Technical Farm-Level Issues in Irrigation for Rice-Based Farming Systems: An Intercountry Synthesis

Sadiq I. Bhuiyan
Agricultural Engineer, Soil and Water Sciences Division
International Irrigation Management Institute, Los Baños, Laguna
Philippines

INTRODUCTION

AS FARMING PRACTICES within an imgation system become more diversified, the demand on the management of water supplies assumes a greater degree of complexity. This process is being currently experienced in many irrigation systems in Asia, which were developed primarily for producing two rice crops within the year. But the profitability from rice production has remained low for various reasons in recent years; consequently, the demand to replace rice with cash crops has increased. So has the value of irrigation water. Since the investments in new imgation development are likely to remain low through the 1990s, it is expected that the demand on irrigation water for both rice and nonrice crops within existing irrigation systems will continue to increase during the present decade.

From technical viewpoints, crop diversification or the substitution of rice with other crops is most attractive in areas where the soil is light-textured and controlled imgation water is available. The climatic suitability, of course, plays a crucial role in the selection of crops to be grown. Favored by the physical and climatic factors, about 9 million ha in China have adopted the rice-wheat cropping system (Zandstra 1990).

Quick draining of excess water from the land and good internal soil drainage are desirable requisites to achieve high yields of nonrice crops. Heavy soils can often be used for profitable production of irrigated nonrice crops by appropriately modifying the land for better water control and excess water removal. But economic production of nonrice crops in the dry season is not practicable in many areas with suitable soils if irrigation water is not available. In many such cases, a supplemental source of water, which is often the groundwater, makes the difference between success and failure to grow the nonrice crops in the dry season.

This paper presents a synthesis of chosen technical farm-level issues and relevant findings conducted in three countries — Bangladesh, Indonesia, and the Philippines — through the Irrigation Management for Rice-Based Farming Systems projects. The project was coordinated jointly by IIMI and IRRI, and implemented in collaboration with selected institutions in each country (e.g., Bangladesh Rice Research Institute [BRRI] and Bangladesh Water Development Board [BWDB] in Bangladesh; Agency for Agricultural Research and Development [AARD] and Directorate General for Water Resources Development [DGWRD] in Indonesia; and Philippines Council for Agriculture, Forestry and Natural Resources Research and Development [PCARRD], National Irrigation Administration [NIA], and Central Luzon State University [CLSU] in the Philippines). It was financially supported by the Rockfeller Foundation. The project activities in each country started with the identification of priority local research issues and problems that should be addressed through the project. The identification was achieved in each country separately through small group workshops or discussion meetings at which selected individuals from key national institutions as well as from IRRI and IIMI participated. Some of these resource persons later became active partners in the implementation of the recommended research.

RESEARCH ISSUES AND FINDINGS: SOME COMMON GROUNDS

A common background of the research studies is that they were conducted in areas where rice is the only crop grown in the wet season and the areas were served by gravity-fed surface irrigation systems developed mostly for rice culture. In Bangladesh, the research on the farm-level issues was concentrated in the G-K Irrigation System (GKIS) and the North Bangladesh Tubewell System (NBTS); in Indonesia it was the Cikeusik Irrigation System (CIS); and in the Philippines it was the Upper Talavera River Irrigation System (UTRIS) and the San Fabian River Irrigation System (SFRIS).

The GKIS and NBTS in Bangladesh are somewhat different from the others in that GKIS uses lift-pumping from the river at the headwork, but essentially works like other run-of-the-river or reservoir-supported systems studied in Indonesia and the Philippines; and NBTS is a conglomerate of over 350 deep tubewells each of which acts independently for a command area of 50 ha or less, and in the dry season it is used mostly for wheat irrigation.

A direct comparison of the research findings from the three countries is not appropriate because, as indicated above, the problems addressed in each country are not the same. Despite this limitation, a number of useful common grounds to discuss, based on the research findings and generalizations, may be made from them. It must be emphasized that one must not make too broad generalizations disregarding important biophysical and socioeconomic differences that may exist between the sites where the research was conducted and other regions of the country.

