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Fig. 1 An 8.5 hp Japanese power tiller with wheels for paddy soils • Fig. 2 Two 36-hp tractors in tandem pulling a 4-m wide disc harrow

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Is Mechanization Possible Where Rice Is King?

By mechanizing farm operations in the tropics three crops could be harvested yearly — in place of the single crop now produced by hand labor. How are farm operations in the tropics best mechanized? How will mechanization affect the economy of these nations?

MOST tropical rice areas now grow only one crop per year — although two or three crops usually are possible. Lack of energy for fast harvest and to process, plow, replant, and water the second or third crops now limits production. Temperature and other factors in the tropics favor continuous growth. With adequate low-cost mechanical energy the farmer could earn more while selling his crop at a lower price. To date, however, little special agricultural equipment has been designed for the tropical, rice region.

In many developing countries the urban population is increasing faster than the available food supply (2) (5)*. Low-cost labor substitutes with continuous use of land resources could produce food for these growing urban populations.

The energy the rice farmer expends on his crop has little influence on the price he receives. He produces rice with many hours of low-wage labor and trades this for manufactured goods produced by a few hours of highly paid labor and many horsepower- or kilowatt-hours of low-cost energy. Thus, the rice farmer competes against low-cost machines. We must examine the cost of energy as well as its production efficiency. More efficient use of all energy promises a greater return than an increase in hours of low-cost labor (3).

*Numbers in parentheses refer to appended references.

In our preoccupation with labor, machines, varieties, fertilizers, irrigation, etc., we forget that 30 to 50 million kg-cal (kilogram calories) of free solar energy is available on every hectare every day in tropical areas. We must use this perennial supply of energy more efficiently throughout the year.

The rice plant uses but a fraction of the available solar energy to produce from 10 to 80 kg of palay (rough, or unhulled, rice) per hectare day. This yield of palay may be converted to white polished rice to supply man with 22,000 to 176,000 kg-cal per hectare per day. The man labor input in Asia ranges from 1 to 4 man-days per day per hectare, and these laborers use from 3000 to 10,000 kg-cal of food energy per hectare day. To man, the energy output as food is 7 to 58 times his own food energy requirements. This energy surplus maintains the family and other non-food producers as well as the farmer.

Table 1 lists the approximate value in the United States per million kg-cal of energy. Solar energy, electrical power, farm machinery, and animal power cost less than subsistence farm labor. Is the problem then that there is not enough land per capita when the land is producing only 150 days a year?

If the tropical rice farmer is to keep his land in continuous production, the mechanization of the tropical rice farm will require an increase in available horsepower and in the efficiency of farm machinery, with a decrease in the machine energy cost.

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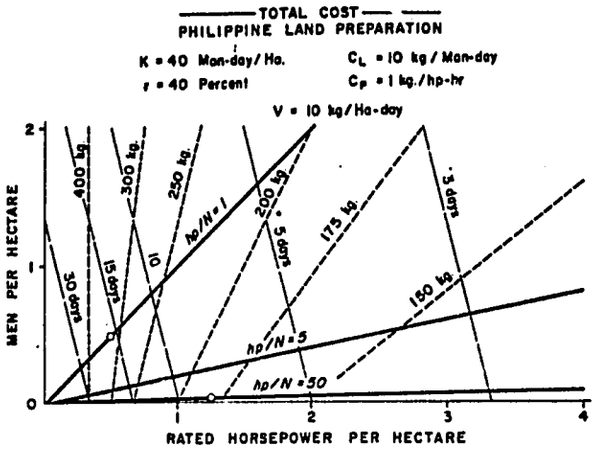

Fig. 3 Cost of land preparation in the Phillipines in Kilograms of rough rice

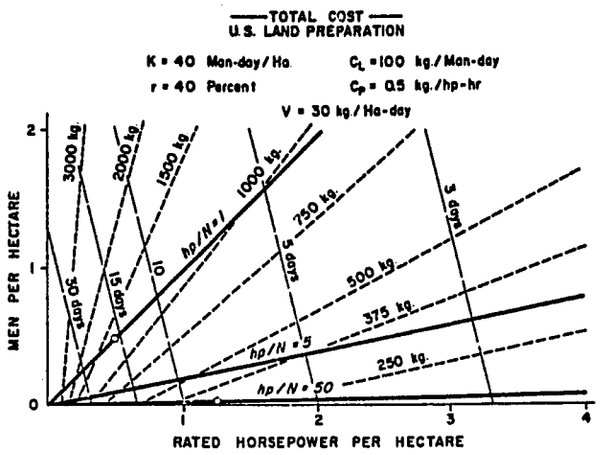

Fig. 4 Cost of land preparation in the United States in Kilograms of rough rice

What has discouraged major manufacturers from developing efficient equipment for the tropical rice-growing region? Common assumptions are that:

- Abundant low-wage labor is available most of the year. Labor-saving equipment would only increase unemployment and other social problems
- Farms are too small and the average per capita income too low to provide a substantial market for farm machinery
- Importation of farm equipment would create a balance-of-payments problem
- Research and extension efforts should be concentrated on small hand tools, animal tools, and cheap simple power equipment "that the farmer can afford"
- First priority should be given to training programs at the farmer's level to teach him to use available equipment.

