was critically observed for the above design requirements during its performance evaluation trials. The results of these observations are presented and discussed.

The Table 5 gives the distance to which crop was windrowed from the end of the discharge plate by the conveyor belts. It was found that the distance of windrowed crop from discharge plate is increased with an increase in the engine speed.

At an engine speed of 1500 rpm, the machine was found to windrow the crop at a distance of 10 cm from the end of discharge plate and windrowing process was found neat and uniform. At an engine speed of 2000 rpm, reaper was found roughly throwing the crop at a higher speed with a distance 25 cm from the end of discharge plate instead of conveying the cut crop smoothly. Because of this, the more windrowing loss were observed at higher engine speeds.

Table 5. Effect of conveyor belt speed on throw distance with PTO pulley No.I

Engine speed (rpm)	Conveyor belt speed (m/s)	Throw distance (cm)
2000	2.84	25
1900	2.80	22
1800	2.63	18
1700	2.51	15
1600	2.35	13
1500	2.19	10

From the same Table 6 it was found that tillers angle, decreased with an increase in forward speed of machine travel for the same engine speed. At an engine speed of 1500 rpm, for the first three gears, tillers was found to be 88 degrees with direction of travel and this angle was decreased to 85 degree for fourth and first gear in low and high range respectively. At an engine speed of 2000 rpm, where the maximum value of conveyor belt speed was observed, tillers angle was noticed to decrease to a value of 55 degrees at fourth low gear.

It was found that, tiller angle was affected by forward speed and conveyor belt speed whereas distance to which crop was conveyed was found affected by the speed of conveyor belts.

The minimum values of distance of crop being windrowed, acceptable limit of tiller angle at all the operated gears as well as smooth and neat windrows were observed at an engine speed of 1500 rpm.

4.4.2 PTO pulley No. II

The tractor front mounted reaper windrower was fitted with PTO pulley No.II and then the unit was field tested for harvesting of paddy crop. The same gears were selected as in case of PTO pulley No.I and the unit was operated at different engine speed from 1000 to 2000 rpm.

Table 6. Effect of forward speed and engine speed on windrowing angle with PTO pulley No.I

Forward gear	Forward speed (m/s)	Tillers angle (degrees)
Engine speed 2000 rpm		
LG-1	0.66	80
LG-2	0.97	75
LG-3	1.30	65
LG-4	1.70	55
Engine speed 1900 rpm		
LG-1	0.62	85
LG-2	0.92	80
LG-3	1.20	80
LG-4	1.60	75
HG-1	2.40	65
Engine speed 1800 rpm		
LG-1	0.58	85
LG-2	0.88	85
LG-3	1.15	80
LG-4	1.55	80
HG-1	2.33	75
Engine speed 1700 rpm		
LG-1	0.55	88
LG-2	0.83	85
LG-3	1.12	85
LG-4	1.50	80
HG-1	2.20	80
Engine speed 1600 rpm		
LG-1	0.50	88
LG-2	0.83	88
LG-3	1.12	85
LG-4	1.50	85
HG-1	2.20	85
Engine speed 1500 rpm		
LG-1	0.50	88
LG-2	0.78	88
LG-3	1.06	88
LG-4	1.40	85
HG-1	2.10	85

It was found that at the engine speed of 1000 to 1300 rpm, the conveyor belt assembly was not conveying the cut crop because of low linear speed of conveyor belts. The conveyor belt assembly was choked with cut crop and tractor had to stop frequently for cleaning of conveyor assembly. The above observations were made at first gear in low range. The field testing of reaper windrower was not continued at higher gears for the above engine speeds because of choking of conveyor assembly.

The reaper front mounted reaper was operated from an engine speed of 1400 to 2000 rpm.

4.4.2.1 Total power and specific power requirement for harvesting

The values pertaining to the total power and specific power requirement for different engine speeds and forward speeds are given in Appendix VIII and IX. The values of inertia and frictional forces of cutterbar were found to be increased with an increase in the engine speed. This increasing trend was due to the increase in cutterbar speed. The minimum and maximum values of inertia and friction force, *viz.* 1.38 hp and 3.50 hp respectively, were observed at an engine speed of 1400 rpm and 2000 rpm respectively. The maximum and minimum values of increase in power due to cutting and F_2, *viz.* 0.38 hp and 0.13 hp, were observed at an engine speed of 2000 rpm at fourth low gear and 1400 rpm at first low gear respectively.

The maximum and minimum values of total power and specific power requirements are given in Table 7. The total power and specific power requirements were found to be increased with an increase in the forward speed of the reaper. At an engine speed of 2000 rpm, at fourth low forward gear, the maximum values of total power requirement and specific power requirement were observed to be 5.42 hp and 2.58 hp respectively. The minimum values of total power requirement and specific power requirement, *viz.*, 2.58 hp and 1.22 hp respectively, were observed at an engine speed of 1400 rpm at first low gear.

The increasing trend of total power requirement with an increase in forward speed was due to the increased in feed rate of crops to the cutterbar and conveyor assembly. The same trend was also observed with specific power requirement.

The minimum values of total power requirement and specific power requirement were observed at an engine speed of 1400 rpm at all the operated gears. Slightly higher values of total power and specific power requirements were observed for PTO pulley No.II than PTO pulley No.I at same engine speed and gear. This was due to the higher cutterbar and conveyor speeds for PTO pulley No.II.

Table 7. Maximum and minimum power for harvesting with PTO pulley No.II

Forward gear	Forward speed (m/s)	Power for cutting (hp)	Power for conveying (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm					
LG-1	0.66	3.89	1.48	5.32	2.53
HG-4	1.70	3.93	1.54	5.42	2.58
Engine speed 1900 rpm					
LG-1	0.62	3.62	1.43	5.01	2.39
HG-1	2.40	3.70	1.55	5.20	2.48
Engine speed 1800 rpm					
LG-1	0.58	3.11	1.35	4.42	2.10
HG-1	2.33	3.19	1.45	4.60	2.19
Engine speed 1700 rpm					
LG-1	0.55	2.71	1.30	3.98	1.90
HG-1	2.20	2.79	1.39	4.15	1.98
Engine speed 1600 rpm					
LG-1	0.50	2.22	1.22	3.42	1.63
HG-1	2.10	2.29	1.30	3.58	1.70
Engine speed 1500 rpm					
LG-1	0.45	1.79	1.13	2.91	1.39
HG-1	1.90	1.86	1.22	3.04	1.45
Engine speed 1400 rpm					
LG-1	0.43	1.52	1.07	2.58	1.22
HG-1	1.80	1.58	1.13	2.70	1.29

4.4.2.2 Harvesting losses and harvesting pattern

The values pertaining to the harvesting losses were noted for all engine speeds and gears and the values are presented in Appendix X. The maximum and minimum values of total harvesting losses are presented in Table 8.

The maximum value of total harvesting losses was, 3.15 per cent, observed at an engine speed of 2000 rpm at fourth low gear and the minimum value of the harvesting, 1.54 per cent was observed at an engine speed of 1400 rpm at first low gear. This increasing trend of harvesting losses with forward speed was due to the higher cutterbar and conveyor belt speeds. This imparted greater impact to earhead, through stems, increased relative speed and rubbing at earhead, with each other. The cutterbar losses were varied from 1.07 per cent to 2.15 per cent at an engine speed of 1400 rpm at first low gear and at an engine speed at 2000 rpm at fourth low gear respectively. The windrowing losses were varied from 0.46 per cent to 1.00 per cent for the above parameters. The minimum values of harvesting losses were observed for engine speed 1400 rpm at all the operated gears.

Harvesting pattern: Due to high cutterbar speed multiple cutting of stubbles were observed at higher engine speed beyond 1600 rpm. This increased the cutterbar losses. At lower forward speeds, for engine speeds rpm 1400 to 1500 rpm,

Table 8. Maximum and minimum harvesting losses with PTO pulley No.II

Forward gear	Forward speed (m/s)	cutterbar loss (g/m^2)	Windrow loss (g/m^2)	Total loss (g/m^2)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.66	5.88	2.52	8.40	2.80
LG-4	1.70	6.46	2.99	9.46	3.15
Engine speed 1900 rpm					
LG-1	0.62	5.76	2.45	8.16	2.72
HG-1	2.40	6.14	2.86	9.00	3.00
Engine speed 1800 rpm					
LG-1	0.58	5.39	2.25	7.65	2.55
HG-1	2.33	5.76	2.49	8.25	2.75
Engine speed 1700 rpm					
LG-1	0.55	4.78	2.05	6.84	2.28
HG-1	2.20	5.35	2.30	7.65	2.55
Engine speed 1600 rpm					
LG-1	0.50	4.41	1.89	6.30	2.10
HG-1	2.10	5.04	2.16	7.20	2.40
Engine speed 1500 rpm					
LG-1	0.45	3.90	1.67	5.58	1.86
HG-1	1.90	4.73	2.02	6.75	2.25
Engine speed 1400 rpm					
LG-1	0.43	3.23	1.39	4.62	1.54
HG-1	1.80	4.51	1.94	6.45	2.15

the total machine harvesting losses were found to be less than 2 per cent because of low cutterbar and conveyor speeds. At higher speeds, the uncut losses were increased due to the increase in forward speed without the proportionate increase in the cutterbar speed.

4.4.2.3 Windrowing pattern

Table 9 gives the distance to which tillers were conveyed from discharge plate end by the conveyor belts. It was observed that the distance of windrowed crop from discharge plate is increased with an increase in the engine speed. This trend is observed because of increase in conveyor belt speed with an increase in engine speed.

At the engine speed of 1400 rpm, windrowing process was found to be neat and uniform with crop getting windrowed at a distance of 13.5 cm from the discharge plate. At the engine speed of 2000 rpm, it was found roughly throwing the crop at a higher speed with a distance of 32.0 cm from the end of discharge plate.

From the Table 10, it was found that tillers angle with respect to the direction of travel decreased with an increase in the forward speed. At an engine speed of 2000 rpm, the lowest tiller angle of 50 degrees was noticed at fourth low gear. The acceptable limit of tiller angle at all the

Table 9. Effect of conveyor belt speed on throw distance with PTO pulley No. II

Engine speed (rpm)	Conveyor belt speed (m/s)	Throw distance (cm)
2000	3.04	32.0
1900	2.97	28.0
1800	2.81	26.0
1700	2.69	23.0
1600	8.52	18.0
1500	2.35	16.0
1400	2.21	13.5

Table 10. Effect of forward speed and engine speed on tillers angle with PTO pulley No.II

Forward gear	Forward speed (m/s)	Tillers angle (degrees)
Engine speed 2000 rpm		
LG-1	0.66	80
LG-2	0.97	75
LG-3	1.30	65
LG-4	1.70	50
Engine speed 1900 rpm		
LG-1	0.62	80
LG-2	0.92	75
LG-3	1.20	75
LG-4	1.60	65
HG-1	2.40	60
Engine speed 1800 rpm		
LG-1	0.58	85
LG-2	0.88	80
LG-3	1.15	75
LG-4	1.55	75
HG-1	2.33	65
Engine speed 1700 rpm		
LG-1	0.55	85
LG-2	0.83	85
LG-3	1.12	80
LG-4	1.50	80
HG-1	2.20	75
Engine speed 1600 rpm		
LG-1	0.50	85
LG-2	0.78	85
LG-3	1.06	85
LG-4	1.40	80
HG-1	2.10	80
Engine speed 1500 rpm		
LG-1	0.45	88
LG-2	0.69	85
LG-3	0.95	85
LG-4	1.30	80
HG-1	1.90	80
Engine speed 1400 rpm		
LG-1	0.43	88
LG-2	0.65	88
LG-3	0.90	85
LG-4	1.20	85
HG-1	1.80	80

operated gears, smooth and neat windrows were observed at an engine speed at 1400 rpm.

4.4.3 PTO pulley No.III

The tractor front mounted reaper was fitted with PTO pulley No.III. The unit was field tested for paddy harvesting. It was operated at higher engine speeds varying from 1300 to 2000 rpm to avoid choking of conveyor assembly as the conveyor belt speed was found to be insufficient to convey the cut crop at an engine speed of 1000 to 1200 rpm.

