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"ENERGY USE IN ALTERNATIVE RICE PRODUCTION SYSTEMS
IN NUEVA ECIJA, CENTRAL LUZON, PHILIPPINES"

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ABSTRACT

This study investigates the significance of rising fossil energy prices for the development of rice production technology, particularly in the field of mechanization. The use and productivity of resources employed on rainfed and irrigated garms in the Philippines are measured in energy as well as financial terms. Fertilizer use on all farms and water supply on pump irrigated accounted for the largest shares of fossil energy yse amd cash expenditure. When expected increases in real prices of chemical inputs are added to existing costs of production they represent 25% of current returns above variable costs per hectare on rainfed and 16% on gravity irrigated farms. In a decade of rising input prices and growing demand for rice mechanical innovations are needed which both increase yields, and simultaneously improve the productivity of resources that are becoming scarce relative to demand. This role of mechanization is illustrated by an ex-ante analysis of a hand powered machine for deep placement of fertilizer.

INTRODUCTION

The significant feature of Modern Varieties (MV) or rice is that, for those areas where they can be grown, yield per hectare is more responsive to increased control over the plants' environment compared to Traditional Varieties (TV). The most important managed factors are known to be water, nutrients, pests and diseases, and weeds. The infrastructure and chemical inputs that enable the farmer to manage these factors, such as dams and waterways, pumpsets, inorganic fertilizer, pesticides and herbicides, and the manufacturing plants which produce them all embody fossil energy. The long term trend of rising real prices for fossil fuels, at a time when rapid growth in rice production must continue if supplies are to meet human needs, is a source of concern to rice scientists.

This study is in two parts the first of which investigates the use and productivity of resources in different types of rice culture and the implications of rising energy prices, and the second the future role of mechanization. Specifically the objectives are:

1. To describe the use and productivity of resources on rainfed and gravity irrigated farms in Nueva Ecija, Central Luzon, in energy and financial terms in order to examine the relationship between these two sets of values at the farm level.

2. To make a preliminary and tentative assessment of the impact of rising fossil energy prices on costs of production.

3. To indicate an appropriate direction for mechanization in the context of rising input prices and a growing demand for rice, and to illustrate it by ex ante analysis of a mechanical technology currently under development for deep placement of fertilizer.

4. Identify areas for further economic research in order to evaluate the potential future role of mechanization in relation to other crop management tasks.

METHODOLOGY

An energy analysis of resource use and productivity, together with a financial appraisal, was carried out using input/output data from case study farms. The resource use information was obtained from the farm recordkeeping component of the Consequences of Mechanization Survey in Central Luzon, Philippines, conducted by the IRRI-Agricultural Engineering Department. From a total of fifty farms, six parcels were

chosen from gravity irrigated, six from shallow-tubewell pump irrigated, and four from shallow rainfed environments (Table 1). Pump irrigated farms were chosen in equal number from areas of 6m and 14m water depths, the latter at the margin of shallow-tubewell irrigation. For each land parcel resources used in the 1979 wet season and the 1980 dry season were listed by crop management activity, with their corresponding energy and money values. Energy values for inputs (Table A1) were drawn from Leach (1976) and Kuether and Duff (1981) and represent both the energy embodied in the input, and the indirect energy required to produce it. A case study approach has the disadvantage of having little extrapolatory value, but provides a comprehensive context for identifying relevant issues for further research.

ENERGY USE AND PRODUCTIVITY ON CASE STUDY AREAS

Before examining resource use on the farms in crop year 1979/80 a brief overview of the resource use in the Philippine agricultural sector and development of rice production technology in the study area following the release of MVs will provide a useful perspective.

Overview.

At a national level rice farmers in the Philippines account for the single biggest share of fertilizer and chemical products used by the agricultural sector, although in percentage terms it is not overwhelmingly large due to diversification. For direct use of petroleum products rice production ranked second in 1974, but the agricultural sector as a whole accounted for less than one percent of national use (Table 2).

The "loop" survey of Central Luzon, carried out by the Agricultural Economics Department of IRRI, reported dramatic change in rice production technology over the last 15 years (Cordova, V., R. W. Herdt, F. Gascon and L. Yambao 1981). As early as 1970 almost 80% of the total rice area was planted to MVs and this figure had risen to 95% by 1980. Although almost all farmers were using fertilizer by 1970 the quantities applied increased substantially over the decade (from 42 kg applied nutrients in the 1970 wet season to 62 kg and 117 kg in the 1979 wet and 1980 dry seasons, respectively) whilst applications of pesticide increased fourfold. Herbicide use also increased over the period, and labour employed for hand weeding declined. Yields during the last decade increased from 2.6 t/ha to 3.4 t/ha. Tractor use increased steadily, including two-wheel types after 1974. In 1980 animals were still employed to some extent on three quarters of farms, and the employment of tractors was concentrated in the higher income irrigated areas. Although small axial flow threshers competed successfully after

their introduction against the long established large mechanical threshers, hand threshing remained predominant in irrigated areas as staggered harvesting dates make many fields inaccessible.

Energy Use and Cash Expenditure on Cast Study Farms.

Among the case study farms total energy inputs in the wet season were highest on 6m pump and gravity irrigated farms, lowest on deep water table and rainfed (Fig. 1). However, there was considerable variation between individual case studies within the same group. In the dry season 6m pump irrigated farms used the most energy, whilst gravity and 14m pump irrigated used similar quantities. About two-thirds of energy used in the wet season came from fossil sources, increasing to four-fifths in the dry season, and utilized a similar or slightly lower proportion of cash expenditure. Dependence on fossil energy sources was highest on pump irrigated farms in the dry season, but in the wet season differences between groups were less marked.

Fertilizer use accounted for the largest single share of fossil energy use on all farms in the wet season, followed by land preparation on gravity irrigated and water supply on pump irrigated (Fig. 2). Fertilizer use also absorbed the largest amounts of pre-harvest cash expenditure on material inputs with the exception of gravity irrigated farms for which crop protection was the most important category. In the dry season fertilizer use accounted for the largest share of both energy and cash expenditure on gravity irrigated farms, whilst water supply accounted for the largest share of both on pump irrigated farms. The correspondence of high fossil energy and cash expenditure for fertilizer and water marks them out as important areas for study.

If all mechanized activities are considered together (cultivation, pumping and threshing), they accounted for the second largest quantity of fossil energy, except on pump irrigated in the dry season where they were the primary user. In terms of cash expenditure on material inputs, mechanization of crop management activities absorbed the highest share on gravity and 6m pump irrigated in both seasons, and on deep water table pump irrigated in the dry.

Productivity of Resource Use on Case Study Farms

In the wet season yields were highest on gravity and 6m pump irrigated farms, and lowest on 14m pump irrigated and rainfed. Output per man-day followed the same pattern (Fig. 3a). In the dry season yields were again highest on gravity irrigated, and very low on 14m pump irrigated (Fig. 3b).

Productivity of fossil and non-fossil energy is a function of the yield and the quantity and mix of energy used to attain it. In the wet season the productivity of both energy source was highest on gravity irrigated farms. Six meter pump irrigated achieved similar levels of productivity in the use of non-fossil but at a lower level for fossil resources compared to gravity irrigated. Fourteen meter pump irrigated and rainfed farms generally achieved lower productivity in the use of both types of resource (Fig. 3c). This trend in the productivity of both fossil and non-fossil resources to decline as environmental potential declines is most clearly seen in the dry season, (Fig. 3d). Where the water table is relatively shallow, the need for large quantities of diesel fuel to provide water constitutes the environmental disadvantage; where it is deeper there may be physical shortages as well as high fuel costs. Fossil energy productivity on gravity irrigated farms was lower in the 1980 dry season than might be expected because the higher yields associated with higher solar radiation at this time of year were not realized.

Financial measures of resource productivity correspond broadly with the trend in physical productivity. Returns above variable costs were generally highest on gravity irrigated and 6m pump irrigated in the wet season and lowest on 14m pump irrigated and rainfed. Returns in the dry season were similar to the wet season except on 14m pump irrigated where they fell greatly (Table 1). The tremendous impact that gravity irrigation has on the potential productivity of current inputs, and the relatively long periods of time over which the benefits can be secured, make the level of such investments a critical policy issue affecting quantity, cost and security of rice supply in the future.

Future impact of rising fossil energy prices.

In attempting to predict a highly uncertain future with regard to energy prices, the experience of the past is a partial guide. During the last decade prices of fossil energy based inputs have risen much faster than the price of rice, but by less than non-fossil inputs. Whilst rice prices have increased in current terms by 123%, urea increased by 190%, and compound fertilizer by 144%.[1] Wages for hired labour use by about 200% and carabao rental by 233%. The cost of material inputs as a proportion of output value across all "loop" survey farms, irrigated and rainfed, rose from 9.4 to 17.4%, despite a 56% increase in yield, and from 16% to 28% of paid out costs (Cordova, et. al. 1981).

