The Economics of Small Farm Mechanization in Asia**

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The special problems of mechanizing small farms is generally associated with the low investment capacity in this sector and the lack of equipment which is compatible with the technical and eccnomic requirements of small holdings. In many instances, however, it is not the lack of technology nor capital which retards use of mechanization, but the low return on investment and the lack of complementarity with other productive resources which has constrained adoption of mechanization. Schutz (1964) has noted that lack of profitable new investment possibilities is one of the major characteristics of traditional agriculture.

Data describing the social-economic and physical environments in the developing countries of Asia reveals that many types of mechanization are not profitable under prevailing condition of farm size, tenancy and output levels. In addition, in many instances there is evidence that mechanization occurred, particularly tractorization, as a result of economic policies which have distorted relative wagecapital prices, exchange rates and output prices, usually to the disadvantage of small-farmers.

In this brief paper, I will attempt to answer five basic questions relating to the use of mechanization on small farms: 1) At what point in development does a country need mechanization? 2) How do we define the size, magnitude and characteristics of the small-farm mechanization issue? 3) What types of machinery are needed on small farms? 4) What are the alternative institutional arrangements for mechanizing small farms? 5) What policies can be employed to ensure the optimal choice in both the technique and the sequence of adoption.

AGRICULTURAL TRANSFORMATION

A fundamental question is how to properly identify and measure the effects of mechanization on output. To provide a conceptual framework within which to examine this issue, we developed a simple model which expresses output per man as the product of yield per unit of land and the land-man ratio.[1] The relationship is shown in the following identity:

$$(Y/L)_t=(Y/D)_t\times(D/L)_t$$

where Y refers to output, D is harvested acreage and L is that portion of the labor force employed in agriculture. By using this model, technological innovations are grouped into two broad areas, those which are land-augmenting (such as higher yielding varieties) and those which are labor displacing (such as tractors). In the event a labor displacing technique is introduced, its impact on average labor productivity will be felt through an increase in land-man ratio with a corresponding increase in labor productivity. Land-augmenting technologies will raise average labor productivity through increased

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yields per unit of land.

Unfortunately, it is nearly impossible to consider the effects of either type of tachnological change as completely independent. In agriculture, the nature of the relationships between labor-saving and land-augmenting technologies is not always clear: there do appear to be significant interactions. It is possible to demonstrate overall changes in average labor productivity resulting from the combined interactions from changes in the two ratios as follows:

$$\text{let } X-(Y/L),\ Y-(Y/D), \text{ and } X-(D/L) \text{ or } x=Y\cdot z$$

differerentiating the expression with respect to time gives the rate of change of output per unit of labor as the sum of the relative rates of change in yleld per acre and the lana-man ratio:

$$\frac{\delta}{\delta_t}(Y/L)/(Y/L)=\frac{\delta}{\delta_t}(Y/D)/(Y/D)+\frac{\delta}{\delta_t}(\mathrm{D/L})/(D/L)$$

The expression then permits derivation of the possible impact of technological innovation on average labor productivity from alternative combinations of rates of changes in yield and the land-man ratio.

Examples of the inferences which can be drawn from the expression follow:

1. If the number of persons engaged in agricultural production is increasing and harvested area is constant, average labor productivity can increase only with increases in yield.
2. If the agriultural labor force is increasing and harvested area is also increasing, average labor productivity can rise if the land-man ratio increases, provided yields do not fall.
3. If the number of workers in agriculture is falling and land under cultivation is increasing, average labor productivation is increasing, average labor productivity can increase even though there may be a decrease in yield.
4. If labor engaged in agriculture is declining and total harvested area is also declining, total agricultural production can only increase with an increase in yields.

The identity thus provides a simple means for assessing the possible implications of two types of technological change on labor productivity and total output in agriculture--land-augmenting (yield increasing) as embodied in the improved rice varieties, fertilizer and irrigation development and labor-saving, such as found in tractors, power tillers and transplanting equipment. In general terms, we would expect use of output increasing innovations under conditions of both increasing and decreasing land-man ratios while labor-saving innovations would normally be used only when the land-man ratio is rising.

Many mechanical innovations have differential effects on yields and the land-man ratio. The net result may be an increase, decrease or no change in labor productivity and/or total agricultural output. A major difficulty in analyzing the impact of mechanization is partitioning effects into a) changes in yield (increased biological yield or reduced losses), b) changes in cultivated area, c) changes in cropping intensity, d) changes in production costs (reductions in labor and animal costs) or, e) changes in the value of the crop (improvements in quality or cropping pattern changes).

Examinations of Figures 1 and 2 indicates the transformation paths followed by Taiwan and the Philippines. There are similarities in the sequence with which each of these countries used available land, labor and capital resources to increase agricultural output. Initially, both used more land (increased the land/labor ratio), In recent years, however, the lack of land which can be developed at reasonable cost has forced planners in both of these countries to rely more on yield increasing innovations (Y/D) to sustain growth rates. Japan followed a similar trend during an earlier period. The degree to which a country uses innovations which augment available land or labor resources will be dependent on initial resource endowments and prevailing economic and institutional factors.

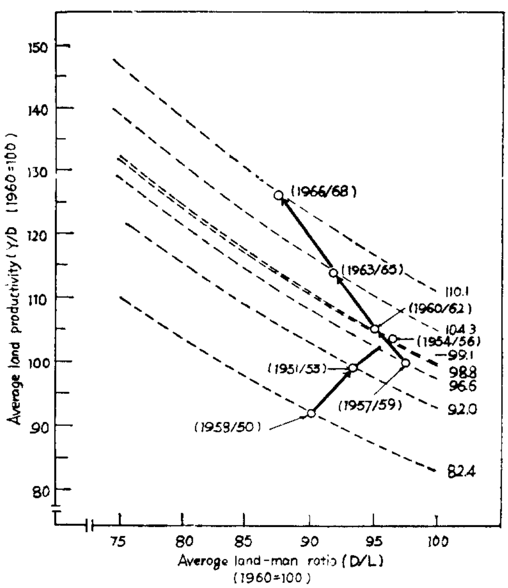

Fig. 1. An increase of the agricultural labor productivity in the Philippines (1948~1968).

It is instructive to very briefly examine the historical experience of countries such as Japan and Taiwan in the use of mechanization to determine whether mechanical innovations were a necessary condition in the achievement of high and sustained rice yields.

