Socio-Technical issues in Diversifying Rice-based Irrigation Systems

Tolentino B. Moya and Senen M. Miranda[1]

Abstract

Since the early 60s many rice-producing countries in Asia have launched agricultural diversification projects to stimulate farm productivity. However, these projects have succeeded in only a few countries. Perhaps, the pressures to diversify agriculture, especially the irrigated rice systems, were less compelling then than today.

At present, the water supply scarcity in rice-based irrigation systems and the low price of rice in the world market will constrain irrigation personnel and farmers to veer away from monoculture rice systems. As rice irrigation systems can hardly maintain productivity and equity under limited water supplies, they will diversify into less waterdemanding non-rice crops. Similarly, as fanners continue to reel under low profits, sometimes losses, from rice farming, they will consider crop diversification.

This paper examines the driving and restraining forces in crop diversification, especially in irrigated rice-based systems. Technical, social and institutional issues in crop diversification are being presented to provide insights on (1) how existing rice-based irrigation systems can be operated or rehabilitated to permit cropping systems flexibilities and/or (2) designing and constructing new rice-based irrigation schemes for crop diversification.

Background

Most rice-based irrigation systems in Asia experience limited water supplies because of the combined effects of erratic climatic behavior, overcommitted water supplies, and deteriorated physical facilities and structures. Erratic climatic behavior has greatly reduced the amount of rainfall resulting in unfilled reservoirs, subsiding river regimes and receding groundwater level. Some irrigation systems experience tight water supplies because their service area are larger than what the expected water supplies can adequately provide for. Or, the predicted water supplies have been committed to a number of competing uses, as in multipurpose irrigation projects.

Confounding the scarcity of system water supplies are rundown physical facilities and structures. Many broken and inoperable structures and facilities clutter rice irrigation systems, so that much less water supply can be captured and transported resulting to low efficiency. The structural capability of many irrigation systems has, indeed, deteriorated that the high physical control required for handling limited water supplies to competing uses is difficult to produce.

The foregoing instances indicate alteration of the original hydraulic regime on which design and operation of irrigation systems has been based. To manage hydraulic changes, a few well-operating systems, like the old farmer-managed systems, complement structural control deficiency with organizational capability. Most likely, these systems have already attained internal and external operational homeostasis, which other irrigation systems find elusive to achieve.

Meanwhile, advances in rice-based production technologies have benefited not only the adequately-watered environment but also the less-watered environment. As a result, rice production

[1]Pre-doctoral Fellow and Senior Scientist, respectively, The International Irrigation Management Institute, Digana Village via Kandy, Sri Lanka.

has risen to a level that reduces price of rice in the world market. To keep rice price from further deterioration, monoculture rice fanners should diversify into non-rice crops?

Non-rice crops are less waterdemanding. To harvest a field of non-rice crops may require much less total water than an equal field of flooded rice. Non-rice crops can maintain physiological growth with water as low as one-fourth to one-third of that supplied to rice.

Because of low field water requirement and moderate tolerance to water deficits, non-rice crops can be a means to maintain productivity and equity of irrigation systems with limited water supplies. Government planners and irrigation practitioners are considering crop diversification, now as a vehicle of sustainable agricultural development.

Technical Issues

Technical issues in crop diversification in rice-based irrigation systems originate from the intricate and differential relationships among edaphic, climatic, hydrologic, biotic and agronomic properties of flooded rice environment and dryland non-rice production systems. The technical and operational properties endogenous to rice-based irrigation systems add to the complexity. This section starts with technical issues relating to basic soil-plant-water relations.

Soil-Plant-Water Relations

Plants. Most terrestrial plants, except rice, need aerated soil for growth and development. Rice can harness oxygen directly from the atmosphere through its hollow stem and supply it to its roots at a rate sufficient to sustain respiration under submerged soil conditions (Van Raalte, 1956; Jensen et al., 1967; Yoshida, 1981; Kramer, 1983). Rice can perform anaerobic respiration, too (Johnson et al., 1974). But due to rice's ability to fully oxidize rhizosphere with atmospheric oxygen, flooded rice develops shallow root system, about 20 cm for lowland rice (OToole and Chang, 1978).

Shallow root system partly explains rice's susceptibility to drought, particularly at soil moisture below saturation (IRRI, 1972; Wickham, 1973a; Wickham, 1974; Wickham and Sen, 1978). On the contrary, rice can tolerate excess water, ranging from saturation to 15-cm submergence; water above 15 cm depresses rice yield (De Datta and Williams, 1968; Williams, 1969).

Owing to physiological characteristics, keeping the soil flooded is the most logical water management strategy for rice.

Unlike rice, the above-ground parts of non-rice crops cannot fully supply the oxygen requirements for normal respiration. Non-ricecrops, must therefore, obtain additional amounts of oxygen from the soil to augment the amount tapped from the atmosphere. To satisfy another growth process, photosynthesis, non-rice crops also need soil water. Thus, for normal growth and development, non-rice crops require favorable air-water balance in the soil. Waterlogging, as well as water deficits, will seriously injure non-rice crops.

Only a deep well-drained soil can satisfy the soil air-water requirements of non-rice crops. Air-water balance in the soil is affected by soil physical properties, particularly soil texture and soil structure.

Soils. Non-rice crops require an approximate soil tilth — one that is adequately aerated but sufficiently water-retentive. Since it highly influences air and water transmission capacity of soils, soil texture limits soil tilth (Hillel, 1982; Kramer, 1983; Hausenbuiller, 1978).

Soils with more sand separates permit higher air and water mobility. Sandy soils have good infiltration, internal drainage, and aeration capacities but have low water-retention capacity'. On the other hand, the high clay content of some soils impedes water movement. Consequently, clay soils have low infiltration and poor internal drainage that restrict aeration capacity. So, clay soils have high water-retention capacity. Because soil texture is a permanent soil physical property, it can be a determinant of soil tilth, and thus of non-rice crop cultivation.

Managing structure of rice soils relaxes aeration and tillage constraints that soil texture poses

[2]Non-rice crops, diversified crops, upland crops, highland crops and dryland crops are interchangeably used to denote crcps that grow and produce best in aerobic soil conditions.

'The aeration capacity of a soil indicates its potential for free gas exchange with the atmosphere. It must not be confused with soil porosity which is the volume fraction of gas to the total soil volume. The larger proportion of macropores rather than the total porosity is more important for air and water mobility in the soil. See Donahue, *et* al. (1977), Hillel (1982), and Hausenbuiller (1978).

to non-rice crop cultivation. Soil structure refers to the size, shape, and arrangement of soil particles to form compound particles and the size, shape, and arrangement of compound particles (Donahue et al., 1977; Brewer and Sleeman, 1960).

From agronomic viewpoint, crops to be planted depend on soil structure. Puddled soil has the best structure for growing rice because it restricts water movement (Sanchez, 1978b; De Datta and Sharma, 1980). Only with adequate drainage or after thorough land preparation can non-rice crops grow on previously puddled soils since they are intolerant of waterlogging, particularly at establishment and reproductive periods (Pereira, 1956; Herrera, et al., 1980).