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[1]During the rapid increase in world prices of fertilizer (1973-76) subsidies of up to 60% of world market prices were applied by the Philippine government. After that period domestic prices were maintained even though world market prices fell below them. In August 1981, the government withdrew from intervention. Averaged out over the decade domestic prices increased at a slower rate than international prices measured in current terms.

Estimating the impact of rising input prices on costs of production is very complex because of the large number of factors involved. A first step is to look at the effect of projected input prices on existing costs of production. Focusing on material inputs fossil energy "values" are of little help in estimating future prices. This is because fossil energy is not homogenous, taking different values according to the alternative possible uses of the form in which it is embodied (e.g. oil is more expensive per megajoule than natural gas), and because it is not the only factor of production in agricultural input manufacture. Other considerations must be taken into account, such as the input's international market structure in the case of oil. World Bank projections indicate real increases in the price of oil and urea fertilizer of a little under 40% over the next ten years compared to about 20% for rice traded on world markets. This figure, which should be regarded with caution, may tentatively be extended to other chemical products such as herbicides and pesticides, and the operation of machinery, which are based on petroleum products.

The effect of such an increase on existing costs of production depends on the proportion of total variable costs (TVC) accounted for by material inputs, and the corresponding rate of increase in non-fossil input prices and level of substitution between them. Reference to the "loop" survey showed little difference between rainfed and 2 crop gravity irrigated farms in the proportion of TVC accounted for by material inputs. Material inputs accounted for 43% of paid out costs on the former and 37% on the latter (Cordova pers. comm.). Proportionate change in TVC arising from a 40% increase in material input prices would therefore be similar for both groups assuming little substitution between categories of material inputs, or between material inputs and human or animal labour. However, such a change represents 25% of existing rainfed annual returns above variable costs per hectare, as opposed to 16% on double cropped irrigated farms where these returns are already six times higher (Cordova, et al. 1980). If labour continues to increase in price at a faster rate, labour displacing technologies will be sought by farmers (e.g. wet seeding with increased herbicide use as opposed to transplanting) and the proportionate change in TVC due to fossil energy based inputs will be greater.

Pump irrigated farms in the dry season appear more vulnerable to rising fossil fuel prices because of the large quantity of fuel they use in addition to other inputs. Will dry season rice production remain profitable? Table 3 sets out the average returns of 6m pump irrigated and 14m pump irrigated case study farms in the dry season, and compares these returns with different increases in the real price of fuel. The higher rate is used to consider the case when the country's oil supplies might be disrupted, or where other material input prices increase by a similar amount. Fourteen meter pump irrigated farms rapidly deteriorate, and with the recent steep increases

in the price of diesel fuel in the Philippines the majority in the study area have already ceased production in the dry season. Six meter pump irrigated appear to remain quite viable in the short run.

The major factor affecting the viability of dry season pump irrigation therefore appears to be the abundance of groundwater rather than the cost of diesel fuel. With centrifugal pumps this depends on the yield of water for a given depth of drawdown (i.e. suction), and the depth of the dry season water table which determines the maximum drawdown the pump can achieve. The longer term viability of pump irrigation when groundwater is adequate, despite rising diesel fuel prices, has been shown by a recent benefit cost analysis of different types of irrigation system in Central Luzon (Moya, P. 1981). A survey of shallow-tubewell pump investments in the province of Bulacan, where groundwater is more abundant than Nueva Ecija, revealed an internal rate of return of 55.3%; increasing the cost of fuel by 100% resulted in an internal rate of return of 48.8%.

THE ROLE OF MECHANIZATION IN RAISING LEVELS OF RICE PRODUCTION AND FOSSIL ENERGY PRODUCTIVITY

The importance of technological development

When the price of an input or group of input rises relative to other inputs, or to the value of output, there is increased pressure on the farm to improve its partial productivity, i.e. output per unit of input in question. In the absence of technological change, improving the partial productivity of fossil energy use effectively means bringing more land and/or labour into combination with fossil energy based inputs. But this would imply (assuming output prices remain constant) a fall in their partial productivities and therefore yields per hectare or wages. Given the inelastic demand for staple foods however, any shortfall due to lower yields would be followed by rapid increases in the price of rice. The very serious consequences of this have been pointed to by Herdt (1981).

> "If production of food proceeds fast enough to ensure that prices remain constant through 1990, the proportion of the population with inadequate diets will fall, but the absolute number will increase by about 100 million. If food prices increase by as little as 1% per year the number will increase by an additional 50 million."

Given the lack of resources and/or institutional flexibility necessary to protect the poorest sections of the community from this threat, technological development has a critical role in enabling both yields

and the productivity of scarce resources (fossil and non-fossil) to increase. Can mechanization contribute to obtaining this relatively more complex goal?

Technological developments with the potential to further this objective fall into three main categories:

(1) a varietal improvement or husbandry technique which enables a higher level of output to be achieved from a given quantity of resources.

(2) technology which makes possible an increase in cropping intensity, enabling more sunlight and rainfall to be utilized by a given area of land.

(3) technology which enables a scarce and costly resource used in production to be substituted by a relatively more plentiful and cheap one.

In relation to all these categories, there are possibilities for mechanical innovation which need to be investigated by engineers and economists together with other scientists. The remainder of this study focuses on the potential economic viability of a mechanical innovation currently under development - a hand powered liquid fertilizer injector for deep placement of urea - as an example of the first category. Possible mechanical innovations for the remaining two categories are briefly outlined as further research areas.

Ex-ante economic evaluation of a hand powered liquid fertilizer injector.

As we have seen, fertilizer accounts for a major share of farmers' expenditure on fossil energy based inputs, and its price is expected to increase considerably in real terms over the decade. The possibilities for yield increases from deep placement of fertilizer, and the high costs of achieving this by hand, have led to attempts to develop a mechanical method for carrying out the operation. A hand powered, twenty row, liquid fertilizer marker-injector is currently under development in the Agricultural Engineering Department of IRRI. Ordinary urea fertilizer is first dissolved in water to form a 30% solution. The liquid is then carried in a back pack and injected into the root zone via 10 nozzles connected to a peristatic pump by plastic tubing, all mounted on a wooden frame. The solution is injected while the machine is simultaneously marking the field for transplanting before the necessary method of crop establishment with deep placement of fertilizer). The machine is expected to cost less than US$200, including manufacturer's and retailer's mark-up, and have a life of approximately 3 years.

Partial budget analysis was used to assess the potential impact of mechanical injection on the economic viability of deep placement of urea supergranules by hand. Hypothetical performance figures for the machine were compared with results of deep placement obtained in a Laguna INSFFER[1] experiment analyzed by Flinn and Kaiser (1981). Their conventions for partial budget analysis of INSFFER experiments are followed here. In this study, analysis was carried out for a relatively high and a relatively low value variety (IR42 and IR36 respectively), for both owners and share tenants. The latter farm of tenure represents a "worst possible" situation where 50% of the yield remaining after the harvesters have been paid is surrendered to the landlord, and the interest rate on cash borrowed for the purchase of inputs is 100% as opposed to 12% per annum for the owner. The baseline method of fertilizer application against which increments in yield arising from deep placement were measured was the so-called "best split" where two-thirds is applied basally and one-third seven days before panicle initiation. Deep placement of urea by liquid injection was assumed to give the same increment as hand placement of supergranules, a reasonable assumption given the close correspondence of the two techniques in terms of the physical aspects of placement. At a level of 54 kg/ha element nitrogen applied on IR42 a yield increment of 500 kg/ha was achieved with deep placement compared to the "best split" application. A slightly lower increment of 400 kg/ha is assumed for IR36 in the dry season. An increment of 200 kg/ha is assumed for both varieties in the wet season. These estimates assume good weed control - a prerequisite for the technology to be productive. Wet and dry season prices were assumed to be 150$/t and 180$/t for IR42, but 130$ and 150$/t for IR36.

Marginal benefit cost ratios and marginal net benefits were calculated for both methods of placement and tenure situations with existing fertilizer prices, fertilizer prices increased by 50%, labour prices increased by 50%, and both fertilizer and labour prices increased by 50%, to assess the economic viability of the technology under a range of future possible input prices. The marker injector is anticipated to operate under a custom hire arrangement. Alternative rental rates were derived for different labour costs (as above), number of seasons of operation per year (one or two), and machine capacities (one hectare per day versus one half). The assumptions and calculations used in deriving the rental rates are given in Table 4. In evaluating the viability of a technique a marginal benefit cost ratio of 2:1 was assumed to be an adequate incentive for adoption if the yield gains can be attained with reasonable certainty. If not then a marginal benefit cost ratio of 4:1 is deemed necessary. This is important because yield gains from deep placement at present show considerable variability within and between sites. An example of how the marginal benefit cost ratios and net benefits were calculated for the different situations is provided in Table A2.

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[1]International Network on Soil Fertility and Fertilizer Evaluation for Rice.