The widespread use of agricultural mechanization in Taiwan and Japan occurred relatively late in the structural transformation of these economies. Hayami and Ruttan (1971) and Johnston (1966) have clearly shown that major emphasis was placed on the developm-ent and extension of land augmenting biological-chemical technologies during the early stages of growth in Japan. These technological changes, coupled with investments in irrigation facilities and the availability of a disciplined and energetic rural labor force permitted Japan to expand rice production consistently and rapidly over the period from 1880 to the present. While there were minor improvements in farm implements and tools during this period, these were primarily designed to increase the productivity of ex-

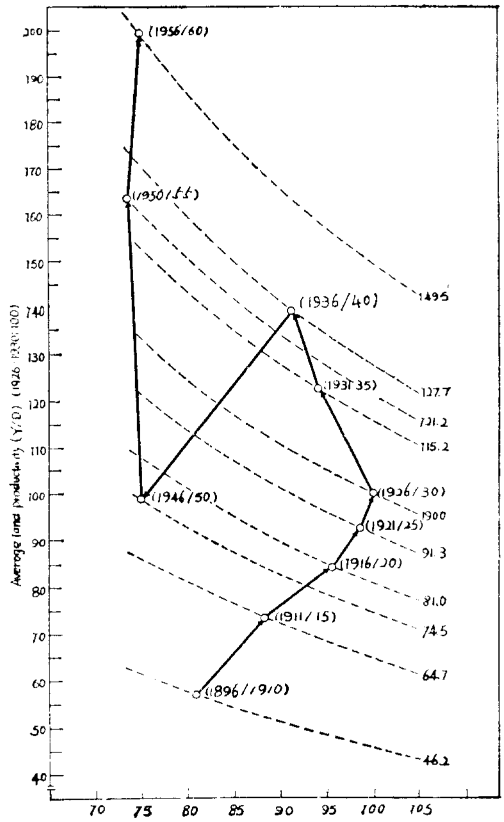

Fig. 2. Historical growth path of labor productivity of agriculture in Taiwan (1896~1960).

isting labor supplies and not to replace labor.

In the years folllowing World War Ⅱ, rapid industralization was the major cause of a ramarkably rapid movement of labor from the rural to urban centered employment. The decline in the rural labor force coupled with rising wages was accompanied by the introduction of an array of agricultural machinery, initially power tillers and more recently, rice transplanters, combine harvesters, dryers and four-wheel tractors. Some would argue Japanese farmers did not mechanize earlier because there were no suitable machinery designs available. This may be partially true, as the first power tillers, introduced into Japan from the United States in the 1950s, had to be modified to meet Japanese conditions. In historical perspective, however, there seems to have been no measurable output benefits obtainable from use of mechanization under the prevailing economic, technical and institutional conditions. It was not until labor became scarce, wages rose and policyincentives fostering labor-saving innovations were introduced that mechanization became an important factor in maintaining agricultural output.

Taiwan, which parallels the agricultural growth of Japan (USDA, 1968 and Hsieh and Lee, 1958) shows a similar chronology in the development and adoption of modern rice technology. Improved varieties and well-developed irrigation facilities proceeded the use of machinery by many decades. Even today, with the ready avilability of equipment designed specifically for conditions in Taiwan, only slightly more than one-half of all farmers are using powered-land preparation equipment (Peng, 1976).

An important factor which has influenced the recent adoption of policies encouraging the use of farm mechanization has been the widening disparity between urban and rural income levels. Rising wages and the higher costs of modern inputs have made farming less attractive to younger farmers. To stem the movement from farms to cities, the government has actively promoted a wide range of farm equipment, particuiarly in rice production.

In contrast to Japan, use of machines in Taiwan has permitted some crop intensification. In Japan, machines were primarily used as a replacement for labor but in Taiwan, they did contribute to a slight expansion in cropped area and output.

The varied experiences of Japan and Taiwan indicate that to achieve and sustain growth in agricultural priority, emphasis was initially placed on developmnent of a suitable package of land-augmenting biological-chemical technologies. With development, changes in economic conditions have dictated the role that machines played in maintaining growth in output. Mechanization was not introduced to increase yields, but to supplement and/or replace labor and animal power. In some instances, the result has been an increase in cropping intensity, although more commonly mechanization has acted to maintain growth rates in land productivity by replacing labor or draft animals. The prospect of creating technological unemployment has not been a major concern of these countries because of the high opportunity costs for the displaced labor.

CHARACTERIZING SMALL FARMS

One difficulty in discussing the small farm mechanization question is defining the characteristics of small farms. Table 1 shows that farms between zero and 5 hectares account for nearly 90 percent of all farms in the countries shown. The same farms,

Table 1. Number of farm operational holdlngs by size, Asian countrles, (1000 of farms, ha.)

Country	.5	.5—1.0	1.1—2.0	2.1—3.0	3.1—5.0	5.1—10.0	10.0—20.0	over 20.0	Total	Year
India[a][b]	9,102	10,783	11,191	6,165	7,465	2,953	1,795	514	49,874	1961
Indonesia[c]	5,332	3,245	2,223	693	431	221	69	22	12,236	1963
Bangladesh[a][c]	1,492	1,677	1,615	698	442	183	27	d)	6,139	1960
Pakistan[a]	742	856	806	581	759	729	388	d)	4,860	1960
Thailand[c][e]	na	595	945	na	884	615	163	11	3,214	1963
Philippines[f]	89	161	642	459	404	290	100	21	2,166	1960
Nepal[g]	630	300	313	na	341	492	d)	d)	2,076	1965
South Vietnam[c]	692	355	41	182	143	70	19	d)	1,872	1960
Sri Lanka[c][h]	411	350	222	132	na	33	8	6	1,167	1962
West Malysia[c][h]	46	158	99	72	57	13	4	1	450	1960
South Korea[i]	210	596	869	282	150	—	—	—	2,107	1975
Total	18,146	19,076	19,336	9,264	11,077	5,614	2,573	575	85,661	
% of total units	22.0	22.0	22.0	10.7	12.9	6.5	3.1	0.7	100.0	
% of total area	2.5	7.6	12.	10.8	19.1	18.4	15.5	14.0	100.0	

a) Size categories are: .4, .4-1.01, 1.01-2.02, 2.2-3.04, 1.04-5.06, 5.06-10.12, 10.12-20.23, over 20.23

b) Source: Directorate of Economics and Statistics, "Indian Agriculture in Brief," 11th ed.

c) Source: FAO report on the 1960 World Census of Agricuiture.

d) Included in previous size class.

e) Size categories are: .96, .96-2.4, 2.4-4.8, 4.8—9.6, 9.6-22.4, over 22.4

f) Source: Bureau of Census and Statistics, 1960 Census of Agriculture

g) Source: Nepal Ministry of Economic Planning, "Physical Input-Output Characteristics of Cereal Grain Production for Selected Agricultural Areas in Nepal." Size categories are: .5, .5-1.0, 1.1-2.0, 2.1-4.0, over 4.0

h) Size categonies are: .4, .4-1.0, 1.1-2.0, 2.1-4.0, 4.1-10.0, 10.1-20.0, over 20.0

i) Size categories are: .4, .4-1.2, 1.3-2.0, 2.1-3.0, 3.1-6.0, 6.1-10.0, 10.1-20.0, over 20.0

j) Source: Yearbook of Agriculture and Forestry Statistics, MAF 1975.