Soil structure partly determines soil workability or trafficability. Wet puddled soils have poor trafficability when tilled for upland crops. When dry, puddled soils are too massive or heavy to he prepared well. So, puddled soils, due to poor workability prolong turnaround time — the period that lapses between any two successive crop cultivations. On account of poor workability of puddled soils, the potential of an extended growing period, which crop production technologies made possible, is foregone.

Technical and Operational Attributes of Rice-Based Irrigation Systems

Water productivity. Under similar atmospheric demands, soil and water management practices, and growth duration, rice and non-rice crops require equal amounts of water to fully mature (FAO, 1979; Wickham and Sen, 1978). Rice, peanut, onions, soybeans, tobacco and tomato can fully mature with 350-750 mm of water under controlled environment (Table 1).

Under controlled conditions, the consumptive *use efficiency* of rice ranges from 0.70-1.10 kg/m^3 (FAO, 1979).

However, productive efficiency of crops is more important than consumptive use efficiency.[1]

***Table* 1.** Basic water requirements of rice and some dryland crops

Crop	Growing period (day)	Basic water** requirements (mm)	Water productivity (Kg/m^3)	Yield	Moisture (%)
Rice	90-150	350- 700	0.7- 1.1	paddy	15-20
Peanut	90-140	500- 700	0.6- 0.8	unshelled nut	15
Corn	100-140	500- 800	0.8- 1.6	grain	10-13
Onion	100-140*	350- 550	8.0-10.0	bulb	85-90
Sorghum	100-140	450- 650	0.6- 1.0	grain	12-15
Soybean	100-130	450- 700	0.4- 0.7	grain	6-10
Sugarcane	270-365	1500-2500	0.6- 1.0	sugar	0
Sunflower	90-130	600-1000	0.3- 0.5	seed	6-10
Tobacco	90-120*	400- 600	0.4- 0.6	cured leaves	5-10
Tomato	90-140*	400- 600	10.0-12.0	fresh fruit	80-90

*Plus about one month nursery period
**Evapotranspiration
Source: Food and Agriculture Organization of the United Nations (FAO). 1979. Yield response to water. Rome.

[1]Consumptive use efficiency is the ratio of a crop's economic yield to its total evapotranspiration demand. On the other hand, productive efficiency is the ratio of a crop's economic yield to the total field water use.

Moya and Murray-Rust **(1985)** compared the seasonal productive efficiency of rice in different types of Philippine irrigation systems (Figure 1). For wet season rice, productive efficiency does not significantly differ among types of system, about 0.20 kg/m^3. For dry season **rice,** productive efficiency varies among types of system, fluctuating from 0.12 kg/m^3 for diversion systems to 0.42 kg/m^3 for a deepwell system, like P-27 in Guimba, Nueva Ecija, Philippines?

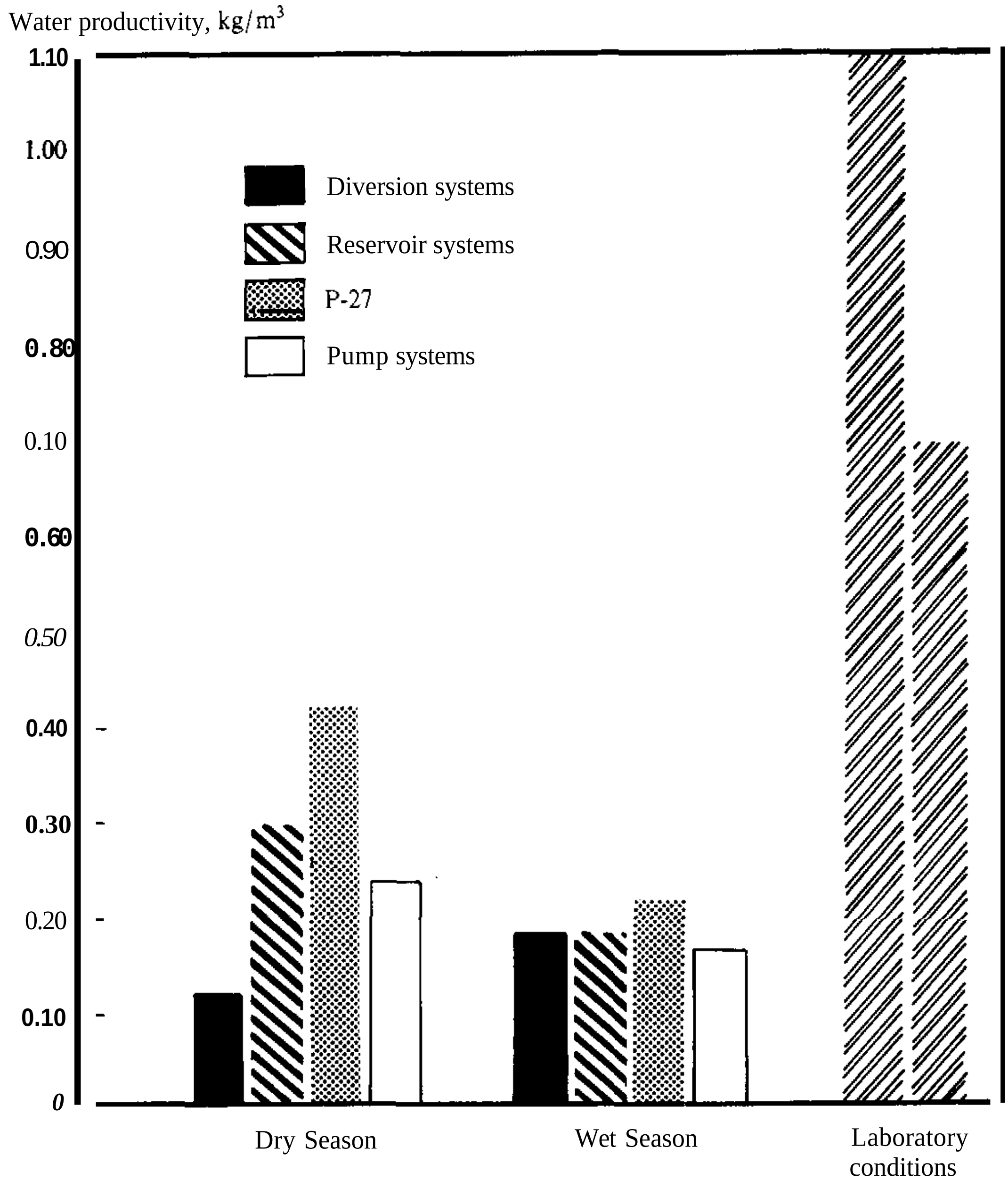

Figure 1. Comparative rice yields per unit of water supplied, different types of irrigation system and under ideal conditions.

'The low productive efficiency of diversion systems was attributed to the conservative estimates of serviceable area and to the preoccupation to reduce area to maintain high relative water supply.

Productive efficiency of field rice did not even equal one-half of consumptive use efficiency. The efficiency gap indicates possibilities for increasing water productivity of irrigated rice-based systems.

