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MECHANIZATION TECHNOLOGY FOR TROPICAL AGRICULTURE

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Preamble

The agricultural revolution that is taking place in most developing countries calls for considerable changes in agricultural production technology. Phenomenal increases in crop yields, resulting from recent advances in seed-fertilizer technology, are increasing farm income and providing possibilities for greater agricultural mechanization. Because of the limitation of power, improved animal-drawn implements can only be of marginal benefit in the developing countries. Imported power-driven equipment from the advanced countries with different agro-climatic and socioeconomic conditions has many problems that limit their applicability. Lack of appropriate machines to mechanize tropical agriculture, within the framework of small farm holdings and low farm incomes, has seriously hampered agricultural development in tropical Asia. To mechanize tropical agriculture, a commensurate growth of the indigenous farm equipment industry is absolutely essential. Yet almost all efforts are geared towards the transfer of mechanization technologies from the industrially advanced countries without any consideration of the manufacturing capabilities of the developing countries. The development of demand-oriented farm equipment to suit local needs, manufacturing knowhow, and other factor endowments is a problem that the engineering communities must face squarely in the developing countries.

MECHANIZATION TECHNOLOGY FOR TROPICAL AGRICULTURE

Tropical regions are characterized by low farm income, small farm holdings, and low-cost labor. Many attempts have been made to mechanize tropical agriculture with equipment from the industrialized countries. Farm equipment from the advanced countries is basically developed for conditions of either large farm holdings and high labor costs such as in the United States, or for small farm holdings and high farm incomes as in Japan. Most imported farm equipment is not well suited for the agro-economic conditions prevailing in the developing countries. Consequently, mechanization of tropical agriculture has been slow and is limited mostly to the larger farm holdings which constitute an insignificant part of the total agricultural land.

Due to the lack of modern farm equipment for individual ownership by small farmers, efforts have been made to introduce large imported equipment in the tropics through various forms of joint use. Such efforts have met with limited success mostly for the difficult operations of land preparation and harvesting. Chancellor (1970) studied the contract hire services in Malaysia and Thailand. His study indicates a rapidly increasing sales of small two-wheel power tillers in Malaysia even when large tractor hire services were economically available to the farmers. It seems that the desire to retain control of the

farm production operations and the prestige of ownership favors the use of small power tillers rather than hiring tractor contract services. This arrangement provides greater flexibility to the farmer for the tiller can be used for haulage and personal transport in addition to the cultural operations.

Small- and medium-sized farm holdings of 2 to 10 hectares constitute a large segment of the arable land in the tropics. It is ironic that with all our technological advances and new farm machinery developments, this large group of Asian farmers have little access to appropriate farm equipment. If mechanization is to be successful in the tropical region, it must be introduced on the small farm and should be considered in this particular frame of reference.

Two technologies

It has been argued that a wide range of farm equipment is readily available from the industrialized countries and that the problems of tropical agricultural mechanization lies primarily in the proper selection of farm equipment. A closer analysis reveals that such an assumption is based on operational considerations only and fails to recognize the other important aspects which have a bearing on the mechanization issue. These aspects are the economic, sociological, and cultural needs of the farmer, lack of foreign exchange to import equipment, the level of local manufacturing knowhow, and the compatibility of the imported technology with the resource endowments of the country.

Two distinct agricultural mechanization technologies have evolved to suit different sets of agricultural and socioeconomic conditions in the world. The western approach emphasizes dryland farming with large, high-powered equipment. This capital-intensive technology has evolved from a primary emphasis on replacing human labor with machines. Introduction of such a technology in the developing countries tends to create labor surpluses and is not so desirable in the populated tropical Asian region. Many attempts have been made to introduce this technology in the developing world. Nearly thirty years of efforts to introduce such a technology has, however, produced rather insignificant results. In India, where tractors of over 35 hp are being introduced since the end of World War II, only one percent of the total arable land is worked with such tractors today.

Mechanization in Japan has not followed the western approach. Rice is a major crop in Japan which is grown on small farm holdings under wetland conditions. The high price support for rice, coupled with the country's rapid industrial growth and a rising standard of living, has resulted in the mechanization of agriculture with relatively low-powered yet quite sophisticated farm machines. This equipment has been developed to meet the requirements of the Japanese farmer and is far too complex and uneconomic for tropical Asia. Recently introduced Japanese combine harvesters and paddy transplanters are excellent examples of functionally suited but economically unacceptable machines for the tropical regions.