4.4.3.1 Total power and specific power requirements

The total power and specific power requirements for the different engine speeds and forward speeds are given in Appendix XI and XII. The increasing trend of inertia and frictional force of cutterbar were observed with an increase in an engine speed. This was due to the increase in cutterbar speed with an increase in engine speed. The minimum and maximum values of inertia and frictional force, *viz.* 1.33 hp and 4.24 hp, were observed at an engine speed of 1300 rpm and 2000 rpm respectively. The maximum and minimum values of increase in power due to cutting and F_2, *viz.* 0.44 hp and 0.13 hp, were observed at an engine speed of 2000 rpm at fourth low gear and at 1300 rpm at first low gear respectively.

The maximum and minimum values of total power requirements and specific power requirement are given in Table 11. The maximum values of total power and specific power requirements, *viz.* 6.33 hp and 3.01 hp, were observed at an engine speed of 2000 rpm at fourth low gear. The minimum values of total power and specific power requirements, *viz.* 2.51 hp and 1.19 hp were observed at an engine speed of 1300 rpm at first low gear. The increasing trend of total power and specific power requirements was observed with forward speed.

The minimum values of total power requirement and specific power requirement were observed at an engine speed of 1300 rpm at all the operated forward gear. The values of total power and specific power requirements were observed to be higher for PTO pulley No.III than other two PTO pulleys at the same operating parameters because of high cutterbar and conveyor belt speeds.

4.4.3.2 Harvesting losses and harvesting pattern

The Appendix-XIII contains the values of harvesting losses for all operated engine speeds and forward speeds. The maximum and minimum values of total harvesting losses are presented in Table 12.

The total harvesting losses were increased with an increase in the engine speed, i.e. with forward speed. The

Table 11. Maximum and minimum power for harvesting with PTO pulley No.III

Forward gear	Forward speed (m/s)	Power for cutting (hp)	Power for conveying (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm					
LG-1	0.66	4.70	1.58	6.21	2.96
HG-4	1.70	4.74	1.65	6.33	3.01
Engine speed 1900 rpm					
LG-1	0.62	4.38	1.53	5.85	2.79
HG-1	2.40	4.46	1.65	6.01	2.86
Engine speed 1800 rpm					
LG-1	0.58	3.77	1.45	5.17	2.46
HG-1	2.33	3.85	1.56	5.36	2.55
Engine speed 1700 rpm					
LG-1	0.55	3.28	1.39	4.63	2.20
HG-1	2.20	3.36	1.49	4.80	2.29
Engine speed 1600 rpm					
LG-1	0.50	2.68	1.30	3.96	1.89
HG-1	2.10	2.75	1.39	4.11	1.96
Engine speed 1500 rpm					
LG-1	0.45	2.18	1.20	3.35	1.59
HG-1	1.90	2.24	1.28	3.50	1.67
Engine speed 1400 rpm					
LG-1	0.43	1.84	1.13	2.95	1.40
HG-1	1.80	1.90	1.20	3.08	1.47
Engine speed 1300 rpm					
LG-1	0.40	1.38	1.05	2.51	1.19
HG-1	1.70	1.43	1.10	2.61	1.24

Table 12. Maximum and minimum harvesting losses with PTO pulley No.III

Forward gear	Forward speed (m/s)	cutterbar loss (g/m²)	Windrow loss (g/m²)	Total loss (g/m²)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.66	7.22	3.09	10.31	3.44
LG-4	1.70	8.08	3.47	11.55	3.85
Engine speed 1900 rpm					
LG-1	0.62	6.13	2.63	8.76	2.92
HG-1	2.40	6.93	2.97	9.90	3.30
Engine speed 1800 rpm					
LG-1	0.58	5.63	32.41	8.04	2.68
HG-1	2.33	6.00	2.57	8.57	2.86
Engine speed 1700 rpm					
LG-1	0.55	4.93	2.11	7.04	2.35
HG-1	2.20	5.56	2.39	7.95	2.65
Engine speed 1600 rpm					
LG-1	0.50	4.83	2.07	6.90	2.30
HG-1	2.10	5.25	2.25	7.50	2.50
Engine speed 1500 rpm					
LG-1	0.45	4.45	1.91	6.36	2.12
HG-1	1.90	4.94	2.11	7.05	2.35
Engine speed 1400 rpm					
LG-1	0.43	3.95	1.69	5.64	1.88
HG-1	1.80	4.37	1.87	6.24	2.08
Engine speed 1300 rpm					
LG-1	0.40	3.25	1.40	4.65	1.55
HG-1	1.70	3.47	1.48	4.95	2.05

maximum values of total harvesting losses, *viz.* 3.85 per cent, was observed at an engine speed of 2000 rpm at fourth low gear. The minimum value of harvesting losses *viz.* 1.55 was observed at an engine speed of 1300 rpm at first low gear.

At lower forward speeds, for engine speeds 1300 to 1400 rpm, the total harvesting losses were found to be well within 2 per cent as compared with the values at higher forward speeds. The values of harvesting losses obtained for PTO pulley No.III were found to be higher compared to PTO pulley No.I and II. This was because of higher values of cutterbar and conveyor belt speeds at the same engine speed for PTO pulley No.III.

4.4.3.3 Windrowing pattern

The Table 13 contains the values of the distance of windrowed crop from the end of discharge plate.

At an engine speed of 1300 rpm, windrowing process was found to be neat and uniform with crop getting windrowed at a distance of 15 cm from the end of discharge plate. At an engine speed of 2000 rpm, machine was found throwing the crop at a distance of 37 cm from the end of discharge plate. From Table 14, tillers angle with respect to the direction of machine travel was found to be decreased with an increase in forward speed. The acceptable limit of tiller angle at all

Table 13. Effect of conveyor belt speed on throw distance with PTO pulley No.III

Engine speed (rpm)	Conveyor belt speed (m/s)	Throw distance (cm)
2000	3.24	37
1900	3.17	35
1800	3.00	33
1700	2.88	28
1600	2.69	23
1500	2.59	18
1400	2.36	15
1300	2.19	12

Table 14. Effect of forward speed and engine speed on tillers angle with PTO pulley No.III

Forward gear	Forward speed (m/s)	Tillers angle (degrees)
Engine speed 2000 rpm		
LG-1	0.66	75
LG-2	0.97	60
LG-3	1.30	55
LG-4	1.70	45
Engine speed 1900 rpm		
LG-1	0.62	80
LG-2	0.92	70
LG-3	1.20	60
LG-4	1.60	55
HG-1	2.40	50
Engine speed 1800 rpm		
LG-1	0.58	80
LG-2	0.88	75
LG-3	1.15	65
LG-4	1.55	60
HG-1	2.33	55
Engine speed 1700 rpm		
LG-1	0.55	85
LG-2	0.83	80
LG-3	1.12	75
LG-4	1.50	65
HG-1	2.20	65
Engine speed 1600 rpm		
LG-1	0.50	85
LG-2	0.78	85
LG-3	1.06	80
LG-4	1.40	80
HG-1	2.10	75
Engine speed 1500 rpm		
LG-1	0.45	88
LG-2	0.69	85
LG-3	0.95	85
LG-4	1.30	80
HG-1	1.90	80
Engine speed 1400 rpm		
LG-1	0.43	88
LG-2	0.65	88
LG-3	0.90	85
LG-4	1.20	85
HG-1	1.80	80
Engine speed 1300 rpm		
LG-1	0.40	88
LG-2	0.60	88
LG-3	0.80	88
LG-4	1.00	85
HG-1	1.70	85

the operated gears were observed at an engine speed of 1300 rpm. At an engine speed of 2000 rpm, the tiller angle was decreased at rapid rate with an increase in the forward speed. The acute tiller angle of 45 degrees was observed at fourth low gear.

4.5 Selection of optimum operating parameters of tractor front mounted reaper windrower

4.5.1 Selection of optimum engine speed

The optimum operating parameters of tractor front mounted reaper windrower for the different field conditions were selected based on the extensive field trails conducted at KCAET Instructional Farm, Tavanur. The optimum parameters were selected by considering the crop conditions, field conditions, traction devices and various combination of forward speeds, reciprocating speeds of cutterbar and conveyor belt speeds. Based on the discussion made earlier in this chapter, the engine speeds of 1500 rpm, 1400 rpm and 1300 rpm were found out as optimum for PTO pulley No.I, II and III respectively. The values of power requirements and harvesting losses were found to be minimum at these engine speeds at all the operated gears except at first gear in high range. The harvesting pattern and windrowing pattern were also observed to be good. The tillers angle with respect to the direction of travel at all the operated gears were found to be within the acceptable limit for the above engine speeds.

4.5.2 Selection of optimum forward speed

The tractor mounted reaper was field tested again to know the field capacity and field efficiency at the optimum engine speeds. The reaper was operated at only in four gears in low range. The trials at first gear in high range were not conducted as the speed of the tractor at this gear was high and it posed problems for harvesting because of inadequate size of field. The trials at above gears in previous cases carried out to know the harvesting pattern, windrowing pattern and power requirements at different engine speeds by selecting a strip of 60 m length.

The values of actual field capacity, theoretical field capacity and field efficiency of the reaper at the optimum engine speeds are given in Table 15. The actual field capacity of the reaper was found to be varied from 0.18 ha/hr to 0.38 ha/hr at an engine speed of 1500 rpm with PTO pulley No.I, 0.16 ha/hr to 0.36 ha/hr at an engine speed of 1400 rpm with PTO pulley No.II and 0.14 ha/hr to 0.38 ha/hr at an engine speed of 1300 rpm with PTO pulley No.III. The variations in the actual field capacity of the reaper were due to the variations in the forward speed.

Table 15. Actual and theoretical field capacity of reaper windrower

Sl. No.	Diameter of PTO pulley (cm)	Forward gear	Forward speed (m/s)	Actual field capacity (ha/hr)	Theoretical field capacity (ha/hr)	Field efficiency (%)
1.	17.78	Engine speed 1500 rpm				
		LG-1	0.45	0.18	0.34	52.00
		LG-2	0.697	0.28	0.52	53.80
		LG-3	0.95	0.38	0.70	54.00
		LG-4	1.30	0.36	0.98	36.73
2.	19.03	Engine speed 1400 rpm				
		LG-1	0.43	0.16	0.32	50.00
		LG-2	0.65	0.25	0.49	51.00
		LG-3	0.90	0.36	0.68	53.00
		LG-4	1.20	0.34	0.90	37.77
3.	20.32	Engine speed 1300 rpm				
		LG-1	0.40	0.14	0.30	46.60
		LG-2	0.60	0.22	0.45	48.80
		LG-3	0.80	0.30	0.60	50.00
		LG-4	1.00	0.38	0.75	50.66

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At first three gears at an engine speeds of 1500 rpm and 1400 rpm, the field efficiency was found to be increased with an increase in forward speed but the minimum value of field efficiency was observed at fourth low gear. This was due to wet soil and inadequate size of fields which increased the idle runs and time losses. The time losses were found to be greater than the actual time taken for cutting (Appendix XIV).

