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HARVESTING AND THRESHING OF PADDY

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SUMMARY

Harvesting and threshing are the most labor-consuming rice production operations in the tropical countries. This paper discusses these operations with special emphasis on the mechanized methods. Recent developments and trends are also reviewed.

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Introduction

Harvesting and threshing of paddy is one of the three major labor-consuming operations of rice production in the tropics. The other two high labor consuming operations are land preparation and transplanting. With the introduction of new varieties, the problems of harvesting and threshing have increased because of the greater amount of crop that has to be handled. In the double-cropping areas, the harvesting and threshing of the first crop and the land preparation for the second crop come so close together that it is often difficult to handle these operations with traditional methods. S. Johnson studied the labor requirements for rice production in the Philippines for both the single- and the double-cropped farms. The study indicated that while there was some surplus of labor during the slack period, a labor shortage occurred during the harvesting-threshing season.

The predominant methods in the tropics consist of manually harvesting the paddy plants and then threshing either by manual, animal, or mechanical means. In the advanced countries, however, harvesting and threshing of rice has almost entirely changed to mechanical methods and this has resulted in tremendous labor savings. Stout estimates that countries of Southeast and Far East Asia expend 5 to 7 hours of labor to produce 20.4 kg of rice while only 5 to 7 minutes are required to produce the same amount of rice by highly mechanized production methods. L. Johnson collected the power requirements for harvesting and threshing of paddy by different methods from various references. These are listed in Table 1. With the exception of Japan, where rice is mechanically harvested and then dried on straw before threshing, the rest of the advanced countries have changed to direct combining of rice. Even in Japan, with the recent introduction of small head-threshing type combines, a shift to direct combining of paddy is rapidly taking place. Table 2 includes the annual production of various harvesting-threshing equipment in Japan during the last few years.

In the tropics, interest in mechanizing the harvesting-threshing operation is high due to the increasing cost and seasonal shortage of labor, and the timeliness of operation in double-cropping. The recently introduced dwarf paddy varieties are also better suited for mechanized harvesting and threshing. Furthermore, the increased income of the farmers from higher paddy yields has provided additional incentive for mechanization. There are, however, a number of constraints which have hindered the mechanization of harvesting-threshing operations. These are:

<u>Farmer constraints</u>. Low income, inability to raise capital, reluctance to change traditional methods (i.e., the ani-ani method of harvesting paddy in Indonesia), poor mechanical aptitude, and the desire to save straw for other uses.

Farm constraints. Small farm holdings, very small plot size with high bunds, poor water control, inadequate ground support for harvesting equipment, and lack of access roads to the fields.

Crop constraints. Excessive moisture content at harvest time, uneven ripening, severe lodging and entangling of paddy (specially the traditional varieties), varieties with high-shattering tendency, and low grain-straw ratio.

Equipment constraints. Lack of functionally and economically suitable equipment for tropical conditions, high cost of imported equipment which must compete with relatively low cost labor.

In spite of some of these impediments, interest in mechanizing the harvesting-threshing operation is substantial in the tropical region. The introduction of new, high-yielding varieties which are less susceptible to lodging and which ripen more evenly has been the most encouraging development for the introduction of mechanized harvesting-threshing practices. The present combines have been developed to a stage wherein crop moisture is no longer a major problem. Some new combines can harvest paddy at moisture levels of 25 to 30 percent. The problems of inadequate ground support and machine mobility are being tackled by reducing machine weight and increasing ground contact area. Adequate water control in the farmers' fields is still a difficult problem and will have to be approached both from the machine design and the farm improvement level.

The various operational elements of paddy harvesting and threshing are cutting, binding, transporting, threshing from panicle, separating grain from straw, separating grain from chaff, separating grain from empty grains and finer impurities, and the delivery of grain for storage or drying. Various harvesting systems have evolved in different parts of the world and some do not necessarily follow the above sequence in total. In the most mechanized system of harvesting-threshing, all the operations are simultaneously done in the field with a combine which facilitates the operation and substantially reduces the labor requirements.

This paper will briefly describe the manual or animal methods and then attempt to go in more detail in the mechanical methods that are available for harvesting and threshing of paddy in the tropics. The subject is dealt in four sections:

(a) harvesting of plants,
(b) stationary threshing,
(c) direct field harvesting-threshing, and
(d) recent developments and trends.

Harvesting of plants

The operation of cutting a plant is achieved by four different actions: (a) slicing action with a sharp, smooth edge, (b) tearing action with a rough, serrated edge, (c) high-velocity, single-element impact with a sharp or dull edge, and (d) a two-element, scissors-type action.

Generally, manual harvesting involves slicing and tearing actions which result in plant material failure due to compression, tension, or shear. The serrated sickle combines a slicing and a sawing action. The serrated edge used in cutting devices restricts the sliding action of the plant on the blade edge and helps to retain the plant on the blade for adequate cutting. It has also been reported that sickles with serrated edges do not require repeated sharpening as the smooth-edge sickles.

Single-element impact cutting is an economical method of cutting unrestrained vegetation and has been widely used in rotary lawn mowers, forage choppers and in some tractor-mounted cutterbars. Generally, machines based on this principle are quite simple. Usually a single-element, sharp-edged blade requires a velocity of about 2,000 fpm for impact cutting. The effect of sharpness of the cutting edge is quite significant on the velocity necessary for effective cutting. A dull-edged, single-element blade requires a velocity of about 9,000 fpm for cutting. Most rotary cutters operate at blade velocities of 8,000 to 14,000 fpm.

A tractor-mounted swath harvester cutterbar based on the single-element impact cutting principle is marketed by a European manufacturer. This machine has a series of small-hinged rotating blades mounted closely on a frame to harvest a wide swath. The machine is popular in Europe for upland crops and brush cutting operations. It is more rugged than the conventional reciprocating cutterbar which is the most popular crop harvesting mechanism. The single-element cutting approach has been used in Japan, in some portable paddy harvesters and two makes of reapers. These machines are equipped with high-speed rotary saws for cutting plants.

The two-element scissors action is the most widely used for harvesting agricultural crops. The reciprocating cutterbars which are commonly used for harvesting paddy use this principle. Cutting is done by shearing rice stems between moving knife sections and ledger plates. The included angle between the cutting edges is about 38 degrees. Serrated blades permit a larger included angle since the plants cannot easily slip between the two cutting edges. Reel cutters also use the two-element scissors action but their use have been limited to lawn mowers and some forage choppers. Reciprocating cutterbars do an excellent job of harvesting but are characterized by high energy losses, short service life, dynamic imbalance, and restricted operating speeds. Improvements have been relatively limited by the high inertial and frictional forces involved in this type of mechanism. Many experimental attempts have been made to replace the reciprocating cutterbar. However, none of the experimental devices have been able to match the overall performance.

Methods or machines

Manual or animal. The practice of harvesting paddy plants, drying in the field and then threshing predominates in the major rice-growing areas of the tropics. A sickle is generally used for manual harvesting of paddy. There are many variations in sickle designs and both smooth and serrated blades are popularly used. Chancellor studied energy requirements for cutting rice stalks with smooth and serrated sickles and concluded that both are equally effective in cutting the plants.

Paddy plants are harvested by holding a sickle with one hand for cutting and the other for gathering. Plants are cut anywhere from 3 to 20 cm above the ground. The hand-holding of straw, while harvesting, reduces grain scatter losses as compared to harvesting with tractor mowers (Fig. 1). Ezaki reports that the harvesting output of a skilled man in non-lodged rice is about 0.01 ha/hr and that of a woman is about 0.006 ha/hr.

In some parts of Indonesia, Malaysia and the Philippines, only the panicles are harvested. This is done by using a small knife or a special tool which has a small metal blade fitted in a short wooden block. This is a high-labor consuming practice which requires about 175 percent more labor than sickle harvesting. Often religious or traditional reasons are given for this practice. In Java, custom allows a harvester to gather only one basket from each field for it is believed that taking more than a basket will displease the "godmother of good harvest." This practice, however, seems to have some practical reasons in areas where fields are inaccessible by roads and the harvested paddy has to be carried for miles while walking along field levees. In such areas, fields are far away from the roads and no threshing equipment can be conveniently carried into the fields. Harvesting of paddy with long straw under such conditions would certainly create a serious transportation problem. The harvested panicles are tied in small bundles for sun drying. Usually a skilled person can harvest about 15 kg of paddy rice per hour.

In Japan, a manually operated, push-type harvester called a hand dropper was developed. It consisted of a pair of serrated blades mounted at a 30-degree angle with each other, a mechanism to retain the harvested plants, and a lever to drop the harvested plants. A harvesting rate of 0.02 to 0.025 ha/hr has been reported by Ezaki. Taneja reported that such a dropper was tried in India on rice but it was not found satisfactory. A manually operated rice binder (Fig. 2) has also been used in Japan in which the plants are harvested with two fixed blades while the machine is pushed forward for a while in the row. A binding mechanism is then activated by a lever to tie the harvested paddy in bundles with twine. This machine was also tried in some Asian countries but was not found satisfactory.

Animal-drawn reapers have been tried at the Central Rice Research Institute at Cuttack, India for harvesting rice. Using a pair of bullocks, an average output of half an acre per hour has been reported. Compared to manual harvesting

working costs were less than one-third. These were old horse-drawn reapers from Western countries and many operational problems were encountered in harvesting rice and as such were not considered practical for harvesting paddy in India.

Power-operated harvesters. In the early stages, the mechanical harvesters developed in Japan were single or multirow side-delivery windrowers (Fig. 3), equipped with reciprocating cutterbars and some type of side-delivering mechanisms. Paddy plants were laid in a continuous swath. These harvesters were equipped with 60- to 70-cm cutterbars and were mostly offered as attachments to small walking tractors. Subsequently, some machines, called droppers, were developed which intermittently dropped untied bundles of paddy, making it easier to collect the harvested crop. In the last few years, portable power scythes (Fig. 4) have been marketed by Japanese manufacturers with rice harvesting attachments. Most of these harvesters have not been well accepted by the farmers. A slightly different Japanese reaper which has been in production for some years is equipped with a small rotary saw mounted on a planetary drive arrangement (Fig. 5). A 1-m wide swath is harvested by the small saw and is collected inside a circular passage. The collected untied bundles of paddy are dropped to one side of the machine.

Ezaki reports that in 1950, work on developing a binder was started at the Institute of Agricultural Machinery at Omiya, Japan. Subsequently, many manufacturers developed binders which dropped tied bundles of paddy on one side of the machine. During the last few years, these new binders have received wide acceptance in Japan. Sales figures of 1,000 units in 1966, 10,000 in 1967, 80,000 in 1968, and 150,000 in 1969 have been reported. The combined production figures of reapers and binders in Japan during 1964-1969 are given in Table 2. A list of different makes of binders, their prices and manufacturers' address are given in Tables 8(a) and 8(d).

These binders are equipped with reciprocating cutterbars. Plants are cut with the cutterbar and are conveyed to the side for tying in bundles. The bundles are ejected on the side and fall at right angles to the plant rows with the panicles away from the machine. These binders have moving nylon fingers for lifting lodged crops with a combing action. The binders can work successfully even when paddy is lodged at 20 to 30-degree angles. Generally the grain losses average about 2 percent.

The earlier binders were designed for one- or two-row operation. However, during the last few years, many manufactures have introduced three- and four-row machines. The one- and two-row, side-delivery binders (Fig. 6) are equipped with offset-mounted cutterbars and this necessitates manual harvesting of one or two rows of paddy before harvesting with the machine. The larger three- and four-row machines (Fig. 7) have in-line cutterbars that do not require the initial manual harvesting. Another interesting low-cost, single-row binder recently introduced in Japan (Fig. 8) is designed to drop the paddy bundles along the travel path of the machine. The manufacturer claims that this feature facilitates the collection of bundles from the ground. The larger tractor-trailed or self-propelled grain harvester-binders from Western countries have not been successful for harvesting rice in the tropics.

Stationary threshing.

Threshing involves the detachment of paddy kernel from the panicle and can be achieved by three methods: (a) rubbing action, (b) impact, and (c) stripping. The rubbing action occurs when paddy is threshed by trampling with men, animals or tractors. It is not an efficient method of threshing. The impact method is the most popular method of threshing paddy. Most mechanical threshers primarily utilize the impact principle for threshing, although in this some stripping action is also involved.

Paddy threshers can be classified by two methods of feeding: (a) the hold-on method and (b) the throw-in method. In the hold-on method, paddy straw is held stationary while threshing is done by the impact on the panicle from cylinder bars spikes or wire loops. In the throw-in type of machines, whole paddy plants are fed into the machine and a major portion of the grain is threshed by the initial impact of the bars, spikes on the cylinder. The initial impact also accelerates the straw and further threshing is accomplished as the moving panicles hit the spikes or bars of the concave.