Developments in the industrialized countries are further widening the gap between the capabilities of their mechanization technologies and the needs of the farmers in the developing countries. In the western countries, there is a trend towards higher-powered machines with sophisticated control systems. To some extent, developments in Japan are following a similar trend along with an ever-increasing complexity of their machines. These developments are making it increasingly difficult to introduce imported agricultural machines in the developing regions.

In addition to their complexity, farm equipment in the developed countries is designed for manufacture with capital-intensive production methods to minimize labor inputs. Production technology to manufacture such designs is not readily available in the developing countries. The design of a machine is intimately related to the production process and this severely restricts the production of imported farm machinery designs in the developing countries. Unless appropriate farm machines are designed to suit the available low-volume production technology in the LDC, production of low-cost machines would not be possible and mechanization will continue to be a luxury which only the rich farmers can afford.

The selling price of imported farm equipment in the developing countries is approximately two to four times its price in the country of its origin. Furthermore, this expensive equipment must compete with low-cost local labor. Thus, the economic yardsticks on which the farm machine is originally based are no longer present in the developing countries. Most developing countries are undergoing varying degrees of balance-of-payment problems. Even a simple calculation indicates that large-scale importation of equipment to mechanize tropical agriculture is not the solution because foreign exchange shortage will not permit such a possibility in most developing countries. This dilemma can be solved through the development of appropriate agricultural machines which are in line with the needs of both the farmers and the manufacturers in the developing countries.

With the introduction of new varieties, problems of drying and processing have assumed new proportions. Technology for drying and processing of crops in large central plants is available from the industrialized countries. The establishment of such plants, however, requires a well developed infrastructure which is usually lacking in the tropics. The development of small, economically viable drying and processing systems for village or farm level operations is an urgent problem in the developing countries.

The author believes that the slow pace of agricultural mechanization in the tropical regions is due to the inadequacy of the available mechanization technologies to meet the overall requirements of the small farmers in the tropics. It seems reasonable to contend that the tropical regions must develop their own mechanization technologies to suit their agricultural, economic, social, and industrial conditions. A closer analysis reveals an urgent need for suitable equipment for almost every farm operation in the developing countries.

Developing new equipment

Development of new equipment is a specialized field which requires a high degree of technical expertise. In the advanced countries, machinery development is primarily an industry function. Because of the struggling state of the local farm equipment industry in the developing countries, equipment development is non-existent today. Manufacturers in the industrialized countries have the resources to develop new farm equipment, however, they do not find it attractive to do so for the tropical countries. Understandably, their strategy has been to develop new equipment for the home markets and to later expand its sales in the tropical regions.

Quite often, a convincing argument is put forth by the manufacturers in the industrially advanced countries that sufficient demand does not exist to justify local production in the developing countries. There is no doubt that the economies of scale are important in the industrialized countries where labor costs are quite high. Unfortunately, production planners tend to use the same yardsticks when considering production in the developing countries. Economical production can be organized in the developing countries with labor-intensive methods provided the machines are adequately designed for manufacture with such a production technology. The author has come across many interesting examples in the developing countries which substantiate this thesis.

Two rather interesting examples of economic low-volume production, the jeepney and the IRRI power tiller, are found in the Philippines. A major portion of the jeepney, a locally adapted version of the Jeep vehicle, is manufactured by numerous small fabricators all over the country (fig. 1). The complete body and all sheetmetal parts are made locally by many local shops in small towns. While the engines and transmissions are generally surplus units, many engine and transmission parts and other difficult components such as the chassis are produced by machine shops in the larger urban areas of the Philippines. The jeepneys are assembled by body building shops from components purchased from various indigenous sources. Due to the popularity of the jeepney, the country has developed a sizeable automotive component manufacturing industry. The jeepney is among the lowest-priced vehicles and is a prominent mode of private and public transport in the country.

