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Waterlogging and Salinity Management
In Sindh Province, Pakistan

Supplement I-A:

IMPROVED WATER MANAGEMENT PRACTICES FOR THE RICE-WHEAT CROPPING SYSTEMS IN SINDH PROVINCE, PAKISTAN

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

This study presents an overview of the rice-wheat cropping systems in the Sindh Province, including environmental constraints of soil salinity/sodicity, waterlogging, irrigation supplies and inadequate drainage to obtain optimum yields for rice and wheat on a sustained basis. The study reviews irrigation and drainage management practices around the world and current irrigation and drainage practices in the Sindh rice-wheat zone. Also, improved irrigation and drainage measures for the Sindh rice-wheat cropping systems are identified in this study.

Pakistan has 21 million hectares (Mha) of farmland, of which 7.8 Mha are used for wheat cultivation. Of this 7.8 Mha, the rice-wheat cropping sequence is adopted on about 2.2 Mha. Currently, the rice-wheat cropping system occupies about 10 percent of Pakistan's total farmland. There are two major rice-wheat cropping zones: the Punjab Rice-Wheat Zone and the Sindh Rice-Wheat Zone. The Punjab rice-wheat zone consists of about 1.126 Mha CCA and receives its surface water supplies from the central Bari Doab, Raya Upper Chenab, Marala Ravi, Jhang and Gugera Branch Canals off-taking from the Chenab River. An intensive private tubewell development has occurred in this zone during the 1980s due to fresh groundwater in this area. The annual cropping intensity of 128 percent is the highest when compared to other areas of the Punjab Province, with *basmati* rice and wheat being the most dominant *Kharif* and *Rabi* crops, respectively. Rice occupies almost 53 percent of the *Kharif* acreage and wheat almost 67 percent of the total *Rabi* acreage.

Combined, the Sindh rice-wheat north (SRWN) and the Sindh rice-wheat south (SWRS) zones, on the Right and Left Banks of the Indus River, respectively, constitute the Sindh Rice-Wheat cropping zone. The average annual cropping intensity for this zone is 65 percent. Rice occupies about 75 percent of the total *Kharif* acreage and wheat occupies about 37 percent of the total *Rabi* acreage. IRRI, especially IRRI-6, is grown on about 60 to 70 percent of the total rice area in the Sindh rice-wheat zone. Wheat yields in this zone are the lowest in the basin, because wheat is mostly sown after the rice harvest, and *Rabi* water supplies in most of the area are unavailable. Rice is grown on about 0.75 Mha, with production of about 1.5 Mt of rice yielding about 2 tons/ha; whereas, area under wheat is over 1.0 Mha yielding an average irrigated wheat crop of 2.1 tons/ha. This reflects that areas of rice and wheat in the Sindh Province are 38 percent and 12 percent of the country's rice (about 2 Mha) and wheat (about 8 Mha) areas, respectively. The Sindh Province's rice and wheat productions are 50 percent and 13 percent of the national rice (3 Mt) and wheat (16 Mt) production, respectively.

The major environmental constraints include waterlogging and soil salinity / sodicity, inadequate and unreliable irrigation water supplies, poor quality groundwater used for irrigation and inadequate drainage. These are the major constraints that restrain the potential productivity of rice and wheat crops in the country.

The water management practices, both at the irrigation system and farm level currently being adopted in various rice-wheat-growing countries of the world, especially in the Asian countries, are:

- Puddling for land preparation: That the water requirement in the case of puddled rice is 40 to 60 percent less than in non-puddled fields due to reduced percolation losses has been reported. Moreover, in puddled soil, rice has a higher water use efficiency than in non-puddled soil;

- Farmers in rice growing countries are switching from the transplanted to the direct-seeded flooded rice system: The direct-seeded flooded rice technique has the advantages of reduced labor costs and a shorter cropping cycle. The direct-seeded rice offers a significant opportunity for the improved management of irrigation water. This requires about 30 percent less water to prepare a typical field up to the same puddled condition for direct-seeded rice than for transplanting rice;

- Irrigation scheduling could play an important role in improving the water use efficiency of rice, specifically for the rice-wheat farming systems. The improved schedules of irrigation developed by the research stations promise considerable savings in water;

- Irrigation water saving regimes: Here, it has been found that for clay loam soil, water use with a saturated soil regime was about 40 percent less than the traditional practice of continuous flooding without a rice yield reduction. High rice yields could be obtained with a saturated soil regime maintained continuously in the field. However, if weed growth is a problem, continuous submergence up to panicle initiation, and then continuous saturation, could be an effective technique of water-efficient irrigation without yield reduction;

- Reuse of drainage effluent has a greater potential for improving irrigation water management in rice–wheat systems in a water shortage situation; and

- Active farmers' participation when managing irrigation systems could result in the improved equity and reliability of water distribution, which in turn results in earlier rice planting, and an increased irrigated area.

Water requirements for rice cultivation vary and depend largely on the soil type. The average requirement in the Punjab Province's rice-wheat zone is considered to be about 1600mm. However, the mean irrigation application was found to be around 1300mm during actual measurements on a fairly large number of farms in the Punjab Province's rice-wheat zone. In this zone, the main sources of irrigation are perennial and non-perennial canals supplemented by tubewell water. In general, farmers who supplement tubewell water realize higher rice yields. Irrigation water management practices being practiced for wheat cultivation in the Punjab Province are:

Insufficient water application: Farmers tend to over-plant and under-irrigate, hoping abundant rains will close the gap between evapotranspiration demands and irrigation supplies. The first irrigation is applied too late, which causes a double negative impact because the majority of farmers apply nitrogen with the first irrigation. The delay in irrigation affects the uptake and utilization of nitrogen in addition to the crop water condition. Farmers terminate irrigation turns in early to mid-March when the wheat crop needs water badly due to high evapotranspiration. This practice has a detrimental effect on wheat yields during the year, with no rainfall during that time period.

In the rice-wheat zone of the Sindh Province all rice is grown in flooded fields, which are initially irrigated individually and later with an increase in water depth. A largely uncontrolled water flow takes place from field to field, thereby resulting in some sort of continuous flow irrigation, called the Pancho System. The necessary irrigation and drainage control for intermittent irrigation is not usually present. Irrigation practices for broadcast and transplanted rice differ in the initial stages, but once the seedlings are established, the same irrigation method is used for both, broadcast and transplanted rice. For broadcast rice, fields are normally flooded as soon as water becomes available and seed is broadcast into the standing water. The next irrigation is given after germination when seedlings are about 5cm high. Additional irrigation turns are aimed at flooding the field and keeping the water surface just below the growing tips of the rice. Once a depth of about 30.5cm is attained, further water applications are provided to maintain this depth. The levelness of the fields is rarely, if ever, up to the standard required for efficient water control for broadcast rice. In the case for transplanted rice, one or more pre-irrigation turns are provided in order to have some soil moisture before transplanting. An additional irrigation is given just prior to transplanting. Once the seedlings are established, normally a few days after transplanting, water is again applied and the field kept permanently flooded. Irrigation is discontinued about 15-20 days before harvesting in order to aid maturity, and also to have fields free of standing water at harvest time.

In the Sindh Province, wheat is grown as *dubari,* or growing crops in the *Rabi* season on residual moisture from the *Kharif* irrigation, which usually occurs in non-perennial areas, and *bosi*, growing crops in the *Rabi* season on water supplied at the end of the *Kharif* season. These practices also take place in non-perennial areas. Crops are mainly grown in non-perennial areas, but are usually grown in the normal basin flood irrigation method in the perennial areas. The *dubari* and *bosi* methods are only used in the non-perennial Rice Canal and Kotri commands. The average yield from normally irrigated fields is about double that from the other two methods. In general, *dubari*-grown wheat yields more than the *bosi*-grown wheat.

The improved irrigation and drainage practices identified for the Sindh Province at the system level include irrigation water delivery accountability, a management decision support system, irrigation management information system, performance indicators, farmer-participation, reuse of drainage effluent and physical rehabilitation. The farm level water management measures consist of water-saving irrigation regimes, irrigation scheduling, an on-farm drainage system, rice establishment method, discontinuation of the *pancho* system, land leveling, improved layout of irrigation ditches and fields, and farmers' awareness of land reclamation. The adoption of these irrigation and drainage management measures and practices would offer a greater opportunity to improve water use efficiency for the sustainability of the rice-wheat cropping systems in the Sindh Province.

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WATERLOGGING AND SALINITY MANAGEMENT IN THE SINDH PROVINCE, PAKISTAN

Supplement I-A:

Improved Water Management Practices for the Rice-Wheat Cropping Systems in the Sindh Province, Pakistan

I. OVERVIEW OF THE RICE-WHEAT CROPPING SYSTEMS IN PAKISTAN

A. Rice-Wheat Cropping Systems

Rice and wheat are main staple food commodities and are grown on larger proportions of the world's cultivated land. Various countries earn foreign exchange by exporting rice and wheat. America, Japan, Philippines, Mexico, Bangladesh, Nepal, China, India, Thailand and Pakistan are major rice-wheat growing countries. In these countries, rice and wheat are grown either in rotation whereby monsoon season rice is usually grown on irrigated puddled soil, which, in the same fields, is followed by wheat that grows during the cooler, drier months or in rotation with other crops like fodder, cotton, vegetables, etc.. The cropping sequence whereby wheat is always grown after rice followed by rice after wheat in the same field, is called a rice-wheat cropping system.

B. Geographical Distribution

Pakistan has 21 million hectares (Mha) of farmland, of which 7.8 Mha are used for wheat cultivation. Of 7.8 Mha, the rice-wheat cropping sequence is adopted on about 2.2 Mha and the remaining 5.6 Mha are used for maize, cotton, fodder or other crops, as well as fallowing. Currently, the rice-wheat cropping system occupies about 10 percent of Pakistan's total farmland. There are four rice-wheat cropping zones located in various Agro-Ecological Regions (AERs) of Pakistan: Zone 1 (Northern Zone), Zone 2 (Punjab Rice-Wheat Zone- PRWZ), Zone 3 (Upper Sindh Zone: Sindh Rice-Wheat North- SRWN) and Zone 4 (Lower Sindh Zone: Sindh Rice-Wheat South- SRWS). The locations of these zones are shown in Figure 1.

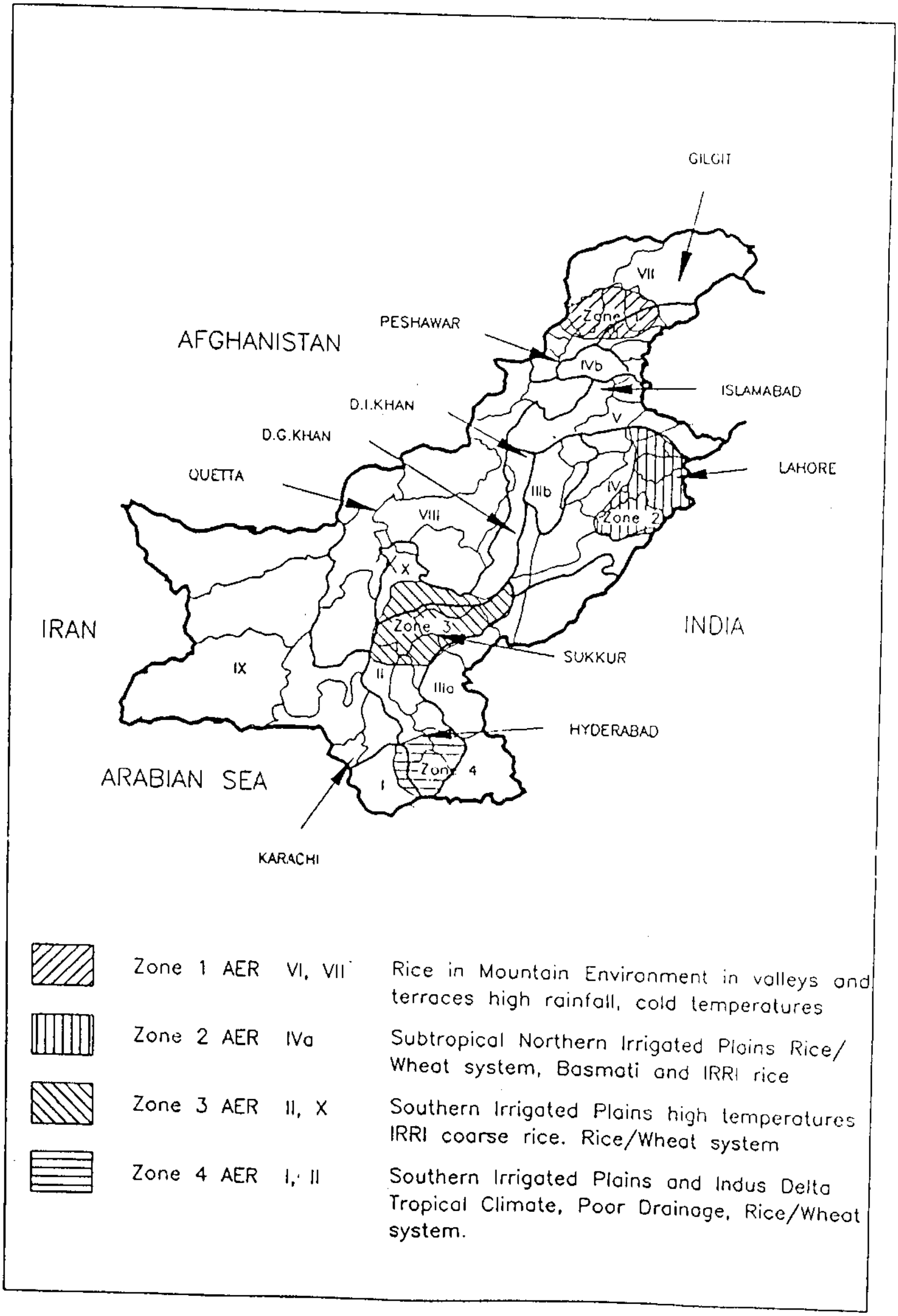

Figure 1. Rice-wheat cropping zones of Pakistan (adapted from PARC, 1993).

The northern rice-wheat zone lies within AERs VI (Rawalpindi, Hazara and Mansehra) and VII (Gilgit, Chitral, Dir, Swat, Malakand, Khyber, the Peshawar and Kohat tribal areas, etc.). In this zone, rice is grown in valleys and hillside terraces. The annual rainfall is 750 to 1000mm. Seventy percent of rainfall occurs during the summer. Cold temperatures and cold water cause low temperature stress. Rice is grown in rotation with wheat, *berseem*, barley and onion.

The main features of the Punjab and Sindh Provinces' rice-wheat zones are provided in Table 1. An intensive private tubewell development has occurred in the PRWZ during the 1980s due to fresh groundwater in this area. It has the highest cropping intensity when compared to other areas of the Punjab Province, with *basmati* rice and wheat being the most dominant *Kharif* and *Rabi* crops, respectively. Combined, the SRWN and SRWS constitute the Sindh Rice-Wheat cropping zone where rice is the dominant crop. Due to waterlogging, yields of non-rice crops are poor, and consequently, cropping intensities are the lowest in the Indus Basin. Wheat yields in this zone are the lowest in the basin. This is due to the fact that wheat is mostly sown after the rice harvest and *Rabi* water supplies in most of the area are not available.