Functional performance of the reaper was considered optimum when the harvesting loss and power requirements turn out to be minimum for a desired field capacity, field efficiency, harvesting pattern and windrowing pattern. The maximum values of actual field capacity, *viz.*, 0.38 ha/hr, and field efficiency, *viz.*, 54.00 per cent, were observed at an engine speed of 1500 rpm at third low gear with PTO pulley No.I. The maximum values of actual field capacity and field efficiency, *viz.*, 0.36 ha/hr and 53.00 per cent respectively, were observed at an engine speed of 1400 rpm at third low gear with PTO pulley No.II. The maximum values of field capacity, *viz.*, 0.38 ha/hr, and field efficiency of 50.66 per cent were observed at an engine speed of 1300 rpm at fourth low gear with PTO pulley No.III. The relationship between the total power requirements and harvesting losses with engine speeds at third low gear for PTO pulley No.I and II and at fourth low gear for PTO pulley No.III are shown in the Fig.7, 8 and 9 respectively. It is observed that, the values

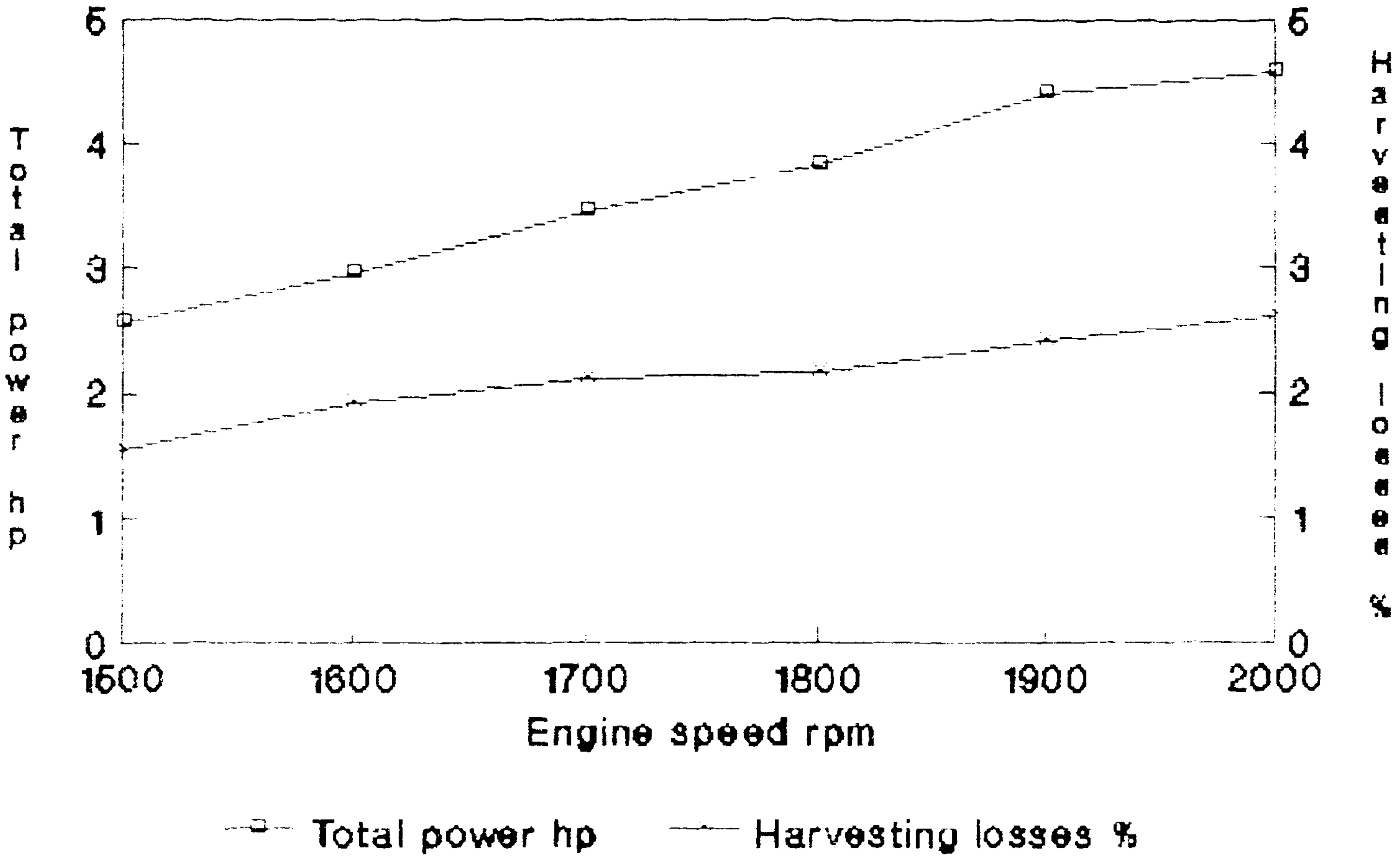

FIG.7 RELATION BETWEEN VARIABLES AT LG3 WITH PTO PULLEY NO.I

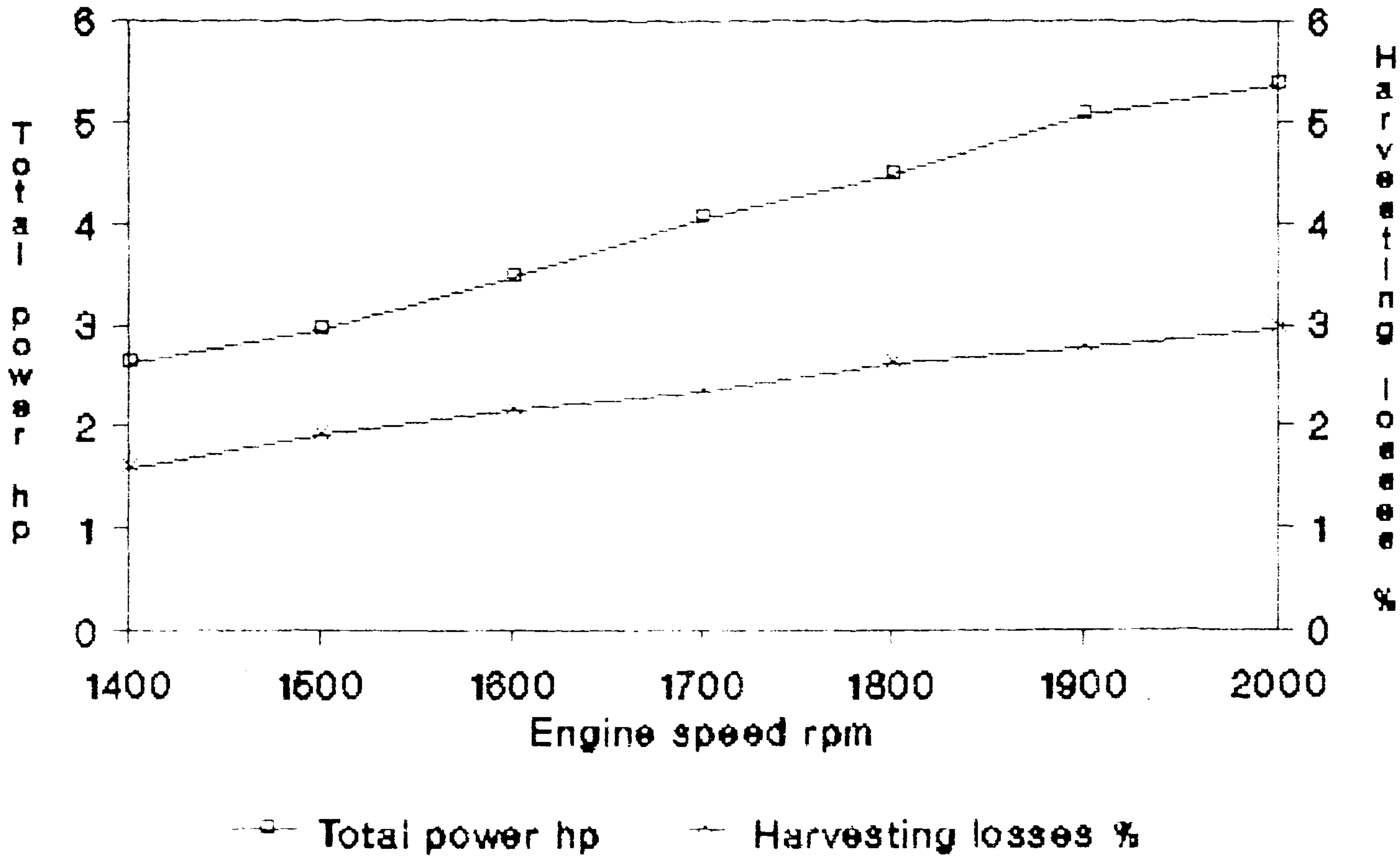

FIG.8 RELATION BETWEEN VARIABLES LG3 WITH PTO PULLEY NO.II

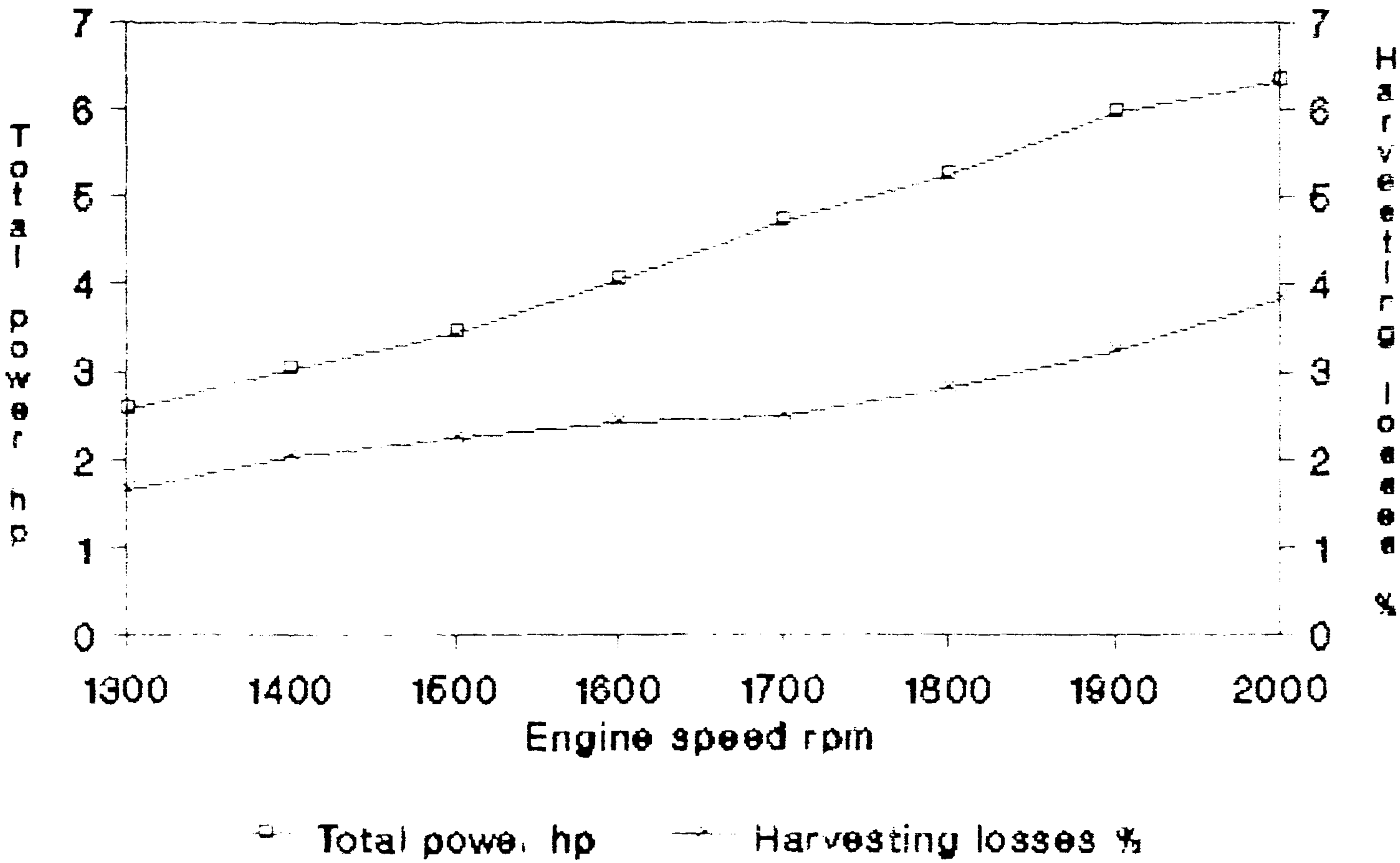

FIG.9 RELATION BETWEEN VARIABLES LG4 WITH PTO PULLEY NO.III

of total power requirements and harvesting losses were found to be minimum at an engine speeds of 1500 rpm and 1400 rpm at third low gear for PTO pulley No.I and II respectively. Similarly, the minimum values of total power requirements and harvesting losses were observed at an engine speed of 1300 rpm at fourth low gear.