The other case of economic low-volume production is the IRRI power tiller which is being produced by eight companies and is marketed for about half the price of comparable imported power tillers in the Philippines. The tiller design was started in late 1971 at The International Rice Research Institute in the Philippines with the specific objective of developing a simple machine that could be fabricated by small shops with standard machine shop equipment. Extensive use of readily available components such as motorcycle and automotive parts has been made to simplify manufacturers' procurement problems. Care was taken to limit the production operations to simple cutting, bending, welding, and machining operations. Standard motorcycle sprockets and roller chain transmissions were utilized in place of conventional gear transmission in its design to facilitate local fabrication.

The design was released in the Philippines to manufacturers in June 1972. By December 1972, two companies had achieved a combined monthly production of over 250 tillers. The eight companies that are currently manufacturing the IRRI tiller are expected to produce 7000 machines this year. This is approximately eight times the total number of all makes of power tillers imported annually in the country. Manufacture of the IRRI tiller has recently started in Sri Lanka, Vietnam, Thailand, and Korea. Because the tiller was developed to suit the low-volume production technology that was readily available in the developing countries, no new production equipment has been acquired by the manufacturers in the Philippines. The companies have hired nearly 700 new workers in the manufacturing operations (Table 1) and additional jobs have been created in the marketing and servicing functions all over the country. The capital needs to create a job has been about US$200 per job, which is much lower than the generally accepted figure of US$2,000 per job.

Another interesting example of appropriate product development in the Southeast Asian region is the case of the motorized lowlift pump (fig 2). This pump was developed by a farmer-mechanic in Vietnam. The first model was tested in December 1963 and by mid-1966, 600 pumps were sold. By mid-1967, the manufacturer was selling 200 pumps monthly. In less than four years after the development of the pump, nearly 43 percent of the farmers in the village owned such a pump (Sansom, 1969). Various versions of this lowlift pump are now manufactured in Vietnam, Thailand, and the Philippines.

A fourth interesting example is that of the Thai Heng Long Company, Ltd in Thailand, which is producing high-speed aircooled engines in Chachiengsao, a predominantly rural area of Thailand. The owner of the company is a highly innovative individual and he has adapted the engine design by incorporating ideas from many popular makes of imported engines. He then set about to develop simple production equipment for labor-intensive manufacture. This company now produces 1500 engines a month in the 10-, 15- and 20-hp size, with very simple, non-automatic production machines and has started to export the engines to neighboring Southeast Asian countries. This is an outstanding example where a highly complex machine is produced by simple production methods without any technical collaboration with manufacturers from the industrialized countries. In addition to these examples, one comes across many interesting cases of low-volume production of machine tools, diesel engines, pumps, and other machines in India and Pakistan.

These examples clearly indicate that economies of scale do not necessarily apply as effectively in the low-cost labor economies and should not be used blindly as an argument against local production in the developing countries. These examples prove that economic production of fairly complex machines is possible in the developing countries provided the product and production process are suitably adapted for low-volume production.

Many economists have understandably pointed to the dangers of displacing farm labor with machines. Unfortunately, such analyses are based on the amount of labor that would be normally displaced by the introduction of large,

high-powered agricultural machines. If appropriate mechanization technologies with small, individually owned farm equipment are considered, the outcome would not necessarily be so unfavorable. In addition, if the production of farm equipment is in the country, employment generated in the production, marketing, and servicing functions can be substantial. The case of Japan is of interest here for it has the most mechanized agriculture in the world (3 hp/ha). Yet among 11 Asian countries (Table 2), it has one of the highest labor input in rice production.

There is little doubt in my mind that the socioeconomic implications of agricultural mechanization will necessitate indigenous production of relatively simple, small, powered farm equipment in the developing countries. In order to maximize employment generation, it would be further necessary to produce such farm equipment in the small- and medium-scale industrial sectors through low-volume, labor-intensive production methods.

An indigenous industry

Agricultural mechanization and local production of farm equipment are so closely related that it is unrealistic to look at one and ignore the other. Yet, most national and international efforts are concerned primarily with the introduction of imported farm machines rather than the development of appropriate indigenous mechanization technologies. The establishment of a strong farm equipment industry is a prerequisite for agricultural mechanization. The availability of appropriate farm machinery designs will play a significant part in the establishment of a viable farm equipment industry.