Results of partial budget analysis.

IR42

In the wet season deep placement of urea by hand does not provide an adequate incentive for adoption of owners, and results in losses for share tenants. The mechanical injector, however, enables deep placement to become a viable technology for owners assuming a rental rate based on two season operation and one hectare per day capacity (Table 5). The technology is viable for share tenants if a reasonable degree of certainty is attached to the gains. If two-man days are required for mechanical injection however, deep placement appears viable only for owners, and only if a reasonable degree of certainty surrounds the gains, particularly at higher fertilizer and/or labour prices.

In the dry season hand placement becomes viable for owners but not for share tenants. However, the decline in the owners' benefit cost ratio with hand placement from 3:1 to 2:1 as fertilizer and/or labour prices rise suggests that adoption of hand placement might not be stable in the longer term. In contrast, a liquid injector with a one hectare per day capacity would provide an adequate cost benefit ratio for owners and tenants even with increases in fertilizer and/or labor prices, and some uncertainty surrounding yield gains (the benefit cost ratios are 8.6 for owner operator and 4.3 for share tenant). If the injector can only achieve one half hectare per day, then while these statements continue to hold for an owner operator (benefit cost of 5), adoption by tenants would be more risky (benefit cost of 2.6).

The capability of an injector to cover one hectare in a day is clearly important. If in the wet season an injector with a capacity of half a hectare per day were only to be adopted by owners as indicated by Table 5, (and only by then with some degree of certainty as to gains) the majority of custom hire operators might have to cover their fixed costs and earn their return solely in the dry season.[2] The rental rate for a half hectare per day machine operating one season per year would still result in a high benefit cost ratio for owners in the dry season. For share tenants however, the technology would become unviable if fertilizer and/or labour prices increased or yield gains were uncertain. Because a transplanting team completes one hectare in a day it is also important that the marker be able to complete this task in the same period to avoid organizational difficulties. The ability to complete one hectare in a day emerges as a key parameter affecting the potential contribution of the injector.

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[2] This would depend upon the relative importance of share tenancy among farms of tenure in an area.

IR36.

Deep placement by hand would not be adopted by owners or share tenants in the wet season (Table 6). A one hectare per day machine makes the technology attractive only for owners, but a half hectare per day machine is unlikely to be adopted if gains are risky or fertilizer and/or labour prices increase.

In the dry season deep placement by hand is attractive for owners if gains are reasonably certain and input prices do not rise. Deep placement by liquid injector provides a much higher benefit cost ratio for owners, and remains viable under conditions of uncertainty or rising input prices. The half hectare per day machine is less attractive, particularly if farmers consider yield gains risky. For share tenants however, even the higher capacity machine provides a barely attractive benefit cost ratio.

For well managed production of high value rice under irrigated conditions, a hand powered liquid fertilizer marker-injector would hypothetically raise the level of adoption of deep placement on both owner operated and share tenanted situations, although a one hectare per day capacity for the machine is vital to the level of success. Under conditions of low prices, the machine would be likely to stimulate adoption by owner operators in both seasons. Although the situations where a liquid injector would have its biggest impact may not be very widespread, the innovation provides an example of how mechanization could raise productivity of scarce resources (fossil and non-fossil) and yields simultaneously.[3]

Two other potential opportunities for increasing yields and/or resource productivity, corresponding to the second two categories of technological development outlined on page are briefly mentioned here as further research areas.

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[3]It should be mentioned in passing that similar developments are underway in the area of crop protection as a result of breakthroughs in the technology for mass production of very accurately machined nozzles permitting more effective and very low volume spraying.

Pump irrigation for multiple cropping

Cropping systems research seeks to increase the efficiency with which the physical resources of an area (land, water, solar radiation) are utilized in agriculture (Zandstra, 1978). Rapid maturing varieties, combined with earlier crop establishment techniques, often permit an extra rice and/or upland crop to be grown. Planting dates become critical, and delays in establishing the second rice and/or upland crop result in serious and progressive declines in yields, and eventually complete crop failure as a result of late season drought stress and/or poor upland crop establishment, (Bolton 1980, Gines, et. al. 1978). Relatively small quantities of supplementary irrigation would be required to avoid or considerably reduce these effects.
This could potentially extend the area where multiple cropping was feasible, greatly reduce the uncertainty surrounding farmer decision-making, and raise incomes (Huysman, pers. comm.). An investigation into the parameters determining the economic viability of investment in supplementary irrigation (taking account of rising fuel prices) in the context of IRRI's cropping systems program has not yet been undertaken. Mixed integer programming has been argued to be an appropriate technique for evaluating the alternative combination of cropping patterns and pumpsets in relation to groundwater supplies (Flinn, 1981). However, because the main benefits would accrue from reduced risk, a careful consideration of its treatment is necessary. Government programs to supply electricity to rural areas, considerably cheaper as an energy source for pumping compared to gasoline or diesel (Fig. 4), present further opportunities in relation to pump irrigation for multiple cropping. Such possibilities now require detailed evaluation.

Utilization of rice hulls

Rice hulls, which account for 20% of threshed grain by weight, represent a considerable energy resource. Their most striking potential application is for use in paddy drying. A study of vertical bin drying by Arboleda, et. al. (1978) revealed that almost 50% of the total annual cost of an advanced conventional dryer operating at capacity would be accounted for by fossil fuel. Rice hull fueled driers situated at rice mills would be assured of a convenient, dry source of fuel, avoiding the logistical problems associated with the utilization of agricultural wastes. However, the authors of a study of rice postproduction systems in the Bicol Region of the Philippines (IRRI 1978) were doubtful that this would stimulate widespread adoption and use in the area. This assessment was based on

- the apparent lack of economic incentives for farmers to dry paddy and of consumer preference for high quality milled rice.

- the low probability that a farmer would need a drier under current cropping patterns. (Increased cropping intensity arising from additional irrigation was expected to change this).

These factors are not universal however, and many farmers experience difficulty in drying wet season paddy.

Following the rapid increases in the price of petroleum products in 1979/80, a project proposal has been drawn up for the design and development of a small scale (15-25 hp) producer gas generator using rice hulls, for use in rice mills (University of California and IRRI, 1981). Corresponding studies are required to assess its potential economic contribution.

CONCLUSIONS

1. Description of resource use and productivity on case study farms from Nueva Ecija in energy and financial terms highlights the importance, both in terms of fossil energy use and cash expenditure of fertilizer use for all farm types, and water supply on pump irrigated farms. The tremendous impact that investment on gravity irrigation has on the potential productivity of current inputs is also clear.

2. Material inputs are expected to rise faster than the price of rice (on world markets) over the next decade. The implied increase in expenditure on inputs based on existing costs of production in Central Luzon, and assuming little substitution between energy sources, represents nearly 25% of existing annual returns above variable costs on rainfed farms and 16% on gravity irrigated.

3. Appropriate technological developments in the field of mechanization in a decade of rising input prices and growing demand for rice will seek to raise yields and the productivity of fossil and other scarce resources simultaneously. Although possibly confined to the better managed gravity irrigated areas, the hand powered liquid fertilizer marker-injector provides an example by its apparent potential to make deep placement of urea fertilizer a more viable technology.

4. Further investigation into parameters determing the economic viability of investment in supplemental irrigation for multiple cropping, and the utilization of rice hulls for drying and other purposes, are needed to assess their potential.

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Table 1. Water availability, land preparation, yield, fossil energy productivity, returns above variable costs on case study farms, 1979-80.

FARM TYPE AND PARCEL NUMBER	WATER AVAILABILITY		LAND PREPARATION TECHNIQUES[a]				YIELD (t/ha)		FOSSIL ENERGY PRODUCTIVITY[b]		RETURNS ABOVE VARIABLE COSTS (US$/ha)	
			WS		DS							
	WS	DS	1C	2C	1C	2C	WS	DS	WS	DS	WS	DS
Gravity Irrig.												
C1	Yes	Yes	2WT	2WT	2WT	2WT	6.9	5.3	5.8	4.3	498	471
G2	Yes	Yes	2WT	2WT	2WT	2WT	4.1	4.7	5.6	2.7	265	366
G3	Yes	Yes	2WT	2WT	4WT	anl.	4.1	4.2	6.5	4.9	516	392
G4	Yes	Yes	2WT	2WT	4WT	anl.	4.8	4.7	8.3	5.3	403	375
G5	Yes	Yes	4WT	anl.	anl.	anl.	5.4	3.7	10.5	9.4	479	439
G6	Yes	Yes	anl.	anl.	anl.	anl.	5.9	5.8	16.0	7.2	651	609
Pump Irrig. (6m)												
P1	Yes	Yes	anl.	anl.	anl.	anl.	5.5	4.9	4.4	3.4	597	578
P2	No	Yes	-[c]	-	anl.	anl.	-	3.6	-	1.2	-	255
P3	Yes	No	2WT/anl.	anl.	-	-	3.1	-	4.7	-	228	-
Pump Irrig. (14m)												
P4	Yes	Yes	anl.	anl.	anl.	anl.	2.2	1.2	5.1	1.9	227	117
P5	No	Yes	-[c]	-	anl.	anl.	-	1.0	-	1.6	-	34
P6	Yes	No	anl.	anl.	-	-	2.1	-	5.8	-	196	-
Rainfed												
R1	No	No	4WT/anl.	anl.			1.6		3.3		109	
R2	No	No	anl.	anl.			3.1		3.7		283	
R3	No	No	4WT	anl.			2.0		3.2		155	
R4	No	No	anl.	anl.			2.0		8.5		198	

NOTES: Wet Season (WS) Dry Season (DS) Primary Cultivation (IC) Secondary Cultivation (2C)

[a] Two-wheel tractor (2WT) -- G1 to G4 2WT are owned.
Four-wheel tractor (4WT) -- all hired.
Animal (anl.) -- a carabao (water buffalo) is used.