Table 1. Main features of the Punjab and Sindh Provinces' rice-wheat zones.

Zone	AER	CCA (Mha)	Districts	Annual rainfall (mm)	Canal commands	Annual cropping intensity	Rice area (%)[1]	Wheat area (%)[2]
PRWZ	IVa	1.13	Sheikhupura Gujranwala, Sialkot, and Lahore	400-700	Upper Chenab, Marala Ravi, Central Bari Daob, Jhang Branch, Gugera Branch	128%	53	67
SRWN	II, X	1.78	Dadu, Larkana, Jacobabad, Shikarpur, and Nasirabad	100-200	Pat and Desert, Bagari, North-Western, Rice, Dadu			
SRWS	I, II	1.12	Hyderabad, Badin, Thatta and Karachi		Kalri, Lined Channel, Fuleli, Pinyari	65%[3]	75[3]	37[3]

1. Rice area in percentage of the total *Kharif* acreage.
2. Wheat area in percentage of the total *Rabi* acreage.
3. For the whole Sindh Rice-Wheat zone.

C. Area and Yield

In various regions of Pakistan, especially in the Punjab and Sindh Provinces, rice and wheat are grown sequentially in the same field during the same farming year. Since 1960, zones for rice-wheat have expanded, especially in the Punjab Province. In 1970-71, the total area sown to rice was 1.54 Mha, of which 0.79 Mha was in the Punjab, 0.66 Mha in the Sindh, 0.05 Mha in the NWFP and 0.04

Mha in the Baluchistan Provinces. By 1987-88, the rice area increased to 2.04 Mha, of which 1.19 Mha was in the Punjab and 0.68 Mha in the Sindh Provinces. The largest increases occurred in the Gujranwala, Sheikhupura and Sialkot Districts of the Punjab, in the Larkana Districts of the Sindh and Nasirabad in the Baluchistan Provinces.

During 1970-71, the total area sown to wheat was 6.09 Mha, of which 4.52 Mha was in the Punjab, 0.86 Mha in the Sindh, 0.59 Mha in the NWFP and 0.12 Mha in the Baluchistan Provinces. In 1987-88, the wheat area increased to 7.73 Mha with the largest increases occurring in Bahawalpur, Bahawalnagar, Jhang, Muzaffargarh and Rahim Yar Khan Districts of the Punjab Province. On the whole in Pakistan, the total area sown to wheat was about four times the area sown to rice in both, 1970-71 and 1987-88.

In 1970-71, the total area for the rice-wheat sequence for the entire Pakistan was estimated to be 1.02 Mha, representing 68 percent of the total rice area (1.54 Mha) and 17 percent of the total wheat area (6.09 Mha). The largest areas were in Gujranwala, Sheikhupura and Sialkot in the Punjab Province, and substantial cropping occurred in Jacobabad and Larkana in the Sindh Province. By 1987-88, the rice-wheat area increased to 1.38 Mha, of which 1.00 Mha was in the Punjab and 0.24 Mha in the Sindh Province. The largest increases occurred in the Faisalabad, Gujranwala and Lahore Divisions of the Punjab, Nasirabad Division of the Baluchistan and the Badin District of the Sindh Province. In 1987-88, 1.38 Mha of rice-wheat represents 67 percent of the total rice area (2.04 Mha) and 18 percent of the total wheat area (7.73 Mha) (Woodhead et al., 1993).

The area under rice and wheat by the SRWN zone canal command for *Kharif* 1995 and *Rabi* 1995-96 is provided in Table 2. The table depicts that rice was grown on about 47 percent of the total CCA of five irrigation canals during *Kharif* 1995, and that wheat was grown on about 14 percent of the total CCA during *Rabi* 1995-96.

Table 2. Area under rice and wheat for *Kharif* 1995 and *Rabi* 1995-96 for the Sindh Rice-Wheat North Zone.

	Kharif 1995		
Canal command	**GCA (Mha)**	**CCA (Mha)**	**Rice cropped area (Mha)**
Desert feeder	-	0.158	0.079
Begari feeder	-	0.341	0.206
North-West	0.319	0.309	0.108
Rice	0.218	0.209	0.135
Dadu	0.259	0.237	0.056
Total	**0.796**	**1.254**	**0.584**

Continued from Table 2

	Rabi 1995-96		
Canal command	**GCA (Mha)**	**CCA (Mha)**	**Wheat cropped area (Mha)**
Desert feeder	-	0.158	0.035
Begari feeder	-	0.341	0.053
North-West	0.319	0.309	0.032
Rice	0.217	0.210	0.000
Dadu	0.275	0.252	0.060
Total	**0.811**	**1.27**	**0.18**

(Source: Sindh Irrigation and Power Dept., 1996)

Table 3 shows the area sown to rice and wheat during *Kharif* 1995 and *Rabi* 1995-96 in different canal commands of the SRWS. According to Table 3, rice was grown on about 19 percent of the total CCA during *Kharif* 1995 and wheat was grown on only about 3 percent of the total CCA.

Table 3. Area under rice and wheat for *Kharif* 1995 and *Rabi* 1995-96 for the Sindh Rice-Wheat South Zone.

	Kharif 1995		
Canal command	**GCA (Mha)**	**CCA (Mha)**	**Rice cropped area (Mha)**
Kalri canal	0.266	0.258	0.043
Fuleli canal	0.379	0.361	0.089
Lined channel	0.229	0.220	0.031
Pinyari canal	0.327	0.323	0.061
Total	**1.201**	**1.162**	**0.224**
	Rabi 1995-96		
Canal command	**GCA (Mha)**	**CCA (Mha)**	**Wheat cropped area (Mha)**
Kalri canal	0.266	0.258	0.0037
Fuleli canal	0.379	0.361	0.0110
Lined channel	0.229	0.220	0.0120
Pinyari canal	0.327	0.323	0.0062
Total	**1.201**	**1.162**	**0.0329**

(Source: Sindh Irrigation and Power Dept., 1996)

Figure 2 shows trends during the 1950-90 period, in yields for rice and wheat (national averages), whether grown in sequence or otherwise. According to Figure 2, during 1960-90 the average yield of rice increased from 1.3 to 2.3 t/ha and wheat from 0.8 to 1.7 t/ha. These increased yields occurred due to improved and higher yielding varieties of rice and wheat, expansion of irrigation, drainage and fertilization and improved soil and crop management, and intensified use of land already under irrigation and cultivation. Figure 2 shows a steady progressive increase in the wheat yield, though at a slightly lower rate during 1980-90 than the earlier years.

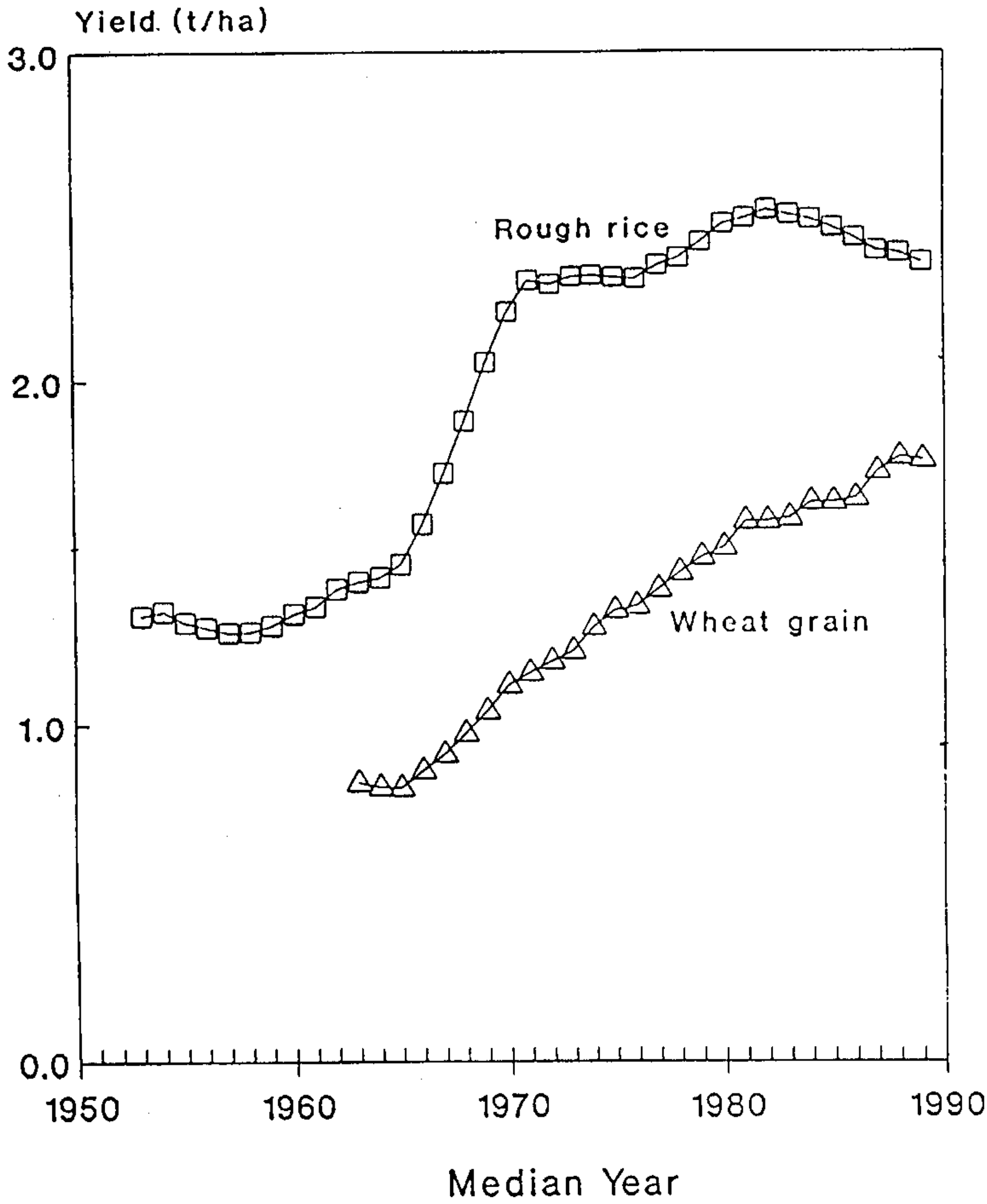

Figure 2. Progression during 1951-1991 for National average yields of rice and wheat in Pakistan (Adapted from Woodhead et al., 1993).

The rice yield increased rapidly during the 1960s due to new rice varieties (shorter duration and higher yielding), but after 1970, small increases occurred. Since 1980 the rice yield has declined, which may be due to the poor quality irrigation water and the adoption of lower-yielding higher-valued *basmati* rice.

Based on the Economic Survey of Pakistan (1992-93), information on area under rice and wheat, and the yield and production of rice and wheat in Pakistan during 1987-93 is presented in Table 4. The table shows that during the1991-92 to 1992-93 period, area sown to rice decreased from 2.10 Mha to 1.93 Mha (8% decrease), the rice yield increased from 1.55 t/ha to 1.59 t/ha (2.6% increase) and rice production decreased from 3.26 Mt (million tons) to 3.07 Mt (5.8% decrease). During 1991-92 to 1992-93, the wheat area increased from 7.88 Mha to 8.22 Mha (4.4% increase) with no change in the yield, but wheat production increased from 15.68 Mt to 16.36 Mt (4.3% increase).

Table 4. Area, Yield and Production of Rice and Wheat in Pakistan (1987-93).

Farm year	Rice			Wheat		
	Area (Mha)	Yield (t/ha)	Production (mt)	Area (Mha)	Yield (t/ha)	Production (mt)
1987-88	1.96	1.65	3.23	7.31	1.73	12.65
1988-89	2.04	1.57	3.20	7.73	1.86	14.38
1989-90	2.11	1.53	3.23	7.84	1.82	14.27
1990-91	2.11	1.54	3.25	7.91	1.84	14.55
1991-92	2.10	1.55	3.26	7.88	1.99	15.68
1992-93	1.93	1.59	3.07	8.22	1.99	16.36
	-8%	**+2.6%**	**-5.8%**	**+4.4%**	**0.0%**	**+4.3%**

(Source: Altaf, 1994)

D. Soil Variations

Most soils in the Indus plains develop from the alluvium of the Indus River system. They are mostly brown to grayish brown, calcareous and weakly structured. The soil texture ranges from coarse to fine with about 85 percent in the moderately coarse to moderately fine categories, which are mostly suitable for irrigated agriculture. About 50 percent of the Indus plains have no, or only minor limitations for agriculture; about 20 percent have moderate problems of excessive salts, too much wetness or light textures; and the remaining area has severe limitations due to excessive salts, wetness, sandy soils or lack of moisture. The result causes about 5 percent of marginal agricultural land and about 25 percent of practically non-agricultural land.

Each soil has certain physical, chemical and drainage characteristics that determine its suitability for various crops and affect its response to management. Soils best suited for wheat are well drained, loamy (silt loam to clay loam) with moderate to high soil fertility and those suited for rice are clayey and slowly permeable (clay loam etc.). Soils in the four rice-wheat zones of Pakistan vary in texture from loams, silt loams, silty clay loams, and sandy loams. These zones also have saline soils. The loam soils are puddled for rice growing, which may cause a reduction in the yield of wheat and other crops grown after the rice harvest in the same field.

E. Varieties

In the case of rice, IRRI (IRRI-6 and IRRI-8) and *basmati* varieties (Basmati 370, Basmati 385, Basmati Pak) are grown in different cropping zones. IRRI, especially IRRI-6, is grown on about 60 to 70 percent of the total rice area in the Sindh rice-wheat zone, and on about 33 percent in the Punjab rice-wheat zone, but *basmati* is grown solely in the Punjab rice-wheat zone. The growth period for important rice varieties like Irri-6, Basmati 385, Basmati 370, and Basmati Pak falls in the range of 105-110, 100-105, 115-120, and 115-120 days, respectively. In the Punjab Province, rice is usually transplanted from mid-June to the 3rd week of July and harvested from the 3rd week of October to the 3rd week of November. In the Sindh rice zone, the transplanting period is from mid-May to the end of July and the harvesting period is from the 3rd week of August to the first week of December. In the north upland rice zone, JP5, Swat 1, Swat 2 and Basmati 385 are the commonly grown rice varieties. In this zone, rice is planted from the beginning of May to the 3rd week of June and is harvested from the 2nd week of October to mid-November.

On average, about 90 percent of the farmers in the Indus Basin grow improved wheat varieties, which are resistant to salinity, pests and diseases, and possess a higher yield potential. A wide range of wheat varieties is grown in different rice-wheat zones. Pasban 90, Inqalab 91, Parwaz 94, Rawal 87 and Faisalabad 85 wheat varieties are grown in the Punjab rice-wheat zone, whereas in the Sindh zone, Maki Pak, Sonalika (Blue Silver), Mehran 89, Tando Jam 83, Abadgar 93 and Anmol 91 are grown by farmers. Pirsaabak, Khyber 87 and Bakhtawar are grown in the northern rice-wheat zone. Farmers in the Northern and Punjab zones generally plant wheat during the period from November to December and harvest during the period from the 2nd week of April to the end of May. Farmers in the Sindh Province plant wheat in the period from mid-November to the end of December and harvest in the period from mid-March to the 3rd week of April.