The limited new machinery developments that have occurred in the developing countries have been due to the efforts of local mechanics and entrepreneurs who have no formal engineering training on the development of new equipment. The academically trained engineering community in the developing countries has failed to provide the much needed leadership in the product development field. Yet opportunities for the development of appropriate machines that would be compatible with local manufacturing technology are immense in the region. It is unfortunate that the public sector engineering institutions are concerned more with research for knowledge rather than commercial type R&D activities. Machinery development is an important link between engineering research in the laboratories and agricultural mechanization in the farmers' fields. Yet it receives little attention in the developing countries. Since the farm equipment industry is not in a position to support R&D, publicly supported research institutions must focus their attention on this activity rather than engineering research.

IRRI machinery development program

In 1967, the Agricultural Engineering Department of The International Rice Research Institute started a program in the Philippines to develop low-cost small, power-operated machines for manufacture in Asia. Under this program, the

Institute has developed a broad range of farm equipment (figs. 3-11), many of which are now manufactured in the region (Table 1). Engineering drawings and other technical assistance is provided under this program to interested manufacturers in the developing countries. In a relatively short period of a few years, the program has achieved a high degree of commercial acceptance and is rapidly producing practical results in the farmers' fields. The Institute is now in the process of developing an intensive industrial extension program that will introduce the IRRI designs to manufacturers in most tropical countries where rice is a major crop.

Table 1. IRRI agricultural machinery development project, June 30, 1974.

	Asian manufacturers reporting										
	1	2	3	4	5	6	7	8	9	10	Total
1. No. of machines manufactured till June 30/74:											
Power tiller	3,900	11	1,234	7	457	-	-	-	-	-	5,609
Batch dryer	-	-	-	35	-	-	-	4	-	74	-	113
Axial flow thresher	20	-	2	8	20	60	9	9	-	-	108
Table thresher	-	-	-	-	84	-	-	-	-	-	84
Grain cleaner	-	-	-	20	-	-	-	-	-	-	20
Bellows pump	-	-	-	100	-	-	-	-	-	-	100
Multihopper seeder	-	-	-	232	-	-	-	-	-	-	232
Single-hopper seeder	-	-	-	338	-	-	-	-	-	-	338
Power weeder	-	-	-	-	-	-	-	-	-	7,500	7,500
2. Production capacity utilization (%):											
Current	85	NR*	50	95	75	70	100	NR	95	NR	
Before start of IRRI machines	70	NR	20	90	45	50	75	NR	90	NR	
Percent change	15	NR	30	5	30	20	25	NR	5	NR	
3. No. of new workers employed	399	4	90	65	42	18	12	5	45	NR	680
4. Additional capital investment (US$)	76,000	NR	120,000	10,000	8,300	1,400	12,000	1,500	3,800	NR	233,000
5. Additional capital investment per worker (US$)	199	NR	1,330	154	197	78	1,000	300	84	NR	330

NR* = Not reported by manufacturer.
US$1 = ₱6.60.

These manufacturers have received engineering drawings and technical assistance from the IRRI project. However, additional manufacturers are now producing IRRI or similar machines by indirectly acquiring the designs for which no data have been collected.

Prototype units of some IRRI machines have been fabricated by manufacturers in Indonesia, Korea, Pakistan, Sri Lanka, Thailand, and Vietnam. Commercial production has started in some of these countries. A total of 11 Asian engineers have received short-term training under this program.

Table 2. Some agricultural mechanization indicators for 11 rice-producing countries in Asia.

Country	Arable land per holding (ha)	Agricultural working population/ha	Horsepower per hectare				Hp per agricultural worker	Labor hours for rice cultivation/ha	Net domestic agricultural production US$	
			Human	Animal	Mechanical	Total			Per person	Per hectare
Ceylon	1.59	1.20	0.120	0.148	0.110	0.378	0.009	N.A.	293	352
Taiwan	1.11	1.95	0.195	0.164	0.164	0.505	0.074	1300	349	696
India	2.62	0.90	0.90	0.204	0.008	0.249	0.009	1000	148	133
Iran	6.17	0.37	0.37	0.048	0.154	0.292	0.418	N.A.	417	154
Japan	1.06	2.16	0.216	0.120	2.664	3.00	1.231	1400	626	1350
Korea	0.90	1.96	0.196	0.236	0.003	0.435	0.0013	830	244	477
Nepal	1.22	2.49	0.249	0.480	0.004	0.733	0.0016	N.A.	99	236
Pakistan	2.37	1.09	0.109	0.288	0.013	0.410	0.012	N.A.	154	169
Philippines	3.66	0.71	0.071	0.104	0.023	0.198	0.030	800	242	186
Thailand	3.64	1.10	0.110	0.184	0.054	0.348	0.050	N.A.	102	112
Vietnam	1.57	2.10	0.210	0.244	0.023	0.477	0.004	N.A.	203	421

Source: APO Expert Group Meeting on Agricultural Mechanization, APO Project SYP/III/67, Tokyo, October 1968, Vol. II.