4.5.3 Cutterbar index and conveyor index

The optimum values of cutter bar index and conveyor index are given in Table 16. The engine speed of 1500 rpm and third low gear were found as optimum with PTO pulley No.I having 17.78 cm diameter. The cutterbar speed and conveyor speed at the above condition were 1.48 m/s and 2.19 m/s respectively. The machine forward speed at third low gear was found to be 0.95 m/s. So the cutterbar index and conveyor index at the above set of operating parameters were found to be 1.56 and 2.30 respectively.

With PTO pulley No.II having 19.03 cm diameter, an engine speed of 1400 rpm and third low gear were selected as optimum. The cutterbar speed and conveyor belt speed at the above condition were 1.50 m/s and 2.21 m/s respectively. The reaper forward speed at third low gear was found to be 0.90 m/s. The cutterbar index and conveyor index were found to be 1.66 and 2.45 respectively.

Table 16. Cutterbar index and conveyor index at the optimum operating conditions

Sl. No.	Diameter of PTO pulley (cm)	Forward gear	Forward speed (m/s)	Field capacity (ha/hr)	Cutter bar speed (m/s)	Conveyor belt speed (m/s)	Cutterbar index	Conveyor index
1.	17.78	Engine speed 1500 rpm						
		LG-3	0.95	0.38	1.48	2.19	1.56	2.30
2.	19.03	Engine speed 1400 rpm						
		LG-3	0.90	0.36	1.50	2.21	1.66	2.45
3.	20.32	Engine speed 1300 rpm						
		LG-4	1.00	0.38	1.48	2.19	1.48	2.19

An engine speed of 1300 rpm and fourth low gear were found as optimum with PTO pulley No.III having 20.32 cm diameter. The cutterbar speed and conveyor belt speed at the above engine speed were found to be 1.48 m/s and 2.19 m/s. The reaper forward speed at fourth low gear was 1.00 m/s. The cutterbar index and conveyor index with PTO pulley No.III were found to be 1.48 and 2.19 respectively.

4.5.4 Optimum operating parameters for different field conditions

In Kerala, the tractor front mounted reaper is expected to work in varying fields from dry to waterlogged condition. On waterlogged fields, where water is standing to a depth of minimum 5 cm, more power is required for traction. The engine speed of 1500 rpm with PTO pulley No.I is recommended for the above condition. The tractor mounted reaper is recommended to operate in low third gear for achieving optimum cutting of paddy, conveying of crop and neat windrowing with enough power for forward movement. It is also found that optimum field performance of the reaper was achieved with the PTO pulley No.III when the reaper was operated in a low fourth gear at an engine speed of 1300 rpm for dry paddy field.

Neat windrowing and minimum harvesting losses, complete harvesting and conveying of crop were achieved when the reaper was operated in low third gear with PTO pulley No. II at an engine speed of 1400 rpm if the field is neither dry nor submerged with water but the moisture content is around its field capacity.

It is obvious to operate the tractor with different throttle position in different field conditions to overcome the problems in field. The same PTO pulley is not suitable to obtain optimum reaper performance when the engine speed is changed. At varying engine speed one of the three PTO pulley is to be fitted and the reaper is to be operated as per the recommendation.

4.6 Statistical analysis

From the total power requirement and harvesting losses, a set of equations were developed using regression technique correlating the forward speed of machine with total power requirement and harvesting loss at optimum engine speeds. The equations are presented in Table 17. The test of significance of correlation coefficients were done using student t-distribution technique. The calculated t-values and table t-values are given in the above table. The correlation coefficients of forward speed and total power requirement were found to be significant at 0.01 level of significance. It indicates that the two variables are linearly correlated and any change in forward speed of the

Table 17. Regression equations and t-values

P = Total power required, hp
H = Total machine harvesting losses, %
F = Forward speed of machine, m/s

Engine speed (rpm)	Diameter of PTO pulleys (cm)	Regression equation	Regression coefficient	Correlation coefficient	t-value (calculated)	Table t-value at = 0.01 3. d.f
1500	17.78	P = 0.108 F + 2.466	0.108	0.995	17.99 (S)	5.841
		H = 0.507 F + 1.131	0.507	0.940	4.772 (NS)	5.841
1400	19.03	P = 0.088 F + 2.542	0.088	0.999	38.70 (S)	5.841
		H = 0.455 F + 1.245	0.455	0.805	3.961 (NS)	5.841
1300	20.32	P = 0.076 F + 2.486	0.076	0.990	12.15 (S)	5.841
		H = 0.433 F + 1.300	0.433	0.938	4.687 (NS)	5.841

S - Significant NS - Non-significant

reaper influence on total power requirement. The correlation coefficients of forward speed and harvest loss found to be non-significant at 0.01 level of significance. It indicates that the two variables are linearly uncorrelated.

4.7 Conveyor belt speed in relation to the length of cutterbar

Better performance of reaper windrower can be obtained when the quantity of conveyed crop per unit time is greater than or equal to the crop cut by the cutterbar. The bunches of the crop should be continuously conveyed without any blockage.

For the same operation conditions like, density of crop, variety, straw and grain moisture content, field conditions, lug height and forward speed, the conveyor belt speed has to be increased as length of cutterbar increases. This is because, as the length of cutterbar increases, the reaper has to handle more quantity of crop per unit time due to increase in the feed rate from the cutterbar. The conveyor assembly of reaper will get choked with the bulkycut crop if the conveyor belt speed is not increased proportionally with respect to the length of the cutterbar for efficient operation.

The conveyor belt speed of one meter self propelled reaper windrower is less than that of 1.6 m power tiller operated reaper windrower for the same forward speed. In case of the tractor front mounted reaper windrower, the conveyor belt speed is greater than the 1.6 m power tiller operated reaper windrower at the same forward speed and field conditions as the cutterbar length in case of tractor mounted reaper windrower is 2.2 m.

4.8 Economic analysis

The economic studies were done by comparing the cost of manual harvesting and harvesting by reaper windrower. The detailed calculations on cost of operation for the tractor front mounted reaper windrower is given in Appendix-XV. The cost indicators for reaper windrower as well as for manual harvesting are given in Tables 18 and 19.

From the analysis it was found that the cost of harvesting paddy per ha by manual method is Rs.1625. The total operating cost of reaper windrower was found to be Rs.462 per ha. Thus there was a financial saving of Rs.1163 per ha. A saving of 71.50 per cent in the cost of harvesting operation alone can be achieved by the introduction of tractor front mounted reaper windrower. The total skilled and unskilled labours used for operating the reaper were found to be only 18.5 man-hrs per ha as compared to 200 man-hrs per ha by manual method. The labour displaced from

Table 18. Cost indicators for tractor front mounted reaper windrower

Sl. No.	Item	Observation
1.	**Tractor**	
	a. Cost of tractor, Rs.	170000
	b. Useful life, years	10
	c. Hours of use per year	1000
	d. Fixed cost	
	(i) Depreciation per year Rs	15300
	(ii) Interest on investment per year, Rs.	9350
	(iii) Insurance, Rs.	120
	(iv) Housing cost, Rs.	1700
	(v) Total fixed cost per year, Rs.	26470
	e. Variable cost	
	(i) Repair and maintenance, Rs.	8500
	(ii) Fuel cost per year, Rs.	32000
	(iii) Oil cost per year, Rs.	10667
	(iv) Labour cost per year, Rs.	30000
	(v) Variable cost per year, Rs.	81167
	Total cost = Fixed cost + variable cost, Rs. per year	107637
	Total cost of operation per hr, Rs.	107.64

Contd.

2. **Reaper**

a. Cost of machine, Rs.	25000
b. Useful life, years	10
c. Hours of use per year	480
d. Fixed cost	
(i) Depreciation per year, Rs.	2400
(ii) Interest on investment per year, Rs.	1300
(iii) Insurance, Rs.	Nil
(iv) Housing cost, Rs.	250
Variable cost	
(i) Repair and maintenance, Rs.	1250
(ii) Labour requirement, Rs./ha	150.31
Total cost per year, Rs.	5200
Total cost per hr, Rs.	10.85
Field capacity, ha/hr	0.38
Total cost for harvesting in one ha by tractor mounted reaper including labour Rs.	462

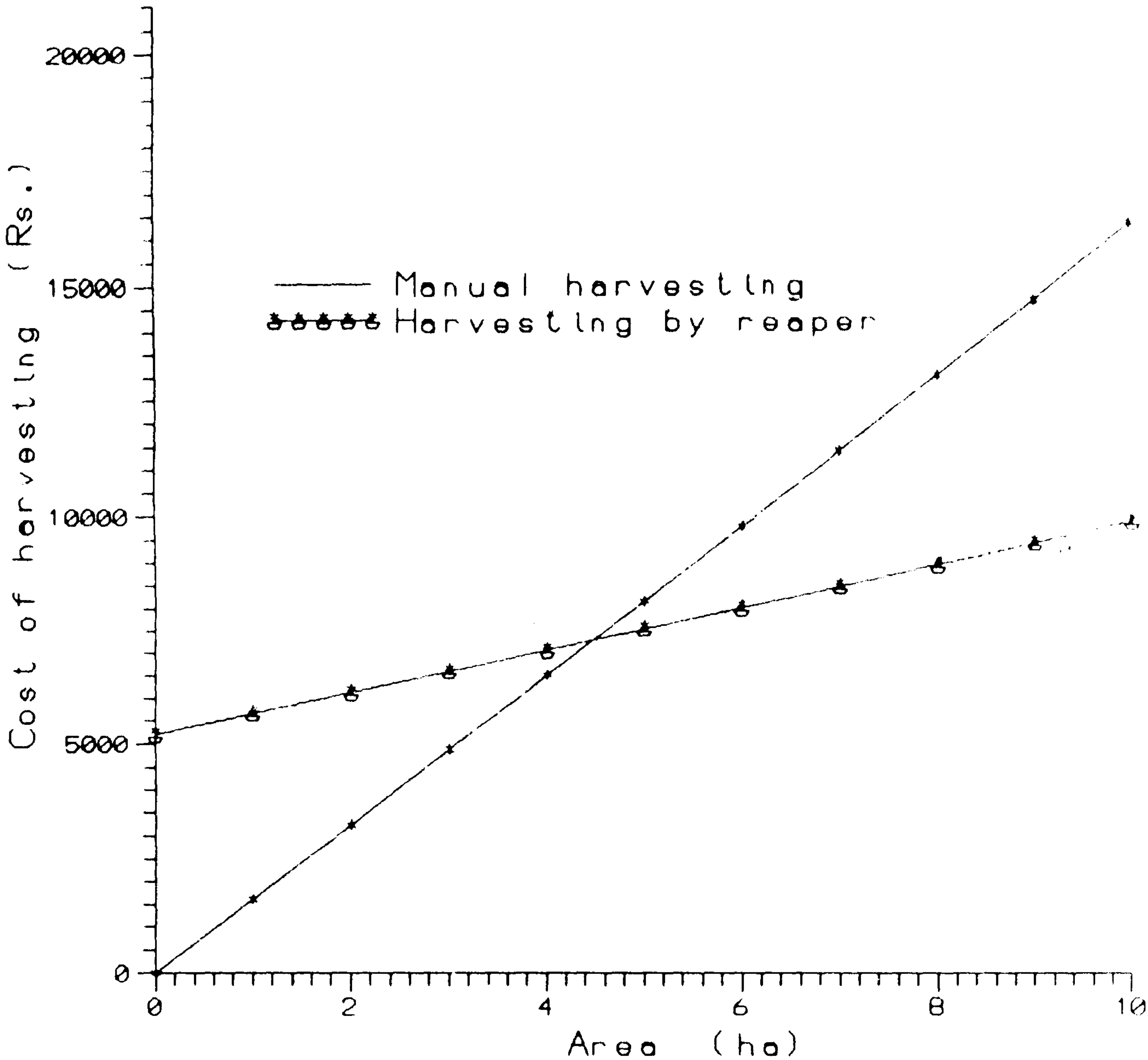

FIG.10 BREAK EVEN ANALYSIS OF COST OF HARVESTING

Table 19. Cost indicators for manual cutting and leaving the crop in the field

Sl. No.	Item	Observation
1.	Average woman days required for cutting and laying the crop of one ha	25
2.	labour wages, Rs. per day	65
3.	Total work hour per day, hrs	8
4.	Total hours required for cutting and leaving the crop on the field of one ha, woman-hrs	200
5.	Cost of cutting and leaving the crop in ha, Rs. per ha	1625

Table 20. Break even analysis of cost of harvesting

Area (ha)	Cost of manual harvesting (Rs.)	Cost of harvesting by tractor mounted reaper (Rs.)
0	0	5200
1	1625	5662
2	3250	6124
3	4875	6586
4	6500	7048
5	8125	7510
6	9750	7972
7	11375	8434
8	13000	8896
9	14625	9358
10	16250	9820

harvesting by the use of reaper can be used for threshing the crop in the same day.