These assumptions should be replaced by more realistic points of view:

TABLE 1. APPROXIMATE VALUE OF VARIOUS FORMS OF ENERGY IN U. S. DOLLARS PER MILLION KILOGRAM-CALORIES OF ENERGY*

Form of Energy	$-cost per million kg-cal
1. Sunlight on agricultural land 30 to 50 million kg-cal per day per hectare. Rental rate of $36.50 to $365.00 per year per hectare	$ 0.002 to $ 0.03
2. Palay based on a farm price of 3¢ to 12¢ per kilogram, a 60 percent milling recovery, and 3600 kg-cal of white rice.	14.00 to 56.00*
3. Man labor at wages of 18¢ to $9.00 per day and equivalent effective work of one-half to one hp-hr per day or 320.8 to 641.7 kg-cal per day.	281.00 to 280,000.00*
4. Animal labor at rental rate of 18¢ to $2.00 per day and work equivalent of 4 to 8 hp-hr, or 2566 to 5133 kg-cal per day. (Usually the rental rate for man and animal are the same per day.)	35.00 to 779.00
5. Tractors and farm machines at rental rate of 3¢ to 15¢ per hp-hr of 641.7 kg-cal when used 1000 hr per yr.	47.00 to 234.00
6. Electrical power at a cost of 1¢ to 10¢ per kwh of 860.5 kg-cal.	12.00 to 116.00

*A man can live and work for 286 to 625 days on one million kg-cal of food intake at 1600 to 3500 kg-cal per day. However, the same man would take 5 to 10 yr to deliver the equivalent energy in useful work with his own muscles.

- Labor or power shortages occur during harvest and land preparation periods. Unemployment or under-employment is at a peak during dry seasons when the farmer is idle, perhaps even leaving the land to work at other jobs. Low-cost power for irrigation, plowing, and harvesting of extra crops could provide additional rural income and employment
- There is a potential market for approximately 40 to 80 million rated horsepower in machines for rice production on the total land area of 78 million hectares. From 100 to 150 animal hours are required to prepare a hectare of land — about the same as to harvest crops. Approximately one rated horsepower per hectare is estimated as the power required for full land utilization. With continuous land use, potential production per hectare day could be 10 to 50 kg of palay — adequate to support the farmer and to pay for his new machinery
- Multiple cropping will reduce the land area devoted to rice and permit production of export crops at lower prices. The export earnings could pay for additional technical assistance and equipment
- Research and extension efforts should be concentrated on obtaining quality equipment to produce rice at

TABLE 2. SELECTED REGIONAL DATA* ON RICE AREA AND PRODUCTION 1960-61

	1000 acres	1000 Ha	1000 metric tons	Kg/Ha average	Kg/Ha† day
TEMPERATE REGION					
INDUSTRIAL COUNTRIES					
Japan	8,174	3,310.5	16,073.8		
United States	1,595	646.0	2,476.2		
Western Europe	688	278.6	1,292.0		
TOTAL	10,457	4,235.1	19,842.0	4,685	33.5
SUB-TROPICAL AND TROPICAL REGION					
Central America	490	198.4	247.5		
South America	9,642	3,905.0	7,039.0		
Africa	8,211	3,325.5	4,542.0		
South Asia[3]‡	173,947	70,448.5	111,679.8		
TOTAL	192,290	77,877.4	123,508.3	1,586	11.3
Non-Communist World					
TOTAL	211,614	85,703.7	149,953.0	1,750	12.5

*Data source: The Rice Journal (66: (9) 30-31, August 1963
†Author's computation based on a 140-day growing season.
‡Excluding Mainland China, Iran, Iraq, Turkey, Japan, Korea and Nepal, but including India and Pakistan.

the lowest cost. Priority should be at the design level rather than at the farm level

- Equipment properly designed for a specific task will decrease the problem of mechanical aptitude on the part of the operator. Lack of spare parts, inadequate design, and poor training are more significant than poor aptitude.