[b] Fossil energy productivity (digestible grain energy output/fossil energy input)

Table 2. Utilization of fertilizers, chemicals and petroleum products by agricultural sub-sector in the Philippines (million ₱).

	Paddy	Corn	Coconut	Sugarcane	Banana	Other	Total
Fertilizers[a]	435.7 (30.6%)	167.2 (11.7%)	28.3 (2.0%)	265.8 (18.7%)	171.4 (12.0%)	354.6 (24.9%)	1423.0 (100%)
Chemicals[a]	32.1 (20.4%)	11.3 (7.2%)	16.0 (10.2%)	29.3 (18.6%)	9.4 (6.0%)	59.4 (37.7%)	157.5 (100%)
Petroleum products[b]	10.1 (16.6%)	4.2 (6.9%)	3.5 (5.8%)	27.4 (45.1%)	3.8 (6.3%)	11.7 (19.3%)	60.7 (100%)

[a]1978 input output tables.

[b]1974 input output tables.

Source: National Economic Development Authority (NEDA), Manila Philippines.

Table 3. Returns above variable costs of dry season pump irrigation in different groundwater situations.

Costs and Returns (US$/ha)	6m pump irrigated	14m pump irrigated
Returns above variable costs	416	76
Fuel costs	81	55
Returns if fuel 50% +	384	54
Returns if fuel 100% +	335	21

Table 4. Derivation of rental costs for liquid fertilizer marker injector. (All costs in US$).

	Double season use	Single season use
Machine initial cost[a]	200	200
Fixed costs:		
Depreciation[b]	70	70
Repairs and maintenance (7% p.a.)	14	14
Interest (12% p.a.)	24	24
Total fixed costs per year	108	108
Total fixed costs per season	54	108

	Existing labour costs	Labour costs + 50%	Existing labour costs	Labor costs + 50%
1. Machine fixed costs per hectare[c]	3.60	3.60	7.20	7.20
2. Operators return on capital per hectare[d]	1.80	1.80	3.60	3.60
3. Labour cost per hectare (one hectare per day capacity)	4.00	6.00	4.00	6.00
4. Labour cost per hectare (half hectare per day capacity)	8.00	12.00	8.00	12.00
Rental rates:				
Capacity of machine: one hectare per day (1+2+3)	9.40 $/ha	11.40 $/ha	14.80 $/ha	16.80 $/ha
half hectare per day (1+2+4)	13.40 $/ha	17.40 $/ha	18.80 $/ha	22.80 $/ha

Notes: For comparison the cost of broadcasting fertilizer by the best split method is $2/ha, and $3/ha at the higher labour rate.

[a]Includes manufacturer's and distributor's mark ups (% of total cost)

[b]Three year life, no salvage value, straight-line depreciation.

[c]Assumed rate of operation = 15 hectares per season.

[d]50% assumed. This may be too low. The double season use, high labour cost rental rate ($11.40/ha) may be used as a proxy for low labour cost and 100% rate of return on capital for the operator.

Table 5. Marginal benefit cost ratios of alternative methods of deep placement of 54 kg N/ha under different prices of labour and fertilizer, and different machine capacities. Variety = IR42.[d]

	Owner				Share tenant			
	A	B	C	D	A	B	C	D
Wet season								
Hand placement	1.6	1.4	1.1	1.0	0.7	0.6	0.5	0.4
Liquid injector[a]	4.1	4.1	3.6	3.6	2.0	2.0	1.8	1.8
Liquid injector[b]	2.6	2.6	2.1	2.1	1.3	1.3	1.0	1.0
Dry season								
Hand placement	3.1	2.7	2.3	2.1	1.6	1.3	1.2	1.0
Liquid injector[a]	9.7	9.7	8.6	8.6	4.9	4.9	4.3	4.3
Liquid injector[b]	6.3	6.3	5.0	5.0	3.2	3.2	2.6	2.6
Liquid injector[c]	4.3	4.3	3.6	3.6	2.1	2.1	1.8	1.8

Marginal net benefits (US$/ha) arising from alternative methods of deep placement of 54 kg N/ha under different prices of labour and fertilizer, and different machine capacities. Variety = IR42

	Owner				Share tenant			
	A	B	C	D	A	B	C	D
Wet season								
Hand placement	11	9	3	1	-8	-12	-16	-20
Liquid injector[a]	22.6	22.6	21.6	21.6	7.6	7.6	6.6	6.6
Liquid injector[b]	18.6	18.6	15.6	15.6	3.6	3.6	0.6	0.6
Dry season								
Hand placement	53	51	45	43	13	9	5	1
Liquid injector[a]	64.6	64.6	63.6	63.6	28.6	28.6	27.6	27.6
Liquid injector[b]	60.6	60.6	57.6	57.6	24.6	24.6	21.6	21.6
Liquid injector[c]	55.2	55.2	52.2	52.2	19.2	19.2	16.4	16.4

A: 1980 prices for labour and fertilizer B: Fertilizer cost increased by 50% C: Labour cost increased by 50%
D: Labour and fertilizer cost increased by 50%

[a]Rental rate of $9.40/ha (and $11.40/ha for higher labour rate) based on 2 seasons per year utilization and one hectare per day capacity. [b]Rental rate of $13.40/ha (and $17.40/ha for higher labour rate) based on 2 seasons per year utilization and half hectare per day capacity. [c]Rental rate of $18.80/ha (and $22.80/ha for higher labour rate) based on 1 season per year utilization and half hectare per day capacity. [d]Wet season price=150$/t
Dry season price=180$/t

Table 6. Marginal benefit cost ratios of alternative methods of deep placement of 54 kg N/ha under different prices of labour and fertilizer, and different machine capacities. Variety = IR36[d]

	Owner				Share tenant			
	A	B	C	D	A	B	C	D
Wet season								
Hand placement	1.4	1.2	1.0	0.9	0.6	0.5	0.4	0.4
Liquid injector[a]	3.5	3.5	3.1	3.1	1.8	1.8	1.5	1.5
Liquid injector[b]	2.3	2.3	1.8	1.8	1.1	1.1	0.9	0.9
Dry season								
Hand placement	2.4	2.1	1.7	1.6	0.7	0.6	0.5	0.4
Liquid injector[a]	6.1	6.1	5.4	5.4	2.0	2.0	1.8	1.8
Liquid injector[b]	3.9	3.9	3.1	3.1	1.3	1.3	1.0	1.0
Liquid injector[c]	2.7	2.7	2.3	2.3	0.9	0.9	0.8	0.8

Marginal net benefit (US$/ha) arising from alternative methods of deep placement of 54 kg N/ha under different prices of labour and fertilizer, and different machine capacities.

	Owner				Share tenant			
	A	B	C	D	A	B	C	D
Wet season								
Hand placement	7	5	-1	-3	-10	-14	-18	-22
Liquid injector[a]	18.6	18.6	17.6	17.6	5.6	5.6	4.6	4.6
Liquid injector[b]	14.6	14.6	11.6	11.6	1.6	1.6	-1.4	-1.4
Dry season								
Hand placement	26	24	18	16	-8	-12	-16	-20
Liquid injector[a]	37.6	37.6	36.6	36.6	7.6	7.6	6.6	6.6
Liquid injector[b]	33.6	33.6	36.6	30.6	3.6	3.6	0.6	0.6
Liquid injector[c]	28.2	28.2	25.2	25.2	-1.8	-1.8	-48	-48

A: 1980 prices for labour and fertilizer B: Fertilizer cost increased by 50% C: Labour cost increased by 50%
D: Labour and fertilizer cost increased by 50%.

[a]Rental rate of $9.40/ha (and $11.40/ha for higher labour rate) based on 2 seasons per year utilization and one hectare per day capacity. [b]Rental rate of $13.40/ha (and $17.40/ha for higher labour rate) based on 2 seasons per year utilization and half hectare per day capacity. [c]Rental rate of $18.80/ha (and $22.80/ha for higher labour rate) based on 1 season per year utilization and half hectare per day capacity. [d]Wet season price = 130$/t
Dry season price = 150$/t

Table A.1. Resources, products, energy values and current relative prices.