The same study reported that productive efficiency of dry season corn in P-27 was nearly three times that of rice (Figure **2).** Furthermore, consumptive use efficiency of corn was about four times the productive efficiency of rice. Therefore, productivity of limited water supplies in irrigation systems will increase by cultivating corn — and other non-rice crops.

The rice's physical environment. As a compromise between cost of irrigation development and size of command area, rice-specific irrigation systems are generally situated on heavy soils (Wickham and Takase, 1978). The maximum area that can he commanded at the lowest cost are the flat lands which are usually situated on deltas and floodplains with heavy clay soils. Similarly, phreatic **or** fluxial lands are usually found on these landforms.

Although heavy clay soils with seepage and percolation (S&P) rate of up **to** 3 mm/day dominate most irrigated rice systems (Wickham and Sen, 1978), soils with good internal drainage can he also found. Soil with good drainage exists in the Chin-nan Irrigation Scheme in southern Taiwan (Hai-Shen, 1987). Ninety-two percent of Chin-nan service area rests on sandy loam to silt loam soils: the remaining 8% on clay soils.

Dual and diversified land classes are found in irrigation systems in the Philippines (NIA, 1976). Dual lands provide good soil environment **for** growing rice during the wet season and non-rice crops during the dry season. The rate of S&P in dual lands is high but does not exceed 8 mm/day. On the other hand, diversified lands can be planted to non-rice crops during both wet and dry seasons. The rate of **S&f** in diversified lands is greater than 8 mm/day.

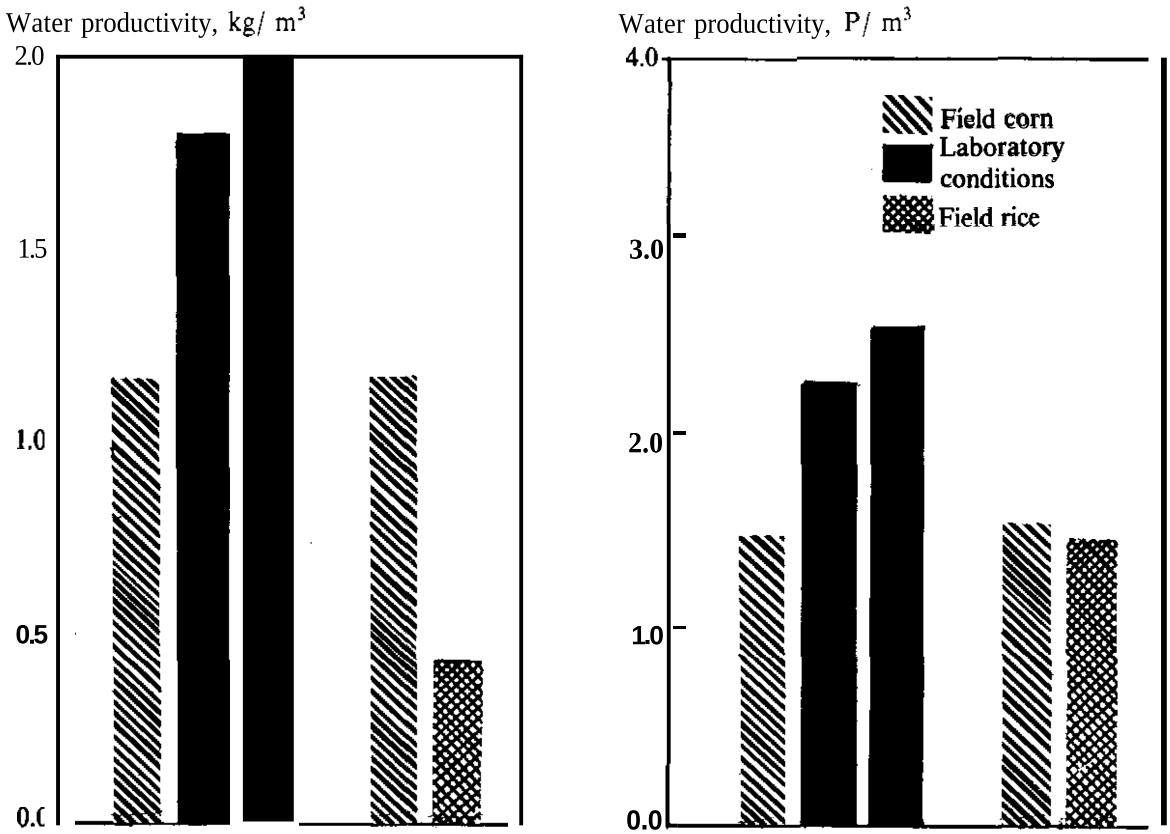

Figure 2. Productivity of water supplied to corn and rice.

Since clay soils have poor drainage properties and are dominant in most rice-based irrigation systems, there may be limited areas suitable for non-rice crop cultivation. This limitation is aggravated by puddling, the universal method of preparing irrigated rice land.

Puddling destroys the macropores and decreases soil air capacity, resulting in a closer packing of soil particles (Sanchez, 1973a) and decrease in hydraulic conductivity (Ghildyal, 1978). Harwood (cited in IRRI, 1985) studied the potential for multiple cropping of different soil textures puddled to different degrees under limited and adequate water (Table 2). Sandy loam (2:1 clay) and silt loam (1:1 clay) soils have good multiple cropping potential for a number of non-rice crops provided puddling does not increase the bulk density by more than 4%.[6]

On the other hand, clay soils that have been puddled to the point that bulk density increases by more than 12% have low potential for non-rice crops. Drying these rice soils naturally to a moisture consistency feasible for dryland preparation will take longer time, thus, shortening crop growing period for non-rice crop. In addition, planting non-rice crops to previously puddled soils will require subsoiling to provide roots with larger soil volume to extract moisture and air. The plow pan, 25 cm deep (De Datta, 1981), should be destroyed.

Climatic pattern. Ideally, rice irrigation systems should be constructed only in regions with uneven rainfall distribution. Irrigation systems stabilize water supplies and thus increase production. But since rice is susceptible to water deficits, irrigation systems have been constructed even in places where rainfall is uniformly distributed.

Farmers in irrigated areas under uniform rainfall distribution (e.g., Philippine rainfall types II and IV) prefer monoculture rice system to diversified cropping system (IIMI, 1986; IIMI, 1987b; Paris and Jayasuriya, 1982) (Figure 3). They perceive even limited water supply as sufficient in satisfying rice water requirements. Farmers simply reduce their planted areas to avert risks from eventual drought. Paris et al. (1982) reported that monoculture rice system dominates irrigated places receiving more than 100 mm of rain per month.

Table 2. Potential of different soil textures puddled to different degrees under limited and adequate water supply.