The break even analysis was carried out between manual harvesting and machine harvesting. This analysis had been carried out with the assumption that some expenditure is incurred for harvester even if no harvesting is carried out. Fig.10 shows the break even analysis and Table 20 gives the calculations of the break even analysis. It was found that for the tractor mounted reaper windrower 4.50 ha is the break even point. It implies that the tractor mounted reaper has to be operated for a minimum of 4.50 ha/year otherwise the cost of operation will be more than the manual harvesting. In actual conditions, the reaper has to be operated several times more area per year to obtain appreciable profit.

4.9 Crop collection unit

It has been observed during previous trials that the quality of grain and straw was affected by the standing water in the fields at the time of harvesting as the swath was conveyed in the water. So a simple crop collection unit was developed to the reaper windrower to collect the crops from reaper's conveyor to avoid falling of crops in the standing water.

A box of size 1.5m x 0.7m x 0.35m was made by using 2.54 cm diameter GI pipes and gunny bags. The collection unit was provided with two rollers, one at the collection box and another at the discharge plate end of the reaper. A canvass cloth belt of 50 cm width was used for conveying the crop into the box through these roller (Fig.4 and 5).

The collection unit was attached to the tractor body and power from right side conveyor belt pulley of reaper was taken as explained in 3.15.2. The speed collection unit conveyor belt at optimum engine speed for the three PTO pulleys are given in Appendix XVI. Because of wet conditions at the time of harvesting it was decided to operate the reaper at an engine speed of 1500 rpm using PTO pulley No.1. The unit was taken to the field and operated to know the turning radius. The speed of conveyor belt of collection unit at an engine speed of 1500 rpm is 2.19 m/s. The turning radius of tractor without reaper and with reaper were found to be 2.95 m and 3.45 m respectively. The turning radius of tractor front mounted reaper with collection unit is 4.25 m. Many problems were faced while using harvestor with collection unit as the total width of the machine was increased to 3 m by providing collection unit.

4.9.1 Field performance of tractor mounted paddy reaper with crop collection unit

The actual field capacity of reaper with the collection unit was 0.18 ha/hr, which was very low as compared to the actual field capacity, *viz.* 0.38 ha/hr, achieved without collection unit. The field efficiency with collection unit was 25 per cent which is low because of increase in the time losses at turning and interruptions. The time lost due to interruptions were high as the tractor had to stop after every 10 m run to unload the crops from collection unit. The conveyor belt of collection unit was discharging the crop only at front end of the unit and no arrangement was available in the collection box to push the crop to rear side. One additional labour was required to move along with the harvester to push the crop to the rear side of collection box. The collection of the harvested crop from the water logged field is to be carried out manually within two days otherwise the quality of straw and grain will be affected. If the manual collection is not possible then the use of collection unit is recommended.

Summary

SUMMARY

The last two decades witnessed a steady decrease in area and production of paddy in Kerala because of high production cost attributed by the use of manual labourers with high wage rates. Labour scarcity is also experienced during harvesting seasons. Tractor is widely used for ploughing and puddling of paddy fields on hire basis. Encouraged by the success of using tractors on hire basis, evaluation of tractor front mounted reaper is in progress in Kerala.

Without knowing optimum forward speed, engine speed (as cutterbar speed and conveyor belt speed depends on it) and diameter of PTO pulley for different field conditions, the tractor engine speed was unnecessarily raised to achieve the required cutterbar and conveyor belt performance. Tractor front mounted reaper was operated at different forward speeds, conveyor and cutterbar speeds to determine the optimum relation between them. The change in the forward speed of the reaper was achieved by changing the throttle position and using different gears. Four gears in low range and first gear in high range were selected for field trials. The change in the conveyor and cutterbar speeds for the above conditions was achieved by using three PTO pulleys having diameter of 17.78 cm, 19.03 cm and 20.32 cm.

The reaper was operated at an engine speed of 1500 to 2000 rpm for PTO pulley having 17.78 cm diameter. The total power and specific power requirements were found to be increased with an increase in engine speed. This was due to increase in cutterbar, conveyor and forward speeds of the machine.

At an engine speed of 2000 rpm at fourth low gear, the maximum value of total power requirement and specific power requirement *viz.* 4.61 hp and 2.20 hp respectively were observed. The minimum values of total power and specific power requirement *viz.* 2.52 hp and 1.20 hp respectively, were observed at an engine speed of 1500 rpm at first low gear. The total machine harvesting losses were increased with an increase in the forward speed the reaper. The maximum value of harvesting loss, *viz.* 3.00 per cent, was observed at an engine speed of 2000 rpm at fourth low gear. The minimum value of harvesting loss, *viz.* 1.50 per cent, was observed for an engine speed of 1500 rpm at first low gear.

At an engine speed of 1500 rpm, the reaper was found windrowing the crop at a distance of 10 cm away from the end of discharge plate and windrowing process was found to be neat and uniform. But at an engine speed of 2000 rpm, the reaper was found roughly throwing the crop at a distance of 25 cm away from the end of discharge plate at a higher speed. The tiller angles with respect to the direction of travel was found to be affected by both conveyor belt and forward speed. At an engine speed of 1500 rpm, for the first three gears, tillers angle was found to be making an angle of 88 degrees and this angle was decreased to 85 degrees at higher gear. At an engine speed of 2000 rpm, tiller angle of 55 degrees was observed.

The minimum values of total power requirement and specific power requirement, harvesting losses and acceptable limit of tillers angle at all operated gears were observed at an engine speed of 1500 rpm for 17.78 cm dia PTO pulley.

The increasing trend of total power and specific power requirement, harvesting losses and distance of crop being windrowed with an increase in engine speed and forward speed were also observed with PTO pulleys having diameters 19.03 cm and 20.32 cm.

For PTO pulley of 19.03 cm diameter the maximum values of total power and specific power *viz.* 5.42 hp and 2.58 hp respectively, were observed at an engine speed of 2000 rpm at fourth low gear. The minimum values of total power and specific power *viz.* 2.58 hp and 1.22 hp, were observed at an engine speed of 1400 rpm at first low gear.

With PTO pulley of 20.32 cm diameter, the maximum values of total power requirement and specific power, *viz.* 6.33 hp and 3.01 hp, were observed at an engine speed of 2000 rpm at fourth low forward gear. The maximum values of the total power requirement and specific power, *viz.* 2.51 hp and 1.19 hp, were observed at an engine speed of 1300 rpm at first low gear.

The maximum value of harvesting losses, *viz.* 3.15 per cent, was observed at an engine speed of 2000 rpm at fourth low gear and the minimum value of harvesting loss, *viz.* 1.54 per cent, was observed at an engine speed of 1400 rpm at first low gear for the PTO pulley at 19.03 cm dia. For the PTO pulley of 20.32 cm dia, the maximum value of harvesting losses, *viz.* 3.85 per cent, was observed at an engine speed of 2000 rpm at fourth low gear and the minimum value of harvesting losses, *viz.* 1.55 per cent, was observed at an engine speed of 1300 rpm at first low gear. The acceptable limit of windrowing pattern was observed at an engine speeds of 1400 rpm and 1300 rpm at all the operated forward gears for PTO pulley with 19.03 cm and 20.32 cm diameter respectively.

The engine speeds of 1500, 1400 and 1300 rpm were selected as optimum engine speeds for PTO pulleys of diameter 17.78 cm, 19.03 cm and 20.22 cm respectively. The field capacity and field efficiency were found to be increased with an increase in the forward speed, except at fourth low gear due to wet field conditions and inadequate size of the field.

The maximum field capacity values of 0.38 ha/hr was observed at an engine speed of 1500 rpm at third low forward gear for PTO pulley having 17.78 cm diameter. The cutterbar speed and conveyor belt speed at an engine speed of 1500 rpm were 1.48 m/s and 2.19 m/s respectively. The reaper forward speed was found to be 0.95 m/s. The cutterbar index and conveyor index at the above operating parameters were 1.56 and 2.30 respectively.

The maximum field capacity of 0.36 ha/hr was observed at an engine speed of 1400 rpm at third low gear for PTO pulley having 19.03 cm diameter. The cutterbar speed and conveyor belt speed at an engine speed of 1400 rpm were 1.50 m/s and 2.21 m/s respectively. The reaper forward speed was found to be 0.90 m/s. The cutterbar index conveyor index were 1.66 and 2.45 respectively. For PTO pulley having 20.32 cm diameter, the maximum value of field capacity of 0.38 ha/hr was observed at an engine speed of 1300 rpm at fourth low gear. The cutterbar speed and conveyor speed for the above conditions were 1.48 m/s and 2.19 m/s respectively. The cutterbar index and conveyor index were 1.48 and 2.19 respectively.

From the economic analysis it was found that an amount of Rs.1163 per ha can be saved by introducing the reaper alone. The cost of harvesting paddy per ha by manual method is Rs.1625 and total operating cost of reaper is Rs.462 per ha. The break even point for the reaper is 4.50 ha.

A simple crop collection unit was developed attached to the reaper to collect the crop from conveyor assembly to avoid falling of crop into the standing water.

The main parts of collection unit are the two rollers, flat conveyor belt and collection box. The rollers were provided at the discharge plate end and at the collection unit. The rollers were made by wing MS pipe of size 7.5 cm diameter and 50 cm length. A canvass cloth conveyor belt of 50 cm width was used. The collection box of size 1.5m x 0.70m x 0.35m was made using 2.54 cm diameter GI pipes and gunny bags. The top roller was provided with 2.50 cm diameter shaft with 10.16 cm diameter pulley. The power to the collection unit was taken from the right conveyor assembly of the reaper. The speed of collection unit conveyor belt at an engine speed of 1500 rpm is 2.19 m/s. Field problems in manoeuvreability, loading and unloading of box and increased idle time were noticed. The field capacity was reduced to 0.18 ha/hr.