Input	Unit	Unit Price[a] (₱)	Fossil (MJ)	Non-Fossil (MJ)	₱/100 MJ
Electricity	K Whe	Max. 0.50[b]	14.4	-	3.5
Gasoline	liter	5.00	39.7	-	12.0
Diesel	liter	3.00	43.3	-	6.9
4 WT	hour	87.50 (hire)	40 + 300[c]	-	25.7
2 WT	hour	12.50 (hire)	11 + 39[c]	-	25.0
Pump	hour	8.00 (hire)	7 + 43[c]	-	20.0
Thresher	hour		60 + 130[c]	-	
Animal	hour	1.5 (hire)	-	10.5	14.3
Man	hour	1.0	-	1.0	100.0
Seed	kg	1.5	-	18.5[d]	8.1
N	kg		84.5	-	
Urea	kg	2.2	39	-	5.7
P	kg		14.0	-	
K	kg		11.0	-	
14-14-14	kg	2.0	14.4	-	13.9
Insecticide	kg ai	100-300	360	-	28-83
Herbicide	kg ai	60-120	360 (dust) 420 (liquid)	-	17-33

Product	Price (₱/kg)	MJ/Kg	₱/100 MJ
Paddy (milled rice equivalent)	1.5 (high quality)	10.26	14.62
" " "	1.36 (med. ")	10.26	13.25
Paddy (brown rice equivalent)		11.72	
Paddy (entire)		14.24	
Brown (10% paddy)	0.4	14.65	2.73
Hulls (20% paddy)	0	12.77	0

[a] Approximate prices, Nueva Ecija, Philippines, 1980-81.
[b] For comparison only. Access limited in rural areas.
[c] Depreciation + fuel.
[d] Includes fossil energy used in production at 3.4:1 total energy productivity.

Table A2.1. Partial budget analysis of alternative methods of deep placement of 54 kg N[a] with different prices for labour and fertilizer, for owners and share tenants.

	WET SEASON											
	Best split				Hand placement[c]				Liquid injector[b]			
	A	B	C	D	A	B	C	D	A	B	C	D
Gross yield (t/ha)	4.9	4.9	4.9	4.9	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Net yield:[d] owner operator	4.1	4.1	4.1	4.1	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
share tenant	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Gross field benefit[e] ($)												
owner operator	615	615	615	615	645	645	645	645	645	645	645	645
share tenant	315	315	315	315	330	330	330	330	330	330	330	330
Marginal field benefit[f]												
owner operator	n.a.	n.a.	n.a.	n.a.	30	30	30	30	30	30	30	30
share tenant	n.a.	n.a.	n.a.	n.a.	15	15	15	15	15	15	15	15
Variable money cost ($/ha)												
Fertilizer: owner	38	57	38	57	42	63	42	63	38	57	38	57
share tenant	66	99	66	99	74	111	74	111	66	99	66	99
Placement cost	2	2	3	3	17	17	26	26	9.4	9.4	11.4	11.4
Total variable costs: ($/ha)												
owner operator	40	59	41	60	59	80	68	89	47	66	49	68
share tenant	68	101	69	102	91	128	100	137	75	108	77	110
Marginal variable costs[g] ($)												
owner operator	n.a.	n.a.	n.a.	n.a.	19	21	27	29	7.4	7.4	8.4	8.4
share tenant	n.a.	n.a.	n.a.	n.a.	23	27	31	35	7.4	7.4	8.4	8.4
Net field benefit[h]												
owner operator	575	556	574	555	586	565	577	556	598	579	596	577
share tenant	247	214	246	213	239	202	230	193	255	222	253	220
Marginal benefit cost[i]												
owner operator	n.a.	n.a.	n.a.	n.a.	1.6	1.4	1.1	1.0	4.1	4.1	3.6	3.6
share tenant	n.a.	n.a.	n.a.	n.a.	0.7	0.6	0.5	0.4	2.0	2.0	1.8	1.8
Marginal net benefit[j]												
owner operator	n.a.	n.a.	n.a.	n.a.	11	9	3	1	22.6	22.6	21.6	21.6
share tenant	n.a.	n.a.	n.a.	n.a.	-8	-12	-16	-20	7.6	7.6	6.6	6.6

A: 1980 costs for labour and fertilizer
B: Fertilizer cost increased by 50%
C: Labour cost increased by 50%
D: Labour and fertilizer cost increased by 50%

Table A2.2. Partial budget analysis of alternative methods of deep placement of 54 kg N[a] with different prices for labour and fertilizer, for owners and share tenants.

	DRY SEASON											
	Best split				Hand placement[c]				Liquid injector[b]			
	A	B	C	D	A	B	C	D	A	B	C	D
Gross yield (t/ha)	4.9	4.9	4.9	4.9	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Net yield[d]: owner operator	4.1	4.1	4.1	4.1	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
share tenant	2.1	2.1	2.1	2.1	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Gross field benefit[e] ($)												
owner operator	738	738	738	738	810	810	810	810	810	810	810	810
share tenant	378	378	378	378	414	414	414	414	414	414	414	414
Marginal field benefit[f]												
owner operator	n.a.	n.a.	n.a.	n.a.	72	72	72	72	72	72	72	72
share tenant	n.a.	n.a.	n.a.	n.a.	36	36	36	36	36	36	36	36
Variable money cost ($/ha)												
Fertilizer: owner operator	38	57	38	57	42	63	42	63	66	99	66	99
share tenant	66	49	66	49	74	111	74	111	9.4	9.4	11.4	11.4
Placement cost	2	2	3	3	17	17	26	26	9.4	9.4	11.4	11.4
Total variable cost ($/ha)												
owner operator	40	59	41	60	59	80	68	89	47	66	49	68
share tenant	68	101	69	102	91	128	100	137	75	108	77	110
Marginal variable costs[g] ($/ha)												
owner operator	n.a.	n.a.	n.a.	n.a.	19	21	27	29	7.4	7.4	8.4	8.4
share tenant	n.a.	n.a.	n.a.	n.a.	23	27	31	35	7.4	7.4	8.4	8.4
Net field benefit[h]												
owner operator	698	679	697	715	751	730	742	721	763	764	761	742
share tenant	310	277	309	276	323	286	314	277	339	306	337	304
Marginal benefit cost[i]												
owner operator	n.a.	n.a.	n.a.	n.a.	3.1	2.7	2.3	2.1	9.7	9.7	8.6	8.6
share tenant	n.a.	n.a.	n.a.	n.a.	1.6	1.3	1.2	1.0	4.9	4.9	4.3	4.3
Marginal net benefit[j]												
owner operator	n.a.	n.a.	n.a.	n.a.	53	51	45	43	64.6	64.6	63.6	63.6
share tenant	n.a.	n.a.	n.a.	n.a.	13	9	5	1	28.6	28.6	27.6	27.6

A: 1980 costs for labour and fertilizer
B: Fertilizer cost increased by 50%
C: Labour cost increased by 50%
D: Labour and fertilizer cost increased by 50%

Notes for tables A2.1 and A2.2

[a]Yield, labour and fertilizer cost data taken from a Laguna INSFFER experiment, dry season 1981 reported in Flinn + Kaiser (1981)

[b]Yield of liquid fertilizer injector assumed to be the same as urea supergranule hand placed.

[c]Urea supergranule assumed to be 110% of prilled urea price.

[d]Gross yield less harvester's share and landlord's share (in the case of share tenant).

[e]Net yield multiplied by price. ($150/t in wet season, $180/t in dry season).

[f]Gross field benefit with deep placement less gross field benefit with best split.

[g]Variable costs with deep placement less variable costs with best split.

[h]Gross field benefit less total variable costs.

[i]Marginal field benefit divided by marginal variable cost.

[j]Net field benefit with deep placement less net field benefit with best split.