		Soil texture			
	2:1 clay	Sandy loam	Silt loam	Clay loam	Clay
	1:1 clay	Silt loam	Clay loam	Clay	
		Percentage increase in bulk density by puddling			
		< 4	4-8	8-12	> 12
Crop	Water supply	Crop potential after rice			
Peanut	Limited	Good	Intermediate	Poor	Poor
	Adequate	Good	Good	Intermediate	Poor
Maize	Limited	Good	Intermediate	Poor	Poor
	Adequate	Good	Good	Intermediate	Poor
Sorghum	Limited	Good	Good	Intermediate	Poor
	Adequate	Good	Good	Good	Intermediate
Soybean	Limited	Good	Good	Good	Intermediate
	Adequate	Good	Good	Good	Good
Mungbean	Limited	Good	Good	Good	Intermediate
	Adequate	Good	Good	Good	Good
Cowpea	Limited	Good	Good	Good	Good
	Adequate	Good	Good	Good	Good

[6] Soil bulk density is the ratio of a mass of soil to its volume. It indicates the degree of compactness or looseness of the soil.

CLIMATIC ZONES OF THE PHILIPPINES

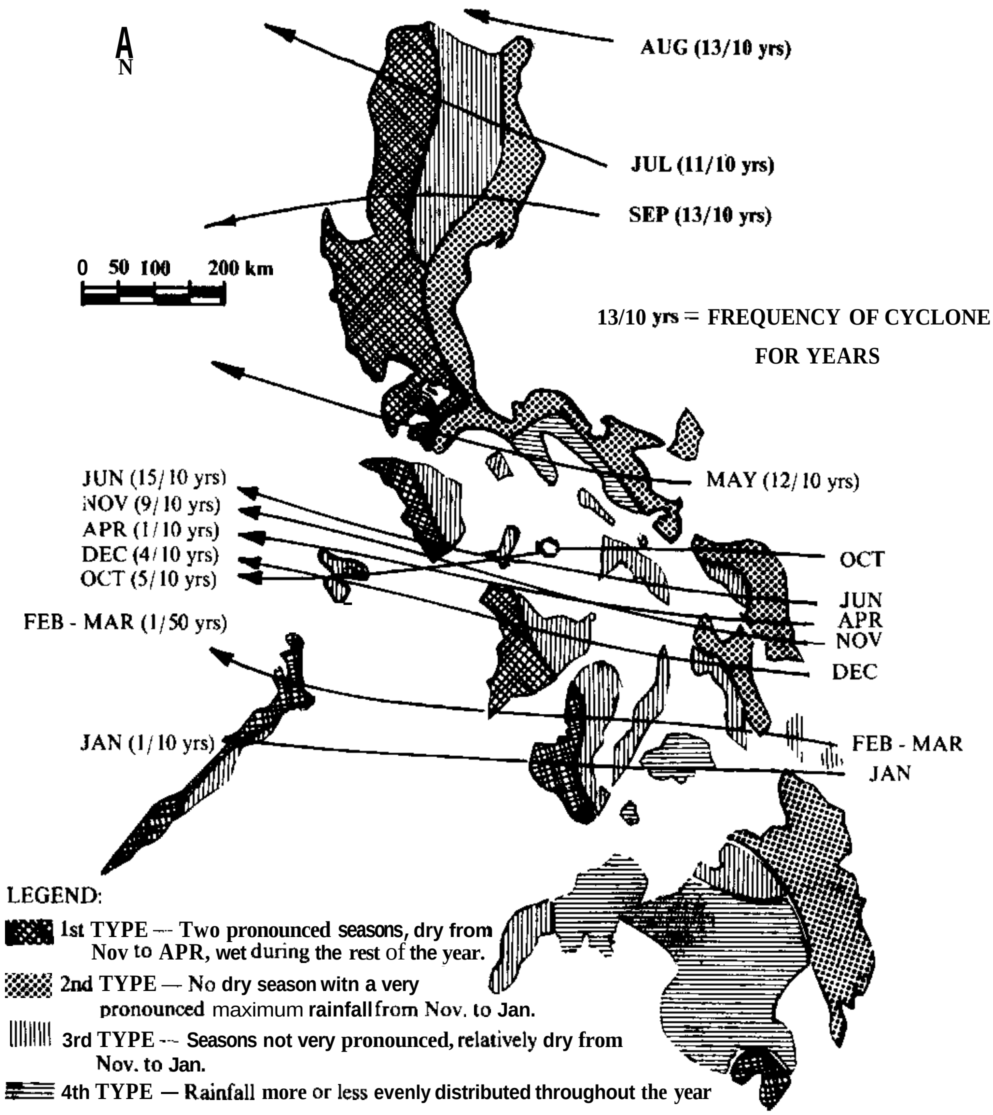

Figure **3. Climatic map** of the **Philippines.**

On the other hand, irrigated-rice farmers under unimodal rainfall distribution will either diversify into non-rice crops or fallow their lands, depending on water supply reliability and soil suitability. Today, more successful crop diversification occurs in irrigated rice systems with well-drained soils under unimodal rainfall distribution.

Operational properties. Although many rice-based irrigation systems experience limited water supplies, they cannot be expected to diversify into non-rice crops. Literature show that limited system water supply is insufficient to encourage irrigation personnel to veer away from monoculture rice system. Only when mandated, pressured or are encouraged to spread limited water supplies to a larger area will irrigation personnel diversify into non-rice crops.

Presently, crop diversification in a few irrigation systems is almost entirely farmerdriven. Irrigation personnel plan and implement rice-based operation scheme and let farmers decide to either diversify into non-rice crops, or continue with monoculture rice. With this strategy, irrigation personnel run the main parts of the irrigation system based on rice, while farmers diversify into non-rice crops. The diversifying farmers contribute a lot to main system operations to meet requirements for non-rice crop irrigation.

Some rice-specific irrigation systems, though, draw operation schemes for dry season mixed cropping. Rice is set for areas with heavy soils and adequate water and non-rice crops for areas with light soils and limited or unreliable water supply.

Rice can be irrigated by either continuous shallow water delivery or by rotational or intermittent delivery, depending on the availability of water. Non-rice crops, however, can be irrigated only by rotational or intermittent water delivery regardless of the availability of water.

Irrigation personnel will most likely avoid allocating and distributing limited water supplies to avoid high-intensity-input management. Reserved management resources to enable them carry through water crisis management are nonexistent. To avoid risking their credibility with uncertain outcomes of water deficit management, irrigation personnel reduce the size of service area commensurate with available water supplies, then plant rice instead of non-rice crops. Clearly, they are unprepared yet to run irrigation systems, at variance with the original operation scheme.'

Structural Capacities and Capabilities

The structural capacities and capabilities of most rice-based irrigation systems may be inadequate for irrigating non-rice crops. Keeping rice soils continuously flooded requires low structural capacities and capabilities. Continuous delivery of water at low flow rates in the main parts of the system and field-to-field water application are adequate to maintain rice under favorable water conditions. Due to low water flow rates, the carrying-capacity of rice conveyance system is low.

Generally, rice conveyance system can carry 1.5 liters per second per hectare (lps/ha). This is much lower than the observed canal-carrying capacity required for non-rice crops which is 2.5 lps/ha in one system in South Cotabato, Philippines (IIMI, 1986). Accumulated over a long irrigation interval and delivered at one shot, the irrigation demands of non-rice crops are higher than those of rice.