A universal element in the research findings of the three countries is that dry-season water supply for irrigation is much less than the demand, and farmers' cropping decisions as well as the choice of crops are critically influenced by the expected availability of irrigation water. The augmentation of water supplies is, therefore, vitally needed for increasing land productivity in the dry season, especially the lands in the tail reaches of irrigation canals. Figure 1 exemplifies this feature for the Cikeusik Irrigation System (CIS) in West Java, Indonesia.

Research conducted toward this goal presents the following comparative findings:

Conjunctive use of groundwater. Use of groundwater to supplement canal supplies in the dry season was significant in both the Indonesian (CIS) and the Philippines (UTRIS and SFRIS) sites. Through an extensive survey of shallow groundwater use in the Philippine sites, Undan et al. (1990) found that open wells with concrete casings, 0.75 to 1.0 m in diameter and 3.5 to 7.5 m in depth, were used in the tail ends of the irrigation systems to pump water using centrifugal pumps with discharge ratings that ranged from about 19 to 38 lps. The static water table in the wells increased up to about 3.0 m from the surface in April; it was about 4.0 m in the wells of SFRIS area in April.

Figure I. Discharge per unit area for 4 tertiaries of the middle section, Cikensik Irrigation System, Cirebon, West Java, Indonesia, for 1988 dry seasons I and II.

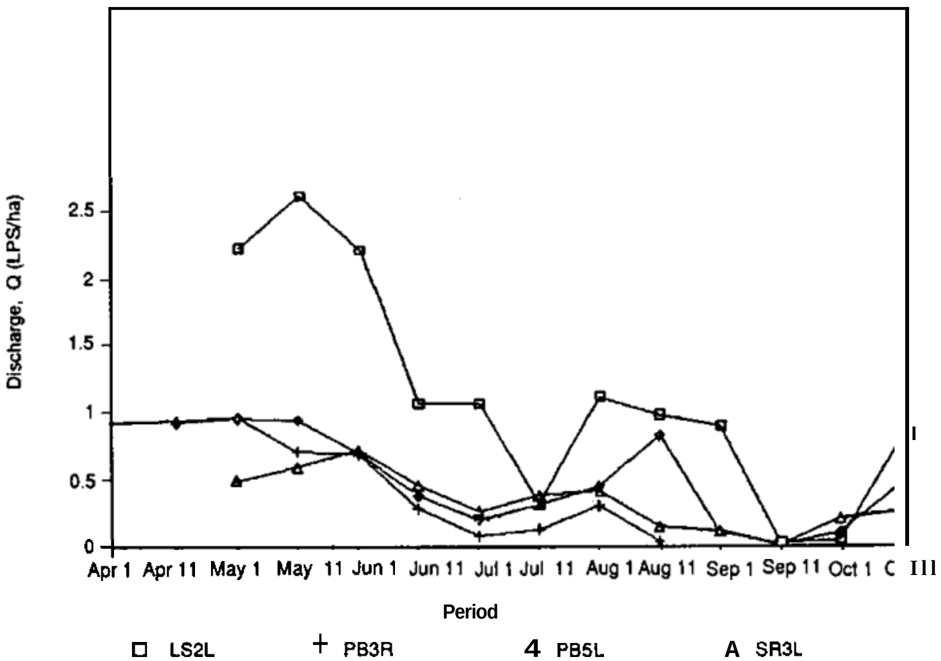

Table 1 gives details of groundwater use to supplement canal supplies in CIS, Indonesia, in the dry season. An interesting feature with CIS, which contrasts with the UTRIS or SFRIS situation in the Philippines, is that there is more use of groundwater in the upper reaches of lateral canals than in the tail reaches. This is because the tail areas have more salinity in the groundwater because of their proximity to the coast and some of their lower areas suffer from waterlogging. It is also probable that the high cost of groundwater development and use discourage the tail-reach farmers from investing on wells, as they have to depend almost entirely on pumped water for dry-season cropping. Canal water deliveries to these areas during the dry seasons is very limited (Figure 1).

Table 1. Groundwater use by section and by season, Cikeusik Irrigation System, Cirebon, West Jaw, Indonesia, 1988 DS I and II.