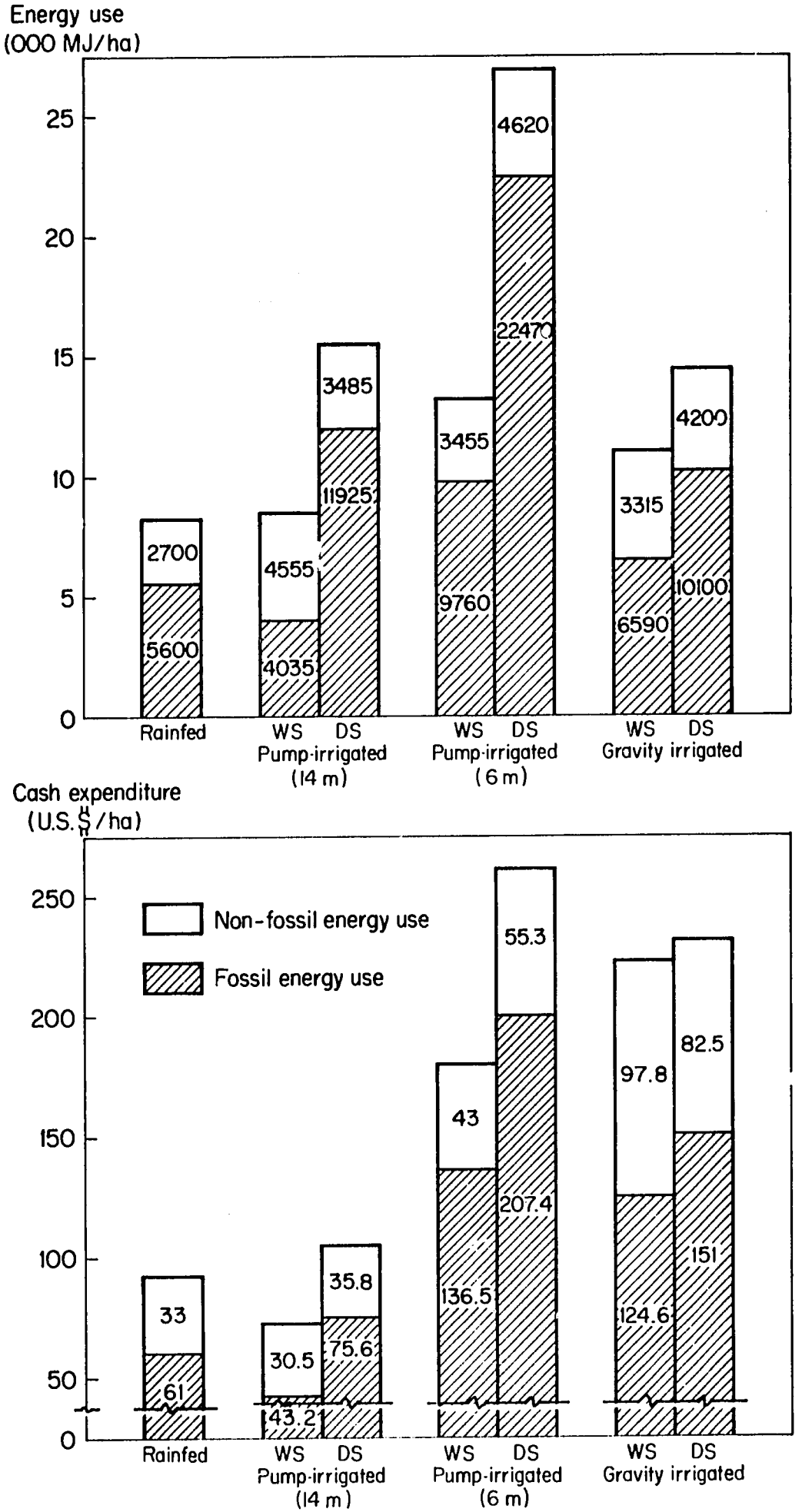

Fig. 1. Energy use and cash expenditure by energy source on case study forms for wet 1979 and dry 1980 seasons.

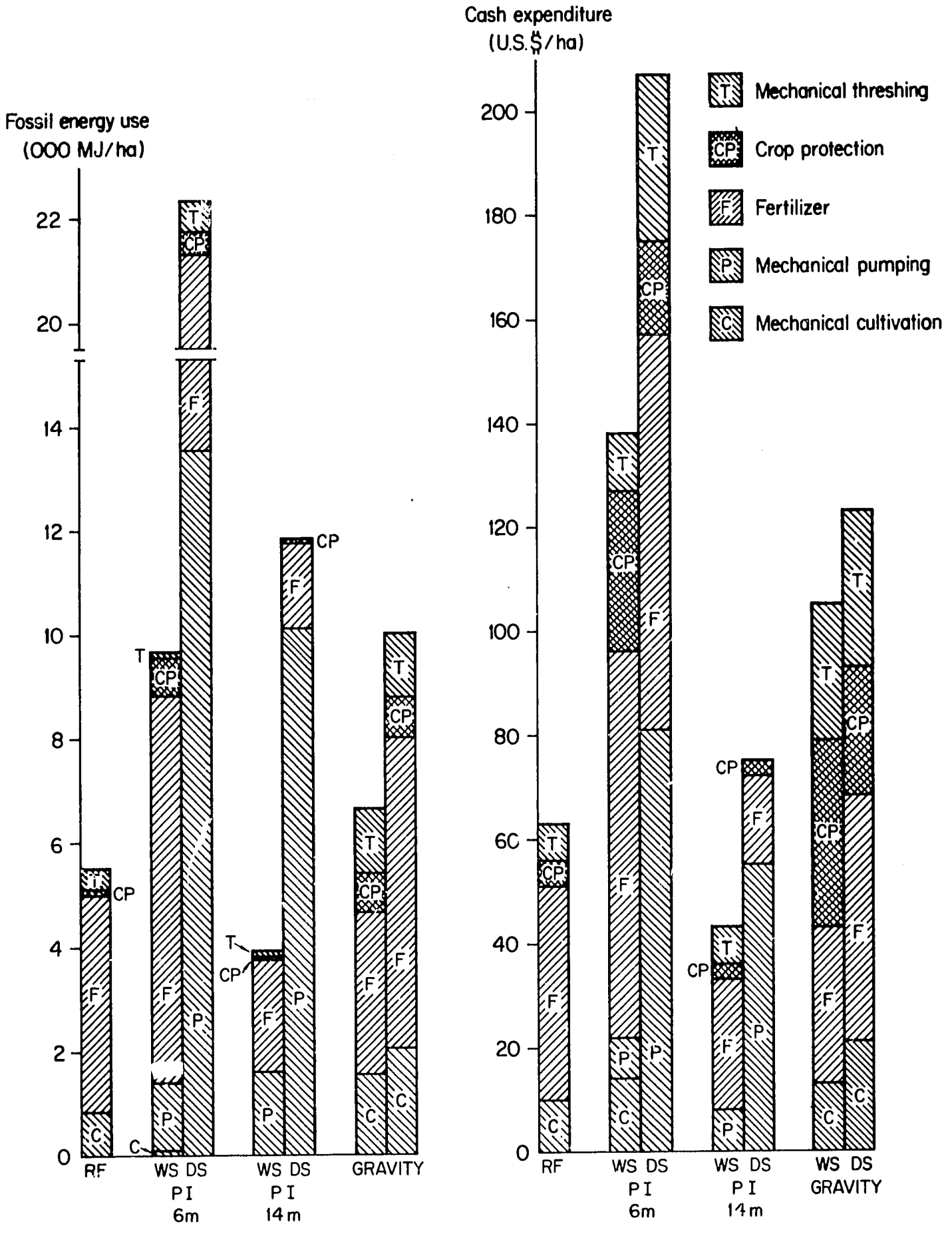

Fig. 2. Fossil energy use and cash expenditure by crop management activity for wet 1979 and dry 1980 seasons.