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Appendices

Appendix-I

Relative speed of main components of paddy reaper windrower with PTO pulley No.I

Engine speed (rpm)	PTO speed (rpm)	Intermediate shaft (rpm)	Vertical shaft (rpm)	3 groove V-pulley (rpm)	Input pulley to conveyor (rpm)	Conveyor belt speed (m/s)	Cutterbar speed (m/s)
2000	700	1225	765	530	433	2.84	1.91
1900	690	1208	754	525	425	2.80	1.89
1800	650	1738	710	490	405	2.63	1.78
1700	620	1085	679	470	385	2.50	1.70
1600	580	1015	635	440	360	2.35	1.58
1500	540	945	590	410	335	2.19	1.48
1400	510	893	555	385	315	2.06	1.40
1300	470	824	515	355	290	1.90	1.30
1200	430	755	470	325	265	1.74	1.18
1100	390	685	425	295	245	1.58	1.06
1000	360	630	395	275	225	1.46	0.98

Appendix-II

Relative speed of main components of paddy reaper windrower with PTO pulley No.II

Engine speed (rpm)	PTO speed (rpm)	Intermediate shaft (rpm)	Vertical shaft (rpm)	3 groove V-pulley (rpm)	Input pulley to conveyor (rpm)	Conveyor belt speed (m/s)	Cutterbar speed (m/s)
2000	700	1312.50	820.31	568	465	3.04	2.05
1900	690	1293.75	808.60	560	455	2.97	2.00
1800	650	1218.75	761.72	525	430	2.81	1.90
1700	620	1162.50	726.56	502	410	2.69	1.82
1600	580	1087.50	679.68	470	384	2.52	1.70
1500	540	1012.50	632.81	438	355	2.35	1.58
1400	510	956.25	598.00	415	335	2.21	1.50
1300	470	881.25	550.00	380	310	2.02	1.38
1200	430	806.25	503.90	345	280	1.83	1.26
1100	390	731.25	457.03	315	255	1.66	1.14
1000	360	675.00	422.00	290	235	1.54	1.05

Appendix-III

Relative speed of main components of paddy reaper windrower with PTO pulley No.III

Engine speed (rpm)	PTO speed (rpm)	Intermediate shaft (rpm)	Vertical shaft (rpm)	3 groove V-pulley (rpm)	Input pulley to conveyor (rpm)	Conveyor belt speed (m/s)	Cutterbar speed (m/s)
2000	700	1400	875	605	495	3.24	2.18
1900	690	1365	854	590	485	3.17	2.13
1800	650	1300	812	562	460	3.00	2.03
1700	620	1240	775	535	440	2.88	1.94
1600	580	1160	725	502	410	2.69	1.81
1500	540	1080	675	465	385	2.50	1.69
1400	510	1020	638	440	360	2.36	1.60
1300	470	945	590	408	335	2.19	1.48
1200	430	860	538	372	305	2.00	1.34
1100	390	780	488	335	275	1.80	1.22
1000	360	720	450	275	255	1.67	1.13

Appendix-IV

Number of plants handled by reaper in one second

Sl No	Forward gear	Forward speed	Total number of plants cut in one second
1.	Engine speed 2000 rpm		
	LG-1	0.66	260
	LG-2	0.97	380
	LG-3	1.30	510
	LG-4	1.70	670
2.	Engine speed 1900 rpm		
	LG-1	0.62	240
	LG-2	0.92	360
	LG-3	1.20	470
	LG-4	1.60	630
	HG-1	2.40	950
3.	Engine speed 1800 rpm		
	LG-1	0.58	230
	LG-2	0.88	340
	LG-3	1.15	450
	LG-4	1.55	610
	HG-1	2.33	920
4.	Engine speed 1700 rpm		
	LG-1	0.55	210
	LG-2	0.83	320
	LG-3	1.12	440
	LG-4	1.50	590
	HG-1	2.20	870
5.	Engine speed 1600 rpm		
	LG-1	0.50	190
	LG-2	0.78	300
	LG-3	1.06	410
	LG-4	1.40	550
	HG-1	2.10	830

Contd.

Appendix IV (Contd.)

Sl. No.	Forward gear	Forward speed	Total number of plants cut in one second
6.	Engine speed 1500 rpm		
	LG-1	0.45	170
	LG-2	0.69	270
	LG-3	0.95	350
	LG-4	1.30	510
	HG-1	1.90	750
7.	Engine speed 1400 rpm		
	LG-1	0.43	165
	LG-2	0.65	250
	LG-3	0.90	330
	LG-4	1.20	470
	HG-1	1.80	710
8.	Engine speed 1300 rpm		
	LG-1	0.40	160
	LG-2	0.60	230
	LG-3	0.80	310
	LG-4	1.00	430
	HG-1	1.70	670

Appendix-V

Power requirements for reaper without the crop for PTO pulley No.I (F_1 = 1.35 kg)

Engine speed (rpm)	Inertia of cutterbar (kg)	Power to overcome inertia and F_1 (hp)	Power for operating converyor (hp)
2000	110.58	2.85	1.34
1900	107.40	2.74	1.32
1800	95.34	2.30	1.24
1700	86.75	2.00	1.15
1600	75.92	1.63	1.10
1500	65.80	1.33	1.03

Appendix-VI

Power requirements for reaper with the crop for PTO pulley No.I

Forward gear	Cutting force and F_2 (kg)	Increase in power due to cutting and F_2 (hp)	Total power for cutting (hp)	Power for conveying the crop (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm						
LG-1	10.72	0.27	3.12	1.38	4.50	2.14
LG-2	11.39	0.29	3.14	1.40	4.54	2.16
LG-3	12.17	0.31	3.16	1.42	4.58	2.18
LG-4	12.56	0.32	3.17	1.44	4.61	2.20
Engine speed 1900 rpm						
LG-1	10.31	0.26	3.00	1.35	4.35	2.07
LG-2	11.10	0.28	3.02	1.37	4.39	2.09
LG-3	11.50	0.29	3.03	1.39	4.42	2.10
LG-4	11.90	0.30	3.04	1.41	4.45	2.12
HG-1	13.49	0.34	3.08	1.46	4.54	2.16
Engine speed 1800 rpm						
LG-1	9.26	0.22	2.52	1.27	3.27	3.79
LG-2	9.69	0.23	2.53	1.29	3.82	1.82
LG-3	10.11	0.24	2.54	1.30	3.84	1.83
LG-4	10.95	0.26	2.56	1.32	3.88	1.84
HG-1	12.21	0.29	2.59	1.37	3.96	1.89
Engine speed 1700 rpm						
LG-1	8.38	0.19	2.19	1.18	3.37	1.60
LG-2	8.82	0.20	2.20	1.22	3.42	1.63
LG-3	9.70	0.22	2.22	1.24	3.46	1.64
LG-4	9.69	0.23	2.23	1.26	3.49	1.66
HG-1	11.47	0.26	0.26	1.30	3.56	1.70
Engine speed 1600 rpm						
LG-1	7.59	0.16	1.79	1.13	2.92	1.39
LG-2	8.06	0.17	1.80	1.15	2.95	1.40
LG-3	8.54	0.18	1.81	1.16	2.97	1.41
LG-4	9.49	0.20	1.83	1.18	3.01	1.43
HG-1	10.44	0.22	1.85	1.21	3.06	1.43
Engine speed 1500 rpm						
LG-1	6.58	0.13	1.46	1.06	2.52	1.20
LG-2	7.09	0.14	1.47	1.07	2.54	1.21
LG-3	7.60	0.15	1.48	1.08	2.56	1.22
LG-4	8.61	0.17	1.50	1.11	2.61	1.24
HG-1	9.62	0.19	1.52	1.15	2.67	1.27

Appendix VII

Total machine harvesting losses with PTO pulley No. 1

Forward gear	Preharvest losses (g/m^2)	Total cutter bar losses = uncut loss + shattering loss (g/m^2)	Windrow loss (g/m^2)	Total loss (g/m^2)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.00	5.25	2.25	7.50	2.50
LG-2	0.01	5.35	2.29	7.65	2.55
LG-3	0.01	5.38	2.32	7.86	2.62
LG-4	0.00	6.12	2.88	9.00	3.00
Engine speed 1900 rpm					
LG-1	0.00	4.78	2.17	6.95	2.32
LG-2	0.01	4.80	2.25	7.05	2.35
LG-3	0.01	4.84	2.26	7.25	2.42
LG-4	0.03	4.88	2.29	7.35	2.45
HG-1	0.01	5.34	2.76	8.10	2.70
Engine speed 1800 rpm					
LG-1	0.00	4.49	1.93	6.42	2.14
LG-2	0.00	4.53	1.94	6.47	2.16
LG-3	0.00	4.56	1.96	6.52	2.17
LG-4	0.01	4.59	2.02	6.75	2.25
HG-1	0.01	5.23	2.72	7.95	2.65
Engine speed 1700 rpm					
LG-1	0.00	4.30	1.85	6.15	2.05
LG-2	0.00	4.37	1.87	6.24	2.08
LG-3	0.01	4.44	1.90	6.35	2.12
LG-4	0.01	4.50	1.94	6.45	2.15
HG-1	0.00	5.10	2.40	7.50	2.30
Engine speed 1600 rpm					
LG-1	0.00	3.82	1.64	5.46	1.82
LG-2	0.01	3.88	1.66	5.55	1.85
LG-3	0.00	4.03	1.73	5.76	1.92
LG-4	0.02	4.09	1.74	5.85	1.95
HG-1	0.00	4.79	2.20	7.05	2.35
Engine speed 1500 rpm					
LG-1	0.00	3.15	1.35	4.50	1.50
LG-2	0.00	3.17	1.36	4.53	1.31
LG-3	0.01	3.23	1.38	4.62	1.54
LG-4	0.02	3.30	1.42	4.74	1.58
HG-1	0.03	4.62	1.98	6.60	2.20

Appendix-VIII

Power requirements for reaper without the crop for PTO pulley No.II (F_1 = 1.35 kg)

Engine speed (rpm)	Inertia of cutterbar (kg)	Power to overcome inertia and F_1 (hp)	Power for operating converyor (hp)
2000	126.94	3.50	1.44
1900	121.20	3.27	1.40
1800	109.45	2.81	1.32
1700	99.58	2.45	1.27
1600	87.15	2.00	1.19
1500	75.54	1.62	1.11
1400	67.38	1.38	1.03

Appendix-IX

Power requirements for reaper with the crop for PTO pulley No.II

Forward gear	Cutting force and F_2 (kg)	Increase in power due to cutting and F_2 (hp)	Total power for cutting (hp)	Power for conveying the crop (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm						
LG-1	12.44	0.34	3.84	1.48	5.32	2.53
LG-2	12.80	0.35	3.85	1.50	5.35	2.54
LG-3	13.17	0.36	3.86	1.52	5.38	2.56
LG-4	13.90	0.38	3.88	1.54	5.42	2.58
Engine speed 1900 rpm						
LG-1	11.63	0.31	3.58	1.43	5.01	2.39
LG-2	12.00	0.32	3.59	1.46	5.05	2.40
LG-3	12.38	0.33	3.60	1.47	5.07	2.41
LG-4	13.13	0.35	3.62	1.50	5.12	2.44
HG-1	14.25	0.38	3.65	1.55	5.20	2.48
Engine speed 1800 rpm						
LG-1	10.26	0.26	3.07	1.35	4.42	2.10
LG-2	11.06	0.28	3.09	1.37	4.46	2.12
LG-3	11.45	0.29	3.10	1.39	4.49	2.14
LG-4	11.84	0.30	3.11	1.41	4.52	2.15
HG-1	13.42	0.34	3.15	1.45	4.60	2.19
Engine speed 1700 rpm						
LG-1	9.48	0.23	2.68	1.30	3.98	1.90
LG-2	9.89	0.24	2.69	1.32	4.01	1.91
LG-3	10.71	0.26	2.71	1.33	4.04	1.92
LG-4	11.54	0.28	2.72	1.35	4.07	1.94
HG-1	12.77	0.31	2.76	1.39	4.15	1.98
Engine speed 1600 rpm						
LG-1	8.82	0.20	2.20	1.22	3.42	1.63
LG-2	9.26	0.21	2.21	1.23	3.44	1.64
LG-3	9.71	0.22	2.22	1.24	3.46	1.65
LG-4	10.59	0.24	2.24	1.26	3.50	1.67
HG-1	12.35	0.28	2.28	1.30	3.58	1.70
Engine speed 1500 rpm						
LG-1	7.59	0.16	1.78	1.13	2.91	1.39
LG-2	8.07	0.17	1.79	1.14	2.93	1.40
LG-3	8.54	0.18	1.80	1.15	2.95	1.41
LG-4	9.02	0.19	1.81	1.17	2.98	1.42
HG-1	10.44	0.22	1.84	1.20	3.04	1.45
Engine speed 1400 rpm						
LG-1	6.50	0.13	1.51	1.07	2.58	1.22
LG-2	7.00	0.14	1.52	1.08	2.60	1.24
LG-3	7.50	0.15	1.53	1.09	2.62	1.25
LG-4	8.50	0.17	1.55	1.10	2.65	1.26
HG-1	9.50	0.19	1.57	1.13	2.70	1.29