F. Input Requirements for Rice and Wheat

1) Fertilizer

IRRI work has shown that increased fertilizer use and improved nitrogen application techniques can provide a 73 percent yield advantage over the normal farm practice (De Datta, 1986). In the Indus Basin, about 77 percent of the farmers apply nitrogen to their rice crop, but only about 33 percent use phosphate. Among the major rice growing zones, except for the Kotri command, the percentage of farmers using nitrogen and phosphates is higher than the basin average. The average amount of nitrogen and phosphate applied by farmers in the basin is 61.7 kg/ha and 52.7 kg/ha, respectively. Table 5 provides fertilizer application rates used by the farmers in the Punjab and Sindh Rice-Wheat Zones. The lower application rates shown for the Punjab Rice-Wheat Zone reflect the more limited response of *basmati* varieties (compared to IRRI rice) to fertilizer.

Table 5. Rice fertilizer application rates for Punjab and Sindh rice-wheat zones.

Area	Nitrogen (kg/ha)	Phosphate (kg/ha)
Punjab rice zone	50.5	47
Sindh rice zone: Right Bank	51.6	43.7
Sindh rice zone: Kotri	50.5	38

Research has shown that for the paddy crop, all types of fertilizers do not give the same response because the system of the uptake of nutrients is different in rice than in other crops. The paddy plants are also of a semi-aquatic type and are raised under standing water. The Rice Research Institute, Dokri, Sindh (personal communication, 1998) report that nitrogenous fertilizers having nitrogen in the form of ammonia are more effective for the paddy crop, i.e. ammonium sulphate and Urea, compared to the fertilizers having N in the form of nitrate, i.e. ammonium nitrate and nitrophos. In the case for phosphatic fertilizers, DAP fertilizer is more effective to achieve good soils, however, TSP also gives better per hectare rice yields.

Based on the Expanded Agricultural Economics Survey, XAES (1978), about 80 percent of the farmers (total farmers interviewed, 2000) on irrigated lands in the Indus Basin use nitrogenous fertilizers and only 40 out of 80 percent make use of phosphate fertilizers for the wheat crop. The use of fertilizer is the lowest in the Sindh Rice-Wheat Zone, where irrigation and drainage are unfavorable for wheat. The average amount of nitrogen and phosphate applied by growers is 63kg/ha and 55kg/ha, respectively. Fertilizer usage for improved varieties is higher when compared to traditional wheat. On a basin basis, the average rate of both, nitrogen and phosphorus applied to traditional wheat is 63kg/ha against 98kg/ha for improved wheat.

2) Seed

The majority of the farmers use their farm rice produce as seed. The seed rate varies according to the method of planting. Higher seed rates are used for broadcast when compared to transplanting. The usual seed rate in the basin is about 7.5kg for the transplanting method and 28kg for the broadcast. The recommended seeding rates for rice nurseries of IRRI and *basmati* varieties are 15–20kg/ha and 10–2kg/ha, respectively. When compared to that used in the Punjab Province (9kg/ha), it has been found that very high seed rates (30-

40kg/ha) are used in the Sindh Province. The higher seed rate in the Sindh Province is due to the fact that covering the risk of an improperly prepared seedbed and having the required plant population, farmers mostly transplant six to seven seedlings per hill, whereas in the Punjab Province, it is mostly one.

That the yields at farmer's fields are low due to low plant densities has been found. Plant density should range from 187500 to 250000 per ha. The majority of the farmers achieve rice plant density less than recommended, in both, the Punjab and Sindh Provinces. Usually, farmers do not practice line transplanting, but prefer random transplanting due to which the correct number of hills per hectare are not planted, and consequently, less yields are obtained. The main reasons for random transplanting are (i) irrigation system '*warabandi*' and (ii) limited time for transplanting at the time water reaches the fields. These two factors ultimately result in the non-adoption of the row planting system, due to which farmers are unable to have an idea about the proper number of hills transplanting per hectare. In order to plant the required number of hills per hectare to achieve plant density within the recommended range of 187500 to 250000 per ha, the line transplanting should be adopted and a distance from row to row and plant to plant should be maintained at 20cm.

Usually, farmers use their farm wheat produce for seed and a few farmers purchase seed from government sale points, unless a new variety of seed is offered for cultivation. However, yields are considerably higher when the seed is purchased from local market and government sale points compared to the seed retained from the farm produce.

Most farmers apply the seed at the rate of 90-95kg/ha for the broadcast wheat crop, against the recommended seed rate of 125kg/ha. The use of a proper amount of viable and healthy seed affects the plant population, which in turn plays an important role in realizing the wheat yield potential. The recommended plant population is 1111500 for optimum wheat growth. Nearly all farmers in the Punjab and Sindh Provinces achieve populations significantly less than the recommended one for higher performance. The main reasons for low plant population are low quality seed and low seed rates, broadcast seeding and unleveled fields, along with delayed irrigation. The majority of the farmers still practice broadcast methods for wheat seeding. However, the progressive farmers use the *Rabi* drill to line sow the wheat seed.

3) Irrigation Water

Rice is a semi-aquatic plant that yields best when kept under constant flood. A maximum of a 4-to-5-day interval between irrigation can be tolerated; beyond that, the crop yield will be considerably reduced. Irrigation is required to permit timely transplanting and also to maintain the field in a ponded condition after transplanting. For rice, the seasonal crop water demand ranges from 1200 to 1600mm for a growing period of 100 to 150 days. The depth of water required for puddling before transplanting is within a 100–200mm range. The depth of water in the paddy to be maintained for the various stages of growth is provided in Table 6.

Table 6. Paddy water requirements during crop growth periods.

Stage	Water depth (mm) in Paddy
Transplanting	100
Recovery period 7-10 days after transplanting.	100
Tillering	20 – 30
Flowering	50 – 100
Before harvesting (10 – 15 days)	Stop irrigation

The most critical periods that are sensitive to water shortages are flowering and head development, and the recovery period immediately after transplanting. Usually, farmers in the Punjab rice-wheat zone apply 14.8 irrigation turns, 28.2 in the Sindh Right Bank (SRWN), and 27.9 in the Sindh Kotri command (SRWS).

In the Punjab rice-wheat zone, the main sources of irrigation are perennial and non-perennial canals supplemented by tubewell water. On average, farmers keep the water standing in the fields for 7 days before planting the nursery. Then, 25 irrigation turns are applied to the standing crop throughout the season (Azeem et al., 1990). In general, farmers using canal irrigation water have a lower yield, whereas rice growers using supplemental tubewell water realize higher rice yields, which reflects the advantage of assured and timely water supplies from tubewells. There is a significant effect of farm location on the rice yield, especially in the Punjab Province, where the yield is highest at the farm located in the head reach of the watercourse. But, in the Sindh Province, the situation is different; farms at the tail end of the watercourse harvest the highest yields when compared to those at the head and middle reaches. This can be explained by the fact that head reach farmers apply water quite in excess of crop water requirements, which causes reduced rice yields. The information on farm location and rice yield is provided in Table 7.

Table 7. Farm location vs. rice yields.

Location	Punjab + NWFP		Sindh	
	% of cases	Yield (kg/ha)	% of cases	Yield (kg/ha)
Head	33	2557	37	2351
Middle	37	2463	48	2687
Tail	30	2323	15	2725

(Source: Watercourse Survey, 1978)

The wheat crop has a growing season of about 130–150 days when the water requirement is about 325 to 450mm. The gross application depth of water per irrigation is 75mm with an irrigation interval of 25–30 days. Crop growth stages sensitive to water shortages are the tillering, flowering and grain filling, more so than the vegetation phase. A pre-sowing irrigation (*rauni* irrigation) is necessary to achieve a full plant establishment. *Rauni* irrigation may not be necessary after rice or heavy soils, as this could delay planting wheat.

Water shortage and uncertain irrigation schedules are severe problems being faced by the majority of farmers growing wheat. Water shortage at critical stages adversely affects the wheat yield. Water availability in adequate and reliable quantities also affects the use of other inputs in proper amounts. In the Punjab rice-wheat zone, the majority of the farmers have access to both, canal as well as tubewell water, whereas in the Sindh rice-wheat zone, canals mostly provide water to wheat. Wheat yields in the Punjab zone are considerably higher than in the Sindh zone. Clearly, the conjunctive use of canal and tubewell water plays a big role in increasing the wheat yield. Over the entire season, 5 to 6 irrigation turns are generally considered adequate for wheat. Most farmers practice several irrigation turns within the 5th to 6th irrigation turns. The average number applied by all growers is 5.7, with the lowest number (3.2 irrigation) in the Sindh rice-wheat area. According to XAES data, the wheat yield increased with the number of irrigation turns (Table 8), but the yield was only 1641kg/ha with more than 8 irrigation turns.

Table 8. Wheat yields according to the number of irrigation turns.

No. of irrigation tuns	Yield (kg/ha)
0 – 3	765
4 – 7	1410
Above 8	1641

The location of farm near the source of irrigation water is also considered very important when harvesting higher yields. The yields are higher at the farms located near the watercourse head when compared to middle and tail reaches (Table 9).

Table 9. Effect of farm location on wheat yields.

Farm location	Yield (kg/ha)
Head	2249.4
Middle	1779.3
Tail	2009.7

G. Environmental Constraints in the Rice-Wheat Cropping Systems

Though in the past several efforts have been made to increase the rice-wheat yields, unfortunately, the per hectare yields of these crops are still far lower than their potential yields, as shown in Table 10.

Table 10. Yields (kg/ha) of rice and wheat (with their potential in Pakistan).

Crop	Present national yield	Potential yield	Crop yield
Wheat	1881	6400	4510
Rice (*basmati*)	1567	5200	3633

(Source: Yaseen and Haroon, 1990)

The yield gap can be attributed to constraints to achieve a potential production of rice and wheat. Generally, these constraints include inadequate levels of vital inputs and cultural practices (seedbed preparation, seeding rate and depth, planting dates, time, method and amount of fertilizers and irrigation water use, pesticides use, etc.). Environmental constraints include soils (soil salinity / sodicity), irrigation water supplies (quantity and quality) and drainage problems. These are the major constraints that restrain the potential productivity of rice and wheat crops in the country.

1) Soils

The majority of the Indus Basin soils is moderately coarse to moderately fine-textured, and considered suitable for irrigated agriculture. Imperfectly drained clay and silty-clay soils are quite suitable for paddy. Well-drained loams and silt loams are suitable for all types of crops, but their lighter texture makes them less appropriate for rice cultivation. Saline-sodic soils are unsuitable for almost all crops. An observation in the Punjab Province has been that farmers use almost all kinds of soils for rice cultivation without considering suitability. At least 15 percent of the paddy fields are found to have soils that are unsuitable for paddy cultivation. On most of these fields, water applications were higher than average, while yields were below average. Growing paddy on unsuitable soils is a major constraint in sustained, or increased, rice production (Bhatti and Kijne, 1992).

Another major constraint for the rice-wheat system is soil salinity and sodicity, which is very widespread throughout the basin and has devoured the potential of agricultural lands that cause poor rice and wheat yields, as shown in Table 11.

Table 11. Average crop yield (kg/ha) on salt-affected land.

EC (ds/m)	Non-saline	Slightly saline	Moderately saline	Highly saline
	0 – 4	4 – 8	8 – 15	Above 15
Wheat	2501	1596	812	395
Rice	2838	1928	1039	593
Percent reduction in yield				
Wheat	-	36	68	84
Rice	-	32	63	73

(Source: Qayyum and Malik, 1988)

Siddiq (1994) conducted a study during *Rabi* 1991/92, on the effects of salinity/sodicity on wheat yields in the Manawala and Pir Mahal Distributary commands of the Lower Chenab Canal (LCC) system of the Punjab Province. He found that farmers are aware of the salinity problem and try to manage by taking different measures, but they are unable to mitigate the soil sodicity problem caused by the use of poor quality groundwater. Soil sodicity has adverse effects on wheat yields, and on average, causes a yield loss of about 411kg/ha in the Manawala Distributary command area, and about 231kg/ha in the Pir Mahal Distributary command area, with a basin-wise loss of 200kg/ha. The losses in the wheat yield are much higher in the tail reaches due to high soil sodicity when compared to those in head or middle reaches. In the Sindh rice-wheat zone, soil salinity is widespread, particularly in the Kotri Barrage (SRWN) command. Over 80 percent of the Kalri command, and approximately half of the Fuleli and Pinyari commands are moderately to strongly saline. In the Right Bank area (SRWS), about one-third of the soils are categorized as moderate to strongly saline. The extensive soil salinity and waterlogging conditions cause the lower yields of rice and wheat in the Sindh rice-wheat zone.

Waterlogging is also a major constraint towards achieving increased productivity of the wheat crop in the country. Wheat cultivation can be successful when the watertable is below 1.5m, as shown in Table 12. This table clarifies that the yield for wheat decreases significantly when the watertable is within a 100cm depth, but it does not decrease when the watertable depth is below 150cm.

Table 12. Effect of different watertable depths on wheat yields.

Watertable depth (cm.)	Percent yield reduction
0 – 5	79
25 – 50	49
50 – 75	28
75 – 100	13
100 – 125	5
125 – 150	1
150 – 175	0

(Source: MacDonald et al., 1990)

Currently, waterlogging and salinity affect about 6.9 Mha (42.5%) of irrigated land (16 Mha). About 1.5 to 3 Mha area has watertable depths within 1.5 m from the soil surface. An area of about 2 Mha is considered abandoned due to severe salinity. The province-wise area with watertable depths within 1.5 m in the months of June and October for the period 1986 to 1989 are presented in Table 13. This table shows that in June and October 1986, the watertable depth within 1.5 m depth covered 2.14 Mha and 4.91 Mha, respectively, which in 1989 covered 2.39 Mha and 4.92 Mha, respectively, showing an increased trend in waterlogging.

Table 13. Province-wise area (Mha), with watertable within 0–1.5 m.

Year	1986		1987		1988		1989	
Province	Jun.	Oct.	Jun.	Oct.	Jun.	Oct.	Jun.	Oct.
Punjab	0.77	1.29	0.96	1.02	0.58	1.72	0.65	1.07
Sindh	1.27	3.41	1.08	3.11	0.86	3.44	1.60	3.67
NWFP	0.04	0.15	0.04	0.05	0.06	0.06	0.04	0.06
Balochistan	0.06	0.06	0.05	0.12	0.04	0.09	0.10	0.12
Pakistan	2.14	4.91	2.13	4.30	1.54	5.32	2.39	4.92

(Source: Yasin and Rao, 1993)

In most cases, soil salinity is caused by shallow saline groundwater and inadequate amounts of irrigation water for leaching salt from the root-zone, but intensive use of poor quality groundwater without improving its quality, particularly in the Punjab Province, is also converting good agricultural lands to salt-affected lands. Waterlogging and salinity have devoured the potential of agricultural lands, causing poor yields for the rice and wheat crops in the rice-wheat zones.

2) Irrigation Supplies

Inadequate and unreliable irrigation supplies are also a major constraint when increasing rice/wheat yields. In the Punjab and Sindh Provinces, the majority of farmers indicate a general water shortage and uncertain irrigation supplies, reflecting the greater needs of rice and the generally high cropping intensities in the rice-wheat zone. The shortage appears to be particularly acute in early *Kharif*, which is the time of transplanting and early growth for rice, and in late *Rabi*. Once water is available in adequate and reliable quantities, farmers seem to start using other inputs in proper amounts. Table 14 presents the effect of water shortage at critical stages for the wheat yield. The yield is lowest when the water shortage occurs during both, November (tillering stage) and February (anthesis stage).