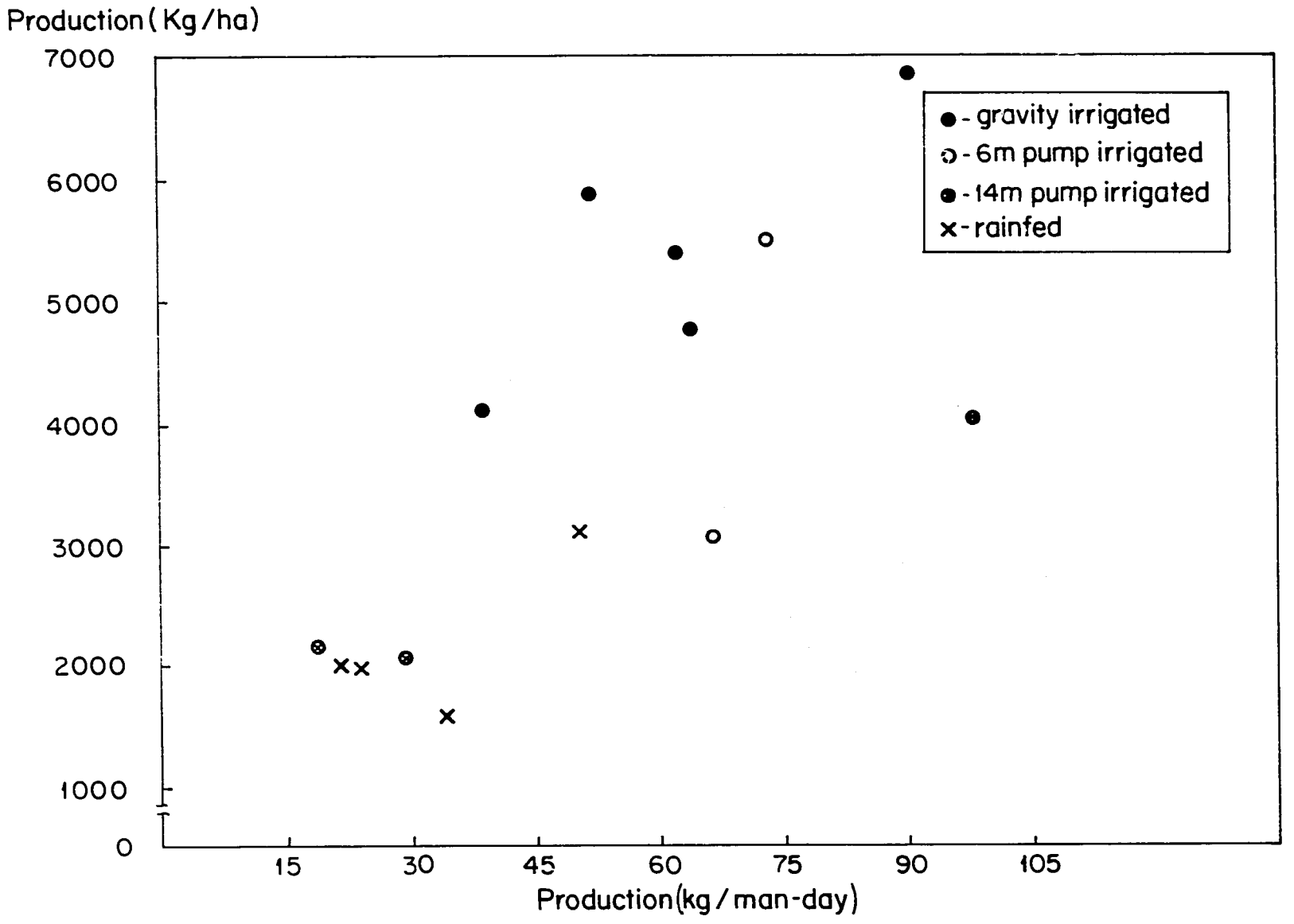

Fig. 3a Output of rice per hectare and per man-day on case study farms, wet season 1979.

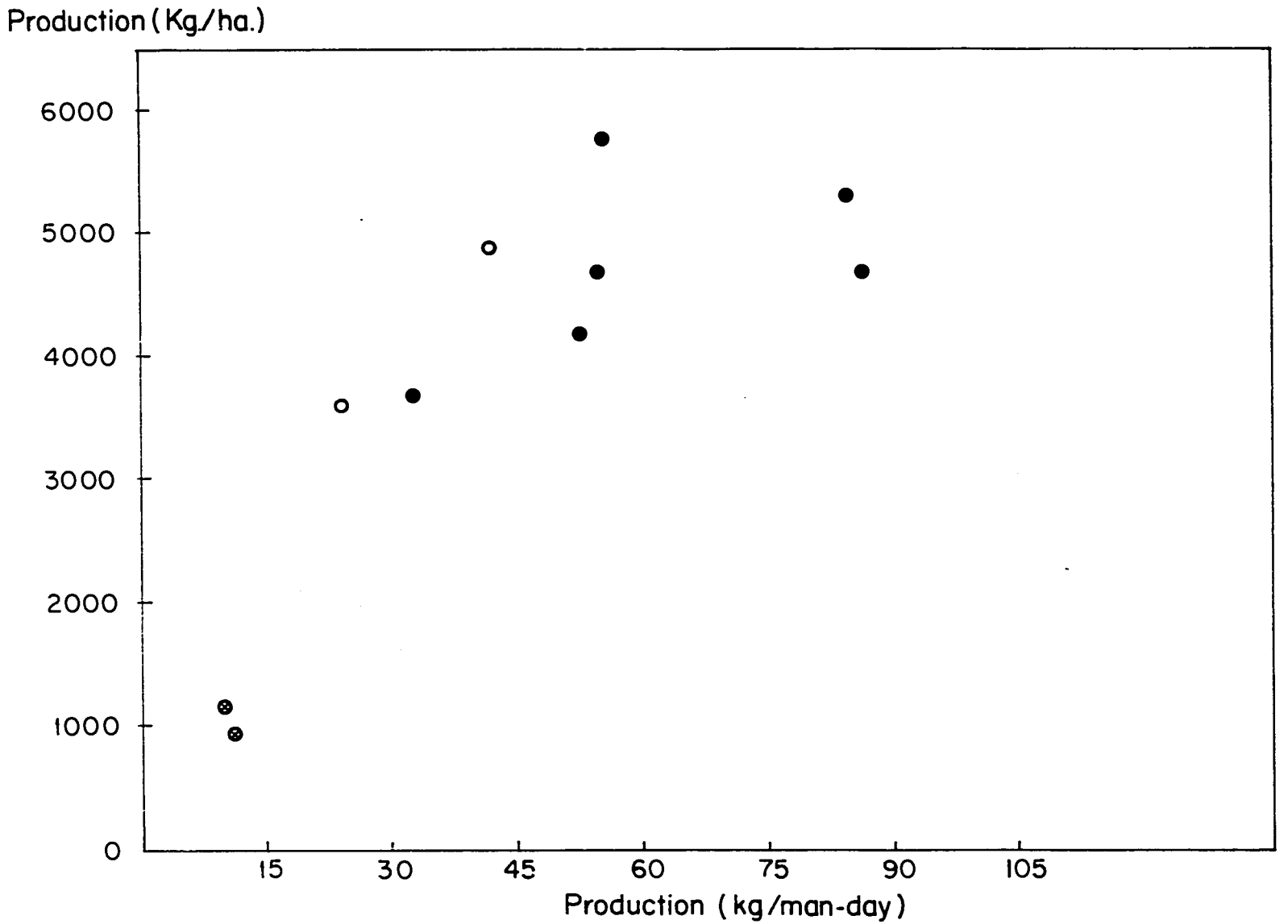

Fig. 3b Output of rice per hectare and per man-day on case study farms, dry season 1980.

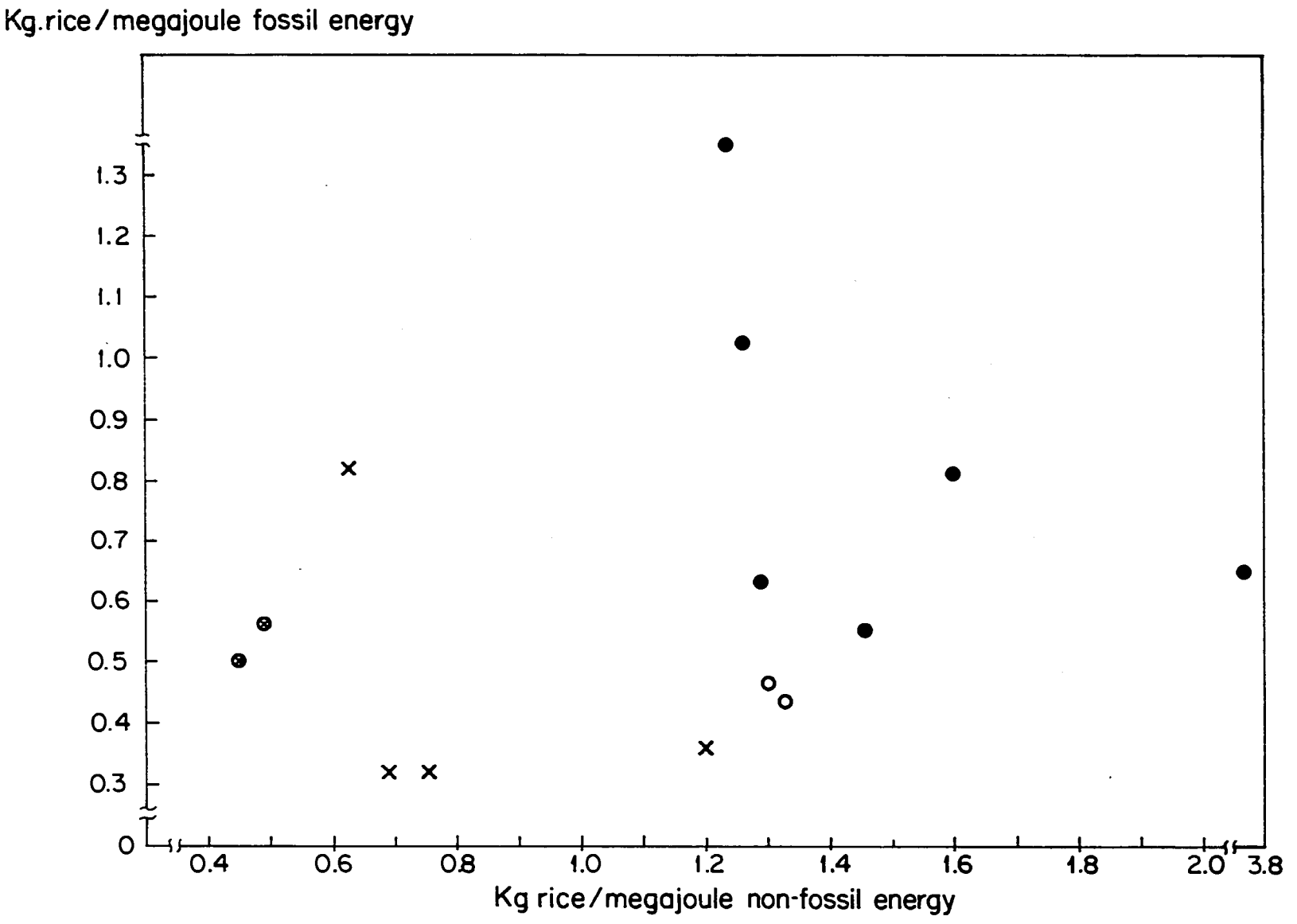

Fig. 3c Output of rice per megajoule of fossil and non-fossil energy, wet season 1979