Item	Head n=26	Middle 2=29	Tail n=24	All farm n=79
Percent of fanners using groundwater				
DSI	23	3	17	14
DS 11	58	52	4	38
Purpose of groundwater use:				
a. To supplement canal supply (%)				
DS I	100	100	75	92
DS II	20	27	0	16
b. For full crop water requirement (%)				
DS I	0	73	25	8
DS 11	80		100	84
Percent of farmers owning the well				
DS I	100	100	25	75
DS II	93	60	0	51
Cost of groundwater use (US$/ha/season)[a]				
DS I	69	45	53	56
DS II	51	58	100	69

US51.00 = Rp. 1800. Only variable costs are included.
Source: Wardana et al. 1990.

In the Bangladesh case (G-K Irrigation System), groundwater use for supplementing canal supplies in the Aus season, or for the winter (Rabi) season cropping is almost nonexistent despite the need and the availability of groundwater in most of its area. The reason behind this situation is the Bangladesh Water Development Board (BWDB) policy which does not allow the construction of tubewells within the service area of their surface water irrigation systems. However, during the past 2-3 years, the Board has relaxed the implementation of the policy and has not been against the use of groundwater by the small number of farmers who have tried it. Clearly, significant benefits can be achieved if this policy is reversed and fanners encouraged to use groundwater. The Rabi season is potentially a very productive part of the year because of abundant sunshine and dry weather, and its fullest possible use should be made for increasing food supplies in the country.

The use of groundwater in the dry season is economically attractive in both the Indonesian and Philippine cases (see Table 2 for the Indonesian example in which the users achieved a much higher gross margin than the nonusers). It is expected that similar groundwater use, especially for the Rabi season cropping, would also be economically attractive to farmers of the GKIS area in Bangladesh.

No study has been conducted in any of the three irrigation systems to determine what amount of groundwater extraction in these areas could be considered sustainable, i.e., the extraction rate which will not initiate a mining effect on the water table due to groundwater withdrawals in excess of the aquifer recharge. However, considering the high rainfall amounts and the vast amounts of surface water that recharge the groundwater aquifers through the unlined earth canal network annually, there should be no major concern about groundwater mining in these systems underlain mostly with unconfined aquifers. In fact, it is expected that greater use of groundwater may help in the control of waterlogging problems in the low areas. Appropriate policies and programs are needed to encourage the use of groundwater in the command areas, especially the tail reaches of these canal irrigation systems.

Use *of residual* soil water. Residual soil water is used in a significant proportion of the GKIS area in Bangladesh for growing Rabi-season crops following Aman-season rice. Wheat, onion, garlic and legumes are the popularly grown Rabi crops with residual soil water. Crop yields vary significantly from year to year due to differences in rainfall amounts (in some years, high rainfall at flowering stage causes yield reduction), planting time (delayed establishment of wheat, for example, is adversely affected by increasing temperatures after February) and inputs used (researcher-managed legume crops have on the average yielded 15-35 percent higher than farmer-managed crops). Table 3 shows the extent of nonrice crop culture in the system during 1983-1990. The number of farmers using residual soil water from a crop did not vary much between 1984 and 1990, but the number of farmers growing the different crops varied widely between years. Kheshari (lathyrus), the most commonly grown crop in the Rabi season, is usually relay-seeded to the rice field a few days before harvesting Aman rice in November, which allows the available soil water to be used for crop establishment. The average kheshari yield achieved by farmers is about 1 t/ha (Mondal et al. 1990). If relay-seeding is not practiced, pregerminated seeds are used.

Table 2. Comparative costs and returns of onion, groundwater users versus nonusers, Cikeusik Irrigation System, Cirebon, West Java, Indonesia, 1988 DS II.

Item	Groundwater		
	Users n=15	Nonusers n=24	Difference
Mean yield (t/ha)	10.74	6.02	4.72***
Total value of production (US$/ha)	2129	I020	1109***
Costs of production (US$/ha)			
Seeds	499	404	95
Fertilizer	144	90	54**
Insecticide	220	113	107**
Labor			
Hired	375	283	92'
Family	207	141	66*
Other costs	107	91	16
Total paid-out costs of production (US$/ha)	1345	981	364**
Total variable costs of production (US$/ha)	1552	1122	430***
Returns above paid-out costs (US$/ha)	784	39	745***
Gross margin (US$/ha)	577	(102)	679**

US$1.00 = Rp. 1800
***, **, * Significant at 1 percent, 5 percent, and 10 percent probability levels, respectively
Source: Wardana et al. 1990.