Table 14. Effect of water shortages on wheat yields.

Water shortage months		% of cases	Average yield (kg/ha)
November	February		
Yes	No	9	2855
Yes	Yes	36	2585
No	No	55	2977

(Source: Revised action program for irrigated agriculture, 1979)

Table 15 shows the adequacy of the water supply versus wheat yields in the Punjab rice-wheat zone.

Table 15. Wheat yields according to the adequacy of irrigation turns.

Location	No. of farmers	Avg. no. of irrigation turns	Percentage use		Avg. yield (kg/ha)
			N	P	
Punjab Rice-Wheat Zone	18	7.1	100	72	1521
Adequate water					
Inadequate water	73	5.6	82	38	1260

(Source: XAES, 1978)

Farmers reporting adequate water in the Punjab Province own tubewells, or have access to groundwater. The above table shows the number of irrigation turns and fields are higher for those with adequate water and fertilizer usage, which tends to be higher. That farmers having assured and timely supplies from tubewells harvest higher yields of rice and wheat has been found. Also, the farm location has a significant effect on rice and wheat yields, especially in the Punjab Province. The yields are high at the farms located in the head reaches of the watercourses. The inequities in the water distribution among the head/tail water users are other constraints that limit the potential rice and wheat yields.

Based on wheat and rice studies, Bhatti (1990) and Bhatti and Kijne (1992) reported that there is considerable spatial variability in canal supplies at sample farms, and distribution inequities. The overall average value exposes that canal supplies were deficient by one-third (32%), while some farmers received more than twice the sanctioned canal supply. Public tubewells, which are supposed to supply additional water supplies to overcome the water shortage, do not meet the requirements (Table 16).

Table 16. Percent of sanctioned water supply (*Rabi* 1988-89).

	Farms	Minimum	Maximum	Average	Standard deviation
Canal supply	100	0	214	68	39
Public groundwater	56	0	114	39	28

(Source: Bhatti, 1990)

Figure 3 presents a histogram of frequency distribution of the percentage of actual canal irrigation supplies received at sample farms. Only 30 percent of the farms received their due share from canal supplies, 70 percent received less than 80 percent of their sanctioned supplies and about half, under 60 percent. The actual groundwater supplies from public tubewells were also less than the sanctioned supplies (Fig. 4). The low percentages of actual irrigation supplies from the canal and public tubewells, on the majority of the farms, forced farmers to install private tubewells in order to be secure against unreliability and variability of irrigation supplies from public sources. Another discovery was that there was a higher percentage of the farm area in the watercourse command areas of the head reach than the tail reach. This reflects a more certain and reliable public irrigation water supply in the head reaches of distributaries. Mostly, farmers do not have sufficient irrigation water for land preparation, which leads to à delay in land preparation and rice transplantation, until the monsoon starts. This is especially the case in tail watercourses, which is usually well in time with wheat sowing, but fall behind in paddy cultivation. A conclusion was that actual irrigation supplies delivered at the farm are not only inadequate, but also highly unreliable. Especially, prolonged periods of canal closure are detrimental to the wheat yield. Variability and unreliability are the main factors that cause lower water use efficiency. System operations of canal and public tubewells have to be more equitable and reliable for farmers to feel that they can depend on their irrigation decisions with confidence, on assured and timely irrigation water supplies for rice and wheat cultivation.

The marginal to poor quality of groundwater used for irrigation is also a major constraint towards improving the productivity of rice and wheat crops. Inequitable and unreliable canal water distribution caused by water shortage, poor operation and maintenance of the irrigation system, week institutions, and illegal cuts and breaks by farmers with large land holdings, creates a heavy dependence on groundwater irrigation for agricultural production. In some cases, groundwater accounts for 50 to 70 percent, even 100 percent of the total irrigation supplies. Approximately 70 to 80 percent of tubewells in the Indus Plain pump saline/sodic water, which cause a gradual increase in salinity and sodicity in the soil profile, and is a serious concern for sustainable cultivation of rice and wheat in the Indus Plain (Aslam et al., 1997).

Kijne and Kuper (1994) reported results based on the analysis of data collected on soil and tubewell water samples at the watercourse level during IIMI's five-year field research in the Upper and Lower Gugera Branches (Punjab rice-wheat zone) and the Fordwah Eastern Sadiqia Irrigation System. They found that watercourse command areas with scarce surface canal water showed higher values of electrical conductivity of the saturated soil extract, ECe and Sodium Adsorption Ratio, SAR. Farmers also heavily depend on tubewell water for irrigation, which increases soil salinity/sodicity. They could manage the salinity problem by adapting various agricultural and irrigation practices, but unable to manage the sodicity problem because of the slower and treacherous appearance of its adverse effects on soil conditions (hard soil, reduced water infiltration through the soil profile and low hydraulic conductivity factors). The soil salinity and sodicity cause reduced rice and wheat yields.

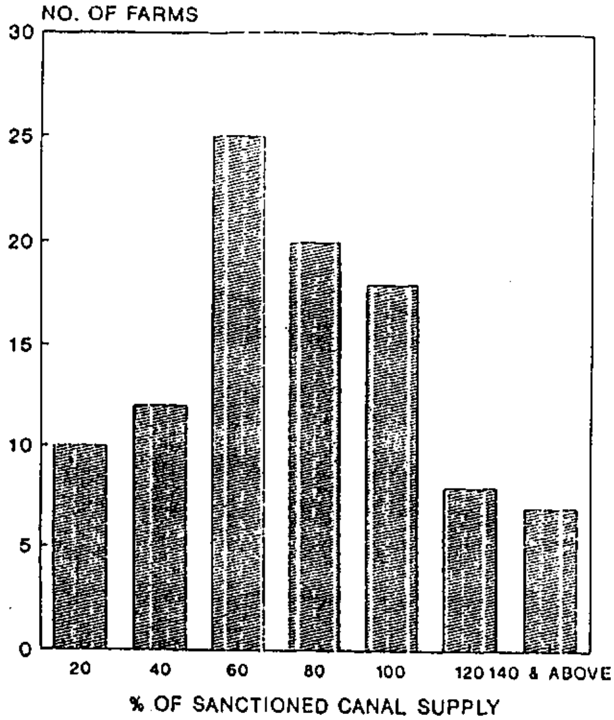

Figure 3. Actual canal supplies percentage(Adapted from Bhatti, 1990).

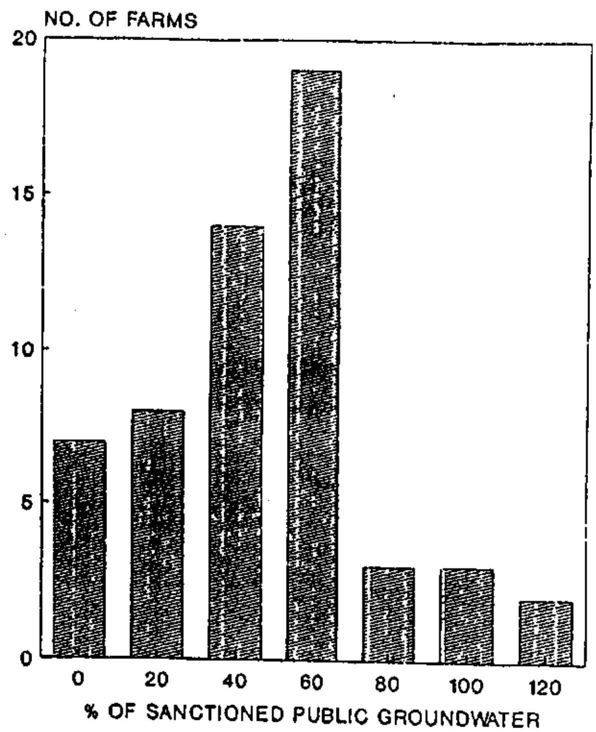

Figure 4. Actual public tubewell supplies percentage(Adapted from Bhatti, 1990).

3) Drainage

Inadequate drainage is another major constraint towards realizing the potential yields of rice and wheat. Inadequate drainage means that irrigation excess and rainfall runoff can only be removed from the area by evaporation and deep percolation. In *Kharif* during the rice-growing season, the watertable is generally at, or near the surface, with a negligible component of deep percolation. The consequent removal of excess water is only by evaporation, leaving behind the concentrated salts. The surface drainage should encourage the removal of surface water and dry out the soil surface without significantly reducing the water available to the crop roots. Drainage requirements for rice are quite different from other crops. The saturation of the root zone and the maintenance of a controlled depth of water on the field are essential for paddy rice production. With fine-textured soils, this may be achieved by puddling the surface horizons, restricting infiltration and trapping ponded water above a deeper watertable. For wheat, good watertable control is required, and maintaining a well-aerated root zone. The desired watertable depth varies according to the rooting depth of crops, and in general, varies from one meter for shallow rooted crops like wheat, to two meters for deep-rooted crops like cotton. Under this situation, it is also important to keep the watertable low in order to avoid the hazard of salinization by capillary rise. Surface flooding due to rainfall is also critical for most non-rice crops. *Rabi* crops (wheat) cannot be planted in rotation with rice in the *Kharif* until the land is sufficiently dry for land preparation to be carried out. Thus, in rice-wheat zones where surface drainage is required for rice grown in *Kharif* followed by wheat in *Rabi*:

- The removal of a proportion of water from land currently flooded to excessive depths, leading to an increased area of land available for cropping;
- The removal of storm water runoff, thus, protecting the crop from flood damage and reducing the risk of losing the entire crop; and
- The improved time lines for the *Rabi* planting due to improved water control and reduced flooding, leading to rapidly drying fields at the end of the *Kharif*.

Excessive rain water should be removed from both, wheat and paddy fields, because the submergence of both crops in flood water due to heavy rain causes a reduction in their yields. The most sensitive stage for the submergence of rice is during panicle booting, and floodwater must be drained within one or two days. Draining water from rice fields is also needed for the application of fertilizers and for soil drying at the end of the season to increase the bearing capacity of the soil for mechanical harvesting and land preparation for the following wheat crop (Kijne, 1994).

The drainage needs in the canal command areas of the Indus Basin consist of both, surface as well as sub-surface drainage. Surface drainage is needed for areas subject to frequent flooding from rain/storm and for the rice areas in the Lower Indus Plain. Sub-surface drainage is required for all areas other than the rice commands. Of the two drainage needs, sub-surface drainage is more critical in the Indus Basin because of the associated soil salinity problem and the effect on crop yields. During the period 1960 to 1989, WAPDA has completed 38 SCARPs covering a gross irrigated area of 4.3 Mha. In these projects, more than 12,000 public tubewells have been installed. About 8200km of surface drains have been constructed and tile drains have been installed in an area of 13800 hectares of agricultural lands. Presently, 13 SCARPs covering an area of 3.2 Mha are under implementation. The Government of Pakistan (GoP) has allocated Rs. 38 billion for investment in the drainage and reclamation program, out of Rs. 55 billion for the total water sector allocations in the 8th Five Year Plan (1993-1998). This shows the GoP's continuing concern for waterlogging and salinity problems. Thereafter, a long-term strategy (emerged from the National Drainage Program) to manage waterlogging and salinity problems, comprises of water conservation measures, rehabilitation and extension of surface drainage system and management studies to improve drainage management and institutions. Though SCARPs have played an important role in controlling the waterlogging to a great extent, the problems of waterlogging and salinity are not completely and effectively solved yet. The large-scale installation of tubewells, surface drains and tile drains can control waterlogging, but soil salinity remains a problem and in many places sodicity is a main concern, which needs chemical amendments and leaching for reclamation. This means the hydrological approach alone is not sufficient for the effective control of salinity, along with waterlogging. For this purpose, the farmers should be made well aware of employing chemical amendments, like gypsum, and biological techniques for reclaiming salt-affected lands, besides lowering the watertable through drainage measures (Aslam et al., 1997).

II. WATER MANAGEMENT PRACTICES FOR THE RICE-WHEAT CROPPING SYSTEMS AROUND THE WORLD

Irrigation water management, both at the irrigation system and farm level, is an important determinant of rice-wheat productivity. The growth stages at which the water shortage is most damaging are well known for both, rice and wheat. Unfortunately, and for well-founded reasons of pre-planned water allocations by irrigation system managers, the delivery of irrigation to every farmer at the required time is not possible. Constraints of water shortage, thus, occur and can be intense in fields with high rates of water seepage and percolation in the rice season. To counter these constraints, many rice-wheat-practicing countries have large numbers of public and private tubewells. Tubewell irrigation can significantly improve on-farm water management. Also, the conjunctive use of canal water and groundwater is the best method to control the emerging problem of waterlogging and soil salinization.

Water use efficiency in the rice-wheat system is generally low. There are also problems of widespread waterlogging and salinity for poorly managed irrigated rice. When wheat growing follows the rice season, poor rice-phase water management results in delayed and a sub-optimal wheat establishment, consequently lowering productivity. Various research studies on irrigation water management have shown that intermittent flooding to keep the soil continuously saturated without standing water during the rice crop growing season can save 40 percent of irrigation without any significant yield loss. Such technological solutions should be coupled with non-technological solutions, such as farmer-participatory management of the irrigation system, and charging for irrigation on the basis of the water quantity used.

Water management practices (irrigation and drainage) currently adopted at both, the irrigation system and farm level in the various rice-wheat-growing countries of the world, especially in the Asian countries, and also, various studies conducted on water management aspects are discussed in the following sections.

A. Water Use for Land Preparation

Much water is used for the land preparation of the rice crop establishment. In the Philippines, more than 33 percent of the total water used for irrigated rice production is during land preparation (IRRI, 1979). Puddling is the most common method of land preparation for rice in Asia. The destruction of the soil structure through puddling results in better weed control, increased water-holding capacity and reduced hydraulic conductivity, and therefore, reduced deep percolation losses. Kawasaki (1975) reported 60 percent reduction in percolation losses due to puddling. Sanchez (1973) reported that in granulated soils, about 30 percent of the water is lost by percolation, whereas only about 10 percent is lost in well-puddled soils. De Datta and Kerim (1974) reported that percolation losses were much higher in non-puddled than in puddled soil (Fig. 5). Because of higher percolation losses, non-puddled soil received twice as much water (1180mm) than puddled soil (588 mm).