The third type, stripping, has also been used in paddy threshing. Some impulsive stripping occurs ordinarily with impact threshing in conventional threshing cylinders. Non-impulsive type of stripping has been experimentally tried in centrifugal threshers and strippers but no commercial machine has so far been successfully developed.

Cleaning of grain involves the separation of bulky straw, chaff, empty kernels, very light and fine impurities from the grain. In the simplest form, straw and chaff is manually separated and the grain is dropped through a cross wind to remove the lighter impurities. Air can only remove impurities which have different aerodynamic properties from the grain. Many different grain cleaning systems are used in threshers, depending mostly on the type of feeding method and the threshing capacity. In the hold-on type of thresher, a major amount of straw does not pass through the machine and only the removal of chaff and light impurities from the grain is necessary. This is achieved mostly by pneumatic means and in some cases by a combination of screens and air. In the throw-in type of thresher, a large amount of straw is handled through the machine. These machines use straw walkers to initially separate the loose grain from the large bulk of straw and chaff. A chaffer screen is used to separate chaff from the grain before the removal of the finer impurities by an air blast.

Methods or machines

Manual or animal. The methods used for threshing rice manually are: treading by feet, both manual and animal; flail-threshing; beating on tubs, threshing boards or racks. A man can thresh anywhere from 15 to 40 kg of brown rice per hour by these methods. The only mechanical equipment used for manual threshing is the pedal thresher which originated in Japan during the early stages of mechanization. This thresher is also popular in Taiwan where a threshing team of 5 to 7

men work with each machine. The crew moves in a circle while one or two men are threshing and the others collect and bring new paddy bundles. The cylinder rotates at about 300 rpm and the inertia of the cylinder keeps the drum rotating as men take turns in pedalling the machine. There is no cleaner with this thresher. Tests at IRRI with this thresher indicate an output of about 30 to 70 kg of cleaned paddy per hour. Attempts have been made to introduce the pedal thresher in other Asian countries. Surprisingly, it has not been well accepted in the tropics. In Taiwan, 60 to 65 man-hr/ha are required for threshing with a pedal thresher which gives an approximate output of about 50 to 80 kg/hr. The improved pedal thresher performance in Taiwan is perhaps due to better coordination and teamwork of the threshing crew.

Power threshing equipment

Treading under tractor tires. This method of threshing paddy has been used in some Asian countries. It is quite popular in Ceylon for custom threshing. The popularity of this method can be attributed only to a lack of suitable tractor PTO-driven threshers. Threshing capacity of 640 kg/hr has been reported from Ceylon when two threshing floors are alternately worked with one tractor.

Types of threshing cylinders. All power paddy threshers are equipped with one of the following types of cylinder and concave arrangement: (1) rasp bar with concave, (2) spike tooth with concave, (3) wire loop with concave, and (4) wire loop without concave. Tests at IRRI indicate that the spike tooth cylinder performs well both with the hold-on and the throw-in methods of feeding and its threshing quality is less affected by changes in cylinder speed. Figure 9 illustrates the cylinder test stands and Fig. 10 and 11 show their comparative performance with the two methods of feeding. The wire loop cylinder exhibited excellent performance with the hold-on method of feeding. The following optimum cylinder peripheral velocities were obtained for threshing paddy based on the performance limits of 2.0 percent minimum unthreshed paddy, 1.0 percent maximum milled paddy, and 85 percent minimum head grain yields:

Cylinder type	Hold-on method	Throw-in method
Wire loop without concave, overfed	2650 fpm	3650 fpm[a]
Wire loop with concave, underfed	2150 fpm	2900 fpm
Peg tooth	2150 fpm	2900 fpm
Rasp bar	2650 fpm	3650 fpm

[a] Compromise cylinder peripheral velocity wherein: unthreshed paddy loss - 2.01%; milled paddy at threshing - 0.64%; head grain yield - 78.9%.

Hold-on type threshers. Custom harvesting and threshing of paddy by manual methods traditionally resulted in only a 3 to 5 percent loss in Japan. The

relatively low grain loss has made the Japanese farmer extremely loss-conscious about mechanized threshing losses. Most Japanese manufacturers attempt to keep thresher loss at levels below 2 percent.

Since paddy straw is needed in Japan for other uses, throw-in threshers which damage straw are not acceptable. The Japanese threshers are hold-on type machines which strip the panicle without damaging the straw. In Japan grain moisture contents at harvest time range from 20 to 25 percent and the grain is dried on stalks to 15 to 17 percent before threshing. Most Japanese threshers are better suited for threshing dry paddy than freshly harvested wet or high-moisture crop.

Three types of hold-on type threshers are popular for paddy:

(1) Engine-driven threshing drum - In Taiwan and some other countries, pedal threshers have been converted for power operation by the mounting of small aircooled engines. These machines have no grain separators or winnowers. Cleaning is a time-consuming problem and the output is relatively low. These threshers are, however, simple and can be manufactured in most Asian countries. Attempts are being made in many Asian countries to incorporate simple separating and winnowing mechanisms in such threshers. A number of small manufacturers have recently introduced such threshers in the Philippines.

(2) Japanese power threshers - These machines are equipped with a wire loop threshing drum and regular cleaning and winnowing mechanisms. Due to the hold-on method of feeding, output is not too high, but the machine can do a good job of grain cleaning. Relatively high labor is required since the paddy bundles have to be held by the operator until threshed. Gupta reports the visible and invisible seed damage with this type of thresher (Fig. 12) in tests conducted in India on Aman paddy.

Both the single- and double-drum threshers (Fig. 13 and 14) are offered by Japanese manufacturers. The double-drum threshers are of interest for multicrop threshing in the tropics. These machines can be operated either as hold-on or throw-in threshers. In the throw-in operation, threshed material is moved axially along the cylinder axis (Fig. 15) because of the helical arrangement of the wire loops and fins in the cylinder cover. Most of the threshing occurs at the first cylinder which operates at a slower speed. The hard-to-thresh grain is threshed in the second cylinder which rotates at a higher speed. The machine will perform well when the quantity of straw is not too excessive. Experience with the double-drum thresher in the Philippines indicates that it is quite well suited for threshing both wet and dry paddy and other agricultural crops such as wheat and sorghum.

(3) The self-feeding automatic threshers (Fig. 16) are similar to the non-automatic thresher except that these machines are equipped with paddy gripping feed chains to automatically feed the paddy bundles. Paddy is fed in a continuous layer by the feed chain. The threshing output is high and the machine requires less labor. In Japan, such threshers are also offered with a crawler

track platform (Fig. 17). These are self-propelled threshers and are conveniently moved in the field for threshing directly from paddy stacks. A list of different makes of self-propelled automatic threshers, their prices and manufacturers' address is given in Table 8(b) and 8 (d). Ezaki reports the following labor requirements for the three types of Japanese threshers:

Type	Motor hp	Labor (No. of men)	Capacity (ha/day)
Pedal, small	-	2	0.15
large	-	4	0.30
Power, small	0.5	4	0.30
large	2.0	8	0.70
Automatic	4.0	7	1.60

Tests conducted at IRRI on a Japanese automatic thresher equipped with a 4.2 hp engine indicated an output of about 200 kg/hr with 3 operators. Comparative performance of nine paddy threshers tested at IRRI in 1968 is listed in Table 3. These tests include the performance results on the two IRRI threshers, the drum and the table threshers (Fig. 18 and 19), which have been released to manufacturers. The table thresher is of a non-conventional design with a flat, rotating threshing surface with a built-in radial fan on its underside. This machine can thresh high-moisture paddy without clogging.

Through-flow threshers. In this type of thresher, paddy plants are completely fed into the machine. This type of machine is equipped with threshing cylinder with concave and has some separating and cleaning mechanisms. The rasp bar cylinder was previously considered suitable for rice. However, all of the new rice threshers and combines are equipped with spike tooth cylinders. The spike tooth cylinder can operate without clogging even with large amounts of straw at fairly high moisture levels. The grain is also not subjected to very high-intensity impact forces which results in lower grain damage.

In the Philippines, large McCormick type threshers (Fig. 20) are widely used for custom threshing. These threshers are exact copies of the old threshers which were developed over 50 to 70 years ago in Europe and America. Many small machine shops fabricate this machine in the Philippines. A major portion of the paddy in the Central Luzon area of the Philippines is custom threshed with these threshers. These threshers are belt-driven from a 60 hp tractor PTO pulley. Usually a crew of 8 to 12 men operate these machines. About 20 to 30 tons of paddy can be threshed per day. Due to the high threshing capacity, the machine is moved often, which results in substantial down time. This type of thresher is equipped with an elevator feeder mechanism, rasp bar cylinder, straw walker, chaffer, sieves, blower, and straw thrower. Since the introduction of combines in the developed countries, new threshers have not been developed. Consequently, the 50 to 70-year-old designs are still being fabricated in the Philippines. These threshers are sold in the Philippines for about US$5,000. Studies at IRRI indicate a need for a lightweight, tractor PTO-driven three-point-linkage mounted thresher of approximately 12 to 15 tons per day capacity for custom threshing in many Asian countries.

Direct field harvesting-threshing

Head-threshing combines (Japanese style). During the late '50s and '60s interest was generated in Western style combines in Japan. Between 1962 and 1968 about 400 such combines with 5 to 8-ft headers were imported in Japan. A number of Japanese manufacturers also developed their own versions of small, through flow type combines which were basically patterned after the Western style through-flow machines. These machines, however, were not well accepted as the grain loss and damage was generally higher than the Japanese farmers were willing to accept. These machines also consumed more power and required larger engines due to the energy lost in bruising the straw. The very small field size in Japan also created some operational problems.

Simultaneously, with the development of the small, Western style, through-flow combines in Japan, some manufacturers developed small head-threshing type combines. Basically, these combines consisted of a Japanese automatic thresher mounted on a self-propelled crawler platform and equipped with paddy plant lifting, cutting, elevating, and feeding mechanisms. Since the straw was not damaged in harvesting, these machines were better accepted by the Japanese farmers than the through-flow combines. The automatic threshers used in these combines were already popular in Japan for threshing dry paddy. The threshers used with the earlier combines did not perform well because of the high moisture levels encountered in direct combining. The major limitations of the Japanese automatic threshers are in the separating and cleaning mechanisms when working with high-moisture paddy. A number of companies have now improved the cleaning capacity of the threshers installed on their combines by adding straw walkers and oscillating sieves. These machines can successfully harvest high-moisture paddy.

These improved head-threshing combines have 2 to 3 percent grain loss, less than 1 percent grain damage. These machines are equipped with well designed dividers and moving nylon pick-up fingers which lift the lodged crop with a combing action. Two-row walking combines (Fig. 21) weigh approximately 600 kg and are equipped with crawler tracks which enable them to work in wet paddy fields. However, these machines still encounter problems of mobility in wet fields with very high clay contents or very deep hardpan.

Manufacturers of two-row machines claim an output of 350 kg/hr at 0.35 m/s travel speed and about 800 kg/hr at 0.6 m/s travel speed. A two-row Japanese combine was tested (Table 4) during the 1968 wet season at IRRI. An output of 250 kg/hr was found with IR20 paddy when travelling in second gear, resulting in a combining capacity of approximately 20 hr/ha. The total grain loss was less than 2 percent during these tests. Tests conducted on the same make of two-row combine in West Pakistan (Table 5) indicated an average output of 411 kg/hr and a fuel consumption of 2.26 lit/hr, at a harvesting capacity of 12.52 hr/ha. Performance results on the same make of machine from Malaysia and Ceylon are also reported in Tables 6 and 7.

During 1970, many Japanese manufacturers introduced three- and four-row riding combines (Fig. 22) which are based on the same principle as the earlier two-row machine. The two-row combines were greater in width than their offset mounted 50-cm cutterbars. Due to the larger width of the machines, a few rows had to be harvested manually before the combines could be operated in the field. The new three- and four-row machines have in-line cutterbars which are of the same width as the combine. This permits straight-through combine operation anywhere in the field and eliminates the problem of manual harvesting of the end rows.

These combines are gaining rapid acceptance in Japan and the sales have jumped from 1,269 units in 1967 to 14,758 in 1968, to 39,224 in 1969. A list of different combine harvesters manufactured in Japan and their manufacturers' list prices is provided in Tables 8(c) and 8(d). The selling price of a two-row combine in some of the Asian countries is from US$3,000 to US$4,000. The high price of rice in Japan and the high cost of labor make the Japanese combines economical to operate in Japan. Experience in the tropics indicate that while these machines can do an excellent job of combining, the economics of operation is not too favorable when compared with conventional methods. Many manufacturers have tried to market their combines in Asia but have not been too successful.

Through-flow type combines (Western style). Prior to 1942, the binder-thresher method was common for rice harvesting in the United States. The practice was changed to combining and drying between the years 1942 and 1948. In the binder method, rice was first cut by a tractor-drawn binder (4.86 has/10 hr) and then shocked by hand. It was left in shocks until it was dry for threshing. On an average, a crew of 14 men threshed 12.25 ha of rice per 10 hours. Artificial drying came into vogue along with combining from 1942 to 1948. Combining is generally done at 18 to 25 percent moisture content and then paddy is dried to 14 percent for storage.