Here is one method of judging the relationship of equipment, land, and labor. Assume that any rice farm operation performed manually (Table 3) requires a fixed range of man-days per hectare, and that one 10-hr man-day is approximately equivalent to one rated horsepower-hour of energy. Since man guides his own energy, the animal or machine power efficiency rating must be reduced by a ratio depending upon the complexity of the work. The various labor and power cost factors may be combined with production losses from the idle land in calculating the efficiency of any particular farming system. These symbols and formulas are used:

A = Area of land to be handled as a unit in preparation, harvesting, etc. — in hectares (ha)

C_L = Daily wage of laborer or operator — in terms of rough rice of equivalent value, kg/man-day

C_p = Cost of hp-hr of machine energy — kg rough rice/hp-hr

D = Total unproductive or idle days. Usually less than 15 days are possible for each operation such as preparing the land, controlling weeds, or harvesting. Weed growth, drying, and shattering of grain may otherwise nullify the operation or cause excessive losses. — Days

r = Efficiency of machinery as a fraction of man labor efficiency (Table 3)

K = Man-days (10 hr) per hectare (or other horsepower-hour substitute) necessary to perform an operation — man-days/ha (Table 3)

hp = Rated engine horsepower or animal units available per hectare of land — hp-hr/ha day (One rated horsepower-hour is assumed to be equal to 10 man-hours or 1 man-day. An animal hour considered equal to 1 hp-hr)

N = Number of men per hectare available for 10-hr workdays — Man-days/ha day

TABLE 3. TENTATIVE COEFFICIENTS FOR COMPUTING THE MAN-DAY OR HORSEPOWER HOURS PER HECTARE OF VARIOUS FARM OPERATIONS WHEN USED WITH DIFFERENT POWER UNITS

Description of operation	K Man-days or 100% Eff. hp-hr/ha	r Ratio Efficiency Percent Man-day/Machine RH_p-Hr
1. Plowing flooded soil	20.0 to 33.3	30 to 50
2. Harrowing	10.0 to 20.1	30 to 50
3. Transplanting rice	10.0 to 16.0	05 or less
4. Handweeding for 15-day period	15	?
5. Pump irrigation daily value	5 to 15	100 +
6. Cutting rice at harvest	7.0	60
7. Carrying and stacking at harvest	3.5	?
8. Threshing, winnowing, and and sacking palay from a stack	18.0	20 to 40
9. Using combine harvester which combines steps 6, 7 and 8	28.5	18 percent

V = Value of total production per hectare day — kg of rough rice/ha day
(Total production per day may be used as a preliminary estimate of lost production when land is idle)

$$D = K/[N + 10(r)\ \text{hp}]$$

$$\text{Total cost kg/ha} = D(V + C_L N + 10C_p \text{hp})$$

$$\frac{K(V + C_L N + 10C_p\ \text{hp})}{N + 10(r)\ \text{hp}} \quad . \ . \ . \ . \quad [1]$$

The total cost of performing any operation varies with the mixture of unit costs and amounts of land, labor, and machine time. Computations may be based on values of K and r for rice production (Table 3). These values are unpublished evaluations based on field tests and an extensive literature review at The International Rice Research Institute. Results were reduced to man-days and rated horsepower-hours per hectare. Farm operations require a relatively constant amount of power to complete. Man labor is important only when the job is complex, as in transplanting; when other forms of power are lacking, as in spading; or require control, as with a horse-drawn plow. Pumping, transporting, plowing and threshing are mainly power operations. One man can control one animal or a team, a 5-hp unit or a 50-hp unit. The combination of man labor and animal or mechanical energy changes the total cost and time to do a job without greatly changing the amount of energy used.

Equation 1 and Figs. 1 and 2 compare cost of preparing a hectare of land in the Philippines and in the United States. The lines indicating total cost in kilograms of palay converge on a common point $N = Vr/(C_p - C_L r)$, and $\text{hp} = V/(10\ r\ C_L - 10C_p)$. When $r < C_p/C_L$ the lowest cost is achieved by the addition of more power. When $r < C_p/C_L$ the lowest cost is achieved by adding more men. In all cases, the cost is lowered by rapid completion of the operation.

The addition of more horsepower in relation to men obviously requires a change in equipment size. When manual labor alone is used, the total cost will be at the value N on the Y-axis. When one man is used in combination with one animal the total cost values will be along the line $\text{hp}/N = 1$. When a 5-hp Japanese tiller is used, the total cost will be on the line $\text{hp}/N = 5$. The U. S. farmer with a 50-hp tractor has a value $\text{hp}/N = 50$. *Example*: From Fig. 3, the Philippine cost of land preparation at present would be on line $\text{hp}/N = 1$. One man and one animal farm 2 hectares, so that N and hp are 0.5. The present cost of land preparation is about 320 kg of palay if the land value $V = 10$ kg per day is used and only 160 kg of palay if based on $V = 0$ kg per day.