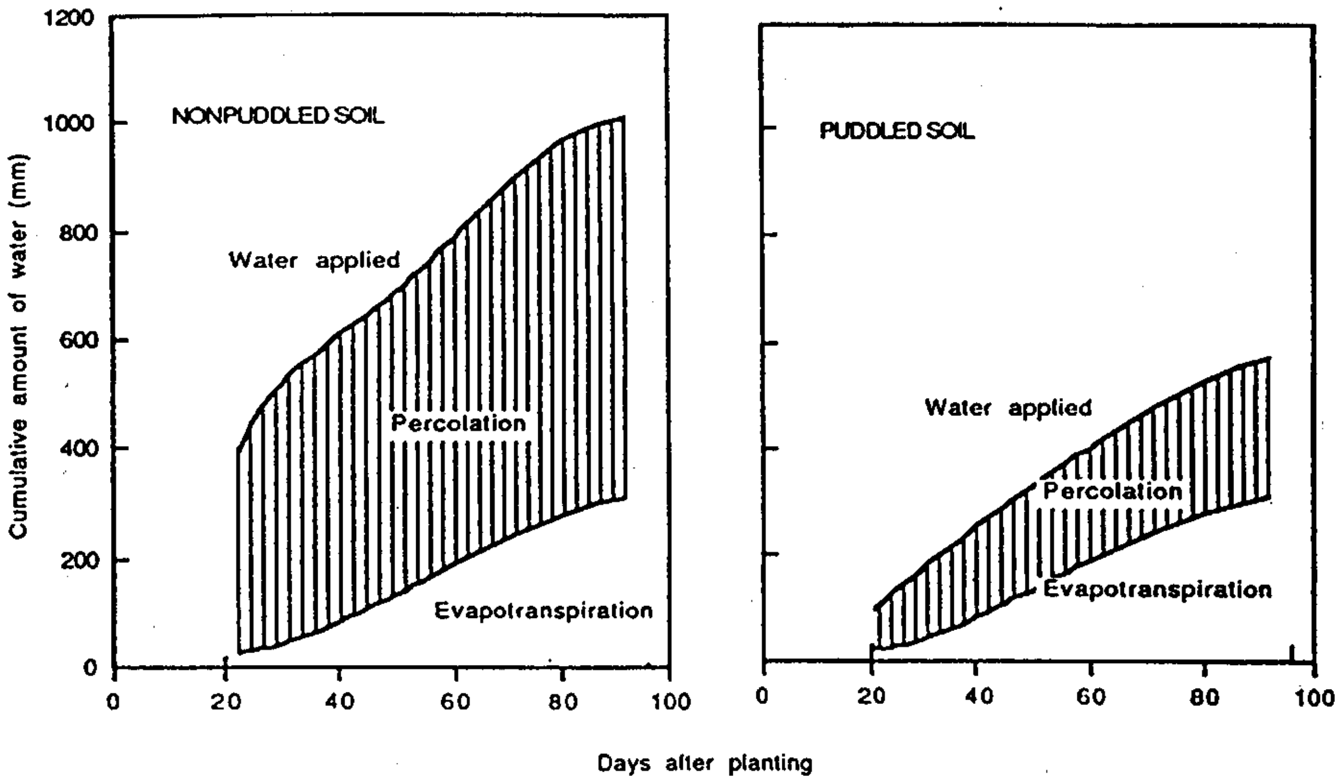

Figure 5. Comparison of cumulative water applied, evapotranspiration, and percolation losses in field studies of puddled and nonpuddled soils (Adapted from De Datta and Kerim, 1974).

The grain yield was 1.2 tons/ha higher in puddled than in non-puddled soil. Rice in puddled soil had 2.5 times higher water use efficiency (7.9 kg/ha/mm) than in non-puddled soil (2.9 kg/ha/mm). Dayanand and Singh (1980) reported that the rice yield was about 40 percent higher in the case for puddled rice when compared to non-puddled rice. Moreover, the water requirement in the case for puddled rice was 40 to 60 percent less than for non-puddled fields, which could be due to reduced percolation losses in puddled rice fields.

Tuong et al. (1994) conducted research on mechanisms of percolation losses in a puddled rice field with permeable sub-soil using simulation models and field experiments. They reported that the inclusion of small non-puddled areas within the field with 5cm ponding water depth increased the field water loss from 2.7mm/day to 15mm/day. The under-*bund* percolation rate was about 10mm/day in a 25 by 100m field. Maintaining a shallow ponding water depth (PWD) did not significantly affect percolation loss through uniformly puddled soil, but greatly reduced losses in non-puddled areas and under-*bund* percolation. Thus, it is an important measure to increase the water use efficiency (WUE) of rice fields in areas with permeable sub-soil. Also found, was that sealing the walls of the *bund* with puddled soil material or plastic sheets could decrease the horizontal conductivity of the *bunds*, and may further reduce under-*bund* percolation.

Muirhead and Humphreys (1995) reported that rice in Australia is grown in soils where deep percolation is less than about 3mm/day (low permeability), thereby resulting in poor internal drainage. All irrigation of non-rice crops is by flood, which causes waterlogging conditions in the soil. Also, soil salinity in the rice-growing areas increases due to rising watertables. The estimate has been that 17 percent of the area currently salinized causes reduction in crop production. Salt, occurring in either, the profile before irrigation or added with the irrigation water, is being redistributed in the soils as the groundwater rises. Deep percolation under the rice crop is estimated to contribute about 50 percent of the water added to the groundwater within the irrigation areas each year.

Waterlogging could be reduced by more efficient irrigation, which can be achieved by an improved irrigation layout, laser grading, raised beds and pressurized irrigation systems. To lower the watertables by improving the water-use efficiency, deep percolation from rice and other enterprises must be minimized. Strategies for soil puddling and the exclusion of elevated land and fields with a high water use could minimize groundwater accessions.

B. Shallow Tillage

Tuong et al. (1996) presented a methodology to quantify flow processes during land soaking for dry, cracked rice fields. The method was applied at two Epiaqualf sites with relatively permeable sub-soil in the Philippines. They found that during land soaking, water moving in the crack networks was about 7m ahead of the surface water front, recharging the watertable through bypass flow (water that flows through the cracks to the sub-soil). At the monitoring sites, the recharge rapidly raised the watertable nearly 2 hours before the arrival of the advancing surface water. The amount of water that bypassed the topsoil accounted for 41-57 percent of the total water applied; and 66-74 percent of the bypass flow was lost to the surroundings through lateral drainage. Reducing bypass flow losses during land soaking and subsequent land preparation increases the water use efficiency for rice cultivation. Since flow processes are dominated by water flow in cracks, water-saving measures may focus on minimizing crack formation, such as by mulching to reduce moisture loss and manipulating crack geometry and surface soil conditions, such as shallow surface tillage during the fallow period prior to land soaking.

C. Water Efficient Methods of Crop Establishment

De Datta (1986) reported that increased labor costs and area under irrigation, the development of modern early-maturing varieties and improved fertilizer and weed management techniques have encouraged farmers in the Philippines, Malaysia and Thailand to switch from transplanted to the direct-seeded flooded rice system. Farmers in India, Bangladesh and particularly Sri Lanka have practiced direct seeding for many years. However, many modifications had been made in Southeast Asia to suit local requirements. One of the most important pre-requisites of broadcast-seeding in flooded fields is control of the water, which is needed for land leveling, fertilizer incorporation, suppressing weed growth and increasing fertilizer nitrogen efficiency. During the first four to five days after seeding, the field should be moist, but not flooded. Following that, 2-3cm of water should be introduced keeping the emerged rice seedling ahead of the water. About 10 days after seeding, the water level should be increased to 5cm and maintained at that depth until crop maturity, or about 7 days before harvest.

Direct seeding is usually faster and easier than transplanting, and grain yields are similar or occasionally higher. Land preparation for direct-seeded flooded rice is essentially similar to that for transplanted rice, but better leveling of the field is necessary for good water control and crop establishment. IRRI found that 100kg/ha pre-germinated rice (24 hours soaking and 48 hours incubation) gives the best results in terms of adequate stand establishment and weed control. The direct-seeded flooded rice technique has the advantages of reduced labor cost because it eliminates nursery preparation, care of seedlings in the seedbed, pulling seedlings, hauling and transportation; shorter cropping cycle because of the absence of transplanting soak and the improved water control.

Bhuiyan (1992) reported that water use for growing transplanted rice could be reduced by about 40 percent without loss in rice yields by replacing the shallow-depth water regime by saturated soil regime. Under high weed pressure conditions, shallow flooding during the first 45 days after transplanting followed by maintenance of a saturated soil regime for the rest of the season will achieve the same yield as the conventional water management, but with over 30 percent savings in water. The adoption of this water-efficient irrigation method requires greater control over the water delivery system and a reliable water delivery schedule. He also mentioned that wet-seeded rice, in which pre-germinated seeds are sown directly on puddled fields in lieu of transplanting seedlings to establish crop, offers a significant opportunity for the improved management of irrigation water. Land preparation is more water-efficient for wet-seeded rice than for transplanted rice. Farmers in transplanted rice systems begin seasonal water use with land soaking at the same time they start to prepare the seedbed to grow seedlings. For about a month from that time until the seedlings are ready to be transplanted, water is used continuously for successive land preparation activities (i.e. land soaking, plowing, harrowing and puddling). During this process, water is wasted through runoff, seepage, percolation and evaporation. In the case of the wet-seeding technique, the preparation of pre-germinated seeds takes place for only 24-36 hours, and land preparation can be completed in about a week, thus avoiding long periods of water losses. Research has shown that about 30 percent less water is required in order to prepare a typical field up to the same puddled condition for wet-seeded rice than for transplanting rice. Wet-seeded rice yields more in both, water-sufficient and water-short situations, requires less labor and produces a better return on investment than transplanted rice.

Bhuiyan et al. (1995) undertook a comparative study in order to evaluate, and compare, the performance of the wet-seeded rice technique in terms of its water requirement (water efficiency), drought tolerance, labor requirement for crop establishment and weed control, and returns from rice farming, to that of transplanted rice. They found that:

(i) Compared to transplanted rice, wet-seeded rice performed significantly better in water stress conditions. In the case of TPR, the yield reduction due to water stress ranged from 14 to 43 percent, and for WSR the yield reduction ranged between 8 and 31 percent, depending on the severity of the stress and the crop growth stage when the stress occurred. In both cases, the maximum yield reduction occurred with severe water stress at the reproductive stage of the crop, but for that condition WSR produced a significantly higher yield when compared to TPR;

(ii) Individual farmers used significantly less water to grow WSR than to TPR. The water-saving was mostly achieved during land preparation when WSR farmers used water to complete the activity over a much shorter time compared to TPR growers; and

(iii) Due to higher grain yields and the reduced cost of labor, especially labor for crop establishment and weed control, higher economic return to farmers, and water efficiency, the majority of the farmers in the Philippines adopt the WSR technique.

D. Efficient Irrigation Scheduling

Prihar and Grewal (1985) addressed the issue of improving water use efficiency for rice, specifically for the rice-wheat farming system. They pose that improved schedules of irrigation developed by the research stations promise considerable savings in water. However, over-irrigation for paddy is done by farmers having higher availability of water relative to their farm size, because of the lack of awareness and the flat rate charges for electric tubewells and canal water. Tubewell owners are charged a fixed amount per horsepower per month, irrespective of their electricity consumption. The cost of canal water does not vary with the use of water since canal water rates are based on irrigated area for each crop and each season. Both policies force farmers to apply irrigation water indiscriminately. Prihar and Grewal (1985) recommended, depending on soil conditions, that the irrigation of rice can be delayed for variable time periods after the infiltration of water from rain or a previous irrigation. They also recommended that the government should consider the introduction of an alternative to flat rate charges for tubewell electricity and canal water.

In Nepal, wheat is grown under irrigation, partially irrigated or rain-fed conditions. The area of irrigated wheat is gradually increasing. Irrigated wheat normally receives 2-3 irrigation turns, the first within a month of emergence, and the second at flowering. Some farmers pre-irrigate if the soils are dry at the time, even before the rice harvest. Partially irrigated wheat usually receives one irrigation turn from a pond, shallow well or any other water source. In the fields with heavier soils, water may stand in the field for longer than a day after an irrigation turn. This results in poor tillering, poor growth, and yellowed plants. Waterlogging patches also occur in poorly-leveled, uneven fields. The farmers' practice of field-to-field irrigation can also cause waterlogging. These problems become more severe when farmers have irrigation supplies for a limited time; they try to get as much water as possible into their fields during the short time allotted to them (Harrington et al., 1989).

Gunawardena (1992) reported that studies on evapotranspiration, seepage and percolation from paddy fields conducted in various irrigation projects in Sri Lanka have shown that seepage and percolation losses exceed evapotranspiration. Thus, the dominant factor in the irrigation scheduling (estimation of water requirement) of paddy becomes the seepage and percolation rather than the evapotranspiration. Studies conducted in other rice-growing countries showed that there is a positive correlation between the water level in the field and water loss. This seepage and percolation loss decreases exponentially as the water level reduces. This suggests that the water losses can be reduced substantially by increasing the frequency of irrigation with a lesser quantity of water (low level of standing water).

In view of the above-mentioned facts, Gunawardena (1992) developed a rotational irrigation schedule for the Mahaweli System B Project in Sri Lanka for improved water management for paddy. The adoption of this rotational schedule of frequent irrigation could reduce water losses significantly from the paddy fields. This practice will also encourage the farmers to stick to their rotations since they are assured of their next supply after a short interval, instead of waiting for 7 days. This assurance will help to reduce the excess water abstraction from the field canal, thereby reducing the inequity in water distribution.

Gill (1994) reported that in the high productivity rice-wheat zone of India (northwestern zone, comprising the states of Punjab, Haryana and Western Uthar Pradesh), efficient irrigation schedules have been developed for both, rice and wheat. Table 17 shows that there is no need to keep water standing in rice after a week's submergence and keeping soil wet for the remaining growing period. This practice saves about 33 percent of irrigation water for rice with a relatively small yield penalty. The adoption of irrigation schedules for wheat can save 20 to 25 percent of irrigation water. Thus, in this zone, if present resources for rice-plus-wheat irrigation were used to irrigate with higher efficiency, a larger area could be irrigated with a net increase of rice-plus-wheat production of 20-25 percent.

Table 17. Effect of standing water on rice yields.

Period of standing water after transplanting (week)	Yield (t/ha)
1	7.20
2	7.25
3	7.25

In the low productivity zone of India (Eastern Uthar Pradesh, Bihar, West Bangal), farmers with smaller holdings usually await the monsoon to transplant rice. Farmers with larger holdings use irrigation, and take advantage of cheaper labor. Canal, tubewell and rainwater is used for irrigation and 2-6 irrigations are applied, depending upon the availability of irrigation water and the drainage conditions of the land. There are possibilities of water shortages, either early in the season delaying transplanting, or later in the season affecting grain filling. For wheat, 2-4 irrigation turns are applied, and their number is reduced in medium to heavy soils, and increased in coarse-textured soils. Usually, no irrigation is applied after heading, to avoid lodging. On-farm water management is very poor in this rice-wheat region and field-to-field irrigation is practiced. The results are flooding of low lying areas, an adverse effect on the standing crops, and delays when sowing the succeeding crops.

Kijne (1994) mentioned that several studies have related ET and irrigation requirements for wheat to the class A pan evaporation (E pan). ET averaged approximately 0.8 of Epan after full ground cover. Irrigation studies in the region indicate that application based on 0.75 to 0.8 of Epan provided adequate water for wheat. In India and Pakistan, where five irrigation turns are commonly applied based on the stage of development, a scheduling procedure based on water application as 0.75 Epan could permit deleting early season irrigation turns and reduce irrigation requirements for the growing season. This demonstrates the value of an irrigation scheduling method that adjusts water application to the climatic evaporative demand and allowable soil water depletion, particularly for wheat grown on high water-storage soils.

E. Irrigation Water Saving Regimes

Hatta (1967) reported on the results of a field experiment under continuous flood conditions; the mean value of evapotranspiration was about 7mm per day and consumption in the paddy field was 9-10mm per day. The intermittent irrigation system caused a saving of nearly 40 percent of irrigation water (without a yield loss) if water loss from the irrigation canal is neglected when compared with continuous flooding. (Flood irrigation for 15 or 20 days after transplanting, flood irrigation from 15 days before the middle stage of heading until 10 days afterwards.)