Appendix-X

Total machine harvesting losses with PTO pulley No.II

Forward gear	Preharvest losses (g/m²)	Total cutter bar losses = uncut loss + shattering loss (g/m²)	Windrow loss (g/m²)	Total loss (g/m²)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.00	5.88	2.52	8.40	2.80
LG-2	0.01	5.98	2.56	8.55	2.85
LG-3	0.00	6.13	2.63	8.70	2.95
LG-4	0.00	6.46	2.99	9.46	3.15
Engine speed 1900 rpm					
LG-1	0.00	5.71	2.45	8.16	2.72
LG-2	0.00	5.78	2.47	8.25	2.75
LG-3	0.01	5.83	2.50	8.34	2.78
LG-4	0.01	5.92	2.54	8.46	2.82
HG-1	0.00	6.14	2.86	9.00	3.00
Engine speed 1800 rpm					
LG-1	0.01	5.39	2.25	7.65	2.55
LG-2	0.00	5.40	2.35	7.71	2.57
LG-3	0.01	5.48	2.34	7.83	2.61
LG-4	0.00	5.56	2.38	7.95	2.65
HG-1	0.00	5.76	2.49	8.25	2.75
Engine speed 1700 rpm					
LG-1	0.01	4.78	2.05	6.84	2.28
LG-2	0.01	4.85	2.07	6.93	2.31
LG-3	0.00	4.89	2.10	6.99	2.33
LG-4	0.00	4.99	2.15	7.13	2.38
HG-1	0.00	5.35	2.30	7.65	2.55
Engine speed 1600 rpm					
LG-1	0.00	4.41	1.89	6.30	2.10
LG-2	0.01	4.45	1.90	6.35	2.12
LG-3	0.01	4.53	1.94	6.47	2.16
LG-4	0.00	4.62	1.98	6.60	2.20
HG-1	0.01	5.04	2.16	7.20	2.40
Engine speed 1500 rpm					
LG-1	0.01	3.90	1.67	5.58	1.86
LG-2	0.00	3.95	1.69	5.64	1.88
LG-3	0.00	4.05	1.74	5.79	1.93
LG-4	0.00	4.16	1.78	5.94	1.98
HG-1	0.00	4.73	2.02	6.75	2.25
Engine speed 1400 rpm					
LG-1	0.00	3.23	1.39	4.62	1.54
LG-2	0.00	3.32	1.42	4.74	1.58
LG-3	0.00	3.34	1.43	4.77	1.59
LG-4	0.00	3.38	1.50	4.88	1.63
HG-1	0.00	4.51	1.94	6.45	2.15

Appendix-XI

Power requirements for reaper without the crop for PTO pulley No.III (F_1 = 1.35 kg)

Engine speed (rpm)	Inertia of cutterbar (kg)	Power to overcome inertia and F_1 (hp)	Power for operating converyor (hp)
2000	144.43	4.24	1.53
1900	137.90	3.96	1.49
1800	124.53	3.41	1.41
1700	113.30	2.97	1.36
1600	99.15	2.43	1.27
1500	85.95	1.97	1.18
1400	76.66	1.66	1.11
1300	65.80	1.33	1.03

Appendix-XII

Power requirements for reaper with the crop for PTO pulley No.III

Forward gear	Cutting force and F_2 (kg)	Increase in power due to cutting and F_2 (hp)	Total power for cutting (hp)	Power for conveying the crop (hp)	Total power for harvesting (hp)	Specific power (hp/m)
Engine speed 2000 rpm						
LG-1	13.42	0.39	4.63	1.58	6.21	2.96
LG-2	13.76	0.40	4.64	1.60	6.24	2.97
LG-3	14.45	0.42	4.66	1.62	6.28	2.99
LG-4	15.14	0.44	4.68	1.65	6.33	3.01
Engine speed 1900 rpm						
LG-1	12.68	0.36	4.32	1.53	5.85	2.79
LG-2	13.38	0.38	4.34	1.55	5.89	2.80
LG-3	13.73	0.39	4.35	1.57	5.92	2.82
LG-4	14.08	0.40	4.36	1.60	5.96	2.84
HG-1	15.49	0.44	4.40	1.61	6.01	2.86
Engine speed 1800 rpm						
LG-1	11.45	0.31	3.72	1.45	5.17	2.46
LG-2	12.19	0.33	3.74	1.46	5.20	2.48
LG-3	12.56	0.34	3.75	1.48	5.23	2.49
LG-4	13.30	0.36	3.77	1.50	5.27	2.51
HG-1	14.40	0.39	3.80	1.56	5.36	2.55
Engine speed 1700 rpm						
LG-1	10.44	0.27	3.24	1.39	4.63	2.20
LG-2	10.82	0.28	3.25	1.41	4.66	2.22
LG-3	11.60	0.30	3.27	1.43	4.70	2.24
LG-4	11.98	0.31	3.28	1.46	4.74	2.26
HG-1	13.14	0.34	3.31	1.49	4.80	2.29
Engine speed 1600 rpm						
LG-1	9.53	0.23	2.66	1.30	3.96	1.89
LG-2	9.94	0.24	2.67	1.31	3.98	1.90
LG-3	10.36	0.25	2.68	1.33	4.01	1.91
LG-4	10.77	0.26	2.29	1.35	4.04	1.62
HG-1	12.01	0.29	2.72	1.39	4.11	1.96
Engine speed 1500 rpm						
LG-1	7.99	0.18	2.15	1.20	3.35	1.59
LG-2	8.88	0.20	2.17	1.21	3.38	1.61
LG-3	9.32	0.21	2.18	1.23	3.41	1.62
LG-4	9.76	0.22	2.19	1.25	3.44	1.64
HG-1	11.09	0.25	2.22	1.28	3.50	1.67
Engine speed 1400 rpm						
LG-1	7.50	0.16	1.82	1.13	2.95	1.40
LG-2	8.44	0.18	1.84	1.14	1.98	1.42
LG-3	8.91	0.19	1.85	1.15	3.00	1.43
LG-4	9.38	0.20	1.86	1.16	3.02	1.44
HG-1	10.31	0.22	1.88	1.20	3.08	1.47
Engine speed 1300 rpm						
LG-1	6.59	0.13	1.46	1.05	2.51	1.79
LG-2	7.09	0.14	1.47	1.06	2.53	1.20
LG-3	7.60	0.15	1.48	1.07	2.55	1.21
LG-4	8.11	0.16	1.49	1.08	2.57	1.22
HG-1	9.12	0.18	1.51	1.16	2.61	1.24

Appendix-XIII

Total machine harvesting losses with PTO pulley No.III

Forward gear	Preharvest losses (g/m²)	Total cutter bar losses = uncut loss + shattering loss (g/m²)	Windrow loss (g/m²)	Total loss (g/m²)	Total loss (%)
Engine speed 2000 rpm					
LG-1	0.00	7.22	3.09	10.31	3.44
LG-2	0.00	7.58	3.25	10.83	3.61
LG-3	0.00	7.85	3.37	11.22	3.74
LG-4	0.00	8.08	3.47	11.55	3.85
Engine speed 1900 rpm					
LG-1	0.00	6.13	2.63	8.76	2.92
LG-2	0.00	6.26	2.68	8.94	2.98
LG-3	0.01	6.42	2.75	9.17	3.06
LG-4	0.00	6.83	2.92	9.75	3.25
HG-1	0.00	6.93	2.97	9.90	3.30
Engine speed 1800 rpm					
LG-1	0.00	5.63	2.41	8.04	2.68
LG-2	0.00	5.71	2.45	8.16	2.72
LG-3	0.00	5.84	2.50	8.34	2.78
LG-4	0.00	5.94	2.53	8.43	2.81
HG-1	0.01	6.00	2.57	8.57	2.86
Engine speed 1700 rpm					
LG-1	0.00	4.93	2.11	7.04	2.35
LG-2	0.01	4.99	2.14	7.14	2.38
LG-3	0.00	5.08	2.18	7.26	2.42
LG-4	0.00	5.21	2.23	7.44	2.48
HG-1	0.00	5.56	2.39	7.95	2.65
Engine speed 1600 rpm					
LG-1	0.00	4.83	2.17	6.90	2.30
LG-2	0.00	4.94	2.11	7.05	2.35
LG-3	0.00	4.99	2.15	7.14	2.38
LG-4	0.00	5.04	2.16	7.20	2.40
HG-1	0.00	5.25	2.25	7.50	2.50

Contd.

Appendix-XIII (Contd.)

Forward gear	Preharvest losses (g/m^2)	Total cutter bar losses = uncut loss + shattering loss (g/m^2)	Windrow loss (g/m^2)	Total loss (g/m^2)	Total loss (%)
Engine speed 1500 rpm					
LG-1	0.00	4.45	1.91	6.36	2.12
LG-2	0.00	4.51	1.94	6.45	2.15
LG-3	0.00	4.58	1.96	6.54	2.18
LG-4	0.00	4.66	1.99	6.65	2.22
HG-1	0.01	4.94	2.11	7.05	2.35
Engine speed 1400 rpm					
LG-1	0.00	3.95	1.69	5.64	1.88
LG-2	0.01	4.03	1.79	5.76	1.92
LG-3	0.00	4.16	1.78	5.94	1.98
LG-4	0.00	4.26	1.83	6.09	2.03
HG-1	0.00	4.37	1.87	6.24	2.08
Engine speed 1300 rpm					
LG-1	0.00	3.25	1.40	4.65	1.55
LG-2	0.00	3.32	1.42	4.74	1.58
LG-3	0.00	3.36	1.44	4.80	1.60
LG-4	0.00	3.40	1.46	4.86	1.62
HG-1	0.00	3.47	1.48	4.95	2.05

Appendix-XIV

Total time taken by tractor front mounted reaper for harvesting an area of 2040 sq m

Forward gear	Forward speed	Cutting time	Idle time	Time taken for harvesting	Field capacity
Engine speed 1500 rpm					
LG-1	0.45	2289	1791	4080	0.18
LG-2	0.69	1397	1225	2622	0.28
LG-3	0.95	1081	852	1933	0.38
LG-4	1.30	750	1290	2040	0.36
Engine speed 1400 rpm					
LG-1	0.43	2365	2225	4590	0.16
LG-2	0.65	1498	1439	2937	0.25
LG-3	0.90	1146	894	2040	0.36
LG-4	1.20	886	1274	2160	0.34
Engine speed 1300 rpm					
LG-1	0.40	2810	2435	5245	0.14
LG-2	0.60	1715	1623	3338	0.22
LG-3	0.80	1231	1217	2448	0.30
LG-4	1.00	860	1072	1932	0.38

Appendix-XV

Economic Analysis

(i) Manual harvesting

An average of 25 woman days are required for harvesting in an area of one ha.