There are three types of through-flow combines: (1) tractor-trailed, (2) tractor-mounted, and (3) self-propelled. The trailed combines have almost been replaced by the self-propelled machines because of improved mobility and performance. One European manufacturer has recently developed a tractor-mounted 6-ft combine (Fig. 23) which is lower-priced than the self-propelled combine and offers somewhat similar field mobility. The manufacturer claims that it can work in rice. However, no test data or information is available on its performance with rice.

The earlier tractor-drawn combines had 6-ft cutterbars and an output of 3.22 ha/10 hr while these combines required about 50 percent more labor than the self-propelled machines. However, these machines required one-third as much labor as with the old binder method. A self-propelled 12-ft combine can harvest about 5.9 ha per 10-hour-working day and a 14-ft combine can harvest about 6.88 has per 10-hour-day.

A standard self-propelled rice combine consists of components for cutting, feeding, threshing, separating grain from straw, cleaning, and temporary

storage. Power is provided both to the wheels and the harvesting-threshing mechanism from an engine mounted on the combine. Figure 24 shows the construction of a standard self-propelled rice combine. The rice combines differ from other grain combines in higher ground clearance, higher header lift for operations over bunds, crawler tracks (Fig. 25) instead of wheels for improved mobility in muddy fields, sealed bearings, adjustable pick-up type reel and lift guards for lodged crops, and oversize straw walkers. Almost all machines are equipped with spike tooth cylinders (Fig. 26) and the cylinder operates at slower rpm with rice than with the other grains.

Manufacturers claim that nearly 80 to 90 percent of the grain is separated from the straw at the concave, thus improving grain separation at the rack and reducing losses with straw. Generally, the popular header size is from 8 to 14 ft although combines of up to 27-ft headers are now being manufactured in the United States. Figure 27 shows a through-flow rice combine working in the fields. The new combines are equipped with hydrostatic transmission drives and make extensive use of hydraulic motors for driving the harvesting and threshing components. The use of hydraulics has simplified the design of the combine and has resulted in easier operation.

Careful operation and adjustments are necessary to obtain satisfactory performance from the modern combine. A brief description of various losses and the precautions necessary to minimize such losses are given below.

Scatter losses are due to natural causes, overripe paddy, wind, rain, birds, etc.

Cutting table losses. Pick-up reels, rather than bat reels, are essential for rice harvesting as nearly all fields have some plants lodged or tangled. In standing rice, pick-up reels are driven 50 percent faster than the forward speed of the combine. In lodged rice, reel speed should be about twice the forward speed. The pick-up fingers should be adjusted about 1 to 2 in. above and 14 to 17 in. ahead of the tip of the knife section when the fingers are in its lowest position. When the crop is flat on the ground, harvesting must be done along the direction of the lodging.

Cutterbar losses may increase due to dull knives and ledger plates, improper register or too fast a reel speed.

Cylinder losses. Spike tooth cylinders are normally used. Cylinder peripheral velocity ranges from 4000 to 5000 ft/min. If rice is dry (14 to 18%), or is harvested for seed, cylinder speed should be set at about 4000 ft/min. Cylinder and concave tooth overlap should be about one-half the tooth length. Concave teeth are usually in two to four full rows and all in the first two blanks with no teeth in the back portion of the concave. Losses depend on cylinder rpm, clearance between cylinder and concave, condition of cylinder and concave, combine travel speed, variety of rice, stage of maturity, moisture content, weather conditions, and straw-grain ratio. Early morning or late evening harvest increases cylinder loss. Minimizing cylinder loss (unthreshed grain) can sometimes result in increased hulling and damage to paddy.

Rack loss is affected by varietal characteristics and amount of straw passing through the racks. In down rice, plants are harvested very close to the ground and often more straw passes through the machine and the rack losses are increased.

Shoe loss. Air blast control is most important to minimize losses. Air should be sufficient to lift and float the chaff and light material and prevent it from falling through the sieves. Air should blow evenly throughout the entire area of the sieves. Air setting must be based on the amount of grain loss rather than the cleanliness of the grain in the tank. Damp and green paddy requires more air than dry paddy.

Hulling and breaking. In long grain varieties, paddy is more easily removed from the panicle than the medium and short grain varieties. Too dry (below 16% moisture content) a crop can result in more hulling.

Operator losses are perhaps the most important. Cutting the rice too high with less straw results in increased cutterbar and cylinder losses. Many heads on shorter straw or lodged straw are lost in the field. Straw when too short cannot be held by the beater and the feed rolls while the cylinder impacts and this can result in higher cylinder loss. If cutting is too low, excessive straw can slug the cylinder. Operating the machine too fast overloads and increases losses.

Loss in down rice. Combine loss in down rice is usually double than in standing rice (Table 9). The proper speed of pick-up reels is essential. The pick-up reel should not have a combing action in down rice as it will knock off some of the grain or panicles. Combining must be down with the direction of lodging and not against it to reduce losses. Combining in a cross-direction is also not too good. The least amount of straw is taken into the machine when cutting with the direction of lodging.

Some rice combines have been tried in Malaysia, Vietnam, and the Philippines, mostly in government farms or farmers with large holdings. During August 1970, a study was made on six Clayson 975 rice combines with 72 hp diesel engines and 13-ft cutterbars. These machines weighed nearly 7 tons each and were equipped with crawler tracks. The average production was found to be 1.74 ha /10-hr-working day. An average of 2.77 machine-hours per ha was considered realistic, which is much more than the 1.23 hours per ha quoted in other reports on combine harvesting. Some of the major causes of high downtime were: (1) rainy weather, (2) mechanical breakdowns, mostly of minor nature, (3) poor field organization in locating farmers' plots for harvesting.

This study showed an inverse relation (Fig. 28) between plot size and harvesting time per unit area. It indicates that beyond the 2.0-acre plot area, the effect of plot area on combine productivity is not too significant. It also indicates poor combining output on plots of areas below 1 acre. The main problems were shortage of access road systems and strong bridges, also of uneven ripening of crop within a farming locality. The initial investment was too large for farmers. The machine cannot work in areas where the soil has very high clay content or a very deep hardpan.

The study indicated, however, that it would be potentially profitable to operate these combines in spite of the high initial costs. Problems of accessibility, soil conditions, and small size of plots limit the areas available for combine harvest in the Muda region. The selling price of some of the self-propelled through-flow combine ranges from US$20,000 to $25,000 in the Philippines and other Asian countries.

It is highly doubtful that even some of the larger farmers in the tropics could raise so much capital. Perhaps such machines could only be bought by governments. The experience in the Muda Irrigation Scheme of Malaysia where these combines are now being used for harvesting crops on a custom basis if found successful needs to be watched carefully for application elsewhere.

Lawrence reports a study in which he compared the economic aspects of seven levels of mechanization in Pakistan from the traditional animal-drawn implements to a completely mechanized system of farming. He concludes that in the cropping sequence considered in this study, the labor demand for field operations fell only slightly when tractors were introduced and lower levels of mechanization actually increased labor demand. Combining, on the other hand, did reduce the demand for field labor considerably. The employment effects of introducing large combines will clearly continue to be a matter of concern.

Recent developments and trends

The idea of directly stripping grain from standing plants in the field has been experimentally tried for some time. A small stripper-harvester has been developed for plot harvesting in Australia (Fig. 29). However, when this machine was tried at IRRI on rice, loss of grain on the ground due to scatter was excessive. Strohman reported the development of a stripper-harvester (Fig. 30) with a conical rotor. The machine performed well with very low grain losses in tests conducted on rice in Arkansas. The large diameter of the conical rotor, however, did not adapt well for multirow harvester design. Experimental stripper-harvesters have also been built in Taiwan and Japan (Fig. 31) but none have reached a commercial stage.

The idea of stripping grain is of special interest for paddy harvesting since the elimination of handling straw through the machine can reduce substantially the machine weight and improve its mobility in soft paddy fields. Also, the cutting and elevating mechanisms can be dispensed with in a stripper. The IRRI Agricultural Engineering department has been working on the development of a swath type stripper-harvester rather than a row machine. This concept differs primarily from all other experimental attempts in that initially, the plants are gently bent into the machine before a violent contact is made with the belt-type threshing mechanism. The deflection of plants is done to reduce grain scatter on the ground and to improve the collection of grain. The experimental machine (Fig. 32 and 33) is able to thresh all the grain on the plant panicles. However, grain loss is still above acceptable limits. Work is underway to minimize the grain loss.

A company in England is also developing a 4-ft wide stripper-harvester based on a principle which is similar to the Connel concept (Fig. 34). They have built a working machine and have tested it in Italy. Further tests are being planned for this summer in Malaysia. The company claims excellent performance although no data have yet been made available. A United States company also experimented with a stripper-harvester which gripped the plants and accelerated the panicles to such a velocity that the grains were threshed by centrifugal force (Fig. 35).

Interest in stripping harvesters has been high and it is hoped that if a successful machine can be developed, it would certainly be better suited for harvesting rice in the tropics than the Japanese or the through-flow Western style combines. From the recent developments it seems probable that within a few years lightweight stripper-harvesters may be offered by manufacturers.

Recent developments in conventional through-flow rice combines are mostly directed toward increasing the machine capacity and size with increased width, wide flexible cutterbars, larger grain tanks, and bigger engines. While these developments are well suited for the advanced countries, this trend, unfortunately, is taking the newer combines farther away from the requirements of the developing countries. It is highly doubtful that such large machines could be widely accepted in the developing areas of the world.

There has been considerable interest in the last few years in developing rotary threshing and cleaning mechanisms to eliminate many of the bulky components of combines such as walkers, chaffers, and other separating devices. A number of new patents have been recently granted in the United States but no commercial machine has yet been offered in the market. Figure 36 illustrates an experimental combine which uses a conventional threshing cylinder with a rotary cleaner. If such developments result in considerable reduction on the price of through-flow combines, then the machine may find better acceptance in the developing areas.

For some years the Institute has been working on the development of a thresher using rotary threshing and separating components. A few years earlier, a cone thresher was built at the Institute on Lalor-Buchele's concept. The separation of grain and straw was found unsatisfactory with this machine. Performance of a cone thresher developed in Thailand has also indicated similar problems. A tractor-mounted, PTO-driven, through-flow thresher (Fig. 37) is currently under development at the Institute and so far the test results are very promising. The machine can thresh high-moisture paddy without clogging. It uses a spike tooth threshing cylinder and a multiscreen rotary cleaner which are mounted uniaxially. The threshed material continuously moves in a spiral path through the threshing cylinder and the rotary cleaner. Up to 92 percent grain-straw separation has been achieved at the cylinder concave. Work is on hand to optimize the recovery of the remaining grain in the rotary cleaner. The thresher concept is such that it can be easily adapted for a low-cost rice combine. Harrington also reports the development of a multicrop, tractor-mounted, PTO-driven thresher in India using a large-diameter beater-type threshing mechanism. The machine can thresh paddy, wheat and many other crops.

Recent developments in Japan on harvesting and threshing machines indicate a rapid shift to combining. The basic Japanese automatic head-threshing machine has remained unchanged in design for a long time. During the last two years, some marginal improvements have been made in the cleaning mechanisms to improve performance with wet crops and increase capacity. These were necessitated since these threshers are used with combines which harvest high-moisture paddy. Combine size is gradually increasing from two rows to three and four rows. The Japanese combine can work well in the tropics for harvesting and threshing of paddy. Recent attempts to introduce this machine in Asia, however, indicate that it is not very economical. The Japanese combine is a complex piece of equipment and from a design point of view, it is doubtful that the basic machine concept could be sufficiently simplified to substantially reduce the price. The home market in Japan is moving towards larger three- and four-row combines which are even higher-priced than the two-row machines.

Requests received at IRRI for information on threshers from tropical countries indicate an intense demand for machines, both for the individual farmers and for custom threshing operators. Attempts are being made in many developing countries to manufacture simple hold-on type drum threshers.

The Japanese automatic threshers are gradually being introduced in Asia but their high landed cost restricts their acceptance. The indigenous manufacture of small threshers is gradually developing in many tropical countries but is hampered by the lack of thresher designs which could be manufactured by simple production methods. Developments indicate considerable interest in large PTO-driven threshers and it is hoped that some successful design will definitely appear in the near future. It seems doubtful if rice harvesting in Asia would go through the reaper-binder stage like in Japan and the United States.

There is little doubt that in the long run the harvesting and threshing of paddy in the tropics will have to be done directly in the field. The present combines, however, do not seem to meet the special requirements of the tropical region. Recent developments indicate an intense interest in developing simpler machines for paddy harvesting and threshing. Looking at some of the recent technical developments, it seems that a breakthrough can be made in the development of economical, small-sized machines for direct field-harvesting and threshing of paddy in the tropical regions of the world.