Sandhu et al. (1980) presented the results of a 4-year (1974-77) field research conducted to study the effect of various irrigation practices on the irrigation requirement of rice on a sandy loam soil. They found that the irrigation needs of rice were highest (170-204cm) with continuous submergence (Table 18).

Table 18. Various irrigation regimes.

Irrigation regime	Irrigation water applied (cm)					Mean irrigation water efficiency (kg/ha-cm)
	1974	1975	1976	1977	Mean	
Continuous submergence	204	195	170	192	190	28.9
1-day drainage	151	138	130	160	145	37.6
2-day drainage	-	117	121	136	125	44.4
3-day drainage	114	92	107	128	113	45.3
5-day drainage	96	94	81	112	96	54.4
7-day drainage	82					

(Source: Sandhu et al., 1980)

Compared with continuous submergence, irrigating one day after the infiltration of water saved 25, 29, 24 and 19 percent of irrigation water in the 1974, 1975, 1976 and 1977 seasons, respectively. In the high-rainfall years of 1975 and 1976, the saving in irrigation water with a 2- to 5-day treatment was, respectively, 40 to 52 percent and 29 to 52 percent without a rice yield loss. The mean increase (average of 4 years) in irrigation water efficiency with 1-day, 2-day, 3-day and 5-day drainage was 30, 54, 57 and 88 percent, respectively, over the mean irrigation water efficiency of 28.9kg/ha-cm with continuous submergence (Table 18). Percolation losses were higher under continuous submergence and amounted to 301-483 percent of evapotranspiration in different years. As the period of drainage between infiltration and irrigation increased, the percolation losses decreased. With 1-day drainage, the percolation losses decreased by 32 to 57cm, and with 5-day by 80 to 108cm in different years. Based on these results, it can be concluded that the continuous submergence of soil is not necessary to obtain high rice yields. Once the transplanted seedlings are well established, irrigation could be delayed for some period after the complete infiltration of ponded water without any yield loss. The potential saving of 20 to 50 percent in irrigation water primarily results from the reduction in seepage losses due to a rapid decline in soil permeability with increasing un-saturation.

Sharma (1989) conducted a field study during the wet seasons of 1986 and 1987 in highly permeable sandy loam soil in order to evaluate the impact of water stress on water use and rice productivity. He found that the rice crop safely withstood 100cm moisture stress without any yield loss. Stress of 300mm suction significantly lowered the grain yield. A 100cm moisture stress after every 17 days of 5cm continuous submergence produced the same rice yield as the continuously submerged irrigation regime, but decreased the total water requirement from 3640 to 2797mm, and increased water-use efficiency from 1.4 to 1.68kg/ha-mm.

Mishra et al. (1990) conducted field and lysimeter studies during two *Kharif* seasons of 1983 and 1984 in order to determine appropriate water regimes for the irrigation management of rice in soils with shallow and medium watertables. In this study, six water regimes, i.e. Ic, Ic_1, Ic_3, Ic_5, Ic_7 and I_o, ranging from continuous submergence of 5±2cm water (Ic) to completely rain-fed (I_o) were evaluated. In the Ic_1, Ic_3, Ic_5 and Ic_7 regimes 7cm irrigation was applied, respectively, 1, 3, 5 and 7 days after the water drained from the surface of the soil. During the entire rice-growing season, the depth of the watertable varied from 0.7 to 92.3cm under shallow watertable (SWT) and from 12.6 to 126.3cm under medium watertable (MWT) conditions. To maintain the Ic regime, when compared to Ic_1 to Ic_7, and an additional amount of 10 to 20cm water under SWT and 25 to 40cm water under MWT conditions was required.

When compared to MWT, the water use efficiency (WUE) under SWT was 6.9 percent higher. The ground watertable contribution towards ET was 27.1 percent higher under SWT when compared to the MWT condition. Percolation losses (PL) were lower by 20.4 and 23.6 percent under SWT and MWT conditions, respectively, when compared to those under the Ic regime. Grain yield, ET, PL and surface runoff losses were found in the order of $Ic > Ic_1 > Ic_3 > Ic_5 > Ic_7 > I_o$. The study's main finding is that the optimum rice yield could be obtained with a high water use efficiency of 3.21-3.67kg/ha-mm by intermittent irrigation turns 3 to 5 days after the water drains from the surface of the soil under SWT, and 1 to 3 days under MWT conditions.

Tabbal et al. (1992) conducted studies on alternative methods of managing water on farmers' rice fields with clay loam soil and an average watertable depth of 95cm for four consecutive dry seasons (1988-1991). The four irrigation regimes considered in this study were: continuous flooding (2-7 cm, WR1); continuous flooding up to the panicle initiation stage, then saturated soil (WR2); saturated soil throughout (WR3); and alternate wetting and drying (WR4). Figure 6 presents these water regimes in graphic form. The results of these studies are presented in Table 19.

Table 19. Average yield, water use, productivity and water savings in the standard and alternative water management practices (for the years 1988-89 and 1990-91).

Water	Yield (kg/ha)			Water Use (mm)			Water Productivity (kg/ha/mm)			Water Saved (%)		
Regimes	88-89	90-91	Mean	88-89	90-91	Mean	88-89	90-91	Mean	88-89	90 - 91	Mean
WR1	5552	5102	5327	1793	2786	2289	3	2	3	-	-	-
WR2	5237	4833	5035	1168	1804	1486	5	3	4	35	35	35
WR3	5153	4198	4676	1068	1644	1356	5	3	4	40	41	40.5
WR4	4336	3757	4046	728	1065	896	6	4	5	59	62	61

The above table reveals that the average water use in the continuous flooding irrigation regime varied between 1793 and 2786mm, with an average of about 2289mm. The average water use in water regimes WR2, WR3 and WR4 was about 35, 41 and 60 percent less, respectively, when compared to the continuously flooded regime. The average yields obtained during the 1988 and 1989 seasons in the saturated soil regime were almost the same as those obtained in continuous flooding or continuous flooding up to the panicle initiation, and then saturated soil regimes. But, in the case of the alternate wetting and drying regime due to water stress, the average yield was significantly less when compared to those obtained in other water regimes.

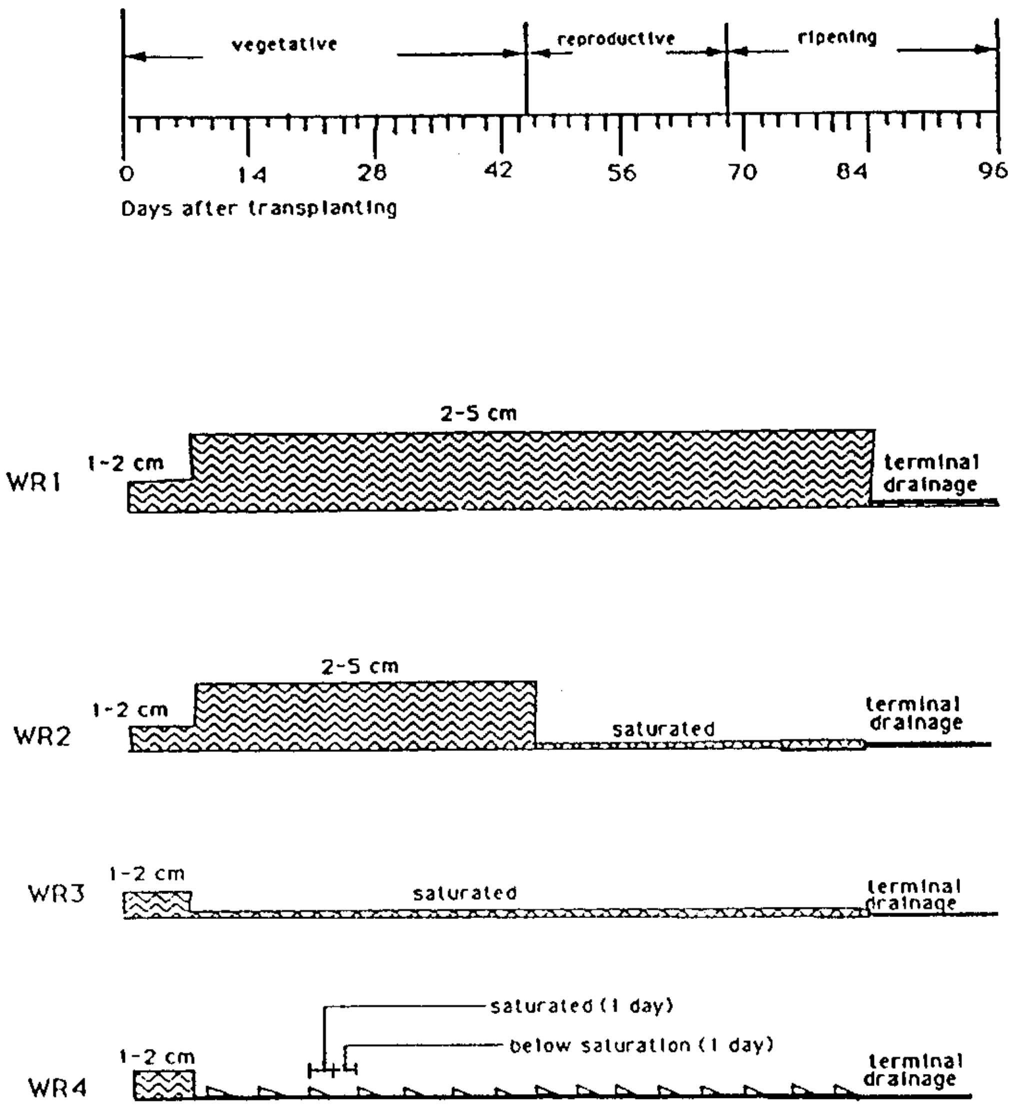

Figure 6. Graphical illustration of the irrigation regimes (Source: Tabbal et al., 1992).

However, during the 1990 and 1991 seasons, the average yields in the saturated soil regime were significantly less than those obtained in the intermediate and the continuously flooded regime. This difference is due to the low yield in WR3 during the 1991 (25% less than the yield in 1990) season when weed control was inadequate. Water productivity was about 5kg/ha/mm in the alternate wetting and drying regime, but was only about 3kg/ha/mm for the traditional practice. The water productively of the intermediate and the saturated soil regimes were about 4 and 4kg/ha/mm, respectively.

Table 20 presents the results of the percolation losses from the studied rice fields under different water regimes.

Table 20. Percolation losses from fields under different water regimes.

Water regimes	Percolation rate (mm/day)			
	1988	1989	1991	Mean
WR1	24.3	17.5	18.1	20.0
WR3	67	9.4	10.9	9.0
WR4	NA	NA	24.0	24.0

NA= Not Available

Clearly, percolation rates decreased from 20mm/day in the continuous submergence to 9mm/day in the continuously saturated regimes. In the alternate wetting and drying regimes, the average percolation rate increased to 24mm/day, which was due to cracks developed in the soil during the drying periods. This implies that percolation losses can be reduced considerably by maintaining a saturated soil regime, provided soil cracks are not allowed to develop.

Based on the above discussion, the main conclusions of the studies were:

I. Water use with the saturated soil regime was about 40 percent less than the traditional practice of continuous flooding without a rice yield reduction. In the alternate wetting and drying regime, water use was 60 percent less than the traditional practice, but it resulted in about 28 percent yield loss;
II. High rice yields could be obtained with a saturated soil regime maintained continuously in the field to allow ET to take place at the potential rate. However, if weed growth is a problem, continuous submergence up to panicle initiation, followed by continuous saturation, could be an effective technique of water-efficient irrigation without yield reduction; and
III. The percolation rate could reduce significantly by maintaining continuous saturated conditions. But, if soil cracks are developed, percolation losses will be increased, which could even be greater than those in the continuously submerged field.

Ogino et al. (1993) reported that in Kazakhstan, rice can be grown in all fields, and every year almost half are used for rice cultivation. A standard plot is 2.5 ha is rectangular in shape, with dimensions of 125m x 200m, and is adjacent to a field farm ditch and a farm drain. Surrounding *bunds* are very large. One application inlet pipe and a surface drainage outlet pipe are set in the *bund*. In April, paddy fields are cultivated and leveled, and then fertilizers are applied. Just before the release of irrigation water, farmers sow seeds directly into the dry field, after which the first application of water immediately follows. In the initial stage, ponding is shallow and according to the development of seedlings, the water depth is increased and maintained at the 10 to 15cm depth level until about 20 to 30 days before harvesting. Ponded water is sometimes replaced by fresh irrigation as a countermeasure for salinity. Generally, water is applied 10 to 15 times in one season. The average yield of un-hulled rice is estimated to be nearly 4 to 5t/ha.

The water requirement for rice is considerably high. In 1993, the standard annual on-farm water requirement was 82.45 million m^3 for 2,100 ha, based on the table of water use planning, which gives the water requirement for each 10 days. During the irrigation season, the applied water in the plan was more than 40mm/day, which is very high even with a high evapotranspiration rate. The total estimated net requirement as 3,926mm per year and the gross water demand, including distribution losses was 6,562mm. The actual water use of rice was compared with the planned one in the Akdaha area (Table 21).

Table 21. Water use of rice in the Akdaha area.

	Item	Water depth (mm)	
		Planned	Observed
Input	Irrigation	3057	2360
	Rainfall	200	200
Output	Evapotranspiration	982	1174
	Soil moisture increase	977	466
	Percolation	953	761
	Surface drainage	195	9
	Ponding	150	150

Though the applied water is less than that planned, Table 21 highlights the general features of water use in paddy field where the total water requirement is about 2500mm. About 1000mm and 800-900m is consumed through evapotranspiration and percolation, respectively. Paddy fields in Kazakhstan use plenty of surface water, resulting in a decline of river discharge. The design capacity of canals in the rice irrigation system is very large and irrigation efficiency is quite low. Generally, the capacity of the farm irrigation ditch is 15-20 l/s/ha, and 5-6 l/s/ha is adopted for farm level canals. The designed irrigation efficiency is 70 to 85 percent in a farm system and is 80 to 90 percent in a conveyance system, resulting in an overall irrigation efficiency of 55 to 75 percent.

Kijne (1994) reported three alternatives to continuous flooding; namely:

(i) Intermittent irrigation, where the field is irrigated as soon as the soil water content falls slightly below saturation, in an amount sufficient to attain shallow submergence of the field;
(ii) The heading stage submergence method, in which the soil is kept at saturation, or is lightly submerged during almost the whole growing period, except for a period of 25 days prior to about 10 days after heading when rice fields are submerged to a depth of 10cm; and
(iii) The water saving method, in which, after puddling and transplanting, the field is supplied with sufficient water to keep the soil water content in the root zone at not less than 75 percent of saturation during the growing period, with moderate submergence only during a period of 30 days starting at the head initiation until the end of flowering.

The claim is that intermittent irrigation saves 20 percent water when compared with continuous flooding, and leads to only 50 percent of the potential yield. The heading stage submergence saves 40 percent water and yields are reduced by 25 percent, whereas controlled water saving requires 25 percent less water without affecting yields.