Aside from increased canal capacity, rice-based irrigation systems should upgrade their structural capabilities to irrigate non-rice crops. Uncontrolled water releases are not detrimetal to rice but are hazardous to dryland crops. Non-rice crops are intolerant to saturated soil even for a short period.

For main canal regulation, this intolerance suggests controlled releases of high water flow rates into farm turnouts to meet high irrigation demands and prevent waterlogging. Hydraulic bead, higher than that required for irrigating rice must be built up at the parent canals to produce high water flow rates into farm turnouts. Thus, system's reserved capacities, specifically canal freeboard, should be utilized to produce the higher hydraulic head.

But even simple reserved capacity as canal freeboard might be absent in many rice-based irrigation systems. Many irrigation systems have much reduced (structural control) capacities due to poor state of disrepair. Thus, to increase rice-based irrigation systems' flexibility for non-rice crops will call for improvement of system structural capacities and capabilities.

'Whether irrigating rice or non-rice crops, rice-based irrigation systems in Asia are operated with a minimum relative water supply equal to 1.4. This **means that irrigation must be supplied 40% more than the field water requirement. See Moya and Walter, (1988).**

The following structural constraints in irrigated rice-based systems must be considered when promoting irrigated crop diversification.

Canal configuration. Irrigation systems that have been designed based on continuous water delivery have a conveyance system of tapered canal configuration, i.e., the canals have gradually decreasing cross section from head to tail. Correspondingly, the system's canal carrying-capacity decreases from head to tail. Axiomatically, crop diversification potential decreases from head to tail of rice-based irrigation systems. In effect, the productivity and equity benefits from crop diversification decreases from head to tail of rice-specific irrigation systems.

Tailend farmers can plant a postmonsoon crop only when the residual soil moisture is adequate or other water sources can be tapped (e.g., shallow wells). Distance from main water source, limited structural capacities and capabilities, and lack of dry season water supply, will all combine to demand extra management efforts on irrigation personnel for bringing water to tailend farmers. However, irrigation personnel are unable or unwilling to meet these high demands. Thus, tailend farmers have slim chances of cultivating even non-rice crops during the dry season if they would depend solely on system water supplies.

Deep canal. Aside from being tapered, canals of most rice-based irrigation systems on large flat plains are also deep-cut, i.e., canal bed is lower than field elevation. Deep-cut canals with moderate structural capabilities are sufficient for continuous shallow irrigation. but inadequate for short-duration, high-flow-rate irrigation of non-rice crops. High-flow-rate at the turnouts requires sufficient hydraulic head at the parent canals to push water into level rice basins fast enough to avoid waterlogging. Filling deep-cut canals to the brim to build sufficient hydraulic head will entail structural supports. Otherwise, high water losses will ensue![8]

Much water will remain in deep-cut canals after a shortduration, high-flow-rate irrigation, and will contribute to canal dead storage. Irrigating non-rice crops can be as inefficient as irrigating rice. Cutback or surge irrigation minimizes water application losses in the fields, but does not necessarily reduces canal dead storage losses.

Impounding residual water in canals can minimize waterlogging, at the same time, serve as buffer or temporary storage.[9] The impounded water can be used to minimize water supply variability or to fully supply rice water requirements in topographically lower sections. Water level in the impoundments creates natural hydraulic head sufficient for continuous shallow irrigation. Should topography limit the distribution of impounded water by gravity, conjunctive use of buffer storage and pumping can be explored. Apparently, without complementary measures to avert water losses, the water savings from non-rice crop cultivation in irrigated rice systems will not materialize.

Technical-operational compromise. In spite of soil limitations and system structural deficiency, some irrigated-rice farmers can diversify into non-rice crops, provided markets are favorable. Irrigation personnel employ *ad hoc* system operation procedures, while farmers *experiment* with irrigation and crop cultivation practices.

Limited systems' water supply for non-rice crops can be distributed in two ways: (1) concentrate water supply into smaller fraction of the service area to accumulate sufficient hydraulic energy for shortduration, high-flow-rate water application, or (2) spread limited systems' water supply to larger service area and employ short-duration, low-flow-rate water applications. The first option indicates a need for upgraded system structural capabilities aside from organizational capabilities, whereas the second option implies organizational capabilities. Either option, however, requires high structural and organizational control because systems' water supply is limited and has to be rotated (Levine et al, 1976).

Furthermore, the productivity and equity objectives of irrigation systems limits the choice between these two options. Higher water productivity follows from the first option; higher equity from the second option.

The efforts irrigation personnel expend to complement the system's structural deficiency are supplemented by fanners' efforts to enable non-rice crop diversification, resulting in many farm level concerns in crop diversification.

Farm *level concerns*. With regard to on-farm water regulation, drainage facilities, much better

[8]Dead storage is the amount of water which is left in the canal after irrigation has been temporary withheld.

[9]Ponding losses attributable to S&P and evaporation will occur but they will be relatively smaller compared to losing altogether the residual water to nonproductive dead storage losses at the same time.

than those for rice are needed because of the inability of non-rice crops to tolerate excessive moisture. Similarly, sufficient on-farm water supply facilities are required for irrigating non-rice crops in level rice basins to allow high-flow-rate irrigation, and avoid waterlogging. However, rice irrigation ordinarily involves neither water removal network nor water supply network in the field as rice tolerates moderate flooding.

Further complication from intolerance to waterlogged conditions arises from non-rice crops' deep rooting systems (FAO, 1986). Unless adequate drainage facilities are provided, non-rice crops cannot be successfully cultivated in rice-based irrigation systems.[10]

Since adequate drainage facilities are not commonly available in rice-specific systems, farmers plant non-rice crops only in welldrained soils.

In some occasions, landforming or landshaping are undertaken in addition to providing drainage facilities. In Japan and the People's Republic of China, shurt growing season and high population density pose as constraints in modernizing their irrigation systems. Intensive on-farm irrigation and drainage facilities have been installed by the Japanese and Chinese in their irrigation systems. Well and subsurface drainage enables rice farmers in China to plant second crop of wheat or other non-rice crops (Soong and Wei, 1985). Likewise, most irrigated-rice systems in Japan include subsurface drainage facilities to speed up soil drying for mechanized harvesting and land preparation (Tabauchi, 1985).

But for rice-based irrigation systems with lower drainage capabilities than those in Japan and the People's Republic of China, arudimentaryand temporary surface removal network, together with sloped furrow or border irrigation methods, may be sufficient to meet the drainage requirements of non-rice crops." However, conventional graded furrow or border irrigation is impractical in flat lands without landshaping or landgrading. A minimum threshold field grade is needed for efficient and uniform water application by either furrow or border irrigation.

Landforming or landshaping may also involve subsoiling (deep tillage) or raising beds to increase volume of aerated soil. Hard pans impede root growth and development. Therefore, breaking hardpan should increase depth of aerated soils (Yoshida, 1981; Kramer, 1983). Extrasoil aeration can also be produced by lowering the water table.