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Table 1 . Power requirements in rice harvesting in man-hours, animal-hours, and rated horsepower-hours per hectare. Information collected from various publications in rice production.

Operations	Man-hrs/ha			Animal-hrs/ha			Rated hr-hrs/ha		
	Min.	Max.	Average range	Min.	Max.	Average range	Min.	Max.	Average range
A. Hand harvest, indiv. panicles w/ small knife			240						
			69*						
B. Hand harvest w/ sickle, transport and stack	72	370	80-160						
C. Tractor & binder (40 hp)									
1. Binding	4.0						80		
2. Shocking	8.0						-		
3. Threshing	12	30					240		
4. Hauling	2						80		
D. Combine, 2-man crew, 60-80 hp									
1. In U.S.	2.2	7.5	4.4						175
2. In tropics	3.2	21.5	6-12				100	600	180-360
E. Thresh									
1. Foot threshing by man	200								
	69*								
2. Flail threshing	16*	35*	20-30*						
3. Beating on bamboo frame, basket, etc.	16*								
4. Pedal thresher	8-10*	25*	100						
			20*						
5. Trample by ox or buffalo	60			150					
	89			178					
	6*			6*?					
6. Powered Japanese thresher 0.5 to 3 hp	48	197	100				15	25	
	20*	25*					3*	5*	
7. Treading w/ standard tractor			80				55	150	80
8. Treading w/ 15-hp tractor & disc harrow							50*	80*	
9. Stationary large thresher	12	30	12				90	180	
10. NIAE thresher	52*	155*	80*				3.2*	9.7*	5*
F. Cleaning of grain									
1. Tossing in air	10*								
2. Field winnowing w/ hand fan			6.7*						
3. Fan mill, hand operated	1.5*	7*							
4. Chaff sieve	4.0*	8.0*							

Note: Figures marked with asterisk (*) are for number of hours per 1000 kg (or M.T.).
Source: Johnson, Loyd. POWER REQUIREMENTS IN RICE PRODUCTION. Agr. Eng. Conference, IRRI, August, 1963.

Table 2 . Annual production of harvesting - threshing equipment in Japan.

Year	Number of machines produced			
	Reapers & Binders	Hand feeding type power thresher	Automatic feeding type power thresher	Combine
1960		138,121	124,124	
1961		118,000	144,927	
1962		102,552	159,497	
1963		95,349	176,863	
1964	57,228	75,126	202,614	
1965	64,186	62,290	253,151	17
1966	86,632	51,164	293,791	9
1967	68,321	32,760	335,223	1,269
1968	133,192	41,400	330,863	14,758
1969	240,202	24,357	249,423	39,224

Source: Farm Machinery Statistics 1971. Farm Machinery Industrial Research Corp., Tokyo, Japan.

Table 3 . Comparative performance of selected rice threshers. IRRI, Los Baños, Laguna, Philippines. 1968.

Thresher model	Threshing blade type	Machine performance			Power performance			Labor performance				Economic performance		
		Kg/hr	Ha/hr*	Rating	Engine hp	Hp-hr per 44 kg	Rating	No. of men**	Man-hr per ha*	Grain output per man-hr (kg)	Rating	Machine cost	Threshing cost per 44 kg (₱)	Rating
1. Pedal thresher	Wire loop	68.64	0.0156	9	-	-		2	128.20	34.32	7	N.A.		
2. Locally manufactured non-automatic single drum	" "	158.40	0.0360	5	4.0	1.333	4	3	83.33	52.80	2	2464	0.930	3
3. IRRI drum type	" "	252.12	0.05373	2	4.2	0.695	2	5	87.26	50.42	4	3000	1.06	4
4. IRRI table type	" "	228.80	0.0520	1	4.2	0.807	1	5	96 17	45.76	3	2500	0.912	2
5. Japanese automatic	" "	195.36	0.0444	3	4.2	0.946	3	3	67.56	65.12	1	3500	0.765	1
6. Locally manufactured drum type	Spike-tooth	117.04	0.0266	8	12.5	4.700	7	4	172.94	29.26	9	6750	1.512	5
7. Vogel nursery	" "	126.72	0.0288	7	10.0	3.473	6	4	138.81	31.68	8	N.A.		
8. Turner "Economy"	Rasp bar	170.72	0.0388	4	10.0	2.577	5	4	120.00	39.60	6	N.A.		
9. Garvie Type DA	" "	163.2[illegible]	0.0371	6	17.5	4.717	8	4	107.85	40.79	5	N.A.		

* Based on 4400 kg/ha yield.

** Number of men includes one man who collects and sacks the grain.

Source: Semi-Annual Substantive Report No. 8 & No. 9, IRRI-AID Mechanization Research Contract. IRRI, Philippines.

Table 4 . Test result of two-row Japanese combine, IRRI, Los Baños, Laguna, Philippines (1968).

Time Trials in Minutes	67.02	43.32	0.50	0.35	0.52	0.49	0.35	0.36
Speed (km/hr)	2nd Gear 0.65	2nd Gear 0.65	1st Gear 0.45	2nd Gear 0.65	1st Gear 0.45	1st Gear 0.45	2nd Gear 0.65	2nd Gear 0.65
Wt. of threshed grain at harvesting threshing, kg	204.30	198.95	1.36	1.22	2.413	2.513	2.413	2.563
Ave. M.C. (%) at harvesting threshing	19.50	22.0	19.0	19.0	22.0	22.0	22.0	22.0
Wt. of threshed grain at 14% M.C., kg	191.24	180.45	1.28	1.148	2.188	2.279	2.188	2.325
Machine output, kg/hr	171.362	249.92	153.60	196.80	252.46	279.06	375.08	387.50
Area harvested threshed, sq.m	450.47	357.75						
Harvesting threshing time, hr/ha	24.794	20.181						
Variety	C-4	IR-20	C-4	C-4	- - - - - - -	IR-20	- - - - -	
Fuel consumption, liter/hr	2.417	3.078	0.09					
Grain loss at 14% M.C.								
a. threshing loss, kg/hr			0.09	1.457	0.512	0.220	2.486	3.617
threshing loss, (%)			0.058	0.749	0.202	0.078	0.662	0.933
b. separating loss, kg/hr			0.04	0.994	0.502	0.611	0.309	0.212
separating loss, (%)			0.026	0.505	0.198	0.218	0.082	0.054
c.*shattered grain, kg/m^2					0.0036	0.00236	0.00136	0.00118

*Average of 3 (one square meter) readings.

Source: Unpublished test data, IRRI, Philippines.

Table 5 . Test results of two-row Japanese combine in West Pakistan. (October __, 1968)

Test No.	1	2	3	4	5	6	Average
Test duration (hrs)	2.0	2.0	2.25	2.167	1.0	1.67	1.84
Driving speed (km/hr)	0.65	0.65	0.65	0.65	0.65	0.44	
Weight of threshed grain obtained (kg)	1054.54	727.27	945.45	1018.20	363.64	436.36	757.57
Machine output (kg/hr)	527.27	363.64	422.73	472.27	363.64	261.82	411.72
Area harvested (ha)	0.178	0.146	0.206	0.174	0.081	0.097	0.147
Harvesting-threshing time (hr/ha)	11.23	13.70	10.92	12.45	12.34	17.18	12.52
Fuel consumption (liter/hr)	2.84	2.12	1.88	2.27	2.57	1.86	2.26
Yield (kg/ha)	5928	4940	4670	5838	4491	4491	5061
Variety				IRRI-PAK			

Source: Unpublished report from Gov't Rice Farm, Kala Shah Kaku, Punjab, West Pakistan.

Table 6. Test result of two-row Japanese combine at University of Malaya. (1969)

Field No.	Area harvested (ha)	Machine No.	Operator	Fuel consumption (liter/hr)	Speed (km/hr)	Rate of work (Hr/ha)	Theoretical field capacity (ha/hr)	Field efficiency %	Machine output (kg/hr)	Grain loss %
1	0.243	1	Company	-	1.93	24.71	0.0809	50.0	745.45	3.46
2	0.405	2	Farmer	2.42	1.96	14.53	0.1250	56.0	339.73	6.94
3	1.110	2	Farmer	2.04	1.64	18.05	0.0939	58.6	346.64	8.01
4	0.324	2	Farmer	2.72	1.53	29.07	0.0607	56.5	321.04	5.07
5	0.040	1	Farmer	-	1.74	29.07	0.0728	47.1	369.09	7.61
6	0.405	1	Farmer	2.16	1.90	13.74	0.1052	70.0	388.18	6.08
7	0.502	1	Farmer	3.56	1.96	27.47	0.0971	44.0	206.82	12.22
8	0.441	1	Farmer	3.25	1.82	22.27	0.0712	67.0	249.54	7.52
9	0.198	3	Company	2.72	1.98	24.47	0.1101	37.4	202.27	2.60
10	0.105	3	Company	3.38	1.99	24.23	0.0971	46.0	233.64	1.45
Mean	0.377			2.78	1.84	22.76	0.1642	52.9	340.24	6.08

Source: Unpublished test report, Univ. of Malaysia, Kuala Lumpur.

Table 7 . Test result of two-row Japanese combine in Ceylon. (1968)

Working rate (hr/ha)	17.67
Average moisture content (%w.b.)	19.0
Fuel consumption (liter/hr)	1.74
Yield (kg/ha)	6633
Variety	H-7
Time lost in turning (%)	27.0
Threshing efficiency (%)	98.5
Separating efficiency (%)	100
Losses:	
Threshing loss (%)	0.31
Separating loss (%)	0.58
Shattered grain	0.22

Remarks:

Dry soil, excellent trafficability

Crop lodged in one direction

Max. standing angle	25°
Min. standing angle	6.5°
Average standing angle	15.5°

Source: Unpublished report, Agric. Machinery Design & Testing Center, Maha Iluppallama, Ceylon. Aug. 31, 1968.

Table 8a. Price list of Japanese rice binder 1970.

Company/Brand	Model	Horsepower (P.S.)	Cutting width (mm)	Row cut	Manufacturer's list price in Japan[1/] US$	¥
Iseki	RS50	5.0	500	2	756	272,000
Iseki	RS25	3.5	250	1	517	186,000
Komma	KB302	2.2	290	1	528	190,000
Kubota	HC-500	3.0-4.0	500	2	861	310,000
Kubota	HC-302	2.2-3.5	300	1	494	178,000
Mitsubishi	KB503C	3.0-4.5	550	2	806	290,000
Mitsubishi	KB251	3.0-4.5	250	1	536	193,000
Noda	RT500N	3-4	500	2	861	310,000
Ohshima	HR500	2.5-3.5	500	2	842	303,000
Ohshima	HR300	2.2-3.0	300	1	542	195,000
Satoh	B-50	3.0-4.5	550-650	2	825	297,000
Satoh	B-30	2.5-3.0	400	1	494	178,000
Suzue	B60	3	600	2	861	310,000
Hinomoto (Toyosha Co., Ltd.)	UB550	3.5-4.5	500	2	717	258,000
Ko-Go (Uemori Noki)	BH60C	3.5-4.5	500	2	861	310,000
Ko-Go (Uemori Noki)	BH30B	2.2-3.0	300	1	550	198,000
Yanmar	LB600A	4.5	580	2	805	290,000
Yanmar	LB300	3.0	320	1	492	177,000

[1/] US$1.00 = ¥360

Source: Japanese Association of Agric. Machinery, Tokyo. Field Day Held at Tendo-city, Yamagata Pref., Japan, October, 1970.

Table 8b. Price list of self propelled automatic thresher 1970.

Company/Brand	Model	Horsepower	Cylinder width (mm)	Manufacturer's list price in Japan[1/] US$	¥
Iseki	HM-1	7.5	400	975	351,000
Iseki	D2LKC	Direct mount to Iseki tractor TB1700 (17 PS)	500	243	87,500
Komma	MT5SD	6.5	-	952	342,600
Kubota	HR-5CR	6.0-8.0		1205	434,000
Kubota	HN-5CR	6.0-8.0	-	1054	379,600
Mitsubishi	A6D	Direct mount to Mitsubishi tractor R2000 (20 PS)		203	73,000
Noda	HB-5BC	6-8		1080	389,000
Ohshima	OHB-7	6.5-8		1083	390,000
Satoh	F-55	6.5-9.0	482	1000	360,000
Satoh	M-55	Direct mount to Satoh tractor S560 (21 PS)	482	565	203,400
Yanmar	PTC1-B	6.0-7.0		1083	390,000

[1/] US$1.00 = ¥360

Source: Japanese Association of Agric. Machinery, Tokyo. Field Day Held at Tendo-city, Yamagata Pref., Japan, October, 1970.

Table 8c. Price list of Japanese combine harvesters 1970.