Table 3. Adoption of different Rabi crops by farmers in the Ganges-Kobadak Project (Phase I), Rabi seasons, 1983-84 to 1989-90.

Year	Percent adoption							
	Kheshari (Lathyrus)	Wheat	Gram	Onion	Pea	Lentil	Oil seed	Total
1983-84	7.3	3.8	0.7	8.4	-	-	1.6	21.8
1984-85	27.8	11.1	5.3	8.2	0.9	-	0.7	54.0
1985-86	22.9	11.1	11.1	8.7	3.3	-	-	57.1
1986-87	9.1	13.6	19.8	8.4	4.2	1.1	-	56.2
1987-88	18.7	5.3	7.3	15.3	2.2	1.8	-	50.6
1988-89	21.0	3.3	16.0	6.9	4.7	-	2.4	54.3
1989-90	13.0	12.3	3.8	15.8	2.3	0.8	2.0	50.0
Mean	17.1	8.6	9.1	10.2	2.9	1.2	1.7	41.9

Source: Mondal et al. 1990.

In contrast to Bangladesh, no significant area is grown to dry-season crops depending entirely on the residual soil water in the case of Indonesian and Philippine irrigation systems. A 1988-89 study looked into the potential availability of residual soil water in the service area of UTRIS, Philippines, for crop use. It was found that in about 40 percent of the nonirrigated, non-waterlogged locations sampled, usable resources of shallow residual soil water existed following the harvest of wet-season rice. In about 25 percent of the nonimgated locations, the perched water table persisted within 10-100 cm depth for more than 20 days indicating the potential of establishing well a leguminous crop such as mungbean (Tenedora et al. 1990). Juliardi et al. (1990) concluded, for the West Java condition, that the yield of shallow-rooted mungbean can be increased by over 30 percent if shallow tillage is practiced.

Irrigation Water Supply Effects on Land Productivity

Land productivity is affected by the availability of irrigation water for all crops grown, rice or nonrice. In an inadequate water supply situation, the crop yield suffers directly from drought stress and indirectly from reduced inputs used by farmers. There may be also a loss of yield due to the interaction effects between stress and other inputs used.

Canal water supply rates to farms are generally inversely related to their distance from the source of water (see Figure 1 for example). This phenomenon was evident in almost all cases that were studied. The Indonesian CIS example has been discussed. A component study in the GKIS in Bangladesh compared the fertilizers used and rice yields obtained by farmers at the head, middle and tail reaches of a main canal during the Aus and Aman seasons of 1986-89 (Bhuiyan et al. 1990). The average rice yield from the 4 Aus seasons was 26-30 percent less in the tail farms compared to the head or the middle farms. The gradient of fertilizer use was likewise steep from head to tail area farms. In the Aman season there was not much difference in yields or fertilizer use because in contrast to the Aus season, when irrigation supply is crucial for good timely crop establishment and growth, the Aman season normally receives high amounts of rainfall. For the same reason farmers used more fertilizers in the Aman than in the Aus season, and the difference was higher for the tail farmers (Table 4). Similar findings have been established in earlier studies in rice in the Philippines.

One approach to solve the problem of low supply of irrigation water at the lower reaches of irrigation canals is to establish better control over the use of water in the upper reaches where much irrigation water is often misused. With implementation of appropriate water rotation methods, improved efficiency of water use and better equity of water distribution among users can be achieved. A study of water rotation for the GKIS, Bangladesh, is currently in progress. However, the cost of sustaining water distribution improvements can be high, which underscores the importance of assessing economic viability of alternative ways of alleviating water distribution problems within various types of irrigation systems.

Table 4. Average fertilizers (NPK) used and rice yields in the head, middle, and fail reaches of the main canal of the G-K Irrigation System (Phase I), Bangladesh, 1986-89.