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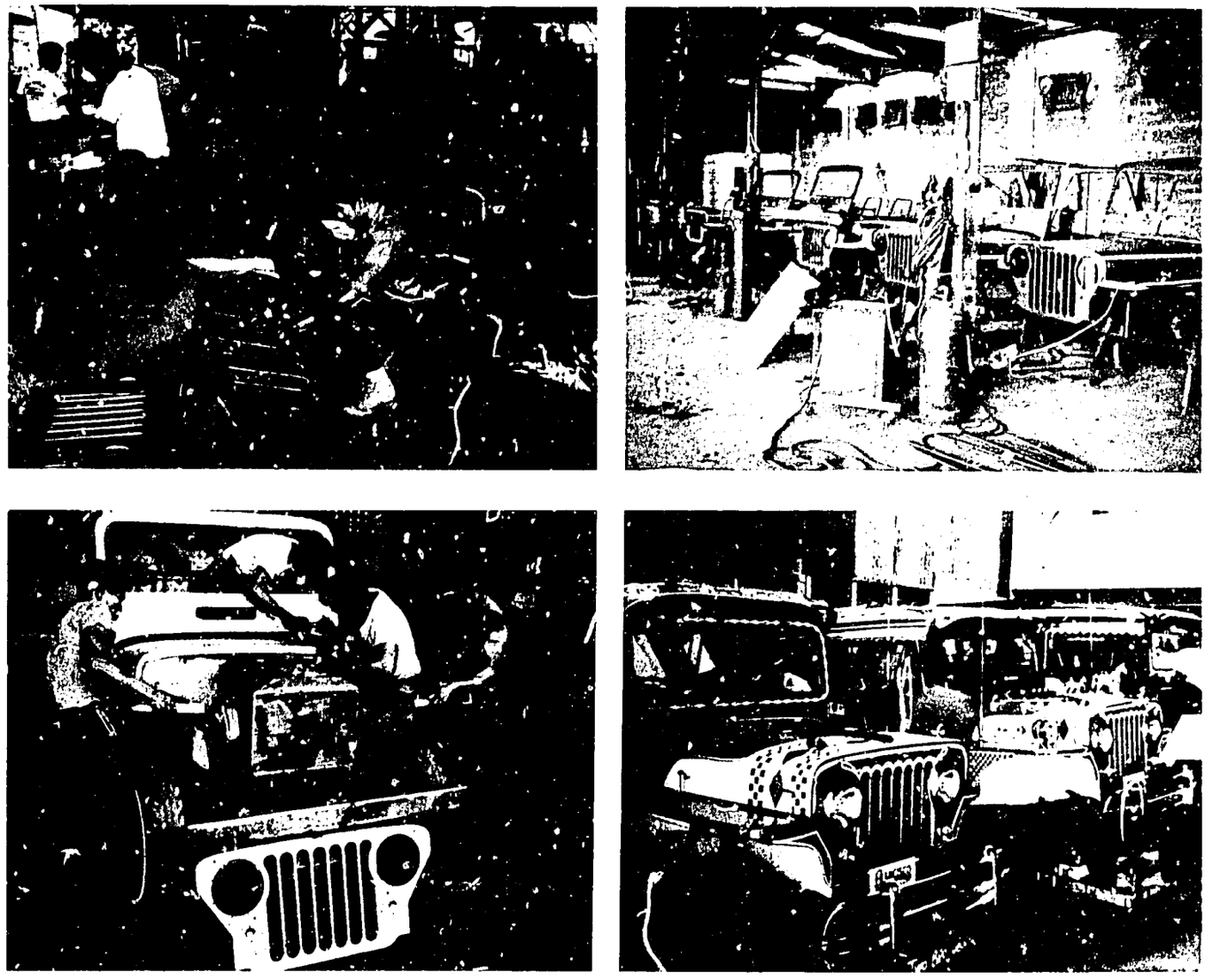

Fig. 1 JEEPNEY FABRICATION: The jeepney, a locally adapted version of the Jeep, is assembled in the Philippines by small shops all over the country. The complete body, chassis, wheels, and many complex steering, engine and transmission components are locally produced by numerous companies.