Mishra et al. (1995) conducted field experiments during two *Rabi* seasons (1983-84 and 1984-85) in order to evaluate the effect of different irrigation regimes on groundwater contribution, irrigation requirement and water use efficiency under fluctuating shallow watertable (SWT), and at depths of 40-90cm and medium watertable (MWT) depths of 80-130cm. Six irrigation regimes tested were:

(i) Rainfed (I_o);
(ii) Irrigation only at crown root initiation (I1);
(iii) At only crown root initiation and milk (I2);
(iv) At crown root initiation, maximum tillering and milk (I3);
(v) At crown root initiation, maximum tillering, flowering and milk (I4); and
(vi) At crown root initiation, maximum tillering, flowering, milk dough (I5).

Due to 166mm effective precipitation during the growing season, 1983-1984 was designated as a wet year and 1984-1985, with 51mm, as a dry year. The finding was that the average groundwater contribution to ET was 58 percent under SWT and 42 percent under MWT conditions in both years. In the wet year, the groundwater contribution was about 20 percent more under SWT and 23 percent more under MWT conditions when compared to the dry year. Of the total net water use (Evapotranspiration, ET+ Percolation losses, PL), about 85 percent were ET and 15 percent percolation losses. The net water use (NWU) was highest (641 and 586 mm) in I_5 under SWT and MWT conditions, respectively, but not the yield. Compared to I_5, the net water use in the I_2 water regime decreased by 10 percent in the wet and 25 percent in the dry year. A similar trend was found in the I_3 regime under MWT conditions. There was no significant difference between yields of the I_1 to I_5 regimes under either watertable depth during the wet year. This was also true during the dry year for the I_2 to I_5 regimes. Based on these results, it can be concluded that irrigation given only at the crown root initiation and milk stages under shallow watertable conditions, and at crown root initiation, maximum tillering and milk stages under medium watertable conditions, could give optimum wheat yields, resulting in higher water use efficiency.

Singh et al. (1996) reported the results of a 4-year (1988-91) field study conducted on sandy loam soil to evaluate the effect of transplanting time and the irrigation regime on the growth and yield of rice. The treatments included combinations of 3 dates for transplanting (16 May, 31 May, 16 June) and 4 regimes of irrigation, i.e.:

i. Continuous shallow submergence throughout;
ii. Continuous shallow submergence for 2 weeks after transplanting and the irrigation at 1-day drainage;
iii. Continuous shallow submergence for 2 weeks after transplanting, and then irrigation at 2-day drainage;
iv. Continuous shallow submergence for 1 week after transplanting and, then irrigation at 2-day drainage).

They found that the crop transplanted on 31 May gave the highest grain yield (7328kg/ha), significantly more than that given by the crop transplanted on 16 May (6796kg/ha), which was higher than that given by crop transplanted on 16 June (6467kg/ha). The crop transplanted on 31 May saved 15.4 percent irrigated water, showing 7.8 percent higher grain yield and 24.5 percent higher irrigation water-use efficiency than the crop transplanted on 16 May. The practice of continuous submergence for the initial 2 weeks after transplanting followed by irrigation at 2-day drainage saved, on an average, 73 percent irrigation water when compared with the traditional practice of continuous shallow submergence.

During 1983 and 1984 Mishra et al. (1997) investigated root length density, leaf water potential and rice yield on clay loam and silty loam in the Tarai region of Uttar Pradesh, India, under naturally fluctuating shallow (7-92cm) and medium (13-126cm) watertable conditions, with six water regimes ranging from continuous submergence under 5 ± 2cm (Ic) to completely rain-fed (Io). In irrigation treatments, Ic_1, Ic_3, Ic_5, and Ic_7, 7cm irrigation was applied on days 1, 3, 5 and 7, respectively, after the drainage of ponded water. The finding was that the maximum rooting depth of 55cm in the shallow and 65cm in the medium depth watertable was attained at the dough stage, i.e., 125 days after transplanting, and was more strongly affected by fluctuations in watertable depth than by the water regime. Based on the results of rice yields under various irrigation treatments, the conclusion is that the optimum rice yield could be obtained in the study area by adopting an intermittent irrigation schedule of 3-5 days after the disappearance of ponded water under shallow watertable and 1-3 days under medium watertable conditions, instead of continuous submergence.

Guerra et al. (1997) provided an excellent review on irrigation water management practices in terms of the rice crop water requirement and the actual water use in irrigated rice cropping systems of Asia. They also presented various options to improve the water use efficiency of rice at the farm level, as well as at the irrigation system level. At the farm level, water-saving strategies and practices consisted of:

- (i) Reduction in water use during land preparation and crop growth periods by controlling water delivery;
- (ii) Shifting from transplanted rice (TPR) to the more water-efficient direct seeded rice (DSR) technique;
- (iii) Agronomic improvement of water use efficiency; and
- (iv) Increasing effective use of rainfall.

At the irrigation system level, the strategies for increasing water-use efficiency included:

- (i) Reuse of irrigation outflow (surface and sub-surface return flows);
- (ii) Rehabilitation and modernization of existing irrigation system infrastructure; and
- (iii) Management intervention on water allocation and distribution.

They stressed the idea of the preparation of a practically useable package by integrating the different water-saving strategies and practices and an holistic evaluation of these measures' impact within, and outside, the irrigation systems within the water basin.

F. Drainage Measures

Yixian (1989) reported that in the lower and middle reaches of the Changjiang River Basin, most paddy fields situated in depressions with a high ground watertable, the majority of the soils are clay to loam clay. After rice harvesting, the paddy fields are wet and the excessive soil moisture damages the growth and high yield of wheat after rice. Constructing a perfect drainage system was effective in minimizing the excessive moisture damage. There are two major kinds of drainage system: the underground channel system and the open ditch system. Due to the high cost, the sub-surface drainage system is not widely accepted by farmers, the open ditch drainage system is more common in Central and South China. The open ditch drainage system consists of transverse ditches, vertical ditches inside the field and drainage canals outside the fields. This ditch network ensures the excessive water to drain off, thoroughly, and in time, and lowers the level of groundwater. Adopting proper tillage and applying abundant compost and manure to enhance the downward seepage of excessive water in soil improves the soil aeration.

In China, the major natural constraints to rice-wheat cropping are from water: too much water causing the waterlogging of wheat in the south, and too little causing drought stress to wheat in the north. Thus, in the middle and lower reaches of the Yangtze River, the wheat season (early November to mid-May) rainfall is 500-700mm, which, in the absence of drainage, results in waterlogging to wheat seedlings. In northern China, wheat seasonal rainfall (early October to mid-June) is only 150mm, which is insufficient to meet the wheat water requirements and irrigation, therefore, is needed. Irrigation for wheat usually comprises of three applications in northern China: the first in early November before the soil freezes, the second in April at wheat-jointing stage, and the third in late-May-early-June at wheat grain filling. Irrigation and supportive drainage is through a system of canals and trenches, though there are some sprinkler systems. Irrigation water for wheat is normally derived from underground sources. Open-ditch drainage systems are more common throughout central and southern China. This drainage system consists of ditches (0.4-0.6m deep) running parallel to, or transverse to the length of the rice-wheat fields, and each ditch is connected to drainage canals (0.8-1.0m deep) surrounding a block of fields. Ditches are constructed using a rotary ditcher powered by a 12 horsepower hand-tractor (Lianzheng and Yixian, 1994).

Ogino and Murashima (1993) reported that in order to grow non-paddy crops and to obtain appropriate soil and working conditions for farm machinery in the large-scale paddy plots, a sub-surface drainage system is installed in Japan. To realize this national policy, land consolidation projects have been promoted and the installation of sub-surface drainage has been intensified, supported by central and local governments' subsidies. In paddy farming the major role of field drainage is not to lower the ground watertable, but to remove the surface water detained in the shallow surface layer. The typical soil profile of a paddy is characterized by two completely separated soil layers, that is, the surface soil layer which is plowed to 10-15cm depth and is highly permeable, and the sub-soil layer, which is never plowed and is impermeable. The plowsole (hardpan layer) is developed just below the surface soil through the process of puddling for transplanting rice seedlings and cementing due to Fe and Mn concentration year by year. This layer is necessary to keep water ponding for rice farming, but does not provide well-drained conditions for non-paddy crops.

At the beginning of the irrigation season, puddling helps in transplanting rice seedlings from nursery beds. Afterwards, as whole paddies are irrigated simultaneously and continuously during irrigation season, there is no need to drain the irrigation water except during the mid-summer dry-up time and the harvesting time. The mid-summer dry-up means that the paddies are dried up thoroughly over one week during the hottest season of the summer (late July to early August). For harvesting, the surface soil layer must be drained in order to facilitate the use of farm equipment.

Ogino and Murashima (1996) reported that agricultural drainage systems consisting of open drainage canals, farm ditches and surface drains are effectively combined with the irrigation canal system to reduce diversion requirements and prevent waterlogging. After an intensive land consolidation project is completed in Japan, each plot has its own inlet for irrigation and outlet for surface drainage and a farmer can control water in each plot independently and without relation to others. Farmers can also grow non-paddy crops, like wheat, individually; thus crop diversification can be realized after the completion of a land-consolidation project. Plot-to-plot irrigation systems cannot satisfy these needs. Waterlogging and a high groundwater table caused by seepage from canals and percolation from paddy restricts the introduction of non-paddy crops.

G. Reuse of Drainage Effluent

Ngion (1994) discussed the measures adopted and to be adopted in Malaysia in order to improve irrigation system performance, as well as water savings and conserve sustained agricultural development (cultivation of paddy to produce not less than 65% of the nation's demand in the staple food, rice by 2010). These measures included:

(i) Drainage water recycling; in a number of existing irrigation schemes, drainage water is being pumped from the drains into nearby canals or directly onto the adjoining paddy field for recycled use, which directly raises the cropping intensity. Future irrigation system improvement works should be planned in consideration of a possible drainage recycling technique as a means of water conservation;

(ii) An efficient water management practice, due to high operation and application losses, present efficiency levels in irrigation schemes of Malaysia are low, with some below 50 percent. At the farm level, farmers are advised to construct proper field *bunds* to efficiently retain and control water to the standing depth required, and to prevent losses direct to drain;

(iii) Estatized rice farming, being more popular in the country, is well organized, managed and commercially oriented. Under this system of modernized rice production, the management allows economics of scale to operate for the major farm activities such as plowing, land preparation, seeding, harvesting and transportation needs. On-farm water control and management is also well organized and efficient. Rice production under this farm management system follows the seasonal planting schedule since the cultivation activities in the fields are better organized under a single management, and are highly mechanized. Indirectly, this has upgraded the irrigation system performance, and saved water;

(iv) The direct seeding rice culture has become the dominant crop establishment method, successfully replacing the traditional transplanting practice in various irrigation schemes of Malaysia. There are two different systems of direct seeding rice, namely the wet and dry systems. Under the wet direct seeding system, pre-germinated seeds are sown on the saturated land that has been prepared under the wet condition. In the dry direct seeding method, land preparation is done under dry condition, followed immediately by sowing seeds before either, irrigation water is supplied or rainfall to enable germination and seedling establishment. Under this system, the total cropping season could be reduced by about 2 weeks, avoiding the nursery preparation and transplanting phases. Thus, the overall irrigation supply schedule can be considerably shortened, resulting in significant water saving. The finding has been that transplanting rice requires more water and causes more wastage than the dry direct seeding system; due to which water savings of 25 percent could be achieved;

(v) Land leveling improves the practice of direct seeding by facilitating seedling and crop establishment by the gradual rising of a uniform water layer. Farmers in the irrigated areas are encouraged to carry out land leveling in order to improve rice farming and also water conservation. Land leveling will also effectively facilitate on-farm water control and management; and

(vi) Water harvesting, i.e., on-farm storage ponds will be an additional water resource for irrigation. The water for storage in the ponds can be obtained from river flows or rainfall by the technique of water harvesting. Water can be diverted from rivers into ponds by either, gravity flows or pumping.

Zulu et al. (1996) presented the results of a three-year (1991-1993) research on water reuse (surface and sub-surface agricultural drainage water, storm runoff, sewerage effluent and industrial waste water recycling) potential for improving irrigation water management in rice land of a water shortage area in Niigata Prefecture, Japan. They found that for three years (1991-1993), the average water reuse component was about 14.5 percent of the total irrigation water supply for the whole Kaliyada area (the average water reuse component of the irrigation water supply for 1991, 1992 and 1993 irrigation seasons was 14.4, 14.9 and 14.1 percent, respectively). Figure 7 shows the daily average water supply components during the 1992 irrigation season, averaged over the net paddy area. Apart from meeting the water needs at peak demand periods, water reuse was a quick response water supply solution during dry spells, increasing both, the water reliability and rice crop security.

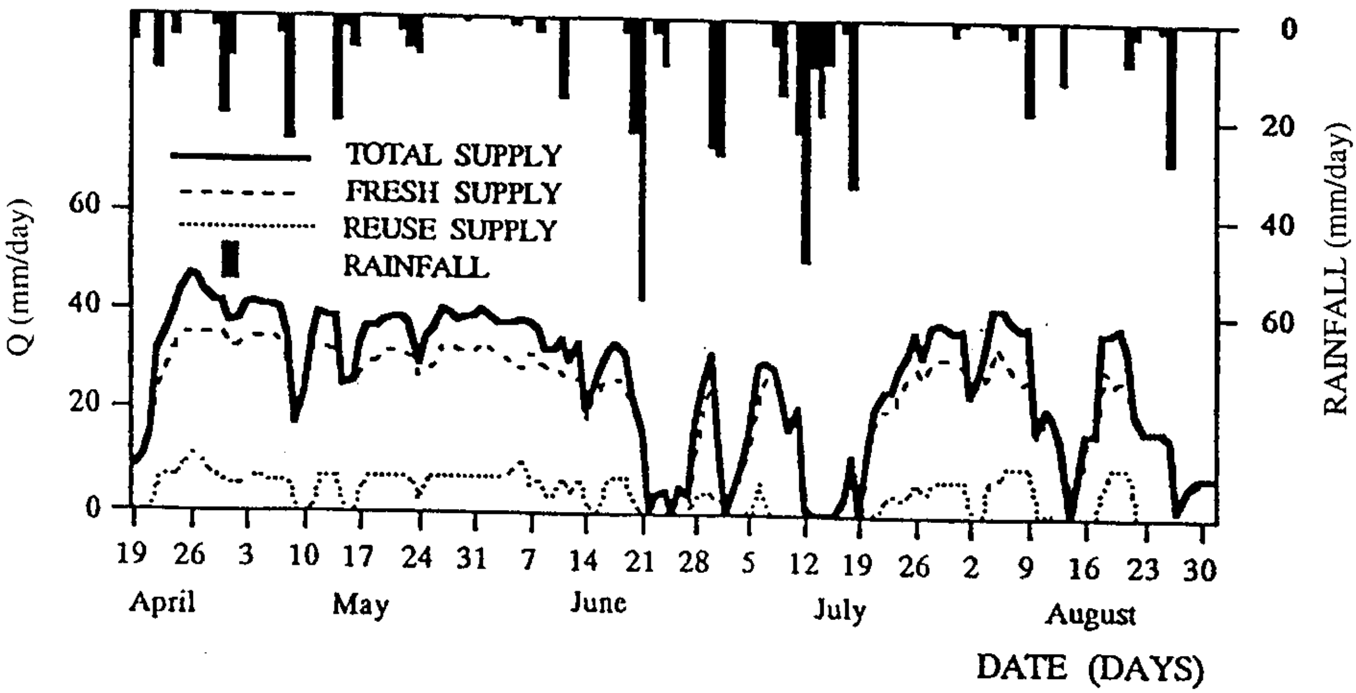

Figure 7. Daily average water supply for the 1992 irrigation season of the Kaliyada area, Niigata Prefecture, Japan (Adapted from Zulu et al., 1996).