	Aus season				Aman season			
	Fertilizer (kg/ha)			Yield (t/ha)	Fertilizer (kg/ha)			Yield (t/ha)
Location	N	P	K		N	P	K	
Head, S4K	73.9	41.1	28.1	3.36	106.9	36.4	24.1	4.53
Middle, S9K	70.4	27.2	17.2	3.20	96.0	39.5	25.0	4.16
Tail, S11K	31.9	14.2	6.9	2.36	82.1	44.1	27.8	4.29

Source; Bhuiyan et al. 1990

Crop Water Requirement versus Actual Use

The higher amounts of water required for rice compared to most other field crops is often a dominant reason for promoting production of nonrice crops in the dry season. In the NBTS, Bangladesh, for example, rice culture in the dry season is prohibited and wheat cultivation encouraged because ideally wheat takes about 20 percent or less of the water required to grow rice in the light-textured soils of the systems area. For the same reason, fanners in UTRIS, Philippines, and CIS, Indonesia, are encouraged to grow nonrice crops in the dry season.

But findings of research conducted in 1988-90 through this project indicate that actual use of water by fanners for nonrice crops is far in excess of the actual requirements and in some cases not much different from the amounts used for rice cultivation. In UTRIS, for example, the average water use for crop growth in onion production was almost the same as that used for rice (834 mm versus 877 mm). Likewise, water used for tobacco in the SFRIS was about 80 percent of the water consumed by rice (Tabbal et al. 1990).

The primary reason for the high water use for upland crops is the high water loss suffered in the methods used in irrigating nonrice crops. In certain cases, adoption of effective water conservation measures, e.g., the use of straw mulching in onion fields, will reduce the field water application requirements drastically (by 45 percent for onion in UTRIS) and also give some other benefits such as reduced weed growth. In UTRIS, straw mulching is practiced in areas which suffer chronic water shortage.

The relative high water requirements for rice have put the crop at a comparative disadvantage and in certain areas served with tubewell water, which is much more expensive than canal water, dry-season rice is being replaced with nonrice crops. Since rice price is expected to continue to be controlled by the governments of the major rice-consuming nations in Asia, continued shifts from irrigated dry-season (when rice productivity is higher than in the wet season) rice to nonrice crops may create a significant decline in rice production.

A desirable solution to this problem is to develop techniques of water management that will reduce water consumption in rice and make rice production more competitive with other crops. Some progress has been made in that direction. Recent research in farmer fields in the Philippines indicates that in clay loam soils with the water table **1** m or deeper, improved techniques of water management aimed at percolation loss reduction will save 25 to 55 percent of water from the amount needed in the standard practice, without sacrificing yields or needing additional weed control measures (Soriano and Bhuiyan **1989).** Similar studies conducted in the GK Irrigation System area in Bangladesh produced comparable results. In the North Bangladesh Tubewell System area, where many farmers have recently abandoned wheat cultivation (apparently because of economic disincentive) and have been keeping some of the previous wheat-growing land fallow, there is a great pressure on the system to deliver water for rice cultivation in the dry season. Water-saving rice irrigation techniques and suboptimal irrigation for rice may become attractive options for that situation.

Water Control, Land Use Efficiency, and Drainage

In areas with adequate supply of irrigation water, farmer's choice of dry-season crop is influenced by the degree of control over excess water that can be economically established on the farm. In certain situations, farmers seem to have no choice but to grow rice because neighboring farms are grown to rice, or because the area has a very shallow water table contributed by seepage and percolation water from the irrigation canals and from neighboring imgated rice fields. Appropriate land surface modifications can alleviate the excess water problem, but usually with a significant proportion of the land used for the purpose and at high costs because they are seasonal and have to be undone for the wet season rice cultivation. In a general sense, a relevant question is: how compatible is nonrice crop cultivation in an imgation system developed primarily for rice and what may be the desired modifications for improving compatibility? Some authors have recently recommended that rehabilitation or upgrading of rice irrigation systems would be necessary to make them suitable for large-scale crop diversification.