Company/Brand	Model	Horsepower (P.S.)	Cutting width (mm)	Row cut	Manufacturer's list price in Japan[1/] US$	¥
Iseki	HD660R	12.0	600	2	2042	735,000
Iseki	HD650R	12.0	500	2	1758	633,000
Iseki	HD550	8.0	500	2	1342	483,000
Komma	CB90	11	1000	3	2500	900,000
Kubota	HT-85	11.0-14.0	900	3	2361	850,000
Kubota	HJ-4WR	8.0-11.0	540	2	1697	611,000
Mitsubishi	MC951D	6.5-9	500	2	1700	612,000
Mitsubishi	MC752	7-10	650	2	1528	550,000
Noda	HCB50	7-9	500	2	1700	612,000
Ohshima	SC-400	6-8	400	1-2	1222	440,000
Robin	GH52-H	8-10	500	2	1750	630,000
Satoh	H120	17	1200	4	4167	1500,000
Satoh	HD50D	6.5-9.0	600	2	1700	612,000
Satoh	HL50	5.5-7.0	700	2	1458	525,000
Suzue	KC60	8	600	2	1611	580,000
Ko-Go (Uemori Noki)	CH60B	10-12		2	1611	580,000
Yanmar	TC500A	8.0-9.0	500	2	1639	590,000

[1/] US$1.00 = ¥360

Source: Japanese Association of Agric. Machinery, Tokyo. Field Day Held at Tendo-city, Yamagata Pref., Japan, October, 1970.

Table 8d. Address of manufacturers of binding, threshing, harvesting equipment.

1a. Iseki Noki Co., Ltd. Overseas Department 2-2 Nihonbashi - Dori Chou-ku, Tokyo, Japan	7. Ohshima Noki Co., Ltd. 3-360 Tera-machi Takada-shi, Niigata Japan
1b. Iseki Noki Co., Ltd. No. 2-5-7 Otemachi Matsuyama, Ehime Japan	8. Satoh Zoki Co., Ltd. Kinsan Bldg., No. 5, 4-chome Nihonbashi-Muro Machi Chuo-ku, Tokyo, Japan
2. Fuji Komatsu Robin Industries, Ltd. Shinjuku Bldg., No. 94, 2-chome Tsunohazu, Shinjuku Tokyo, Japan	9. Suzue Agric. Machinery Co., Ltd. 144-2, Gomen-cho Nangoku-City Kochi, Japan
3. Koma Mfg. Co., Ltd. Izumi-cho, Tsuruoka-shi Yamagata Japan	10. Toyosha Co., Ltd. 55, Joshoji -16 Kadoma-City, Osaka Japan
4. Kubota Tekko Co., Ltd. 22, Funade-cho, 2-chome Naniwa-ku, Osaka Japan	11. Uemori Noki Co., Ltd. Kannonji-cho, Tsuruoka-shi Yamagata-chi Japan
5. Mitsubishi Heavy Industries Co., Ltd. 2-10 Marunouchi, Chiyoda-ku Tokyo, Japan	12. Yanmar Noki Co., Ltd. No. 62, Chayamachi, Kita-ku Osaka, Japan
6. Noda Industries Co., Ltd. 1-2-2 Kawara-machi Takamatsushi, Kagawa Japan	

Source: Japanese Association of Agric. Machinery, Tokyo. Field Day Held at Tendo-city, Yamagata Pref., Japan, October, 1970.

Table 9. Summary of losses and damages recorded on ten varieties of standing rice, with all combines studied, 1947-49.

Rice variety	Tests	Shatter loss	Combine loss: Cutterbar	Combine loss: Cylinder	Combine loss: Rack	Combine loss: Shoe	Combine loss: Total	Yield	Combine loss	Damaged grain: Hulled	Damaged grain: Broken
	Number	← Bushels per acre →							← Percent →		
Nira	38	0.47	1.44	0.79	0.57	0.14	2.94	61	4.94	3.01	3.67
Bluebonnet	15	0.41	1.43	1.19	1.16	0.14	3.91	64	5.85	4.71	3.93
Rexark	3	0.19	0.93	2.24	1.04	0.15	4.36	56	8.08	5.50	3.92
Fortuna	12	0.41	1.49	1.03	0.50	0.12	3.13	60	5.55	3.02	3.95
Zenith	47	0.12	0.65	1.44	1.00	0.26	3.35	60	6.02	6.47	3.43
Arkrose	10	0.18	1.12	1.90	0.59	0.06	3.68	62	5.95	4.71	3.06
Prelude	6	0.02	0.38	1.14	0.83	0.14	2.49	60	4.15	6.64	4.18
Kamrose	2	0.11	1.00	4.65	0.34	0.18	6.17	56	10.09	6.44	2.36
Early Prolific	2	0.27	1.47	3.66	2.51	0.68	8.31	63	13.16	6.60	5.85
Magnolia	3	0.25	0.22	0.83	0.45	0.07	1.57	66	2.45	7.36	1.55
Total or average	138	0.28	1.06	1.30	0.82	0.18	3.36	61	5.71	4.91	3.59

Summary of losses and damages recorded on seven varieties of down rice, with all machines studied, 1947-49.

Rice variety	Tests	Shatter loss	Combine loss: Cutterbar	Combine loss: Cylinder	Combine loss: Rack	Combine loss: Shoe	Combine loss: Total	Yield	Combine loss	Damaged grain: Hulled	Damaged grain: Broken
	Number	← Bushels per acre →							← Percent →		
Nira	13	0.62	2.93	1.27	1.72	0.29	6.21	73	8.79	3.38	4.08
Bluebonnet	2	0.50	3.93	1.41	2.37	0.39	8.10	65	12.59	2.74	3.46
Fortuna	1	0.42	3.37	1.21	3.07	0.45	6.34	65	17.82	2.83	2.36
Zenith	1	0.23	2.50	1.04	1.65	0.06	5.25	45	11.67	4.42	3.64
Jap	1	0.00	0.30	0.85	3.60	0.21	4.96	55	9.02	1.72	4.68
Rexark	3	0.46	3.13	4.95	4.61	0.64	13.33	57	22.58	4.54	1.98
Arkrose	1	0.27	1.33	1.50	0.92	0.20	3.95	59	6.69	1.40	0.68
Total or average	22	0.52	2.86	1.76	2.28	0.34	7.16	67	11.47	3.34	3.51

Source: McNeal, Xzin. Effect of combine adjustment on harvest losses of rice. Ark. Agr. Expt. Sta. Bull 500. 1950. p. 7.

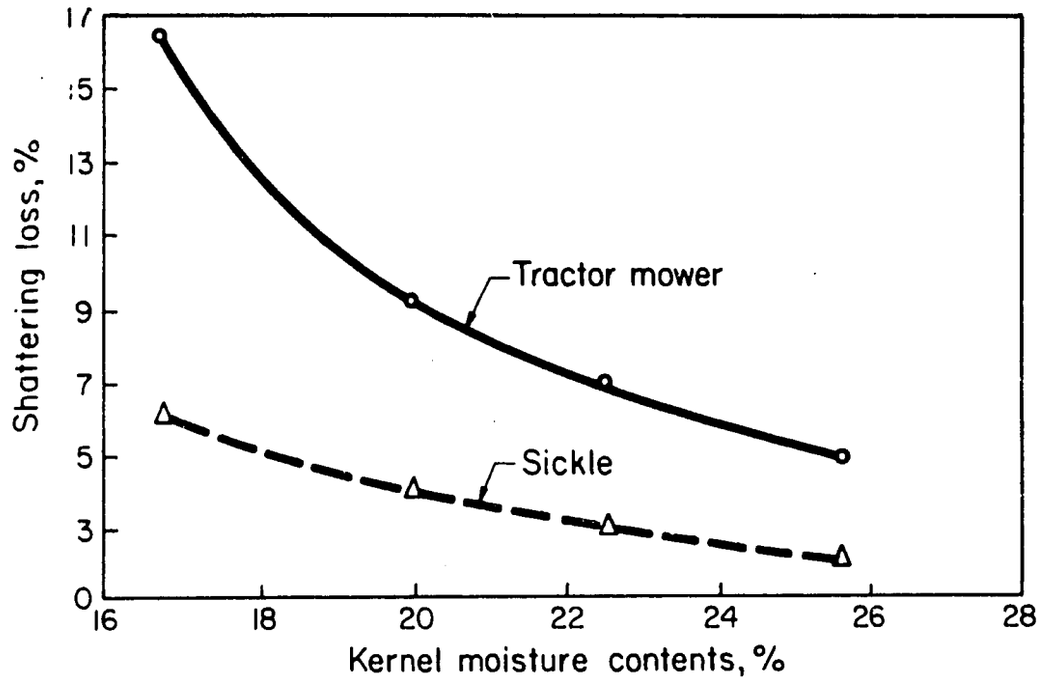

Fig. 1 Effect of two methods of harvesting on shattering loss at different kernel moisture levels. Paddy variety Dular. Source: (Gupta).

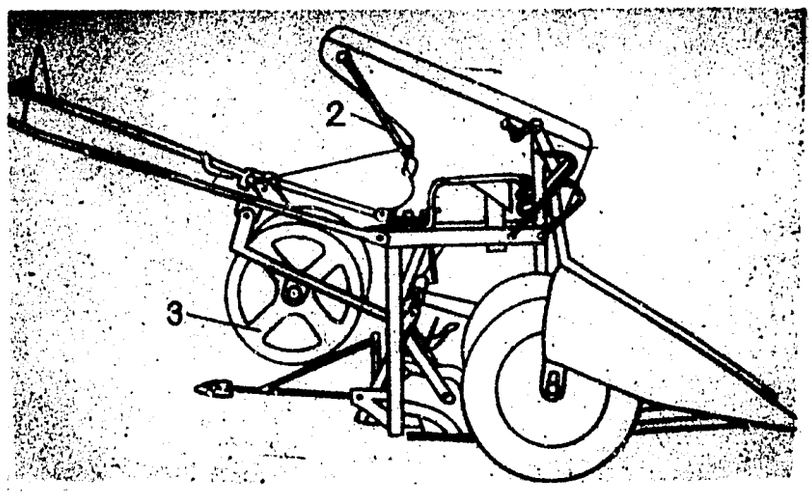

Fig. 2 Hand-operated reaper-binder.

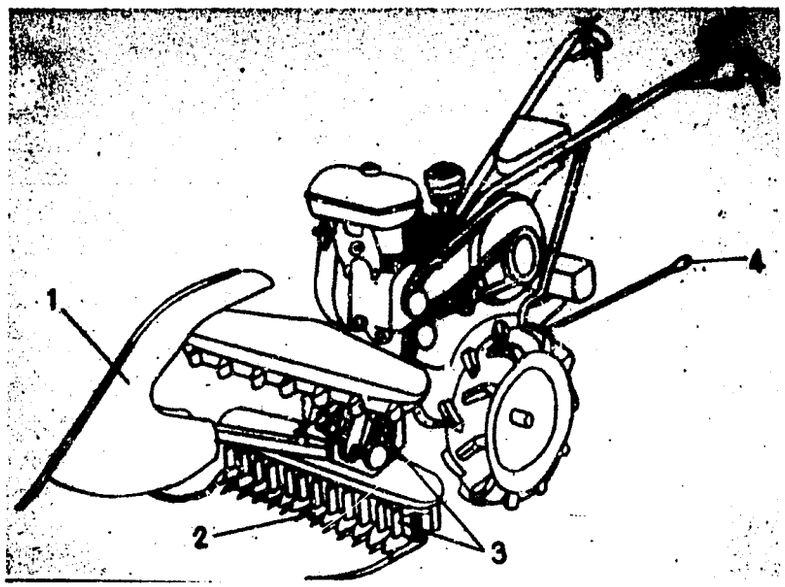

Fig. 3 Multirow side-delivery windrower.

Fig. 4 Portable power scythe harvester.

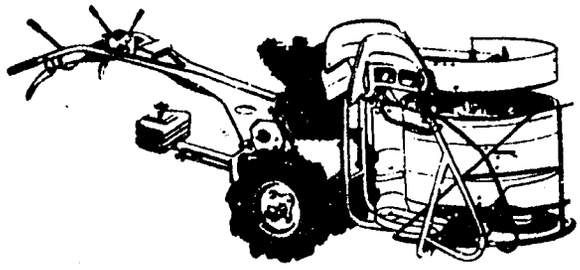

Fig. 5 Single-row power reaper. (Shibaura).

Fig. 6 Two-row side-delivery binder (Kubota).

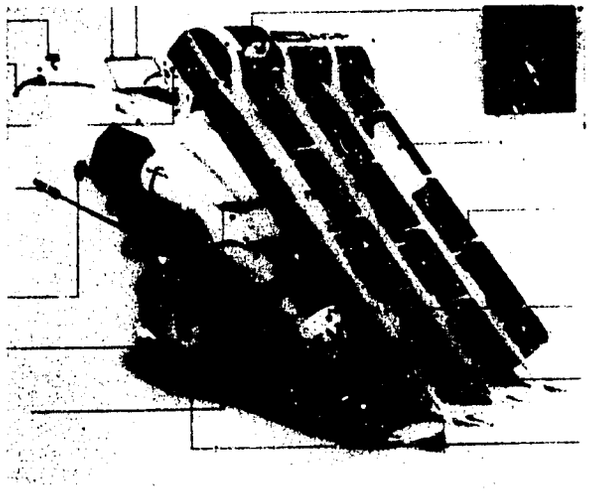

Fig. 7 Three-row side-delivery binder (Kubota).