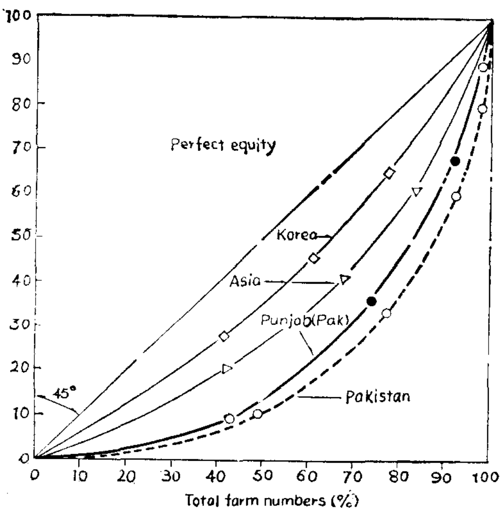

Fig. 3. Distribution of farmunits by area of holding in Asia.

however, cultivate only slightly more than 50 percent of the area well over two thirds of the farms are less than two hectares and more than 40 fercent are less than one hectare in size. Figure 3 shows the relationship between farm size and number for Asia and selected countries in the region. There is considerable variability in the degree of concentration of landholdings although it is clear that there exist large numbers of very small farms. Following introduction of modern rice varieties, the area under irrigation expanded rapidly (Table 2). However, much of these areas still have extremely poor water control. There is considerable debate among those concerned with irrigation de-

Table 2. Estimated percent of rice crop area and production by specific land type in Southeast Asia, early 1970's.

	Crop Area		Production	
	mid-60,s	early-70's	mid-60's	early-70's
Irrigated				
Single crop	10	19	15	24
Double crop	10	14	25	24
Rainfed	50	47	42	40
Upland	20	10	10	5
Deep water	10	10	8	7
	100	100	100	100

velopment as to the appropriate degree of land forming and consolidation needed to ensure adequate irrigation, drainage, and water distribution throughout the system. In some systems, the task of constructing tertiary canals and farm ditches is left completely to the farmers with the result that water is used very inefficiently. In other cases, a very intensive land consolidation scheme is being tested similar to Taiwan or Japan. Nothing is left to the farmers and the development cost is so high as to be economically unsound. Some intermediate steps need to be developed which will make use of appropriate mechanical technology and the existing pool of local human resources. Institutional innovations such as irrigation associations coupled with appropriate irrigation equipment such as pumps and land leveling devices are examples.

The spread of modern rice technology has changed the marginal productivity and the demand for various complementary inputs that go into the production process.

What is particularly significant about the new rice varieties in relation to mechanization is not only their yield increasing potential per se, but also their shorter growing season and non-photoperiod sensitivity which make possible a considerable shift in the cropping pattern. The introduction of modern varieties results in an increased demand for machinery to: (a) improve the timing of operations, (b) lift power constraints, and (c) make more efficient use of purchased inputs such as fertilizer and insecticides. In many instances, existing mechanical technology can be adopted or modified to meet these needs. In other instances, a new design may be required. The appropriate combination of mechanical and biological technology must be developed.

Eight rice farming systems based upon degree of water control are sketched out in

Table 3. Rice farming systems in South, Southeast and East Asia based on water control showing dlfferent levels of input intensity.

Farmlng Systems[a]

	IRRI Focus				Other			
	1	2	3	4	5	6	7	8
	Irrigated small	Irrigated very small	Rainfed multiple crop	Upland multiple crop	Irrigated[b] East Asia	Rainfed single crop	Upland slngle crop	Deep water
Infrastructure	M	M	L	L	H	L	L	L
Cash Input	M	M	M	M	H	L	L	L
Labor	M	H	M	M	M	L	L	L
Estimated % of Farms	15	40	6	1	12	17	4	5
Estimeted % of Area	23	9	10	2	6	32	8	10

[a] For the typical farm in each system the level of infrastructure development (irrigation, roads, etc.), cash inputs, and labor use is designated as L=low, M=moderate, H=high.

[b] Japan, Taiwan, and Korea.

Table 3. The level of infrastructure investment (irrigation, roads, etc.), cash inputs, and labor use are designated for the typical farm in each category (H=high, M=moderate, L=low). At IRRI, the engineering program is focused on small farms using a moderate amout of cash inputs and labor (100 man-days per hectares). This includes most of the irrigated area where modern varieties are now grown extensively, and that portion of the rainfed and upland areas where the potential for intensification of cropping systems seem to exist (Systems 1-4).

The remaining four systems include the relatively small but well-irrigated farms in East Asia-Japan, Taiwan, and Korea where wage rates are rising and labor-saving technology is being rapidly adopted, and at the other extreme, the less commercialized rainfed, upland, and deepwater areas where not only capital but labor inputs are low.

The first four systems account for more than 60 percent of the farm operating units and 45 percent of the farm area. However, there is considerable variation in the number of farmers and area represented from one farming system to another. While there are pressures to serve the very small farmers who represent 40 percent of the total, it would be difficult to design machinery for this group that would have a major impact on production. It is perhaps fair to say that the machinery designs available to date have been more appropriate for farming system 1, although considerable thought has been given to the extension of services of equipment owned by farmers in this group to those in system 2 through contract operations or possible joint ownership.

Rice farms in Asia typically hire a high percentage of the labor used in rice production. With the exception of East Asia, hired labor usually makes up more than 60 percent of the total. The hired labor force includes a growing number of landless laborers who depend on this work for a major course of their income. Thus, mechanization of these tasks which use a large amount of hired labor should probably receive low priority. Major tasks in irrigated rice production together with their labor requirements (H=high, M=moderate, L=low) using traditional practices are listed below:

Operations	Labor Requirement[1]	
	Total labor	Hired labor
Land preparation	H	L
Transplanting	H	H
Fertilization	L	L
Plant protection	L	L
Weed	H	H-M
Water management	M	L
Harvesting	H	H
Threshing	H	H

[1] There is considerable variability among countries in the degree of intensity with which labor is employed in tasks in the rice production sequence. There will also be differences by country and within countries in the division hired and family labor use for individual tasks. The above represent an aggregate estimate of a "typical" rice farm in the irrigated regions of Asia.

From this listing, it can be seen that transplanting, harvesting, threshing, and in some cases weeding require large amounts of hired labor.

MECHANIZATION NEEDS OF SMALL FARMERS

Generally, mechanization is employed to meet one or more objectives:

1) increase crop yields
2) increase cropping intensity
3) expand cultivated area

4) improve cropping patterns
5) improve quality and value of product
6) decrease production costs

The specific set of objectives will be conditioned by local circumstances. One or even all objectives may be consistent with overall development goals.

Mechanization requirements of small farms in Korea markedly differ from those of for example Java. In addition to differences in resource availabilities, dissimilarities in the rate and level of economic development in each country has created differences in the relative value of the labor and capital resources used in agriculture. Wages in Korea, particularly in industry, have increased rapidly in recent years. As a result, lack of labor has become a major constraint in operations such as harvesting and transplanting. In contrast, wage rates in Indonesia have risen only slightly in the recent past with little change in real value. For agriculture in Indonesia, a small holding continue to be the residual and major claimant of surplus labor.