Consequently, farmers end up using heavy machinery as animal draft power will be insufficient for landshaping and landgrading if a farmer plants more than a hectare of non-rice crops." Heavy tractors, however, destroy paddy bunds and weigh down or break plow pans. Broken or sunken plow pans increases soil drainage and aggravates water losses from succeeding flooded rice cultivation.

Furthermore, temporarily graded fields previously planted to non-rice crops must be levelled back to distribute water evenly within the rice basins. Sunken or broken hard pans and the lopped paddy bunds must be restored to control water outflow from ricefields.

Reconstructing paddy bunds and recreating hard pans require a lot labor. It also take sometime to mend a broken pan and to produce a watertight bund, hence large S&P losses will occur from fresh pans and bunds during land preparation for rice. Collectively, breaking and mending of hard pans, lopping and building of paddy bunds, and field grading and levelling result in a vicious problematic cycle for wet season-rice:dry season-non-rice cropping pattern in irrigated systems. The cycle can create both economic and technical disincentives to dissuade irrigated-rice farmers from diversifying into non-rice crops.

How do diversified farmers contend with these physical and technical limitations?

Farmers who diversify their cropping pattern can cope up with these limitations by first, Limiting non-rice crops to a small fraction of their farmholding of welldrained soils. For instance, farmers under the Upper Talavera River Irrigation System

[10]In addition to drainage facilities, sufficient supply should also be provided to distribute water at a rate fast enough to effect waterlogging of level basins planted to rice.

"As discussed elsewhere, farmers select crops that can be irrigated by techniques that either closely approximates flooding for rice or modify the conventional border and furrow irrigation techniques, such as the *inverted* border irrigation.

[12]Moya and Murray-Rust (1985) observed that almost all farmers who received water from P-27 deepwell pump system in Guimha, Nueva Ecija, Philippines and who planted at least a hectare to non-rice crops, either corn or peanut, following the wetseasonricecrop, resorted to landforming and landgrading using heavy machinery to cut turnaround lime

(UTRIS) and Laoag-Vintai River Irrigation System (LVRIS) plant onion and garlic to only 1,000-1,200 m[2] (IIMI, 1988; Bumanlag, 1988). Second, by selecting shallow- or medium-rooted non-rice crops, which can be irrigated by flooding. This ad hoc measure may partly explain the choice of a rice-onion and rice-garlic pattern by UTRIS and LVRIS fanners, respectively.[13] Third, some farmers dry seed their wet season rice in plots intended for dry season non-rice crops. They may also seed their wet season rice in dry and compacted soils rather than in puddled soils (Ghildyal, 1978). Other tillage practices for wetland rice, such as zero and minimum tillage, are also practiced when appropriate (De Datta and Barker, 1978). Fourth, if attempts to break or circumvent the vicious cycle entails prohibitive costs, some farmers just fallow their lands during the dry season.

In summary, because rice and non-rice crops basically differ in physiological and agronomic characteristics, they grow and produce best in contrasting soil-water environments. Consequently, they require contrasting water management strategies.

Continuous water distribution is adequate for rice, but rotational or intermittent irrigation is a must for non-rice crops. A skeletal water distribution and removal network is enough for rice irrigation while a more complete water distribution and application network, coupled with drainage network is a must for non-rice crop irrigation.

To satisfy non-rice crop's drainage requirements, diversifying farmers may end up using heavy machinery. Heavy machinery destroys paddy hunds and plow pans, thus increasing water and nutrient losses from flooded ricefields through leaching. Converting ricefields to non-rice crop fields creates a vicious cycle of technical and management problems for farmers and irrigation personnel. Presently, farmers and irrigation personnel skirt around the vicious cycle through a number of ad hoc measures. Basic soil-water and irrigation management research should backstop farmers and irrigation personnel directly to break into the vicious cycle.

For example, **it** is important to consider an optimal percentage of the total service area with **soil** properties that are suitable for non-rice crops before a diversified crop imgation system is designed. Constructing irrigation systems on light and porous **soils, as** well as on heavy and less pervious soils must he carried through only after a rigorous technical and economic analysis had confirmed the feasibility. The savings in water expected from low water use by diversified crops on light soils may be offset by high conveyance losses, or by the high costs of lining conveyance system to rule out water losses. Similarly, the high costs of providing drainage facilities to non-rice crops on heavy soils may offset the expected water savings.

Climatic pattern prevailing in irrigation systems that will be operated, rehabilitated or constructed to allow crop diversification should also be considered. Rainfall distribution greatly affects soil moisture and aeration capacity, which in turn, affect cropping sequence. Farmers in areas with unimodal rainfall pattern have more incentives to diversify than farmers in areas with uniform rainfall distribution. In areas with unimodal **rain**fall distribution, the soil is aerated part of the year, while in areas with uniform rainfall distribution, the soil is saturated most of the year.

From the operational point of view, imgation field personnel will veer out of monoculture rice systems to increase productivity and equity of limited water supply only when mandated, pressured or encouraged to do **so.** Otherwise, these personnel will just reduce their service area and program the area for rice **so** as to avoid high-intensity-input management. The resource capacities found in many rice-based systems cannot meet the high operational control needed for crop diversifcation.

Design of new diversified crop irrigation systems or rehabilitation of old rice-based systems to accommodate non-rice crops should pay attention to these technical issues. Important, economic, institutional and social issues to crop diversification should be also accounted for towards a more comprehensive understanding of diversified cropping.

Economic Issues

In evaluating benefits and costs of water savings expected from **non-rice** crop cultivation,

[13]Onions and garlic have a maximum effective rooting depth of 30 cm. In comparison, peanut has a maximum effective rooting depth of 80 cm; corn, 100 cm; and tomato, 100 cm. The rooting depth of garlic and onions approximates that of rice, which is about 20 cm. See FAO (1986), Yoshida (1978) and O»Toole, el al. (1978).

two economic issues must be accounted for. First, as non-rice crops will be cultivated on porous soils, the expected benefits of savings in water from crop diversification can be offset by either high water losses in the conveyance system or high costs of canal lining to minimize these losses. Second, the costs of high operations control needed for irrigating non-rice crops should be compared with the value of benefits derived from increase in production.

Other economic issues revolve around the profitability of cultivating non-rice crops compared to rice. Improved rice technologies have sufficiently increased rice productivity which caused a major rise in world food supply. This, in turn, caused a decline in the price of grains in the world market. Eventually the global price decline renders rice farming less profitable than before. Hence, rice farmers must look for other ventures that can increase their incomes; an alternative is to veer out of rice monoculture and plant high value, low water-requiring non-rice crops.

Most rice-producing countries have comparative advantage in non-rice crop production, such as corn, soybean and mungbean. These countries spend large fraction of their foreign exchange earnings on imports of non-rice feedgrains. Governments therefore, have large economic incentives to encourage local production of non-rice crops. From economics point of view, non-rice crops grown locally can still be profitable.