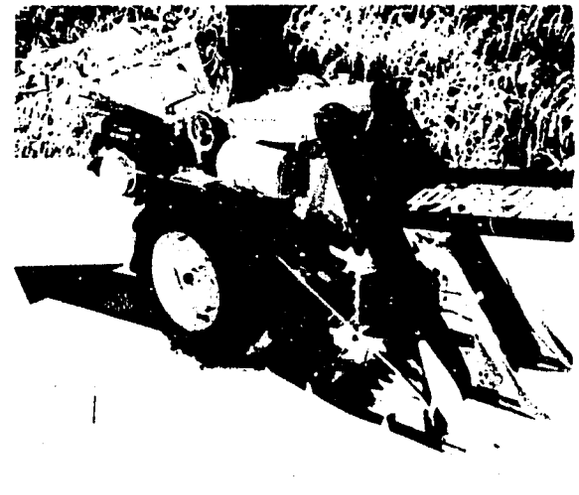

Fig. 8 Single-row center-discharge binder (Hinomoto).

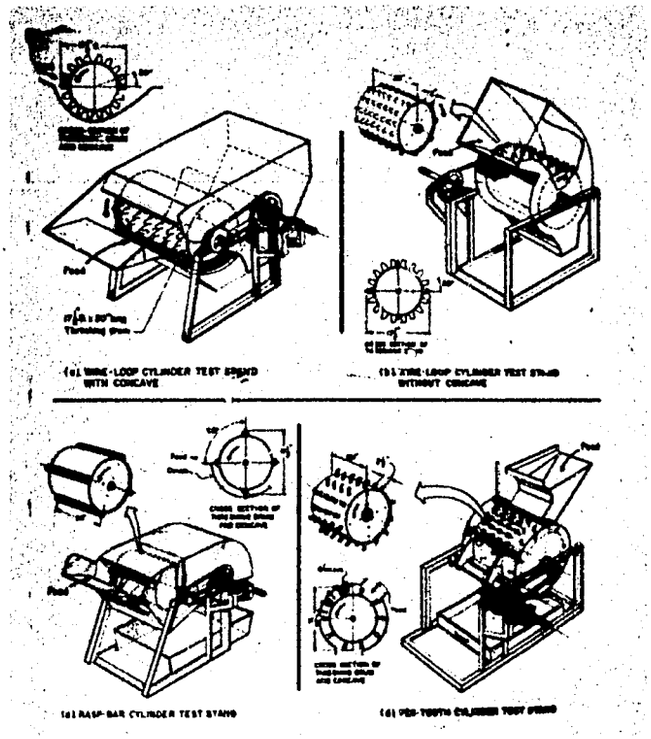

Fig. 9 Threshing cylinder test stands.

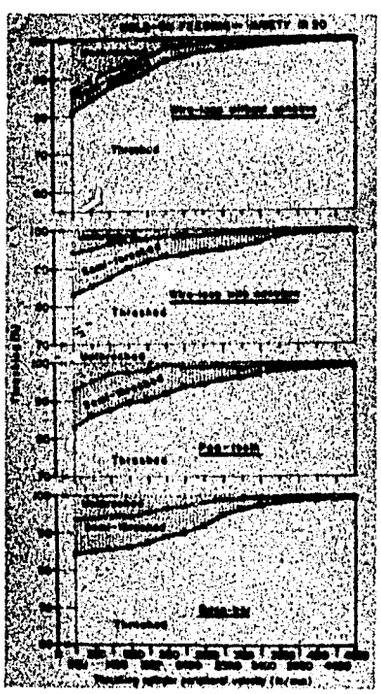

Fig. 10 Comparative threshing cylinder performance for hold-on feeding.

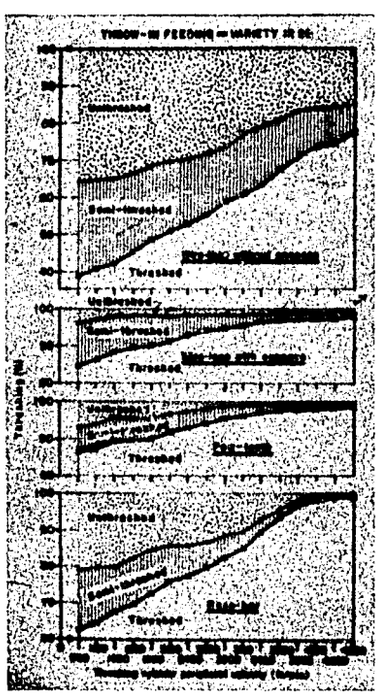

Fig. 11 Comparative threshing cylinder performance for throw-in feeding.

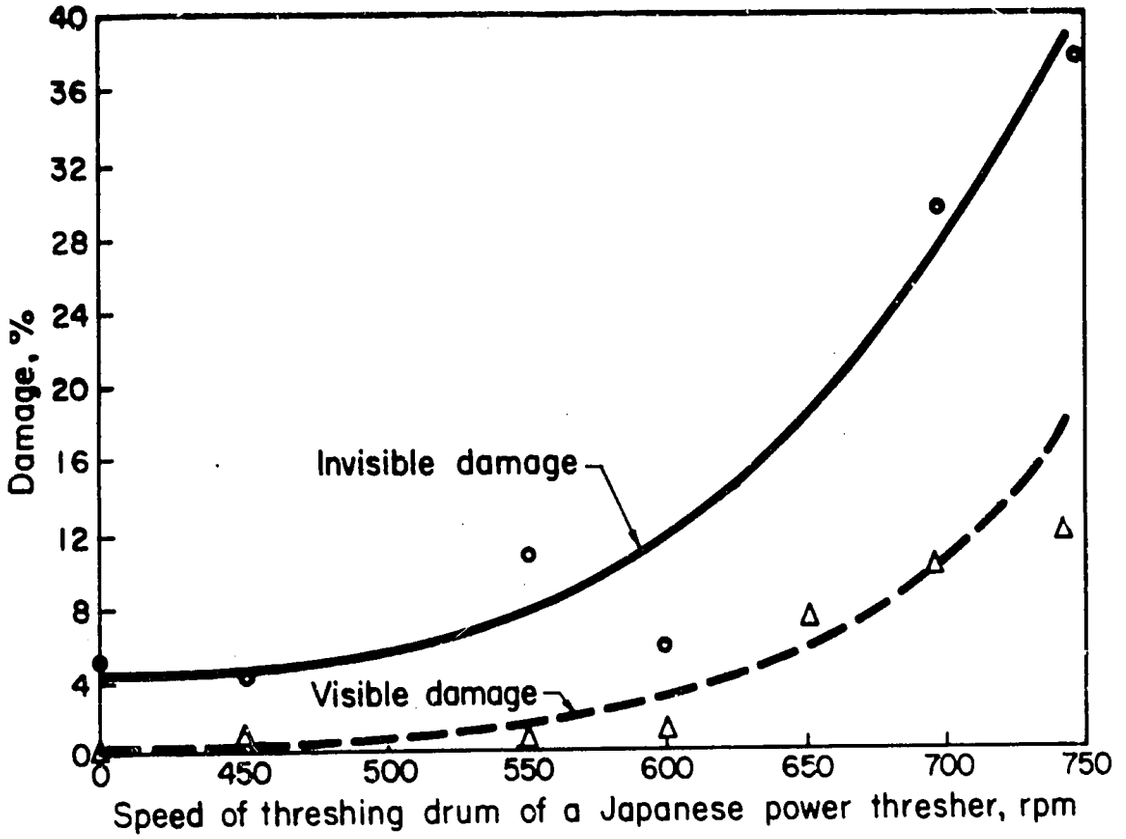

Fig. 12 Visible and invisible seed damage at different threshing drum speeds. Source: Gupta.

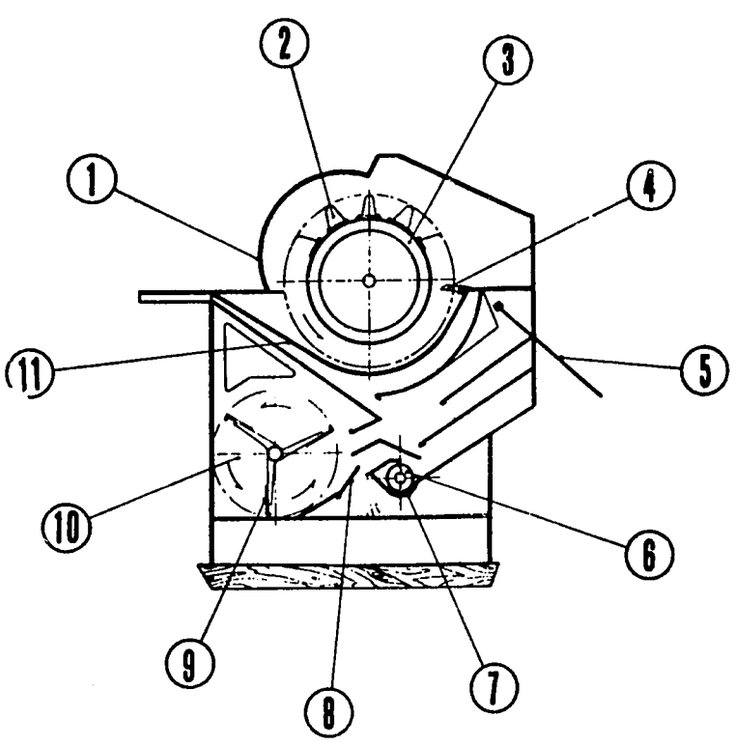

Fig. 13 Single threshing drum.

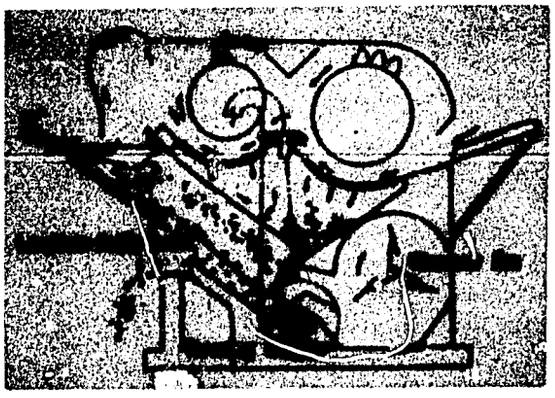

Fig. 14 Double threshing drums.

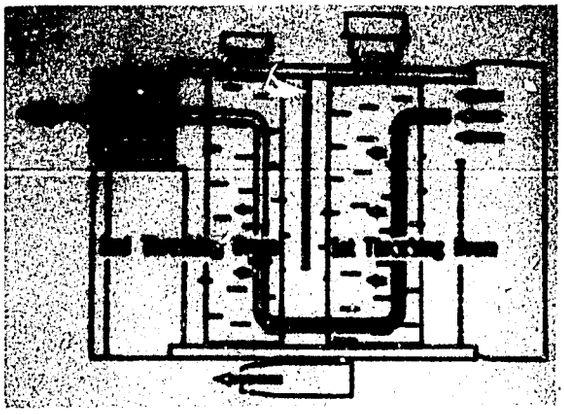

Fig. 15 Axial movement of material in a double-drum thresher.

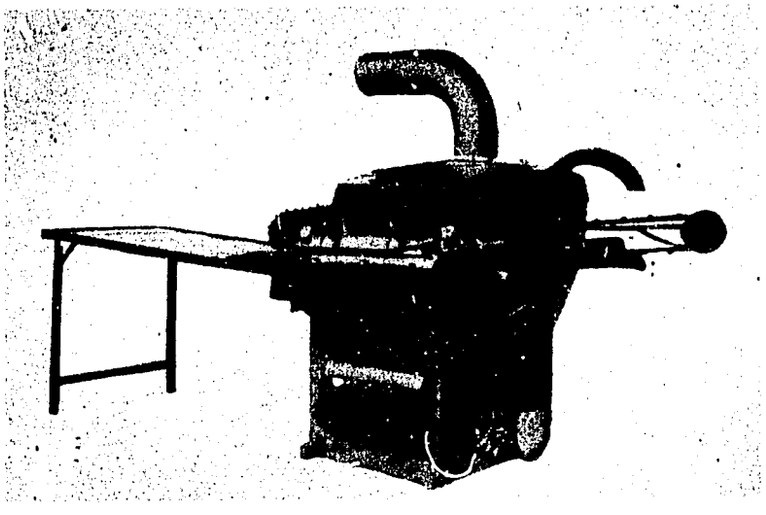

Fig. 16 Japanese automatic thresher (Kubota).