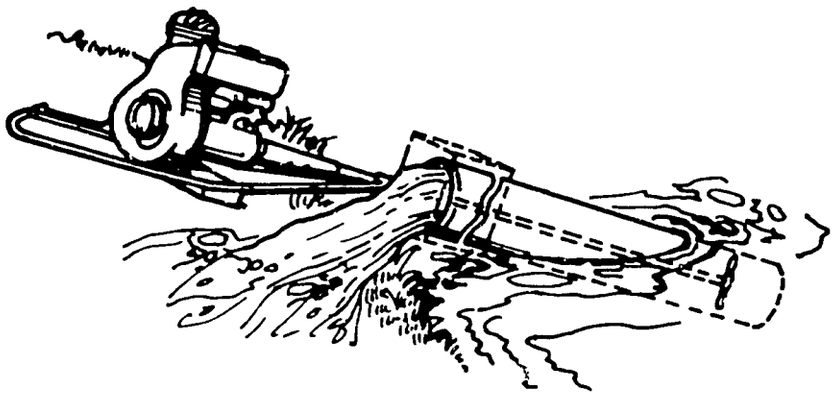

Fig. 2 VIETNAMESE MOTORIZED LOWLIFT PUMP: Various versions of this pump developed by a Vietnamese farmer-mechanic are now in production in many Southeast Asian countries.

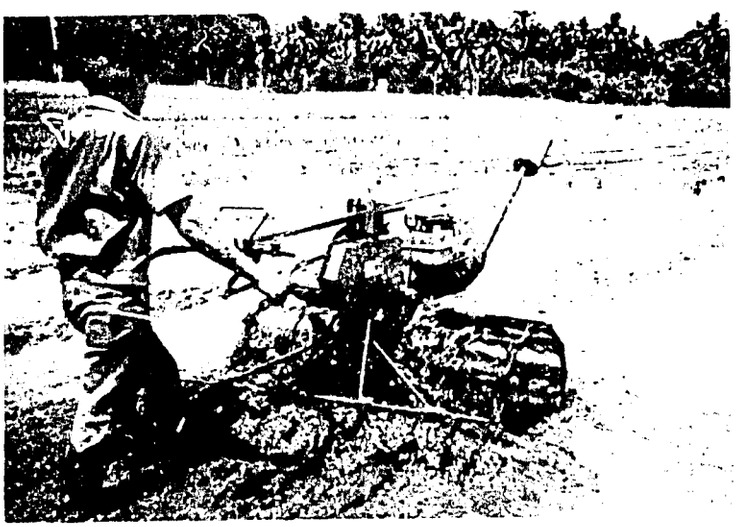

Fig. 3 IRRI 5-7 HP TILLER: Developed for easy operation and fabrication by small manufacturers with readily available materials and components in the developing countries, the machine can be employed for plowing, puddling, pumping water, and transportation. Nearly 7000 of these tillers are being produced in the Philippines this year. It is sold for approximately one-half the price of comparable imported machines. Local production has also started in Thailand, Sri Lanka, Vietnam, and Korea.

Fig. 4 IRRI 7.5 HP TILLER: Prototype power tiller with 8-12 hp diesel engine and standard three-speed automobile transmission. This tiller has the same features found in the larger Japanese machine but can be easily manufactured by small machine shops in the developing countries with available production technology.

Fig. 5 IRRI MULTIHOPPER SEEDER: This machine is for seeding pregerminated paddy. It meters paddy seeds without damaging the shoots and places them in rows in puddled lowland fields. The machine has six seed-metering hoppers mounted on a low-profile skid with a handle bar assembly. One man can plant 1 hectare in approximately 8 hours. It is commercially produced in the Philippines.