Irrigation infrastructure compatibilrty between rice and nonrice crops. Research conducted in two diversion type rice irrigation systems in the Philippines (UTRIS and SFRIS), in which both rice and nonrice crops are grown in the dry season, concluded that the canal network facilities of well-functioning rice irrigation systems can adequately support the water delivery needs of both rice and nonrice crops in the dry Season without any redesign or upgrading specifically for that purpose (Bhuiyan **1989).** At the farm level, water control, distribution, application and drainage functions for nonrice crops may require some facilities, mostly in the form of channels, additional to those in existence for rice culture for specific nonrice crops (such as tobacco) which are normally handled by the farmers adequately. These additional facilities are seasonal and erased out in the beginning of the wet season to release the occupied land for rice cultivation (Tabbal et al. 1990).

Land *use efficiency.* In UTRIS, Philippines, onion is grown after rice keeping the rice landscape and size essentially unaltered, but adding some special water control facilities such as interceptor channels to protect the field from seepage water from an adjacent canal or farm ditch and mid-rice field drainage channels for quick removal of extra surface water after application. Irrigation water is applied using the basin-flushing method at 1-to 2-week intervals (less frequent irrigation if straw mulching is used). The extra water control facilities normally use about 15 percent of the rice land (Tabbal et al. 1990). In contrast, the Maneungteung Irrigation System (MIS) farmers in Indonesia lose 25-30 percent of their land from production in order to construct the high beds and deep trenches on the rice field to grow onion or chili following wet-season rice. The beds are usually 1.2-1.4 m wide and the trenches are about 50-cm deep and 40-cm wide, which are kept filled with imgation water up to about 25-30 cm from the bed surface. All crop establishment and crop husbandry operations as well as irrigation applications, done at least once daily, are done manually from the trenches. These trenches are again filled up when rice is grown on the fields.

The Philippine (UTRIS) method of onion cultivation was tested through a farmer's field experiment in two seasons of 1988-89 in the clay loam soil of the MIS area. The findings show that significantly higher land productivity can be achieved without constructing the trenches than with the trenches, when irrigation is applied at 4- or 6-day intervals (Setio Budi et al. 1990). The yield per unit cropped area (With only the bed area counted) was higher in the traditional Indonesian model which received daily irrigations, because the amount of land savings achieved in the UTRIS model was significant. There is potential for greater gains if the yield per unit cropped area in this model of onion culture could be increased, which should be expected with experience. Another major advantage to be reaped from using the UTRIS model is the reduced cost of production due to savings in labor input, especially the labor for irrigation.

Drainage and water table management. The prospect of drainage water reuse has been studied in the G-K Irrigation System in Bangladesh to extend the benefit of irrigation to adjacent rain-fed or poorly irrigated areas within the system's command. Drainage discharge measurements were made in a selected major drain during 1988-89 and it was estimated that an additional area of 1,225 ha could be irrigated during both the Aus and Aman seasons if the drainage outflows were checked by an appropriate structure and the water lifted by pumping (Islam et al. 1990). The authors reported that several check structures that were initially provided for drainage reuse at other points within the system have fallen to disrepair and disuse.

In UTRIS, the Philippines, it seems that there is a similar scope for drainage water reuse, 'especially the excess outflow at night, but no study has been undertaken to establish the extent of the scope or its viability.

The challenge of managing a high water table contributed by seepage from the adjacent unlined canal and surrounding rice fields was addressed in a research conducted on a farmer's field in the service area of the Lower Talavera River Irrigation System (LTRIS), the Philippines, in the 1990 dry season. It established that a properly designed interceptor-cum-drainage channel constructed around and across the average size field could convert a high water-table area unsuitable for crops such as maize to a maize production area. The best treatment area, in which no irrigation input was needed throughout the crop growing season because of the presence of a shallow water table, produced 7.3 t/ha of maize compared to 3.3 t/ha in the control area. The cost of managing the water table for the best treatment area was only $40/ha which yielded a gross margin difference of $660/ha from the control. There was a gross margin advantage of $193/ha in favor of the maize grown in the best treatment area when compared to rice production (6.2 t/ha yield) on part of the same farm (Alagcan and Bhuiyan 1990). This method of water table control provided the much desired option to the farmer for his choice of crops in the dry season.

Other Technical Concerns

In addition to the above-stated topics of general interest, a number of other technical issues have been addressed through the project in the specific country situations, which also have a bearing on irrigated land productivity on other regions. These would include issues such as water-fertilizer interactions and annual productivity maximization for areas with unreliable water supplies in the Aus season in Bangladesh; and tillage and irrigation interactions on leguminous crops in the Philippines and in Indonesia.