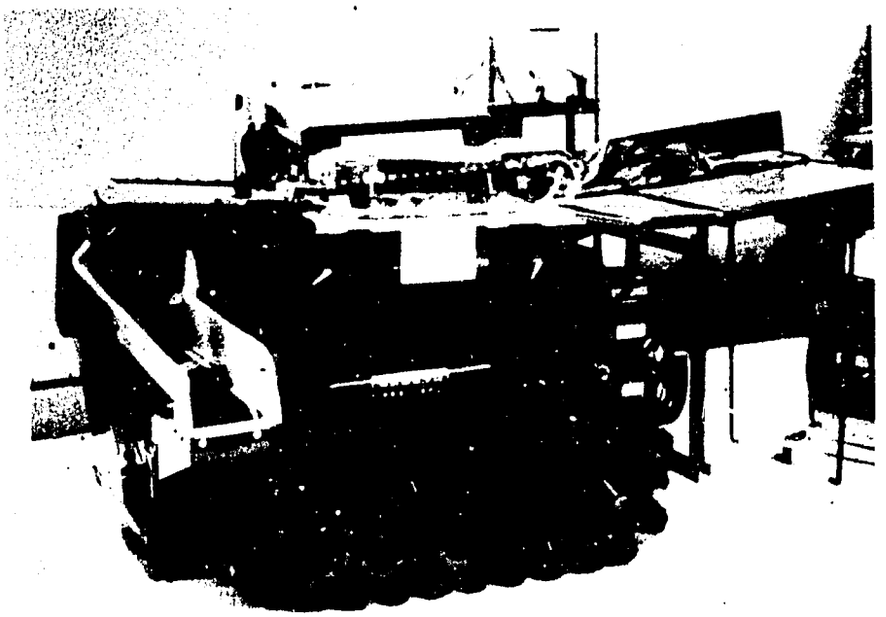

Fig. 17. Self-propelled Japanese field thresher with straw chopper.

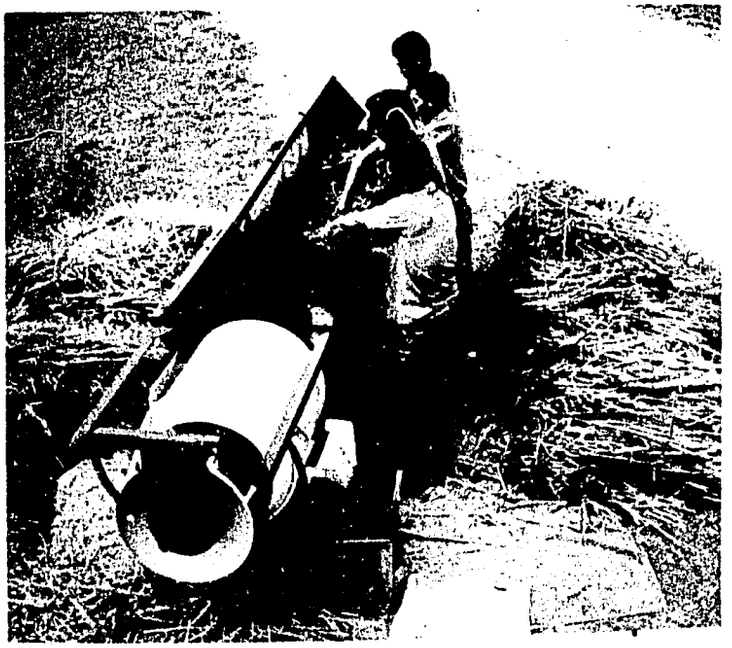

Fig. 18. IRRI drum thresher.

Fig. 19 IRRI table thresher.

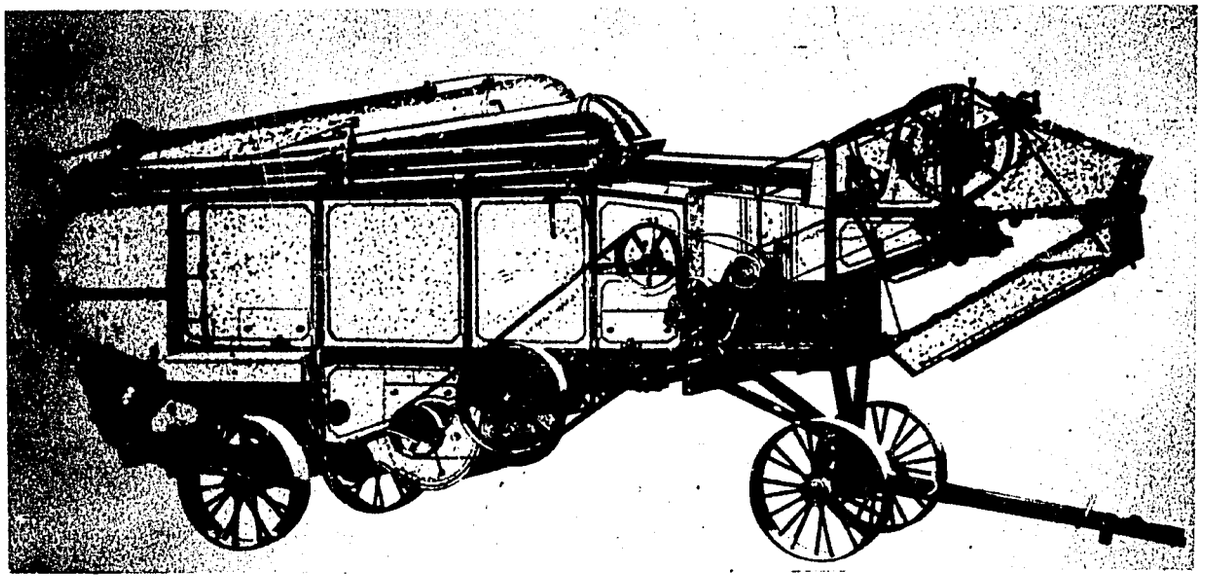

Fig. 20 Stationary through-flow thresher.

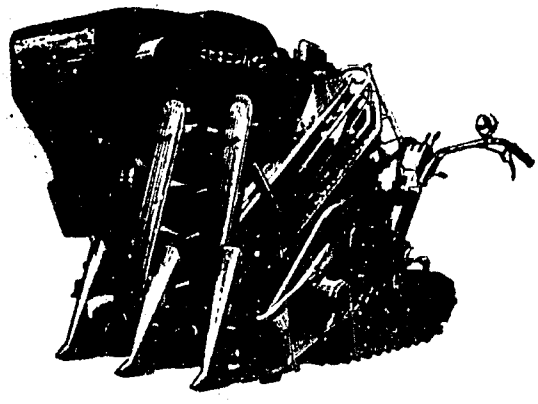

Fig. 21. Two-row Japanese head threshing type rice combine (Iseki).

Fig. 22. Four-row Japanese head threshing type rice combine (Kubota).

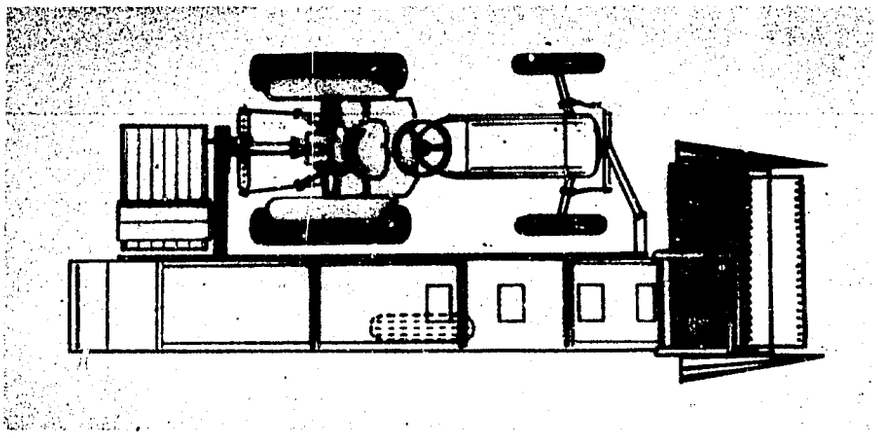

Fig. 23. European tractor-mounted through-flow type combine (Make JF).

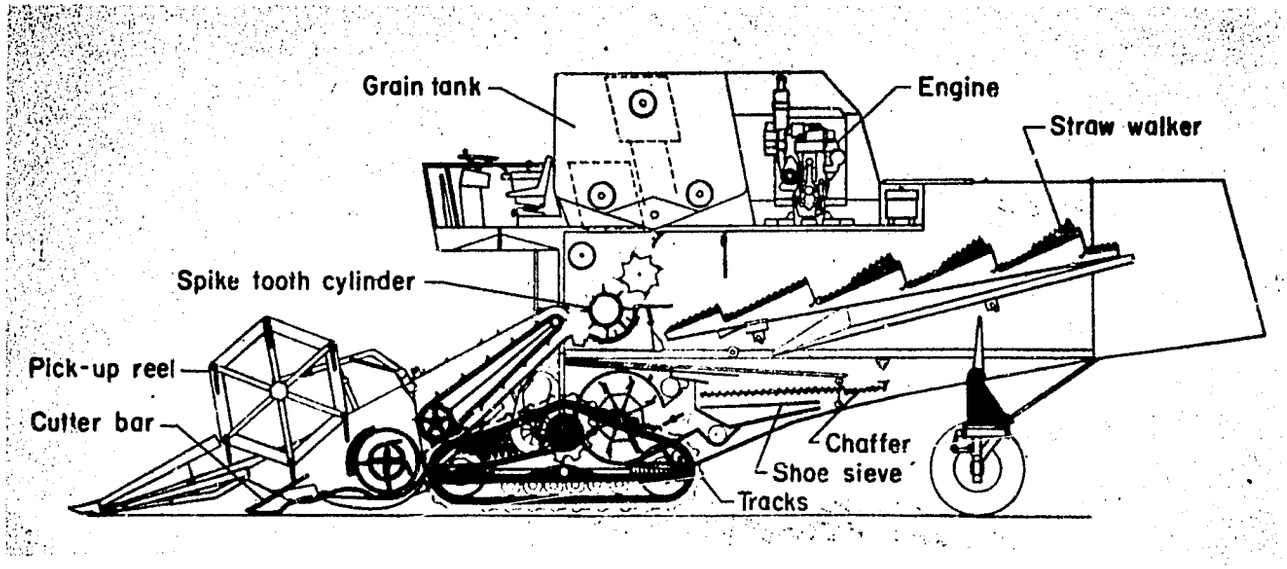

Fig. 24. Cross section of a standard self-propelled through-flow type rice combine.

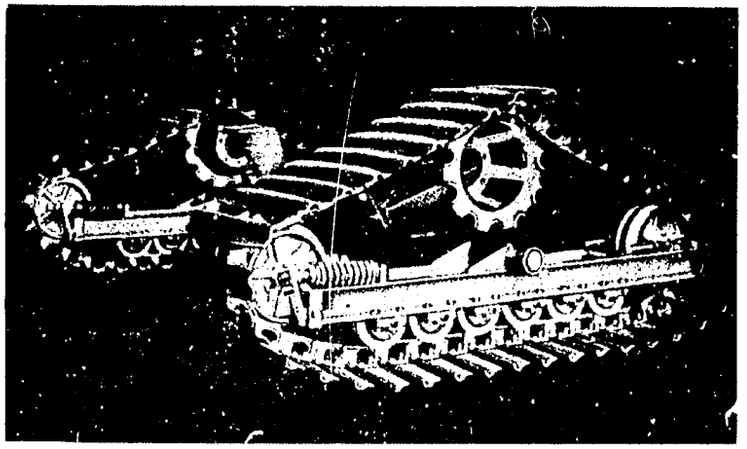

Fig. 25. Rice combine crawler tracks.

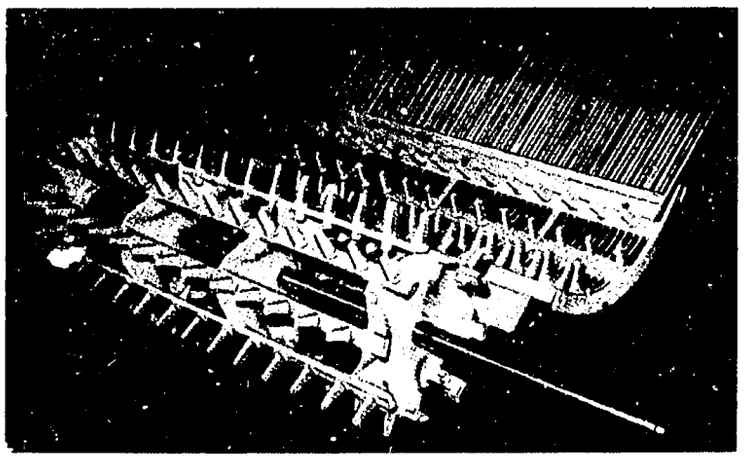

Fig. 26. Combine spike tooth cylinder and concave.