Korea, will use mechanization primarily to increase the productivity of varilable labor, generally through a process of substituting capital (in the form of machines) for labor or animal power. While the aim may also be to increase outpvt (as was illustrated in the intensification of cropping in Taiwan), the rapidly developing countries are usually attempting to maintain agricultural growth rates while simultaneously offsetting an absolute decline in the agricultural labor force. A concomitant feature of the decline in the agricultural labor force is usually an increase in farm size. The latest stasistics for Korea show the beginnings of a change in the size distribution of holdings towards larger farms (MAF, 1975).

In almost all cases involving very small farms(0-2ha), the mechanization technologies which have been available are generally too large, too expensive and not technically compatible with the needs of small farmer. Given these limitations, what type of technology is needed?

Equipment which can be locally manufactured and maintained at low cost and which are complementary with on-farm resources of labor and power should be given priority, particularly those which improve the efficiency of purchased inputs such as water and have high social as well as private returns.

Increased yields are often cited as a major reason for mechanization. For some upland crops, such operations as deep plowing have demonstrated significant advantages in yield over traditional methods. For lowland rice, the situation appears to be less clear-cut.

To determine the effects of alternative land preparation techniques on the yield of IR20, a series of experiments and a field survey

Table 4. Alternative land preparation treatments, 3 villages. Philippines, 1973 wet season.

Treatment	Land preparation method: Primary		Secondary[a]	
	Power Source	Implement	Power source	Implement
1	65hp tractor	rotary tiller	carabao	comb harrow
2	14hp tiller	rotary tiller	carabao	comb harrow
3	7hp tiller	moldboard plow	7hp tiller	comb harrow
4	carabao	moldboard plow	7hp tiller	comb harrow
5	carabao	moldboard plow	carabao	comb harrow

[a] Secondary tillage consists of two passes over the field repeated three times at one-week intervals.
Source: Orcino and Duff, 1974.

were conducted in 1974 (Orcino and Duff, and Bautista and Wickham, 1974). Replicated field plots were laid out at four sites with variable soil and water characteristics. Five tillage treatments were used (Table 4). Soil depth varied from very shallow at one location to very deep at another. One rainfed site was also included to measure the effect of uncontrolled water supply on tillage requirements. The results of the experiments are summarized in Table 5. Grain yield data do not support the hypothesis that mechanization

Table 5. Site characteristics, soil conditions and level of inputs used in land preparation trials, 3 villages, Philippines, 1973 wet season.

Site/	Labor input (hr/ha)			Fuel cons.	Weed weight[a]	Means[a] yield
treatment	Plow	Harrow	Total	(lit/ha)	(g/0.2m²)	(t/ha)
Baluarte (shallow hardpan)						
T_1	4	30	34	13	16.0	3.85
T_2	6	30	36	12	12.1	3.80
T_3	12	12	24	32	16.5	3.65
T_4	27	11	38	17	13.5	3.88
T_5	27	31	58	—	12.6	3.74
Pulo I (medium hardpan)						
T_1	5	40	45	19	16.3	3.91
T_2	8	41	49	16	15.0	4.00
T_3	13	21	34	47	8.6	4.14
T_4	34	20	54	32	10.9	4.01
T_5	32	40	72	—	25.4	3.94
Rulo II (deep hardpan)						
T_1	4	42	46	19	8.1	3.53
T_2	7	42	49	13	9.6	3.57
T_3	9	20	29	31	8.1	3.65
T_4	27	21	48	27	6.6	3.57
T_5	27	39	66	—	5.9	3.71
Kapalangan (rainfed)						
T_1	74	7	54	28	9.8	3.03
T_3	11	53	64	20	12.7	2.93
T_3	—	—	—	—	—	—
T_4	61	21	82	28	12.4	2.97
T_6	63	66	129	—	27.7	3.01

[a] Averaged over three weeding treatments.
Source: Orcino and Duff, 1974.

increases rice yields. Mean yields are not significantly different across treatments and show a minimal variation among means. Survey data from the same locality indicated farmers agreed with this finding. The irrigated farms included in the survey indicated the main reason for using tractors was ease of land preparation with timeliness and quality of work as secondary considerations. Rainfed farmers, however, indicated their use of tractors was primarily to permit better timing to maximize the area of land planted following initiation of the rainy season. The issue of timeliness will be discussed further in a later section.

It has also been hypothesized that land preparation may have an indirect effect on yield through more effective weed control, an issue mentioned earlier and which stems directly from use of the higher rates of fertilizer used with the modern varieties. Table 6 provides evidence from the field experiments cited above relating to weed control. The differences in mean yields for different land preparation measures was statistically significant, but quantitatively small. In this

Table 6. Average grain yield (t/ha) from alternative tillage and weeding trials.[a]

Site	Tillage treatment	Weeding			Treatment mean	Site means
		hand	chemical	control		
Marilo	T_1	3.78	3.77	4.01	3.86b	
(shallow	T_2	4.40	3.58	3.42	3.80b	
hardpan)	T_3	3.64	3.78	3.54	3.65b	
	T_4	4.17	4.16	3.32	3.88b	
	T_5	3.92	3.69	3.60	3.74b	3.79b
	Weeding means	3.98a	3.80ab	3.58b		
Pulo Ⅰ	T_1	4.30	4.07	3.53	3.97a	
(Medium	T_2	4.46	3.86	3.69	4.00a	
hardpan)	T_3	4.46	4.19	3.76	4.14a	
	T_4	4.23	4.04	3.75	4.00a	
	T_5	4.52	3.52	3.78	3.94a	4.01a
	Weeding means	4.39a	3.94b	3.70b		
Pulo Ⅱ	T_1	3.85	3.77	2.97	3.53b	
(Deep	T_2	4.03	3.54	3.13	3.57b	
hardpan)	T_3	3.96	3.85	3.14	3.65b	
	T_4	3.94	3.80	3.16	3.56b	
	T_5	3.80	3.90	3.43	3.71b	3.61b
	Weeding means	3.88a	3.77a	3.16b		
Kapalangan	T_1	3.40	3.16	2.68	3.08c	
(Rainfed)	T_2	3.10	2.94	2.74	2.93c	
	T_3	—	—	—	—	
	T_4	3.28	2.98	2.66	2.97c	
	T_5	3.36	2.93	2.66	2.98c	2.99c
	Weeding means	3.28a	3.00ab	2.68b		

$LSD_{.05}$ (W—means at each $S \times T$) 0.77t/ha

[a] *Weeding means at each location followed by a common letter are not significantly different at 5% level.*

particular study, the weed population was primarily a sedge, a weed type which research has shown to affect yields only slightly. Hence, although weed weights were affected by the land preparation techniques, with the advantage given to tractors, yields were not. These studies appear to demonstrate few direct yield advantages from use of mechanized land preparation compared to traditional methods.

In the areas of crop establishment, crop protection and fertilizer application, there is no available evidence which suggests any strong interaction between choice of technique and resulting yields. Weed control has been repeatedly mentioned as an operation which provides very high returns when used in conjunction with the modern varieties. The method chosen, however, appears to reflect relative costs rather than an inherent technical advantage for one method over another. The same is true of crop establishment. Modern rice varieties tend to be relatively insensitive to row-spacing and seedling density in respect to yield. There is, however, a strong degree of interaction between method of stand establishment and the use of mechanical weed control. Row-sown transplanted rice tends to give higher yields than higher broadcast or direct seeded rice if weed control is a limiting factor.