From Fig. 4 the U. S. cost of land preparation at present would be on line $\text{hp}/N = 50$. One man and a 50-hp tractor farm about 40 hectares of rice. The values are $N = 0.025$ and $\text{hp} = 1.25$. The cost would be about 310

TABLE 4. WAGES POSSIBLE TO CONTRACTOR OPERATOR IF LAND PREPARATION IS VALUED AT 160 KILOGRAMS OF RICE PER HECTARE, $K = 40$, $r = 40$, $K = 40$, $r = 40$, $C = 1.0$, $V = 0$

	C_L kg palay/man-day	Rh_p/N

kg of Palay if the land value $V = 30$ kg per day is used and only 70 kg of palay if based on $V = 0$ kg per day.

In either case, the U. S. farmer has an economic advantage because of low-cost machine power. The Philippine rice farmer is able and willing to pay up to 160 kg per hectare for low-cost power. A contractor with an hp/N ratio of 5 or higher and an hp of 3 or greater would save the Philippine farmer money and keep his land in production longer. There are two important points to note: First, hp/N values can only change with the change in size of the power units; second, hp values change only as greater amounts of power are immediately available for smaller areas of land. The first point requires larger power units specially designed for wet land preparation. The second point requires contractor service to concentrate the power as needed for low-cost service.

The increase of specially designed 5 to 9-hp Japanese power tillers (Fig. 1) offers promise of lowering cost of land preparation if the unit is used on a contractor basis for over 1000 hr per year. Larger articulated four-wheel drive units such as the experimental 72-hp tandem tractor (Fig. 2) should prove even more attractive to contractors. Table 4 shows how the contractor operator's earnings or wages per day should increase with the size of unit when conditions permit the efficient use of larger machines.

Contractor work with efficient machines can make best use of the equipment to achieve a rapid return of land to production at the lowest cost. The contractors should be mechanically trained and be prepared to serve a wide area.

The farmer will stay on the farm as manager and to care for the growing crop, including the weeding, irrigation, fertilization, and pest control. The land will be in almost continuous production.

With more days of production per year to provide full-time employment of farm labor and the resulting stimulus to added productivity of the urban population, the standard of living should approach

$C_L = [(365 - \Sigma D)V - \Sigma\text{costs}]/(\text{Days work per year} \times N)$ with

$C_L = [365V - \Sigma\text{costs}]/300\,N$ as a limit.

Assume that one man farms 3 hectares, works 300 days, averages 40 kg of palay per hectare day and Σ costs are 4600 kg palay per hectare per year. The minimum wage could possibly approach

$$C_L = [365(40) - 4600]/300(0.333) = 100 \text{ kg/man day} \quad [2]$$

The potential 4600 kg palay per hectare for the sum of the other inputs indicates a market and means to pay for additional machinery, leasehold rent, fertilizer, insecticides, herbicides, and other expenses.

Machines for the Rice Farm

Manufacturers and designers should be aware of certain basic differences between the temperate dry land farm and the tropical rice farm:

- Rainy periods of 4 to 6 months are common, with rainfall of 10 to 20 in. per month and 15 to 25 rainy days per month. Dry cultivation is not possible during this period. Puddling of the soil is the accepted practice for land preparation and weed control
- The land preparation, harvesting, and other equipment must be mobile in wet soils with a cone penetrometer index of 20 to 30 psi at 12 in. (4).
- At the end of the rainy season, the soil is puddled. A long drying period would be necessary to use dry land preparation. Reflooding and repuddling is the most rapid means of returning the land to rice production
- Power operations in developed countries are justified by the high cost of C_L which will permit a low value r. The present problem in the underdeveloped countries is to obtain higher values of r by better design so that equipment may be used for power operations. To be economical the machine-to-labor efficiency ratio (r) must be higher than C_p/C_L. The addition of power when $r > C_p/C_L$ will then permit additional production to raise the value C_L and the standard of living
- Small farms cannot use the equipment enough hours per year to justify purchase; however, in the tropics contractors may use the equipment in excess of 1000 hr per year to obtain low costs
- Productive capacity, available spare parts, and durability are prime considerations for contractor equipment. Low cost per unit of work performed should be more important than low original cost

Many developing countries have a bewildering choice of equipment from around the world. Confusion is caused by the excessive variety of equipment, the rapid change in models, the lack of dealers and spare parts in agricultural areas, the high import duties or mark-up, and the shortage of foreign exchange. Farm equipment users would benefit from fewer models, standard parts, local production, and local dealers in all agricultural areas.

The major manufacturers who will design for the market and help develop local production will have access to a high-volume market. The foreign exchange to cover cost of license rights, special components, and remittance of profits can be more easily obtained than can currency for complete units. Competitive design and bidding might be the best method of alloting the market in the developing countries. The present practice of splitting the market and supplying available but unsuited equipment — even if given as foreign aid — can do more harm than good.

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