Fig. 6 IRRI POWER-DRIVEN ROTARY WEEDER: One man using the three-row power weeder can cover 1 hectare in approximately 20 hours. Using a 1 hp two-stroke engine in conjunction with a worm gear drive and a reduction system, the machine has found wide application in Japan where 7000 machines have been produced and sold.

Fig. 7 IRRI MULTICROP AXIAL FLOW THRESHER: With an output of 1 ton of grain per hour, this throw-in type thresher employs axial movement of materials around a threshing drum to thresh and clean rice and other small grains. Powered by a 7 hp engine and operated by three men, the machine is highly mobile and easily maintained. Eight companies have started production in the Philippines. Manufacturers in Pakistan, Vietnam, Thailand, Sri Lanka, and Korea have built their prototype machines and are planning local production soon.

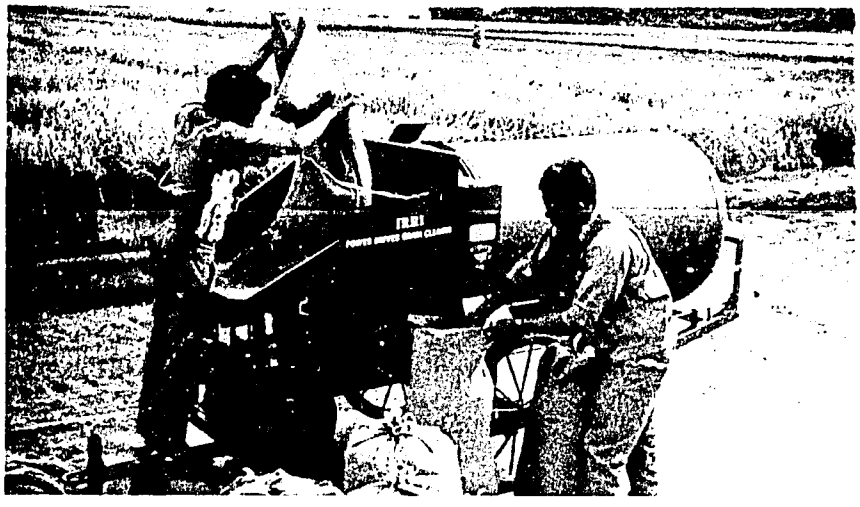

Fig. 8 IRRI ROTARY GRAIN CLEANER: Dirty grain is screened first for large and small impurities in two concentric rotary screens. The grain is then tumbled as it moves through a counterflow airstream to remove lighter impurities. Up to 3 tons per hour output has been obtained. The machine is commercially available in the Philippines.

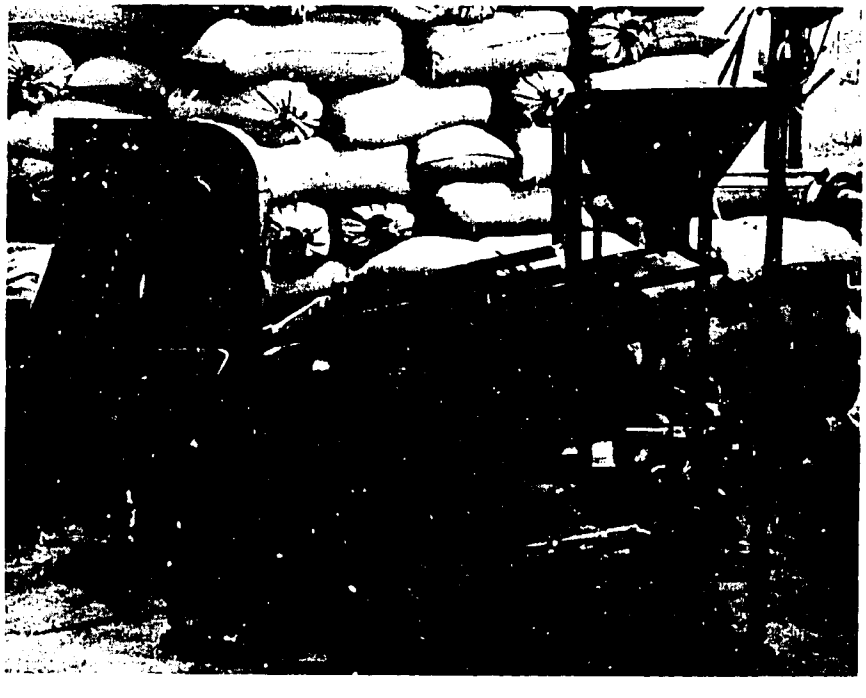

Fig. 9 OSCILLATING GRAIN CLEANER: Prototype grain cleaner with up to 2.5 tons per hour grain cleaning capacity. It has replaceable double screens for multicrop operation.