The farm level constraints study being undertaken at IRRI to determine why farmers are not realizing the yield potential of the modern varieties indicates ineffective use of fertilizer and the lack of profitabliity in the use of insecticides as the chief causes of differences between farmer's yields and optimum yields achieved under similar conditions. Contemporary work at IRRI among agronomists, entomologists and engineers to develop low-cost methods for root-zone placement of these chemicals have striking implications for yield increases on insect control as shown on Tables 7 and 8 and Figs. 5 and 6. The chief limiting factor is the

Table 7. Yields of IR34 rice and fish, Tilapia mosambica as affected by carbofuran root-zone and broadcast applications.[a] Central Luzon State University, 1976 dry season.

Method	Cost of insecticide applicaton (US $ /ha)	Rice yield (t/ha)	Fish[b]		
			Yield (kg/ha)	Value (US $ /ha)	Income[c] (US $ /ha)
Broadcast					
1kg at 3 DT	30	4.919[bc]	141	115	673
1kg at 3, 23, 43, & 63 DT	120	4,935[abc]	0	0	552
Root-zone					
1kg at 3 DT	46	5.116[ab]	166	136	786
1kg at 3 DT	92	5.613[a]	150	123	794

a) In a column, means followed by a common letter are not significantly different at the 5% level (Duncan's Multiple Range Test).

b) Fish seeded 7 days after first insecticide appliction at the rate of 3000/ha.

c) Income=value of rice+fish minus insecticide and application costs. Based on price of rice at $0.82kg.

Table 8. Control of the tungro virus vector the green leafhopper, Nephotettix virescens with a carbofuran as broadcast and root-zone applications with a liquid band injector at 1kg a.i./ha.[a] Variety IR 22. IRRI, 1976 wet season.

Treatment[b]	Applications	Leafhopper/10 sweeps 47 DT	Tungro virus (%) 97 DT	Yield (t/ha)	Income[d] (US $ /ha)
Broadcast	1	25[c]	68[b]	1.302[b]	147
Broadcast	4[c]	9[ab]	33[a]	2.516[a]	222
Root-zone	1	3[a]	20[a]	3.092[a]	375
No insecticide		212[d]	100[c]	0[c]	0

a) In a column, all means followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).

b) All treatments applied 3 days after transplanting (DT).

c) The four brocadcast applications were made at 20 days intervals.

d) Income=value of rice−cost of insecticide application. Cost of 1kg granules used in broadcast =$30/kg a.i. and flowable formulation used in root zone=$46/kg a.i.

availability of a device (Fig. 7), for proper and precise placement of plant nutrients and insecticides. Reductions in application rates of 50 and 70 percent for fertilizer and insecticides respectively without sacrifices in yields are possible.

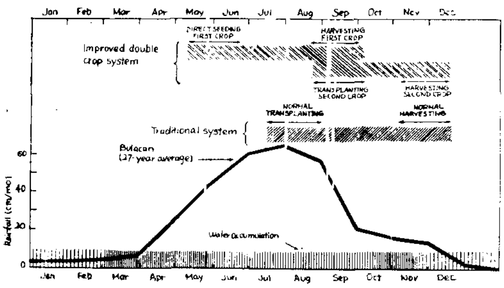

Fig. 4 Actual and potential rice production systems under rainfed conditions in Central Luzon, Philippines.

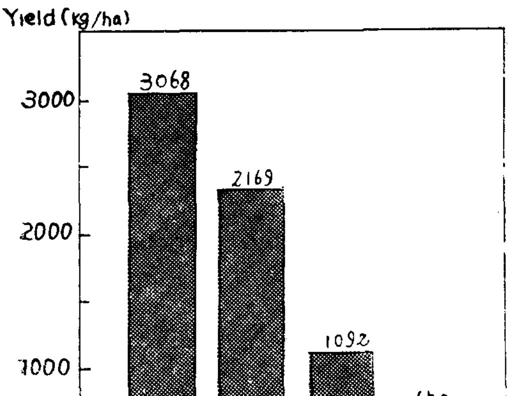

Fig. 5. Yield as affected by various methods of insecticide application Carbofuran at 1kg a. i/ha was applied 3 days after transplanting into root zone and as the broadcast treatment. Monochotophos was applied four times at 20 day intervals as a folior spray. At 0.75kg a.i./ha. IRRI, 1975 wet season.

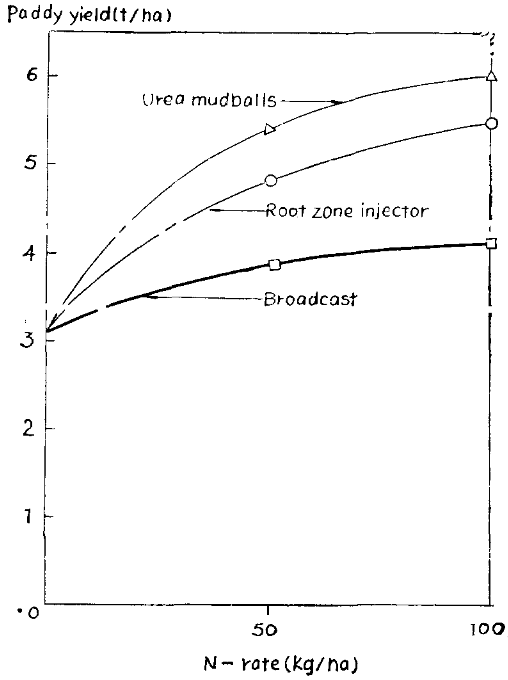

Fig. 6. Yield response curves to fertilizer using three application techniques

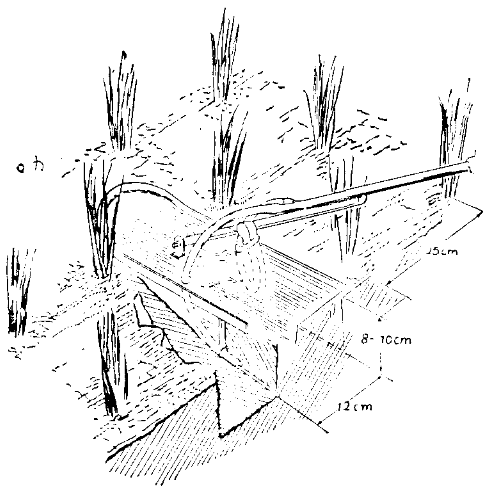

Fig. 7. Liquid root-zone chemical applicator for floode rice

Harvesting, threshing, drying and storage represent the terminal operations in the rice production cycle for most farmers. Efficient performance of these tasks is important if the farmer is to achieve optimum crop yields and maximize incomes. The modern rice varieties with their higher yields have tended to increase the absolute level of grain loss in post-production operations. The degree of loss which can be expected using traditional technologies in operations following harvest is appreciable. Table 9 presents the results from use of alternative systems of technology on yield and level of grain loss for a series of village level pilot trials conducted from 1975—77 (Toquero, et. al., 1977). Introduction of a small mechanical thresher and/or mechanical dryer significantly reduced losses and improved yields by up to nine percent. Laboratory analysis of paddy samples taken from the same trials showed an increase of six percent in total milled rice and 12 percent in head rice from using the mechanized systems in contrast to manual harvesting-threshing and solar drying.