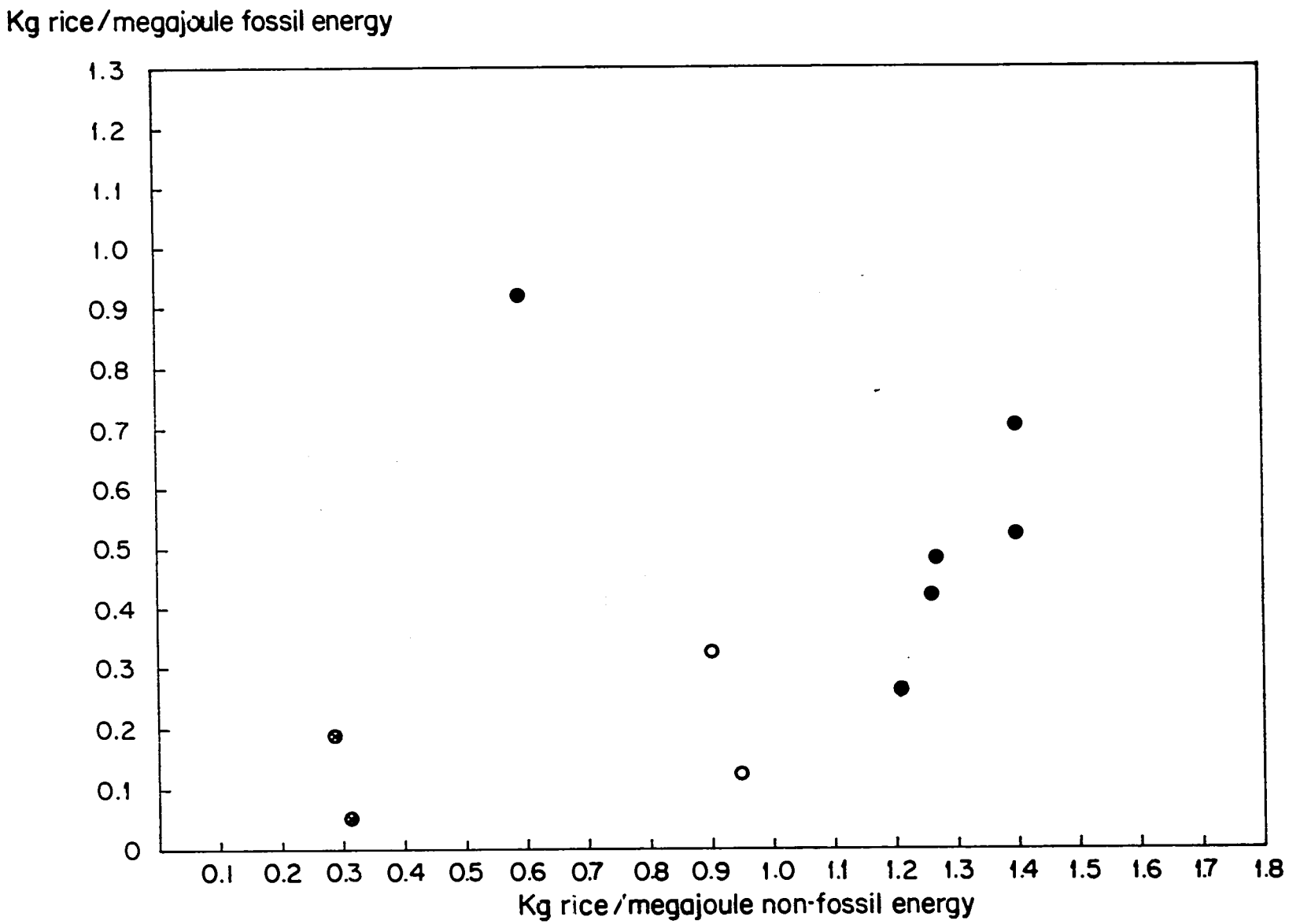

Fig. 3d Output of rice per megajoule of fossil and non-fossil energy, dry season 1980.

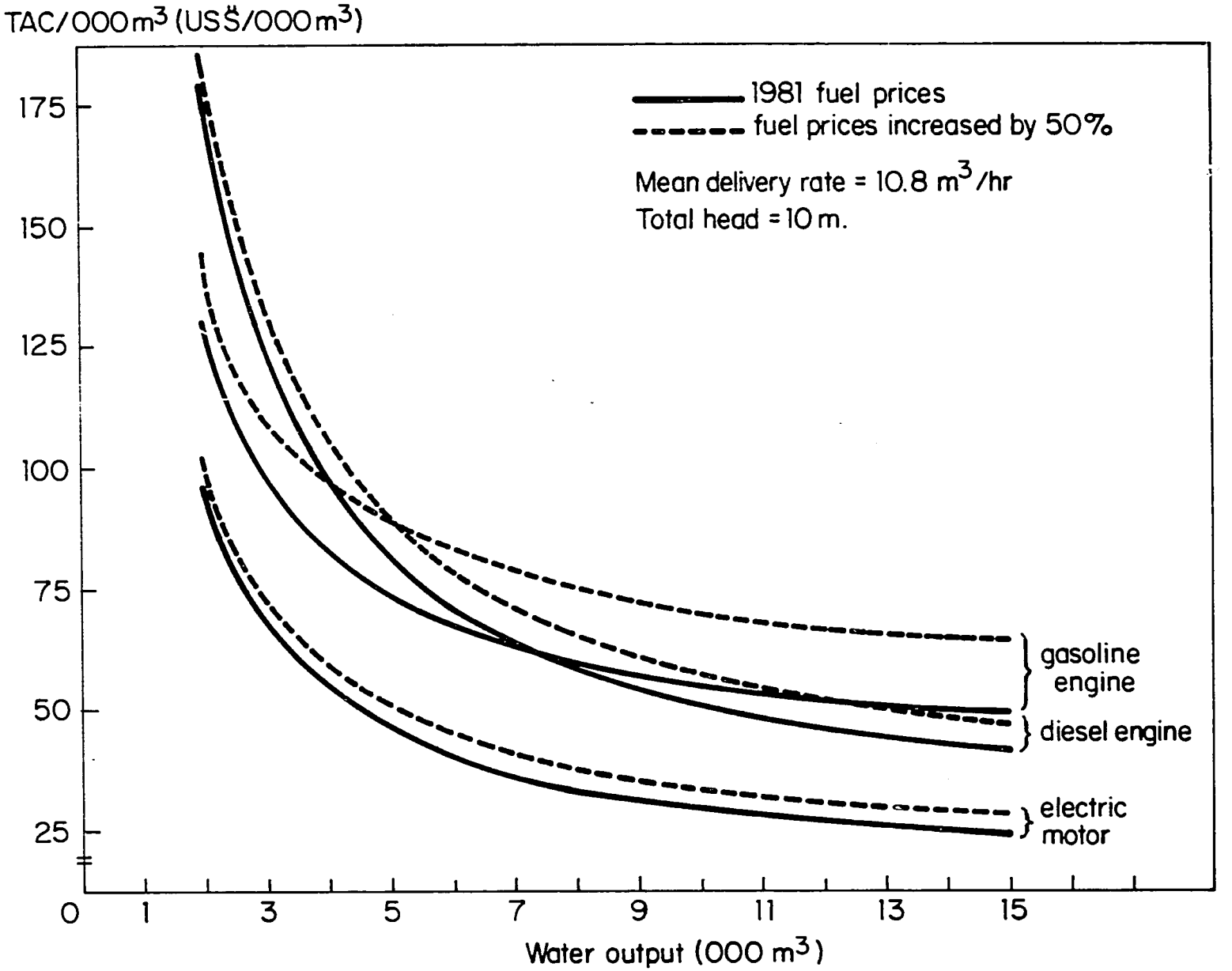

Fig. 4. Comparative total average cost/000 m^3 water output from a 1981 shallow tubewell investment in Pangasinan, Philippines with alternative prime movers.