However, at the local level, markets for non-rice crops are not established, so their prices are unstable. The price ratio of rice:non-rice is usually bigbenough to induce farmers to grow rice rather than non-rice crops. The price ratio affects water productivity of rice and non-rice crops, too. Moya and Murray-Rust **(1985)** compared water productivity for rice and corn at **P-27,** a deep tubewell irrigation system in Nueva Ecija, Philippines, in terms of value of output per cubic meter of water supplied (**P/m^3**) (Figure 2). Water productivity for corn, in terms of yield per cubic meter of water was about three times that for rice, but since corn price was one-third of that for rice, water productivity for corn, in terms of pesos per cubic meter of water does not differ from that for rice. Therefore, prices for non-rice crops have to be competitive enough to create water productivity incentives fornon-rice crop cultivation.

Growing non-rice crops entails higher production costs per hectare than rice because of higher inputs, especially labor and chemical (IIMI, **1986;** IIMI, **1988).** In most developing countries however, inputs are not readily available prompting farmers to use inputs at suboptimal levels resulting in low yields. Considering further that price of non-rice crops fluctuates widely in local markets coupled with inadequate production inputs, a farmer's profit from non-rice crop production is less and more variable than profit derived from rice. Thus, there must be enough economic incentives to encourage rice farmers to diversify into non-rice crops.

Input subsidy, guaranteed markets and higher price for output have been found to induce fanners to plant non-rice crops. For instance, most rice farmers in the Gal Oya Imgation scheme in Sri Lanka shifted to cultivating chili during the **1979** dry season when the government guaranteed higher price for chili than for rice. A similar case has been observed in farmers' adoption of diversified cropping in the Kemubu Imgation, a pump irrigation scheme in Malaysia (Ng, **1976).** There were great cost-cutting incentives to adopt crop diversification in this system. The government subsidized production inputs and guaranteed markets and higher prices of non-rice crops to encourage Malaysian farmers in sections of command area with suitable soil to cultivate tobacco and peanut. Moreover, the government assured each diversifying farmer with 1000 kg of rice to cover the basic family rice consumption. Taiwan has also instituted a diversification scheme similar to that of Malaysia. These economic incentives, in a way were created to cover-up for the risks involved in non-rice crop production technologies.

However, the incentive-creating process entails costs and a financially strapped government will be unable to sustain the giving of these incentives for a long time. Fanners will thus remain in status quo that is, they will rather reduce their area to be planted to rice than expand it through diversified cropping.

Social and Institutional Issues

Institutional issues will inhere from potential technological or economic disequilibrium concomitant with crop diversification. First, government and research institutions might be induced to supply, through cooperative efforts, additional information to bridge any knowledge gap on diversified cropping. Second, to alleviate the constraints imposed by the unavailability of production inputs, the government might supply low interest

credits to diversifying farmers. More importantly, institutional issues might be expected from changes in water allocation and distribution rules to accommodate soil-water requirements of upland crops. Irrigation service fee payment could be also a significant institutional issue for diversified cropping.

With regard to social issues, fanner's water-related behavior and attitudes toward changes to be brought about by diversified cropping technologies might be consequential. Changes in communication pattern might be expected since non-rice crops would be cultivated under tight water supplies and better means of communication and coordination will be important. Farmer participation might also be a social issue for crop diversification.

Conclusions

Important technical, economic, institutional and social issues in diversifying rice-based irrigation systems have been presented. Issues on crop-soil-water environment, climatic pattern and on physical and operational control capacity of rice-based irrigation systems are the basic technical considerations in crop diversification. Soil-water related issues focus on soil aeration.

With respect to climate, diversified rice-based systems can be constructed in areas with unimodal rainfall distribution. In areas with uniform rainfall distribution, fanners will insist on growing rice.

The increased physical and operational control required to accommodate non-rice crops *may* be beyond the resource capabilities of *many* rice-based irrigation systems. These systems *may* lack physical control facilities and structures to effect rotational or intermittent irrigation. Excess management capacities do not *usually* exist for high-intensity-input operations to deal with limited water supplies. Moreover, on-farm facilities needed to produce the level of control for appropriate diversified crop irrigation techniques are *mostly* lacking.

A major economic issue is the assessment of cost of water expected to be saved from crop diversification in relation to projected benefits From increased production. The relative price of rice:non-rice crops is an important indicator. Water productivity for rice and non-rice crops depends upon this relative price. Input subsidy, higher prices, and guaranteed markets for non-rice crops have been found by previous studies to induce short-term diversilication.

Anticipated changes in water allocation and distribution rules to accommodate changes in soil-water conditions for non-rice crops might be significant institutional issues. Moreover, the willingness of government and research institutions to bridge the knowledge gap on non-rice crop cultivation could be counted important. Likewise, farmer attitudes and behavior toward expected changes in water allocation and distribution rules might be significant social concerns. Issues on improved communication and coordination relating to diversified cropping should be also dealt with.

Technical, economic, institutional and social issues which are expected to be consequential to crop diversification have been presented in this paper. Each issue can uniquely influence crop diversification, but interactions among these issues will contribute to a broad understanding of factors that drive irrigated crop diversification.

References

Brewer, R. and J.R. Sleeman. 1960. Soil structure and fabric: Their definition and description. J. Soil Sci. 11:172-182.

Bumanlag, G.S. 1988. Personal communication on preliminary survey findings from the Upper Talavera River Irrigation System.

De Datta, S.K. 1981. Principles and Practices of Rice Production. New York: John Wiley and Sons, Inc.

De Datta, **S.K.** and A. Williams. 1968. Rice cultural practices. B. Effects of water management practices on the growth characteristics and grain yield of rice. *In* Proceedings and papers, Fourth Seminar on Economic and Social Studies (Rice Production). Committee for the Coordination of Investigations of the Lower Mekong Basin. Laguna, Philippines. pp 78-93.

De Datta, **S.K.** and M. **S. A.** A. **A.** Kerim. 1974. Water and nitrogen economy of rainfed rice as affected by puddling. Soil Sci. Soc. Am. Proc. 38(3):515-518.

De Datta, **S.K.** and R. Barker. 1978. Land preparation for rice soils. *In* Soils and Rice. International Rice Research Institute, Laguna, Philippines. pp 623-248.

Donahue, L., R.W. Miller and J.C. Shickluna. 1977. Soils: An Introduction to Soils and Plant Growth. Englewood Cliffs, New Jersey: Prentice Hall.

Food and Agriculture Organization. 1984. Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24. FAO, Rome, Italy.

_________ 1986. Yield Response to Water. FAO Irrigation and Drainage Paper No. 33. FAO, Rome, Italy.

Ghildyal, B.P. 1978. Effects of compaction and puddling on soil physical properties and rice growth. *In* Soils and Rice. International Rice Research Institute, Laguna, Philippines. pp 317-336.

Gomez, A.A. and **K.A.** Gomez. 1979. Multiple cropping in the humid tropics. (Mimeographed).

Goonasekere, **K.** and T. Wickham. 1978. Some findings on field water use and the productive efficiency of water for chillies, soybeans and rice in the dry zone of Sri Lanka. IRRI Saturday seminar, 28 January 1978. International Rice Research Institute, Laguna, Philippines.