Table 9. Percent grain loss using four alternative post-production systems, Philippines, 1975—76.

Item	System			
	Manual threshing and solar drying	Manual threshing & mechanical drying	Mechanical threshing & solar drying	Mechanical threshing and drying
Percent grain loss				
harvesting to threshing	11.0	11.8	1.7	2.5
threshing to drying	15.3	1.2	11.4	8.2
harvesting to drying	24.6	12.9	12.9	10.5

Source: Toquero, et. al., 1976.

Reductions in qualitative and quantitative losses in post-production operations seem particularly amenable to engineering solutions. Use of mechanized equipment is, however, sensitive to economic factors. Premiums for high quality paddy provide an added incentive for farmers to exercise care in the operations following harvest. Enactment and enforcement of grading and quality standards for paddy entering commercial markets would have a similar effect.

Introduction and use of short season varieties with non-sensitivity to day length offers not only the prospect of higher yields but crop intensification. Undoubtedly, much of the intensification will take place in irrigated areas. However, the biological technology combined with techniques to permit early land preparation, crop establishment and rapid turnaround at the peak of the rainy season may permit intensification in areas with poor water control. Generally characterized as rainfed rice production, the environment represents nearly 50 percent of the current rice cropped area in Asia (Herdt and Barker, 1977).

Figure 4 contrasts the traditional rainfed cropping system with an improved double-cropped system. Under the traditional system, crops are normally planted near the peak of the rainfall distribution and harvested when rainfall is declining. Under the improved system, two crops can be planted utilizing the same moisture currently available for single crop. Under the new system, land is prepared dry at the end of the rainy season and moisture conservation practices are employed during the dry season. The first crop is direct-seeded at the beginning of the wet season and harvested at the peak of the rainy season. A second crop is immediately transplanted. Subsequent operations for the second crop are similar to those employed for the traditional cropping system. Effective use of this cropping system will require changes in cultural practices and the scheduling of operations. Some degree of mechanized land preparation and planting for the first crop may be necessary. Because direct seeding is employed for the first crop, weed control will become a greater problem. Threshing and drying equipment are needed for the first crop harvest. Cultural practices which maximize water use efficiency will be mandatory. Timeliness is the critical element in the successful use of the rainfed double cropping system.

The importance of timeliness will be conditioned by the physical entvironment within which a rice crop is grown and the characteristics of the varieties themselves. Differences in topography, degree of water control, soil type and seasonality interact differently with the timing of individual operations in their impact with the output components mentioned above. For example, a single crop regime may not be affected as adversely by the degree of precision in scheduling operations as a double or triple crop pattern where the potential intensity effects of timeliness are most pronounced. An important exception is found in comparing single crop irrigated and rainfed rice production systems. An irrigated farmer's programming of land preparation and transplanting may be determined to some degree by the timing and availability of water deliveries, but he would have much greater flexibility in this regard than the rainfed rice farmer who is constrained by the availability and quantity of rainfall and must prepare his land quickly to take advantage of this moisture. In this regard, the short season varieties may reduce the urgency of early land preparation and transplanting in rainfed areas if farmers do not attempt to grow a succeediug crop. The opposite is true when rainfed farms initiate double cropping. Binswanger has also mentioned that the timeliness factor in crop establishment becomes more imperative in rainfed areas characterized by permeable soils with low moisture retention characteiistics (Binswanger, 1977).

Correct timing of the harvest may interact singly or in combination with both yield and output depending again on the environment. Optimal timing of harvest maximizes yields, a precondition for high grain quality and reduces the turnaround time between crops in double cropping.

For tasks such as water delivery, weed control, crop production and fertilizer application, it is both the <u>timing</u> and the <u>frequency</u> which ensure optimal yields from the modern varieties. Untimely water delivery subjects the rice plant to moisture stress and can cause significant yield reductions, particularly if they occur at flowing, when the modern varieties are particularly susceptible (de Datta, et. al., 1973). Mechanized pump irrigation in areas such as Pakistan and India have helped to reduce the risks associated with water deficiencies and moisture stress.

Pest control, fertilizer application and weeding have shown marked yield responses to level of application, timing and placement (Heinrichs, et. al., 1977). Equipment which can accurately meter and place chemicals under flooded conditions lowers both yield variability and the frequency of application. In a time when chemical prices continue to rise and irrigation development becomes increasingly expensive, mechanization which increases the application efficiency of water and cash inputs such as pesticides and fertilizers will become increasingly important.

Agronomists have long recognized the yield depressing effects of delays in planting. The depression in yields for upland conditions are primarily the result of water stress as available soil moisture is depleted during the later stages of plant growth. A similar, though perhaps less dramatic decrease can also be shown for lowland irrigated rice. Delays resulting in inefficient use of solar energy during grain formation is the primary reason, a phenomena which emerges most strikingly during the dry season when sunlight is most intense. Thus, in addition to the importance of timely crop establishment as the basis for obtaining more than one crop, yield may also be adversely affected by delays in planting.

In the above example, it is clear that better timing in the completion of land preparation can improve water use efficiency.

In 1973-75 study of irrigation systems in the Philippines, Valera and Wickham presented information describing the relationships between the timing of water deliveries, land preparation and transplanting. Data for the analysis were collected from rainfed, gravity irrigation and pump irrigation sites (Fig. 8).

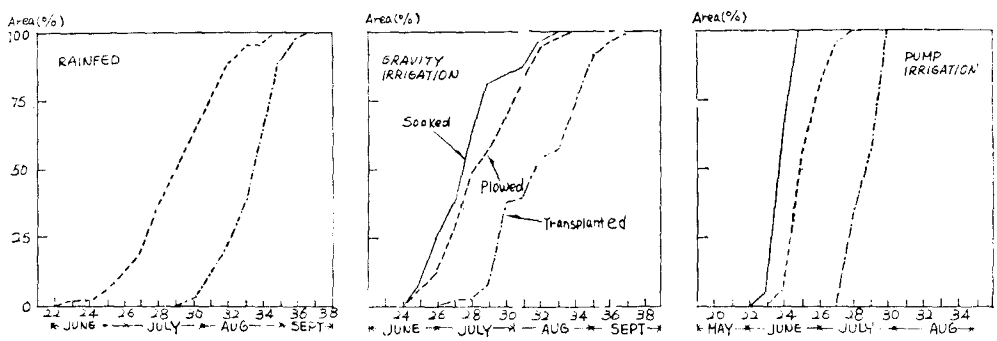

Fig. 8. Timing and duration of land preparation and transplanting under three alternative water supply regimes, Central Luzon, 1973 wet season, Source: Valera and Wickham, 1975.