CONCLUDING COMMENTS

Many technical water and land productivity issues and problems within "rice irrigation systems" of the different countries are similar, although the settings in which these problems exist and interact with the farming systems may be quite different in the various countries. Most of the specific findings generated through research under this project seem to have wider applicability. Needless to say, caution should be exercised in applying recommendations of research from one location to another, and the need for appropriate adjustments should be kept in mind.

Technical farm-level production problems are many and they must be alleviated if diversified farming systems are to be adopted by farmers. However, it must also be recognized that socioeconomic constraints to achieving higher productivity and farmer income are often dominant. Much more efforts should be given to identify these constraints and to assess means to alleviate them.

The project has greatly benefited the involved institutions and professionals. It has provided the opportunity for collaborative undertakings in the three countries for research focused mainly on water-related problems of rice land productivity, which were identified jointly by concerned local institutions with inputs from IIMI and IRRI. The experience gained and knowledge generated are of significant importance toward the goal of attaining higher food production and farmer income.

References

Alagcan, M.A. and S.I. Bhuiyan. 1990. Excess water management for growing upland crops in rice irrigation systems. Paper presented at the Workshop on Irrigation Management for Rice-Based Fanning Systems, Los Baiios, Laguna, Philippines. 10-11 September 1990.

Bhuiyan, S.I. 1989. Irrigation and water management for diversihed cropping in rice irrigation systems: Major issues and concerns. ODI-IIMI Irrigation Management Network Paper *89.e.* Overseas Development Institute, London.

Bhuiyan, L.R. et al. 1990. Fertilizer-water interactions in rice land productivity, BRRI (mimeo).

Islam, N. 1990. Some analysis of irrigated wheat cultivation in the North Bangladesh Tubewell (NBT) Project, Thakurgaon. BRRI (mimeo).

Juliardi, I., A.M. Fagi and T. Woodhead. 1990. Effects of soil preparation method and water supply on yield of mungbean grown after irrigated rice. Paper presented at the Workshop on Imgation Management Improvement on Rice-Based Farming Systems, IIMI-IRRI, Yogyakarta, June 13-14, 1990.

Mondal, M.K. et al. 1990. Water regimes and crop diversification. BRRI (mimeo).

Setio Budi, D., A.M. Fagi and S.I. Bhuiyan. 1990. The productivity of land and water in alternative techniques for growing onion after rice. Paper presented at the Workshop on Irrigation Management Improvement on Rice-Based Farming Systems, IIMI-IRRI, Yogyakarta.

Soriano, R. and S.I. Bhuiyan. 1989. Irrigation application alternatives and their effects on water use and rice yields. IRRI Seminar paper. October 28,1989.

Tabbal, D.F., S.I. Bhuiyan and R. Lampayan. 1990. Water control requirements and complementarities for rice and nonrice crops. Paper presented at the National Workshop on Irrigation Management for Rice-based Farming Systems. University of Philippines, Los Banos, Philippines, 10-11 September 1990.

Tenedora, M.E., T. Savares-Sali and T. Woodhead. 1990. Tillage and soil-water management for legume following irrigated lowland rice. Paper presented at the National Workshop on Irrigation Management for Rice-based Farming Systems. University of Philippines, Los Banos. Philippines, 10-11 September 1990.

Undan, R.C., J.L. Tabago and D.F. Ringor. 1990. Water augmentation and drainage studies in diversified areas. Paper presented at the National Workshop on Irrigation Management for Rice-based Fanning Systems. University of Philippines, Los Banos, Philippines, 10-11 September 1990.

Wardana, I.P. et al. 1990. Water relations to dry season crop choice and profitability in the Cikeusik Irrigation System. West Java. 1990. Paper presented at the Intercountry Workshop on Irrigation Management for Rice-Based Farming Systems, IIMI, Colombo, 12-14 November, 1990.

Zandstra, H.G. 1990. Technological considerations of agricultural diversification. Paper presented at the Regional Workshop on Agricultural Diversification, Central Research Institute on Food Crops (Agency for Agricultural Research and Development) and the World Bank, Bogor, Indonesia, 20-22 March 1990.