Hai-Sheng, K. 1987. Adoption of diversified cropping in rice irrigation projects. *In* Irrigation Management for Diversified Cropping. International Imgation Management Institute, Digana Village, Sri Lanka. pp 13-26.

Harwood, R.R. 1975. Farmer-oriented research aimed at crop intensifications. *In* Proceedings of the Cropping Systems Workshop. International Rice Research Institute, Laguna, Philippines. pp 12-32.

Hausenbuiller, R.L. 1978. (2nd ed.). Soil Science: Principles and Practices. WM. C. Brown Co., Duburque, Iowa.

Hillel, D. 1982. Introduction to Soil Physics. Academic Press, Inc., Orlando, Florida.

Horst, L. 1983. Imgation Systems. Unpublished Preliminary edition. Agricultural University, Wagenigen, Netherlands.

International Irrigation Management Institute. 1986. Final Report on Study on Irrigation Management for Crop Diversifiiation (TA 654 Philippines). IIMI, Digana Village, Sri Lanka.

_________ 1987a. Irrigation Management for Diversified Cropping. IIMI, Digana Viage, Sri Lanka.

_________ 1987b. First Progress Report on Study on Irrigation Management for Diversified Crops (TA 859 Philippines). IIMI, Digana Viage, Sri Lanka.

__________ 1988. Second Progress Report on Study on Irrigation Management for Diversified Crops (TA 859 Philippines). IIMI, Digana Village, Sri Lanka.

International Rice Research Institute. 1972. Annual Report for 1971. IRRI, Laguna, Philippines.

__________ 1985. Soil Physics and Rice. IRRI, Laguna, Philippines.

James, L. 1988. Principles of Farm Irrigation System Design. John Wiley and Sons, New York.

Jensen, C.R., L.H. Stolzy, and J. Letey. 1967. Tracer studies of oxygen diffusion through roots of barley, corn and rice. Soil Sci. 103:23-29.

Johnson, C.D., V. Limpinuntana and H. Greenway. 1974. Adaptation of rice to anaerobiosis. Aust. J. Plant Physiol. 1:513-520.

Kramer, P. J. 1983. Water Relations of Plants. Academic Press, New York.

Levine, G. 1982. Relative water supply: An explanatory variable. Technical Note 6. Determinants of irrigation problems in developing countries, (Contract No. AID/TA 6-1412). Cornell University, Ithaca, New York.

Levioe, G., L.T. Chin and S.M. Miranda. 1976. Requirements for successful introduction and management of rotational irrigation. *In* Agricultural Water Management. Elsevier Scientific Publishing Co, Amsterdam, Netherlands. pp 41-56.

Miranda, S.M. and C.R. Panabokke. 1987. Irrigation management for diversified cropping: concept paper. *In* Irrigation Management for Diversified Cropping. IIMI, Digana Village, Sri Lanka. pp 3-12.

Moya, T.B. and D.H. Murray-Rust. 1985. Operational requirements for a rice-based deep tubewell irrigation system. Paper presented at the International Rice Research Institute Saturday Seminar, Laguna, Philippines.

Moya, T.B. and M.F. Walter. 1988. Irrigation system operations intensity and relative water supply. Water Management Synthesis Project Report No. 92. Cornell University, Ithaca, New York.

Ng, P.K. 1976. A model for crop diversification in the Kemubu irrigation scheme of Malaysia. Unpublished M. Eng. report. Cornell University, Ithaca, New York.

O'Toole, J.C. and T.T. Chang. 1978. Drought and rice improvement in perspective. IRRI Res. Pap. Ser. 14. 27p.

Paris, T.R., E.C. Price and S.K. Jayasuriya. 1982. Comparative analysis of cropping systems: An exploratory study of 14 rainfed sites in the Philippines. IRRI Res. Pap. Ser. 83. 17p.

Pereira, H.C. 1956. A rainfall test for structure of the tropical soils. J. Soil Sci. 7:68-74.

Ponnamperouma, F.N. 1977. Physiochemical properties of submerged soils in relation to its fertility. IRRI Res. Pap. Ser. 5. 32p.

Ponnamperouma, F.N. 1978. Electrochemical changes in submerged soils and the growth of rice. *In* Soils and Rice. International Rice Kesearch Institute, Laguna, Philippines. pp 421-441.

Sanchez, P.A. 1973a. Puddling tropical soils. 1. Growth and nutritional aspects. Soil Sci. 115(2):149-158.

Sanchez, P.A. 1978b. Puddling tropical soils. 2. Effects on water losses. Soil Sci. 115(4):303-308.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York.

Schwab, G.O., R.K. Frevert, T.W. Edminster and K.K. Barnes. 1981. (3rd ed.). Soil and Water Conservation Engineering. John Wiley and Sons, New York.

Soong, S. and Z. Wei. 1985. Subsurface drainage of lowland rice fields in China. *In* Soil Physics and Rice. International Rice Research Institute, Laguna, Philippines. pp 351-366.

Steiner, R. and M. Walter. 1988. Classification of gravity irrigation systems and their operations. Water Management Synthesis Report 78. Cornell University, Ithaca, New York.

Tabauchi, T. 1985. Underdrainage of lowland rice fields. *In* Soil Physics and Rice. International Rice Research Institute, Laguna, Philippines. pp 147-159.

Tadano, T. and S. Yoshida. 1978. Chemical changes in submerged soils and their effects on rice growth. *In* Soils and Rice. International Rice Research Institute, Laguna, Philippines. pp 399420.

Tiangco, W. 1987. Personal discussion about crop diversification with the Upper Pampanga River Integrated Irrigation System's (UPRIIS) operations staff. UPRIIS office, Cabanatuan City, Philippines.

Van Raalte, M.H. 1944. On the oxidation of the environment by the roots of rice (*Oryza* sativa L.). Ann. Bot. Gardens Buitenzerg. 54:15-24.

Wickham, T.H. 1973a. Effect of moisture stress periods in relation to irrigation systems. Paper presented at the International Rice Research Conference. 23-27 April 1973. Laguna, Philippines.

Wickham, T.H. 1973b. Some soil-plant-water research findings useful to irrigation design and management. Paper presented at the FAO water management seminar. 23-27 July 1973. Malaysia.

Wickham, T.H. 1974. Tropicallowland rice: Some findings regarding its water requirements and yield loss due to drought. Paper presented at the national teaching seminar on water management and control at the farm level. 1-19 July 1974. Jakarta, Indonesia.

Wickham, T.H. and C.N. Sen. 1978. Water management for lowland rice: Water requirements and yield response. *In* Soils and Rice. International Rice Research Institute, Laguna, Philippines. pp 649-669.

Wickham, T.H. and V.P. Singh. 1978. Water movement through wet soils. *In* Soils and Rice. International Rice Research Institute, Laguna, Philippines. pp 337-358.

Williams, A. 1969. Effect of water management practices on the growth characteristics, grain yield and water requirements of rice. Unpublished M. Sc. thesis, University of the Philippines, College of Agriculture, College, Laguna, Philippines.

Yoshida, S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute, Laguna, Philippines.