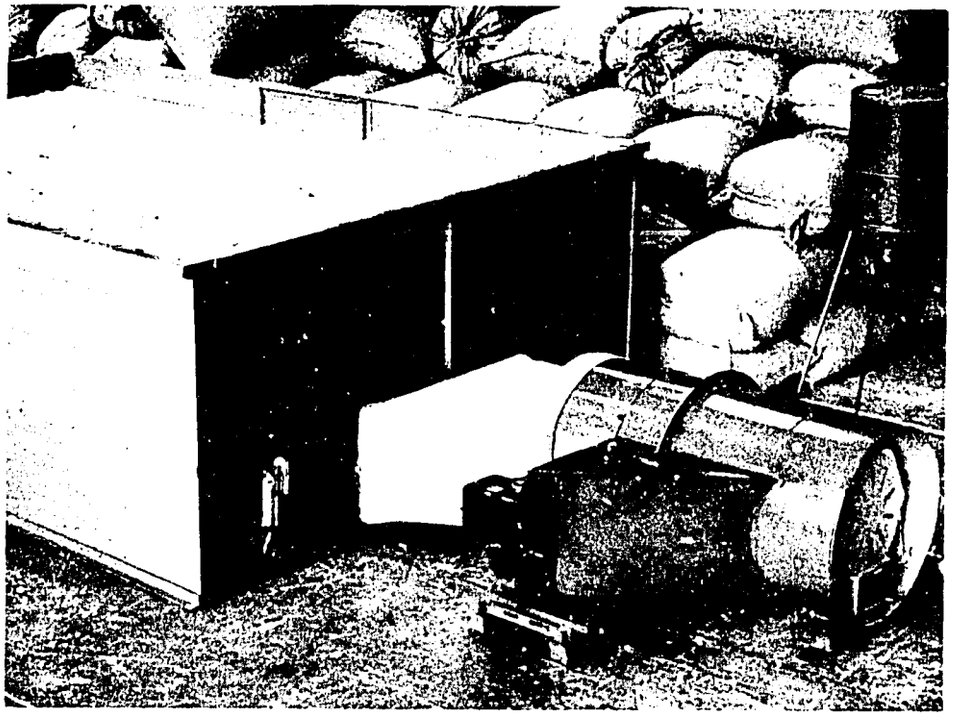

Fig. 10 IRRI BATCH TYPE DRYER: Using either a kerosene burner or an alternate rice hull furnace, the machine can dry 1 ton of paddy every 6 hours. Suitable for manufacture in small shops, it has a safety fuel cutoff mechanism and is powered by a 3 hp gasoline engine. It is locally manufactured in the Philippines.

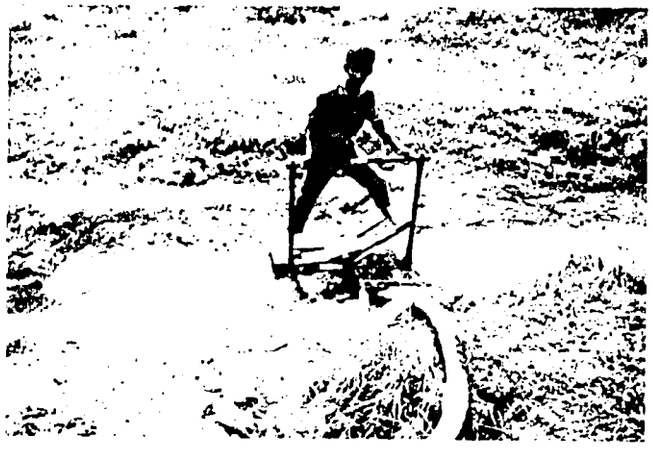

Fig. 11 IRRI LOWLIFT BELLOWS PUMP: This device is capable of lifting 180 liters of water per minute at 1.5-meter head. The pump employs two flexible bellows with flapper valves and the water is pumped as the operator transfers his weight from one foot to the other.