The existing wage rate = Rs.65/woman-day

The cost of harvesting per ha = Rs.25 x 65

= Rs.1625

(ii) Harvesting by tractor mounted reaper windrower

A. Tractor

Initial cost of tractor = Rs.1,70,000

Fuel consumption = 4 lit/hr

Fuel cost = Rs.8/lit

Oil cost = 1/3rd of fuel cost

Life of tractor (L) = 10 years

Operating hours per annum (H) = 1000

Salvage value(s) = 10% of initial cost

= Rs.17,000

Fixed cost

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

= 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 = 1000 x 4 x 8

= Rs.32000

Oil cost per annum = $\frac{1}{3} \times 32000$

= Rs.10667

Labour cost annum = Rs.1000 x 30

= Rs.30000

Variable cost annum = 8500 + 32000 + 10667 + 30000

= Rs.81167

Total cost = Fixed cost + Variable cost

= 26470 + 81167

= Rs.107637

Cost of operation at tractor per hr $= \dfrac{107637}{1000}$

$= Rs.107.64$

(B) Reaper

Initial cost of reaper = Rs.25000

Life (L) = 10 years

Operating hours (H) = 480

Salvage value (S) = Rs.1000

Annual depreciation $= \dfrac{25000-1000}{10}$

= Rs.2400

Annual interest on investment @ 10% per annum $= \dfrac{C+S}{2} \times \dfrac{10}{100}$

$= \dfrac{25000 + 1000}{2} \times \dfrac{10}{100}$

= Rs.1300

Annual repair and maintenance @ 5% of interest cost $= 25000 \times \dfrac{5}{100}$

= Rs.1250

Housing cost @ 1% of initial cost $= 25000 \times \dfrac{1}{100}$

= Rs.250

Annual cost of reaper = 2400 + 1300 + 250 + 1250

= Rs.5200

Cost of operation of reaper per hr	=	$\frac{5200}{480}$
	=	Rs.10.85
Cost of operation of tractor mounted reaper per hr	=	107.64 + 10.85
	=	Rs.118.47
Field capacity of tractor mounted reaper	=	0.38 ha/hr
Time required for harvesting one ha	=	2.63 hrs
Cost of operation by tractor mounted reaper per ha	=	2.63 x 118.47
	=	Rs.312

Labour requirement for harvesting at the boundaries and clearing the field is 18.5 man-hrs per ha (in case of circuitous pattern)

Cost of labour for cutting	=	$\frac{65}{8}$ x 18.5
	=	Rs.150.31
Total cost for harvesting one ha by tractor mounted reaper including labour	=	312 + 150.31
	=	Rs.462

Appendix-XVI

Speed of collection unit conveyor belt

Sl. No.	Engine speed (rpm)	PTO (rpm)	Cutter bar speed (m/s)	Reaper conveyor speed (m/s)	Collection unit conveyor speed (m/s)
1.	1500 PTO pulley-I	540	1.48	2.19	2.19
2.	1400 PTO pulley-II	510	1.50	2.21	2.21
3.	1300 PTO pulley-III	470	1.48	2.19	2.19

Field capacity of tractor mounted reaper

Windrower with collection unit (at 1500 rpm in third low forward gear) = 0.18 ha/hr

Theoretical field capacity = 0.70 ha/hr

Total time taken for harvesting = Cutting time + Idling time

= 1080 + 3000

= 4080 sec.

$$\text{Field efficiency} = \frac{0.18}{0.70} \times 100$$

= 25%

Appendix-XVII

Sample calculations on force and total power requirements for harvesting

Force and power requirement for harvesting for an engine speed of 2000 rpm at first gear in low range. The cutterbar and conveyor belt speed for the above engine rpm are 1.91 m/s and 2.84 m/s respectively.

Average number of hill per sq m = 45

Average number of plant per hill = 4

Average number of plants per sq m = 180

The forward speed of reaper windrower = 0.66 m/s

Area covered by reaper windrower in one second = 2.1 x 0.66

= 1.39 m^2

Total number of plants for the above area = 260

Force required for cutting per stroke = $\frac{260 \times 0.1}{25.5}$

P_{av} = 1.00 kgf

$P_j = \frac{wk}{g} r w^2$

$= \frac{4.5 \times 3.75 \times (80.11)^2}{981}$

Where, $W = \frac{2 \pi n}{60}$

$$W = 80.11 \text{ radians/sec}$$

$$P_j = 110.58 \text{ kgf}$$

$$F_1 = W_x \; f$$

$$F_1 = 4.5 \times 0.3$$

$$F_1 = 1.35$$

$$B = \sin^{-1} \frac{(7.5+3.75 \times 1)}{44}$$

$$B = 14° \; 48'$$

$$F_2 = \frac{(110.58+1.00+1.35)}{1-0.3 \times \tan 14°48'} \times \tan 14°48' \times 0.3$$

$$F_2 = \frac{112.93}{0.92} \times 0.2642 \times 0.3$$

$$F_2 = 9.72$$

Power required to overcome inertia and frictional force of cutter bar

$$= \frac{(\text{inertia force} + F1) \times \text{cutter bar speed}}{75}$$

$$= \frac{(110.58 + 1.35) \times 1.91)}{75}$$

$$= 2.85 \text{ hp}$$

Increase in power due to cutting of plants and F_2

$$= \frac{(P_{av} + F_2^2) \times \text{cutter bar speed}}{75}$$

$$= \frac{(1 + 9.72)}{75} \times 1.91$$

$$= 0.27 \text{ hp}$$

Total power required for cutting

$$= 2.85 + 0.27$$

$$= 3.12 \text{ hp}$$

Power required for operating conveyor assembly without crop = 1.34 hp

Power for conveying the cut crop

$$= 1.34 + \frac{260 \times \text{weight of single plant} \times \text{Conveyor speed}}{1000 \times 75}$$

$$= 1.34 + \frac{260 \times 4 \times 2.84}{1000 \times 75}$$

$$= 1.34 + 0.04$$

$$= 1.38 \text{ hp}$$

Total power required for harvesting

= Power required for cutting + Power for conveying cut plants

$$= 3.12 + 1.38$$

$$= 4.50 \text{ hp}$$

Specific power $= \frac{4.50}{2.1}$

$$= 2.14, \text{ hp/m}$$

Appendix-XVIII

Sample calculation on field capacity of paddy reaper windrower

(ii) Field capacity of tractor front mounted reaper windrower

For an engine speed of 1500 rpm at first low gear.

The forward speed of tractor	=	0.45 m/s
Area of the plot	=	2040 sq m
Total time taken for harvesting	=	cutting time + idle time
	=	2289 + 1791
	=	4080 sec
	=	68 min

$$\text{Theoretical field capacity} = \frac{0.45 \times 2.1 \times 3600}{10000}$$

$$= 0.34 \text{ ha/hr}$$

$$\text{Actual field capacity} = \frac{2040 \times 3600}{4080 \times 10000}$$

$$= 0.18 \text{ ha/hr}$$

$$\text{Field efficiency} = \frac{\text{Actual field capacity}}{\text{Theoretical field capacity}} \times 100$$

$$= \frac{0.18}{0.34} \times 100$$

$$= 52\%$$

Appendix-XIX

Sample calculation of statistical analysis

(iii) Regression equation and testing of significance of correlation coefficient (for 1500 engine rpm, 17.78 cm dia PTO pulley)

Total power required (hp)			Forward speed (m/s)			
(x)	$(x-\bar{x})$	$(x-\bar{x})^2$	(y)	$(y-\bar{y})$	$(y-\bar{y})^2$	$(x-\bar{x})(y-\bar{y})$
2.52	-0.06	0.0036	0.45	-0.605	0.366	0.0363
2.54	-0.04	0.0016	0.697	-0.358	0.128	0.0143
2.56	-0.02	0.0004	0.95	-0.105	0.011	0.002
2.61	0.03	0.009	1.30	0.245	0.06	0.00735
2.67	0.09	0.0081	1.88	0.825	0.680	0.07425
2x=12.90		0.0146	y = 5.277		1.245	0.1342

$\bar{x} = 2.58$ $\bar{y} = 1.055$

The regression equation of on y is given by

$$(x-\bar{x}) = n \quad (y-\bar{y})$$

$$(x-2.58) = r \frac{\sigma_x}{\sigma_y} (y-1.055)$$

where,

$$r \frac{\sigma_x}{\sigma_y} = \frac{\sum(x-\bar{x})\ (y-\bar{y})}{\Sigma y^2} = \frac{0.1342}{1.245}$$

$$= 0.108$$

$$(x-2.58) = 0.108\ (y-1.055)$$

$$x = 0.108\ y + 2.466$$

$$\text{Correlation coefficient, } r = \frac{\sum (x-\bar{x})\ (y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

$$\frac{0.1342}{\sqrt{0.0146 \times 1.245}} = 0.9954$$

Test of significance of correlation coefficient

Hypothesis, Ho: r = 0

Ha: r = 0

$$\text{Test statistic, } t = \frac{r}{\sqrt{1-r}} \times \sqrt{n-2}$$

with (n-2) degrees of freedom

$$t = \frac{0.9954}{\sqrt{1-0.9954^2}} \times \sqrt{5-2}$$

$t_{cal} = 17.9955$

The table value of t = 0.01 and 3 degrees of freedom is 5.841. The t_{cal} is greater than t table value. So reject Ho and accept Ha. Correlation coefficient is significant.

Appendix-XX

Details of field and crop conditions

1. Field condition

a.	Shape of the test field	:	Rectangular
b.	Area of the test field	:	60 x 34 square metre
c.	Topography of the field	:	Level
d.	Type of field	:	Dry field, moist field and waterlogged field
e.	Moisture content of soil	:	22 per cent (db)

2. Crop conditions

a.	Variety of paddy	:	Thriveni, Hraswa
b.	Appearance	:	Straight
c.	Moisture content		
	(i) straw	:	20 per cent (db)
	(ii) grain	:	18 per cent (db)
d.	Straw grain ratio	:	1.5:1
e.	Maturity of crop	:	100 days
f.	Number of tillers per m^2	:	40
g.	Total mass of crop with weed if any	:	750 g/m^2
h.	Number of grains per earhead	:	92
i.	Extent of weed	:	Negligible
j.	Type of weeds present	:	Not applicable

Appendix-XXI
Specification of instruments used

a. Hot air oven

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

b. Tachometer

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

c. Wattmeter

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

d. Moisture meter

Name	:	Osaw Agro Moisture meter
Make	:	The Oriental Science Apparatus Workshop
Accuracy	:	± 0.2 per cent
Range	:	8 to 40 per cent

e. Motor

Type	:	Squirrel Cage Induction Motor
Hp	:	7.5
rpm	:	1440
Volts	:	400/440
Phase	:	3

DYNAMICS OF POWER TRANSMISSION IN TRACTOR MOUNTED PADDY REAPER

By

SUSHILENDRA

ABSTRACT OF A THESIS

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ABSTRACT

A tractor front mounted 2.2 m wide paddy reaper windrower was evaluated to find out the optimum forward speed, cutterbar speed, conveyor belt speed and engine speed for different field conditions to achieve better harvesting and windrowing pattern, maximum field capacity and field efficiency with less harvesting losses.

Three PTO pulleys of 17.78 cm, 19.03 cm and 20.32 cm diameter with internal splines were fabricated and used with an engine speed from 1000 to 2000 rpm with four gears in low range and first gear in high range. In addition to pneumatic tyres, a pair of special cage wheels and a simple collection unit were developed and evaluated.

In water submerged fields with special cage wheels and PTO pulley of 17.78 cm diameter better results were observed when reaper was operated at an engine speed of 1500 rpm with third low gear with a forward speed of 0.95 m/s. The optimum cutterbar index and conveyor index were found to be 1.56 and 2.30 respectively. The actual field capacity was 0.38 ha/hr and field efficiency was 54 per cent. The crops were found to throw within 10 cm from the discharge plate with an tiller angle of more than 85 degrees with only 1.54 per cent of total loss of grain.

When the soil is moist and pneumatic wheels fail to give sufficient traction, the special cage wheels were used with a PTO pulley of 19.03 cm diameter. An engine speed of 1400 rpm with third gear and with a forward speed 0.90 m/s was found to give satisfactory performance. The optimum cutterbar index was 1.66 and conveyor index was 2.45. The reaper had the field capacity of 0.36 ha/hr with field efficiency of 53 per cent. The windrowed crop were found to throw within a distance of 13.5 cm with 85 degrees of tillers angle with total grain loss of 1.55 per cent.

For dry fields, the reaper with pneumatic wheels was found to operate satisfactorily with 20.32 cm diameter PTO pulley at an engine speed of 1300 rpm with fourth gear and with a forward speed of 1.00 m/s. The optimum cutterbar index was 1.48 and conveyor index was 2.19. The actual field capacity was 0.38 ha/hr and field efficiency was 50.66 per cent. The tillers angle was 85 degrees with total grain loss of 1.62 per cent.

It is found that the better field performance was achieved when the reaper is operated at a cutterbar speed of 1.50 m/s and conveyor belt speed of 2.20 m/s.

A simple crop collection unit of size 1.5m x 0,7m x 0.35m was developed with the provision for conveying the windrowed crop directly into the collection box. The unit was field evaluated with reaper. The box was found to fill within 10 m of travel and problems were observed in its manoeuvreability, loading and unloading of box and increased idle time.