Under traditional rainfed conditions, land preparation and transplanting generally follow the rainfall distribution pattern. Land preparation is delayed until sufficient moisture has been accummulated to allow plowing with the water buffalo. The total duration of these two operations is considerably longer for the rainfed site than for the irrigated areas. The long interval between plowing and transplanting may partially reflect the practice of allowing weeds to germinate between primary and secondary tillage operations. It may also indicate a lack of power and labor to carry out those two operations. From a related study, we note that only those farmers owning tractors were able to transplant earlier than before adoption of the modern varieties (Bautista and Wickham, 1974).

Both of the irrigated areas showed a close relationship between the timing of water deliveries and land preparation, although the gravity irrigation site had a longer overall interval for completion of those tasks. One conclusion was that there exists a substantial oppportunity to improve water use efficiency by reducing the land preparation-transplanting interval using improved techniques for plowing and transplanting. Within the gravity irrigation system. it was estimated that a reduction of 3½ weeks in the land preparation-transplanting phase would save 200 too 600 mm/ha of water from that actually observed.

CHOICE OF TECHNIOUE

In the preceeding section, several examples were given which illustrate the possible role which mechanization may play in fostering increased economic growth on small farms. In some instances, the machine technology to realize these increases is available but unused. In other instances, new engineering developments are required. In all cases, a major constraint facing small farmer's use of innovations, is the lack of capital resources. The lumpy nature of investments in agricultural equipment requires that the farmer reach some minimal threshold level of use before the machine becomes profitable. In many cases, this threshold area is beyond the size of an average holding.

There are alternative institutional arrangements which can be employed to capture the advantages of mechanical technologies inspite of the investment constraint. In Figs. 9 to 12, I have presented graphically some typical use patterns. Figure 9 illustrates the purchase and use of a single machine by an individual owner. In this case, the capacity of the machine is assumed to be closely tailored to the needs of a small holder. As long as utilization is less than the capacity of the machine and average total costs are less than other alternatives, the farmer will be able to use the machine profitably. If annual use requirements exceed the size of his holdings, the farmer may employ the excess capacity of the machine for contract work. In Fig. 10, three small machines are purchased and used under one management. Multi-machine use expands capacity and may also lower overall costs because fixed cost components such as maintenance facilities are now used for more than one machine. This arrangement also embodies the flexibility to meet a wide range of capacity needs and can provide timely service to more than one user simultaneously. To meet total in-

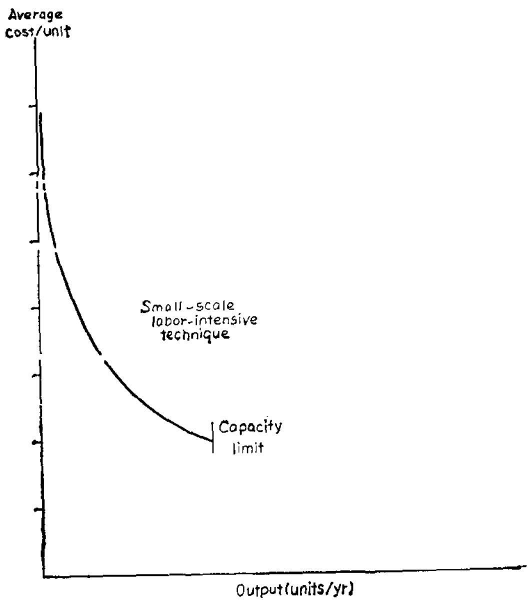

Fig. 9. Average total costs for individually operated small-scale mechanization system.

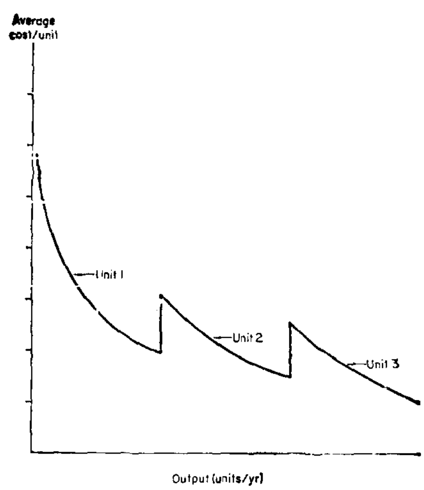

Fig. 10. Average total costs for small-scale mechanization systems replicated three times.

vestment requirments, however, the machines shown in Fig. 10 must cover an area approximately three times greater than the single machine shown in Fig. 9. This arrangement also illustrates the potential embodied in joint ownership and use by organizations such as irrigation associations or cooperatives.

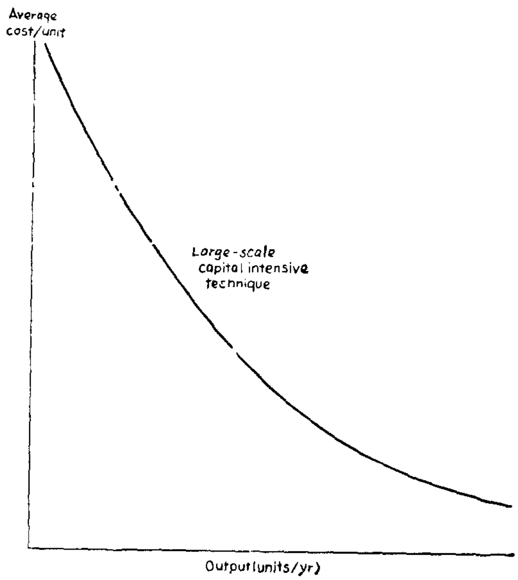

Fig. 11. Average total cost for large-scale capital intensive mechanization system.

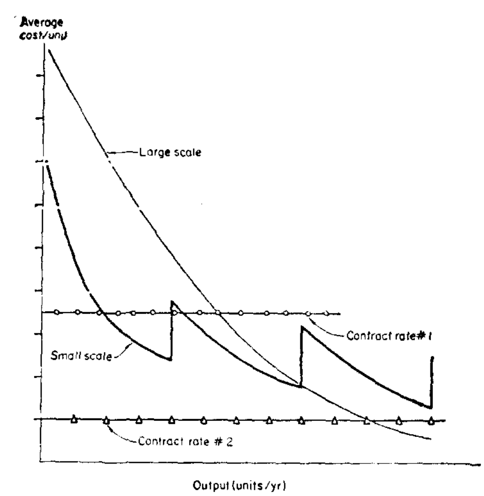

Fig. 12. Comparative average total costs of four alternative mechainzation system.

Figure 11 shows the total average costs for ownership and use of a single, large capacity machine. Generally, this technology would typify investment in a large four-wheel tractor or heavy irrigation pumping unit. Fixed costs are high which means the machine must be utilized at high levels of output to achieve minimal costs. While use requirements are high, there are at least two methods by which small holders can realize the benefits from such a technology. One is through private ownership and custom hiring services. This pattern is widely used in Thailand and the Philippines for four-wheel tractors. A second pattern is through collective or cooperative pooling of investment resources to purchase the machine. The latter method is generally more complicated to implement and requires a well-developed system of management to properly schedule the use of the machine. It also does not embody the timeliness and convenience features of larger numbers of small machines. At higher output levels, the large machine may, however, have lower overall costs compared to the smaller units. In some instances, it has also been shown that larger equipment is technically more efficient, using less energy and resources per unit of output than smaller units performing similar tasks.