Fig. 27 Large through-flow rice combine (Kubota).

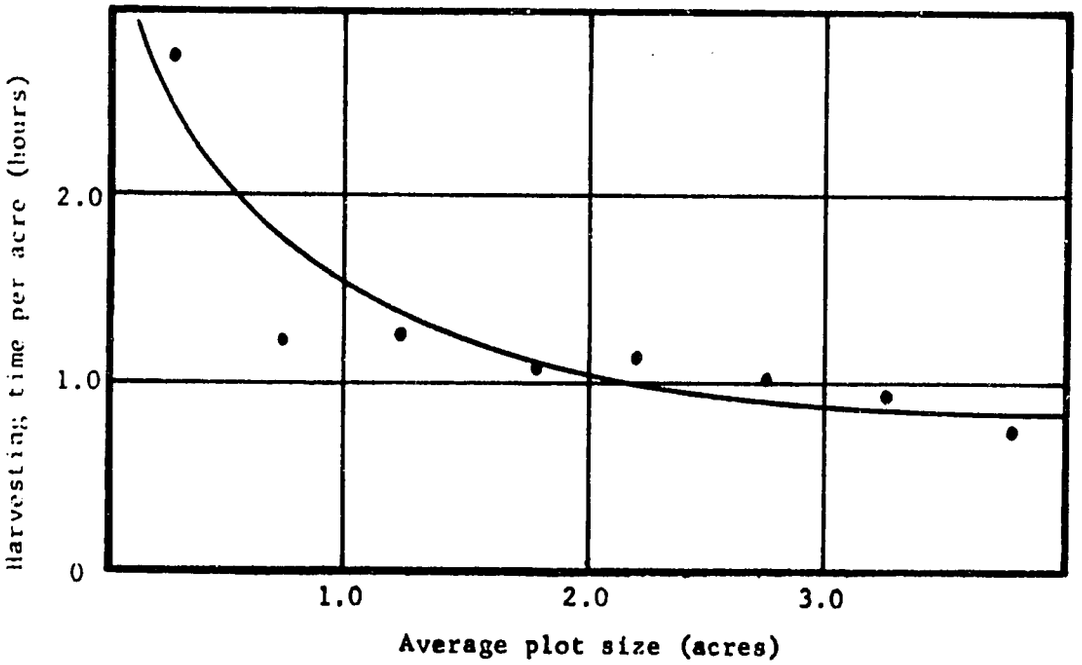

Fig. 28 Relationship between plot size and combine harvesting time (13-ft cutterbar combine). Source: Muda Agricultural Development Authority, Malaysia.

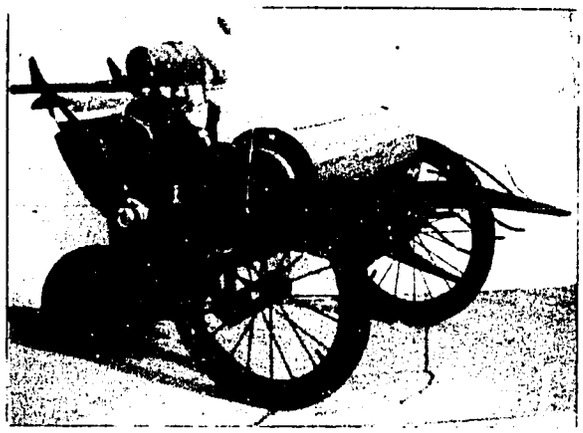

Fig. 29 Australian plot stripper.

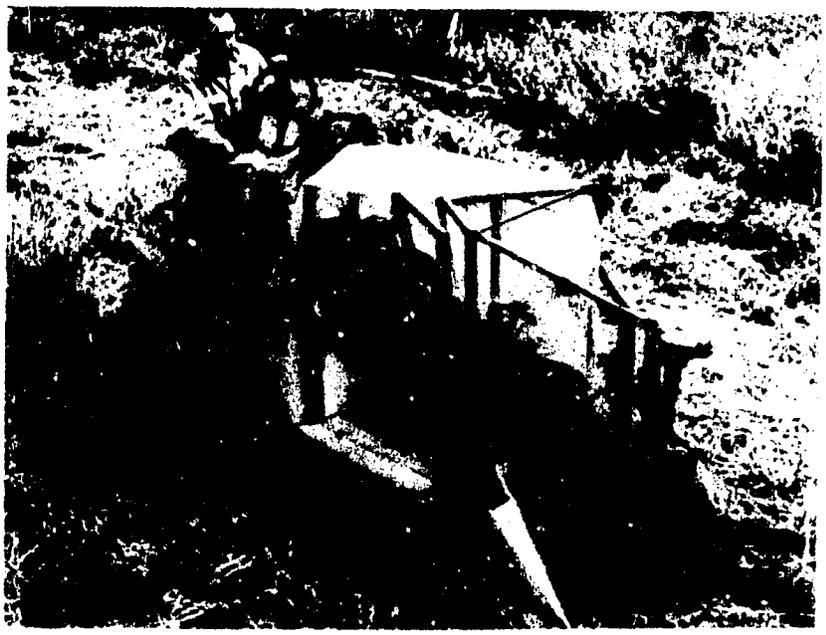

Fig. 30 Strohman stripper.

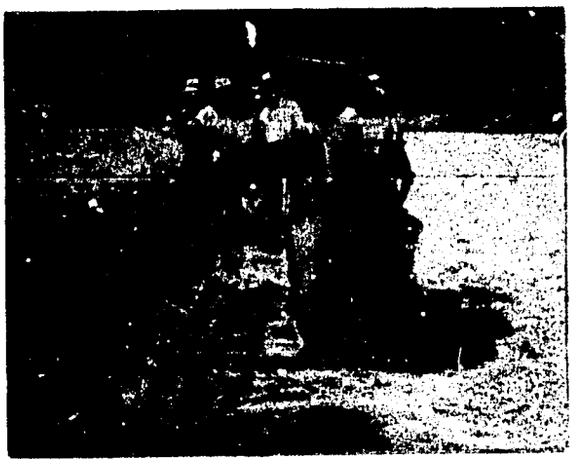

Fig. 31 Japanese experimental stripper harvester.

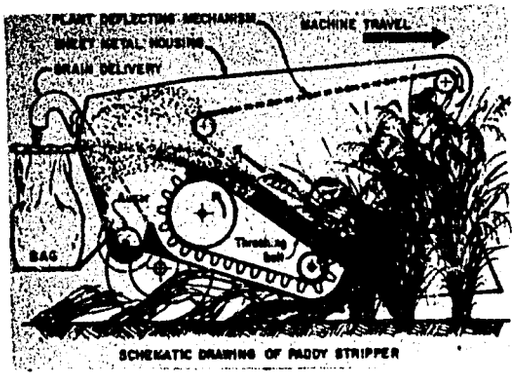

Fig. 32 Schematic drawing of the IRRI experimental stripper-harvester.

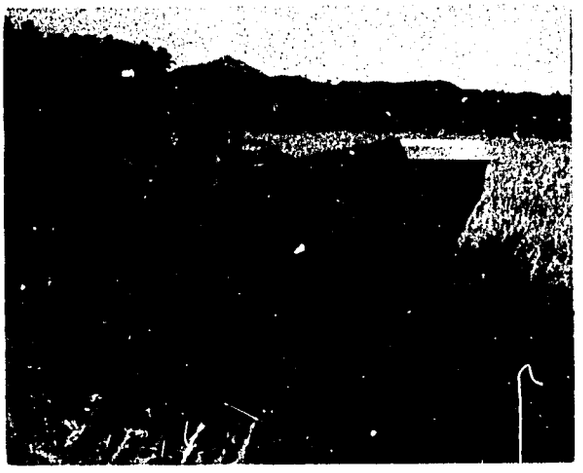

Fig. 33 IRRI experimental stripper-harvester.

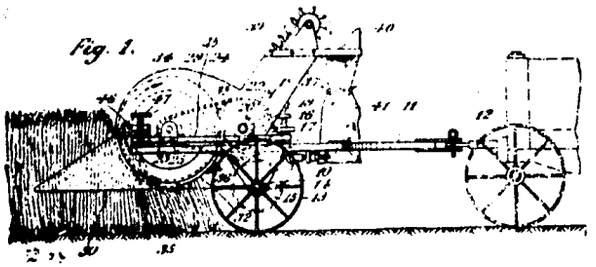

Fig. 34 Connell stripper-harvester.

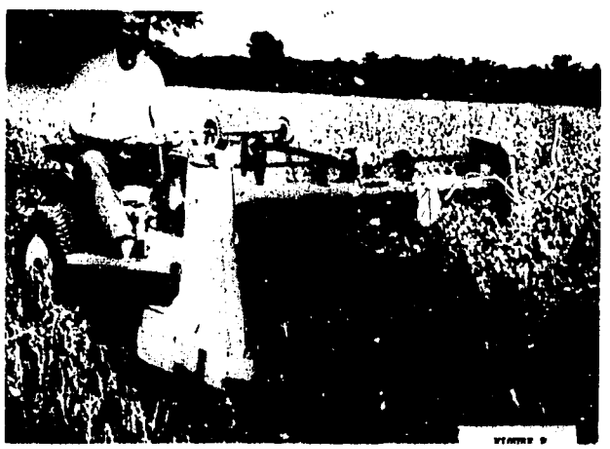

Fig. 35 U. S. experimental rice stripper using centrifugal force.

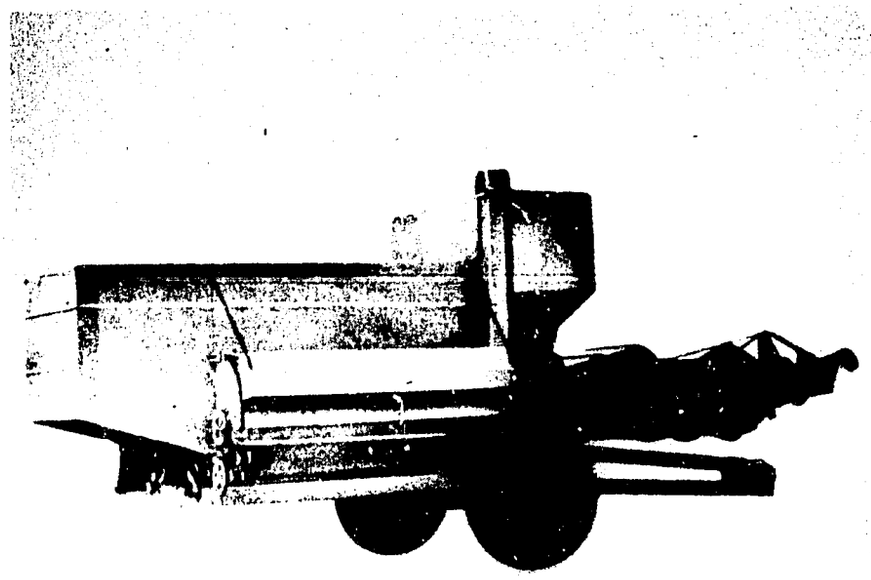

Fig. 36 Experimental combine using conventional threshing cylinder with a rotary cleaner.

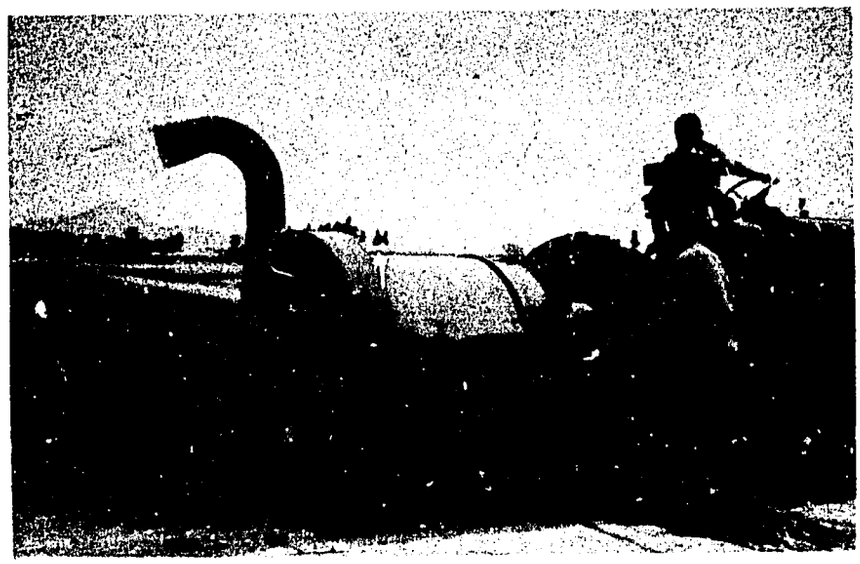

Fig. 37 Prototype tractor PTO-mounted thresher using a rotary cleaner (IRRI).