Figure 12 compares the large and small equipment options. It is not possible to generalize about the desirability of any of the alternatives shown in the figure. Choice will be dictated by local factor pricing, the ability of farmers to pool resources and manage investments and the importance of timeliness and convenience in owership. Where individual ownership by small farmers is indicated, small equipment may prevail.

In situations where viable community or political institutions exist to effectively consolidate and manage capital, larger equipment may be chosen. Large irrigation pumps serving adjoining holdings or village-level grain drying facilities, both of which embody technical economies of size would be candidates for joining ownership and use. Where simultaneous peak loading occurs on large numbers of small farms, such as in harvesting, threshing or transplanting, individual ownership of small machines or pools of small-scale equipment may be more efficient.

The degree of private ownership will also determine the extent of custom services which may develop in an area. Figure 12 indicates that with contract rate no. 2, only the large scale machine is able to compete effectively and then only at high annual use levels. Using contract rate no. 1, however, only the smallest farm would find individual ownership unattractive.

The above example is only illustrative. There are many factors which affect the decision to purchase or use equipment. The value of leisure time, the prestige factor, the degree of drudgery associated with a particular task, the amount and cost of hired as opposed to family labor used or a task and the availability of service and maintenance facilities also condition decisions to employ mechanization. In recent years, the availability of low-cost credit for acquisitions of the machines has also been a decisive facter. Coupled with government controls over interest, foreign exchange rates, import restrictions and wage laws, the final choice of technique may diverge significantly from an optimal one based on social cost criteria.

PUBLIC POLICIES AFFECTING MECHANIZATION AND RESEARCH

In this paper, I have not attempted to compare the economics of alternative mechanization strategies nor develop a methodology for carrying out such an analysis. The report highlights those components of agricultural production systems (particularly for rice) which seem particularly amenable to mechanization to achieve and sustain increase in output. The actual choice of a particular machine to perform a specific task within a given environment will be very location specific. The evidence from use of the modern rice varieties demonstrates that while mechanization plays a minor role now, there are many opportunities where the application of sound engineering design in conjunction with developments in agronomy and plant breeding embody great potential for significant increases in production.

Leadership in research and the development of public policies have a great impact on the nature and type of innovations made available to farmers. Organization of research to ensure that engineers work closely with biological scientists in the evolution of improved technology will ensure that research resources are used effectively and results are a composite of complementary technologies and not splintered fragments. Multi-disciplinary working relationships, while more difficult to affect and administer than others, ensure that problems are correctly identified and specified before development to correct them begins.

The establishment of a sound research base is highly dependent on the availability and training of scientists and engineers. Engineers in particular often bring to their jobs a preconception that designs should be judged on the basis of their complexity and sophistcation rather than their performance in the field. Engineers, economists and biological scientists must embody a fuller appreciation for simplicity, low cost and ease of extension and use in their research programs.

New and innovative organizational forms are needed to make available to small farmers the advantages of mechanization. There exist inherent economies of size in some mechanical technologies which preclude efficient applications on small size farms. Until joint use mechanisms are developed to finance and manage such technologies, they will remain out of the reach of the small farmer.

The role of rural credit in the acquisition of machinery should be examined in more detail. Over the past decade, the propensity for financing agencies such as the World Bank to support capital intensive, largescale mechanization programs has deprived many countries of the opportunity to combine development of local semi-modern industry with assistance to a wide cross-section of the rural population. Methods are need to reduce both the risk to financing institutions and the costs in providing credit to small farmers.

Research is also needed to develop public policies affecting the quality and diversity of agricultural products. Improving consumer preferences for good quality rice will have the indirect effect of inducing use of better harvesting, handling, threshing, drying, storage, milling and transport practices. Improving quality also has the concomitant effect of increasing the volume of commodities reaching the consumer because of lower losses.

Further research is badly needed to clearly identify and specify the nature and magnitude of the technical relationships between the new biological technology and mechanization. In addition, the interaction of these effects with the institutional and economic factors must also be evaluated. The full impact of mechanization on output, employment and incomes may not be felt for a period of many years. Research on these consequences must embody a dynamic as well as a cross-sectional dimension. This research shoud be carried at both a farm and regional level to sort out the "confounding" effects of technical change and to predict their aggregate effect.

In this effort, we have not examined the effects ef mechanization on changing cropping patterns or costs. Clearly, these two issues together with an evaluation of institutional structures and policies affecting the use of capital and labor on small farms would need to be incorporated into a comprehensive research effort. Lastly, the interdependencies between the level and pattern of mechanization and non-farm industrial activities are also required to fully assess the consequences of particular strategies to mechanize the rice sector.

REFERENCES

Bautista, F. and T. Wickham. 1974. The tractor and the carabao: a socioeconomic study of choice of power source for land preparation in Nueva Ecija. Paper No. 74-13(mimeo).The International Rice Research Institute, Los Banos, Philippines.

Barker, R., H.E. Kauffman and R.W. Herdt. 1975. Production constraints and priorities for research. Paper No. 75-8. Dept. of Agricultural Economics, International Rice Research Institute, Los Banos, Philippines 10p.

Binswanger, H. 1977. Personal communication with the author dated July 14, 1977.

De Datta, S.K. and R. Barker. 1977. Economic evaluation of modern weed control techniques in rice. in Integrated control of weeds. I.D. Fryer. and S. Matsunaka(eds.), Univ. of Tokyo Press, Tokyo. pp. 205-228.

De Datta, S.K., W.P. Abilay and G.N. Kalwar. 1973. Water stress effects in flooded tropical rice. in Water management in Philippine irrigation systems: research and operations. International Rice Research Institute, Los Banos, Philippines. pp. 19-35.

Heinrichs, E.A., G.B. Aquino, J.A. McMennamy, J. Arboleda, N. Navasero and R. Arce. 1977. Increasing insecticide efficiency in lowland rice. Agricultural Mechanization in Asia 8(3): pp. 41-47.

Herdt, R.W. and R. Barker. 1977. The status and potential of food production in Asia (mimeo). The International Rice Research Institute, Los Banos, Philippines pp. 43-51.

Orcino, N. and B. Duff. 1974. Experimental results from alternative techniques of land preparation. International Rice Research Institue, Dept. of Agricultural Engineering. (mimeo).

Peng, T.S. 1976. Agricultural mechanization in Taiwan, Republic of China. Pages 132-159 in Taiwan Agricultural Machinery Guide. JCRR. Taipei.

Toquero, Z., C. Maranan, L. Ebron and B. Duff. 1977. Assessing quantitative and qualitative losses in rice production systems. Agricultural Mechanization in Asia 8 (3) pp. 31-40.

Valera, A. and T. Wikham. 1974. Land preparation in lowland rice: its speed in relation to rate of water supply. Paper No. __. (mineo). The International Rice Research Institute, Los Bonos, Philippines.