Because drainage water within the irrigation area is used for irrigation, the water intake from the headwork could be reduced without sacrificing productivity and reducing cropped area. By using drainage water for irrigation, the system fresh water requirements were reduced by 14.5 percent of the irrigation water supply for the whole Kaliyada area, and hence, the conveyance structures need not be unnecessarily large. This study proved that coupled with efficient water use methods, water reuse has a high potential for improving irrigation water management in paddy areas.

H. Farmers' Participation

Magliano et al. (1990) reported that in the Philippines, active farmer participation resulted in improved equity and reliability of water distribution, which in turn resulted in earlier planting of rice and an increased irrigated area.

Khan (1992) studied the basic issues of water management in the paddy fields located in the low-lying areas of Bangladesh during 1986-89. The important water management issues included irrigation command area delineation, canal layout, water distribution system, water losses, O&M of irrigation equipment and water pricing and payment system, etc.. He found that irrigation practices are made in both study villages during the dry season for *boro* cultivation. Surface water irrigation by traditional methods is still prominent in the *hoar* village, whereas irrigation in the flood plain village is solely dependent on the use of groundwater by shallow and deep tubewells. Due to the limited availability of surface water in the medium to high land areas of the *hoar* village during the winter season where the farmers practice shallow tubewell irrigation, which covers about 20 percent of the total irrigated land of the village. Another finding has been that there is a discrepancy in the mode of payment of water charges and there is a great variation in the rental charges, even within the same village. Khan (1992) stressed the increased participation of farmers in the irrigation programs and a uniform water pricing policy and legislation for efficient water management in the paddy fields in order to sustain increased crop production.

I. Summary

The water management practices at both, the irrigation system and farm level currently being adopted in the various rice-wheat-growing countries of the world, especially in the Asian countries, are summarized in this section.

Puddling is the most common method of land preparation for rice in Asia. The destruction of the soil structure through puddling results in better weed control, increased capacity to retain water and reduced hydraulic conductivity, and therefore, reduced deep percolation losses. The finding is that the water requirement in the case of puddled rice was 40 to 60 percent less than in non-puddled fields, which could be due to reduced percolation losses in puddled rice fields. Moreover, in puddled soil, rice had a higher water use efficiency than in non-puddled soil. Thus, it is an important measure to increase the water use efficiency (WUE) of rice fields in areas with permeable subsoil. Waterlogging could be reduced by more efficient irrigation, which can be achieved by an improved irrigation layout, laser grading, raised beds and pressurized irrigation systems. To lower the watertables, deep percolation from rice and other enterprises must be minimized, by improving the water-use efficiency. The strategies of soil puddling and the exclusion of elevated land and fields with a high water use could minimize groundwater accessions.

For dry, cracked rice fields, flow processes are dominated by water flow in cracks; water-saving measures may focus on minimizing crack formation, such as mulching to reduce moisture loss and manipulating crack geometry and surface soil conditions, such as shallow surface tillage during the fallow period prior to land soaking.

Farmers in rice-growing countries are switching from the transplanted to the direct-seeded flooded rice system. Direct seeding is usually faster and easier than transplanting and grain yields are similar, or occasionally higher. Land preparation for direct-seeded flooded rice is essentially similar to that for transplanted rice, but better field leveling is necessary to achieve good water control and crop establishment. IRRI found that 100kg/ha pre-germinated rice (24 hours soaking and 48 hours incubation) gives the best results in terms of adequate stand establishment and weed control. The direct-seeded flooded rice technique has the advantages of reduced labor costs because it eliminates nursery preparation, care of seedlings in the seedbed, pulling seedlings, hauling and transportation; shorter cropping cycle because of the absence of transplanting soak and the improved water control. The direct-seeded rice offers a significant opportunity for the improved management of irrigation water. Land preparation is more water-efficient for direct-seeded rice than for transplanted rice. About 30 percent less water is required to prepare a typical field up to the same puddled condition for direct-seeded rice than for transplanting rice.

Irrigation scheduling could play an important role in improving the water use efficiency of rice, specifically for the rice-wheat farming system. The improved schedules of irrigation developed by research stations promise considerable savings in water.

Irrigation water saving regimes offer a greater opportunity for improving water use efficiency in irrigated agriculture. The finding has been that for clay loam soil:

(a) Water use with a saturated soil regime was about 40 percent less than the traditional practice of continuous flooding without experiencing a rice yield reduction. In the alternate wetting and drying regime, water use was 60 percent less than the traditional practice, but resulted to about 28 percent yield loss;
(b) High rice yields could be obtained with a saturated soil regime maintained continuously in the field to allow ET to take place at the

potential rate. However, if weed growth is a problem, continuous submergence up to panicle initiation followed by continuous saturation, could be an effective technique of water-efficient irrigation without experiencing a yield reduction; and

(c) The percolation rate could reduce significantly by maintaining continuous saturated conditions.

In various rice-wheat-growing countries, drainage water reuse potential for improving irrigation water management has been evaluated. The finding was that the average water reuse component constitutes a considerable portion of the total irrigation water supply in the various irrigation schemes. Apart from meeting the water needs at peak demand periods, water reuse was a quick response water supply solution during dry spells, increasing both, the water reliability and rice crop security. Because drainage water within the irrigation area is used for irrigation, the water intake from the headwork could be reduced without sacrificing productivity and reducing cropped area. With efficient water use methods, water reuse has a high potential for improving irrigation water management in paddy areas. Reuse of drainage effluent acts as a means of water conservation; an efficient water management practice: due to high operation and application losses, present efficiency levels in various irrigation schemes are low.

At the farm level, farmers should construct proper field *bunds* to efficiently retain and control water to the standing depth required, and to prevent direct drain losses. Land leveling improves the practice of direct seeding by facilitating seedling and crop establishment by the gradual rising of a uniform water layer. Farmers in the irrigated areas are encouraged to carry out land leveling in order to improve rice farming, and also water conservation. Land leveling will also effectively facilitate on-farm water control and management.

Farmers' active participation in the irrigation programs is necessary for efficient water management in the rice-wheat systems in order to sustain increased crop production. Actually, farmers' participation results in improved equity and reliability of water distribution, which in turn results in sustainable rice-wheat productivity in irrigated areas.

In summary, the traditional methods of growing rice and wheat use much more water than actually required for crop productivity. Most water used during land preparation for rice and crop growth is lost to runoff, seepage and percolation, and evaporation. Consequently, water use efficiency in most of the irrigation systems is low. Puddling the soil during land preparation would reduce percolation loss during the crop growth, and the land preparation period could be reduced by using water distribution in farms with a higher irrigation channel density, so that each farm receives irrigation water individually, and field-to-field irrigation could be avoided.

Water-saving irrigation regimes (maintaining a thin layer of standing water in the field, saturated, or alternate wet and dry soil conditions, could save about 25-70 percent of irrigation water, compared with continuous shallow submergence, without experiencing a considerable yield loss. Direct-seeded systems offer a major opportunity to reduce water use during rice growth, as less water is required for direct-seeded rice. Reusing drainage effluent can also increase water-use efficiency in an irrigation system.

The equitable and reliable distribution of water heavily depends on adequate water supplies and committed operation and maintenance of the irrigation system. The initial benefits derived from improving irrigation facilities could not be sustained without performing regular and adequate maintenance activities. A strong managerial capacity can play an important role in implementing a reliable and sustainable system of water distribution, which results in equitable and reliable irrigation water supplies to the farming communities. Important determinants for water use efficiency in irrigation systems are:

- (i) The system's own capacity to control and deliver timely water and the actual use of such capacity;
- (ii) Communication between the manager and farmers;
- (iii) The quality of the information feedback system;
- (iv) Commitment of the Irrigation Department staff; and
- (v) The cooperation provided by the farmers.

III. CURRENT IRRIGATION AND DRAINAGE PRACTICES FOR THE RICE-WHEAT CROPPING SYSTEMS IN PAKISTAN

A. Punjab Rice-Wheat Zone

Rice after wheat is a major crop rotation in the Punjab rice-wheat zone. In the Punjab Province, rice is grown mainly in rotation with wheat, on about 1.3 Mha (1989-90) out of total 9.3 Mha of canal commanded area. The main sources of irrigation water are perennial and non-perennial canals supplemented by electric and diesel tubewells. Irrigation and drainage practices by rice and wheat farmers in this zone are discussed in the following sections.

1) Rice

Typically, rice is cultivated in *bunded* fields with standing water on the soil surface, which is maintained during most of the growing season. For high yields, the water depth in the paddy field is said to range from 'shallow' to 'deep', depending on the growth stage. The most sensitive periods of water deficits are during flowering and the second half of the vegetative period (head development). When the soil water content decreases to 70 to 80 percent of the saturation value, rice yields begin to decline. At a soil water content of 50 percent of saturation, the yield decrease is as much as 50 to 70 percent.

Water requirements for rice cultivation vary and depend largely on the soil type. The average requirement in the Punjab rice-wheat zone is considered to be about 1600mm, which includes water that is needed for land preparation, intentional drainage and deep percolation. However, the mean irrigation application was found to be around 1300mm during actual measurements on a fairly large number of farms in the Punjab Province's rice-wheat zone.

1.1) Irrigation Water Availability and Irrigation Practices

Azeem et al. (1990) reported that rice was planted on about 73 percent of the fields after wheat, 19 percent after fodder and 4 percent after vegetables, and 4 percent on fallow lands. Electricity (43%) and diesel tubewells (27%) supplemented canal water. On average, farmers kept the water standing for 7 days in the fields before transplanting the rice seedlings and applied 25 irrigation turns to the standing crop during the whole growing season. Such irrigation application practices were much higher in Sialkot (55% of farmers studied) and Gujranwala (33%) in the zone.

Bhatti and Kijne (1992) reported that during the *Kharif* season of 1989, 10 out of 89 sample farms did not grow paddy because of the shortage of irrigation water. On average, paddy represented 50 percent of the farm area for other sample farms, with a higher percentage in the watercourse command areas of the head reach than the tail. This reflects a more certain and reliable public irrigation water supply in the head reaches of distributaries. Mostly, farmers do not have sufficient irrigation water for land preparation, which leads to a delay in land preparation and transplantation until the monsoon starts. This is especially the case in tail watercourses that are usually well in time with wheat sowing, but fall behind in paddy cultivation. They also reported that about 21 percent of sample farmers (89) had access to canal supplies during a period equal to, or less, than 2.25 hours per week. Irrigation water available for such a short duration simply cannot be managed efficiently considering the distribution network at the tertiary level and surface irrigation practices employed at the farm.

A major cause of short turns is the continuing fragmentation of farm holdings when the land is distributed among male family members. The decrease in farm size affects directly the water rights and therefore, the duration of the turn in the same proportion. Also found, is that the majority of the farms received less than 50 percent of their actual share of canal water turns. To manage weekly irrigation supplies more efficiently, there are farmers who trade their water turns by borrowing, lending, selling and buying among themselves according to their needs and/or convenience. They reported that paddy received nearly all of the irrigation supplies available at the farm during *Kharif* 1989, especially from July to October (Figure 8). The water requirement for other *Kharif* crops is met mostly by rainfall. The average amount of irrigation water, excluding rainfall, applied to paddy at the study farms over the growing season varied from 465mm to 3642mm with a mean value of 1309mm, and the median value of 1107mm (Figure 9).

The mean irrigation application of about 1300mm was considerably lower than the paddy's gross water requirements of about 1600mm considering the consumptive water use of 650mm, land preparation of 450m, and seasonal seepage and percolation losses of 500mm in the case of a fine-textured soil. In view of the average rainfall in the study area during the *Kharif* season, 350mm, the mean seasonal application almost equal the gross requirement for paddy. But, there is a large variation around the mean water application; about 33 percent of the sample paddy farmers apply irrigation water in excess of 1600mm.

1.2) Unsuitability of Soils

The efficiency of water application to paddy is dependent on the soil type. The normal soils are distinguished according to its soil textures and drainage characteristics. Imperfectly drained clay and silty clay soils are quite suitable for paddy. Well-drained loams and silt-loams are suitable for all types of crops, but their lighter texture makes them less appropriate for rice cultivation. Saline-sodic soils are unsuitable for nearly all crops. In practice, farmers were using about all kinds of soils for rice cultivation without considering their suitability. This resulted in large percolation losses in land preparation and from irrigation turns during the paddy-growing season. Infiltration rates measured on selected fields ranged from less than 1, to more than 10mm/day (in some cases, as high as 20mm/day), which result in losses as high evapotranspiration. In soils with high infiltration rates, much of the water applied for the land preparation and irrigation of the rice crop is lost through deep percolation. The estimate was that at least 15 percent of the paddy fields have soils that are not suitable for paddy cultivation. On most of these fields, water applications were higher than average, while yields were low (low water use efficiency). An observation, especially in the tail ends of watercourse commands, was made that farmers grow paddy on permeable or saline soils to get either, some silt deposited or to leach the salts in order to grow a reasonable crop of wheat in the following *Rabi* season.

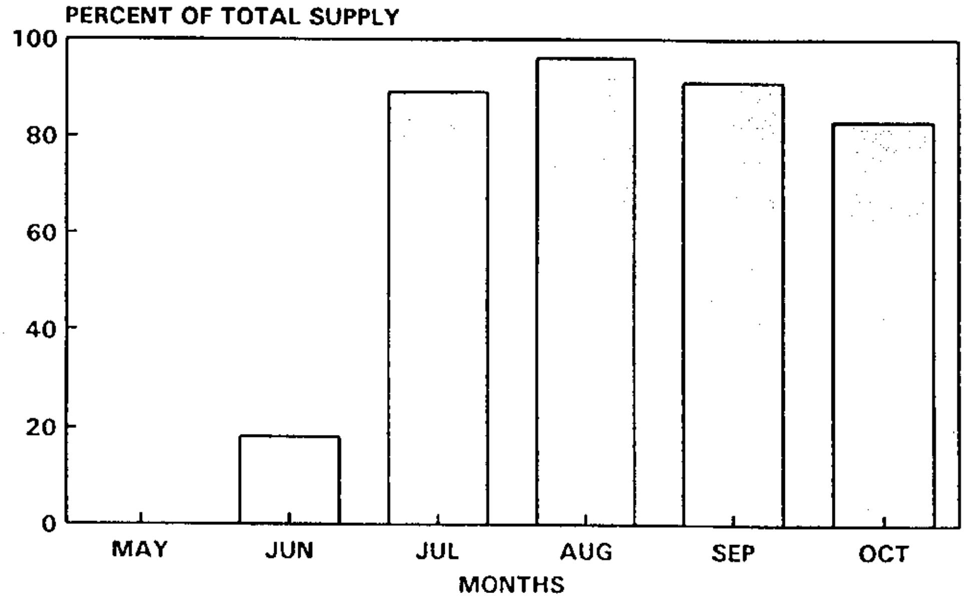

Figure 8. Water allocation to rice crop during kharif 1989. (Source: Bhatti, 1992).

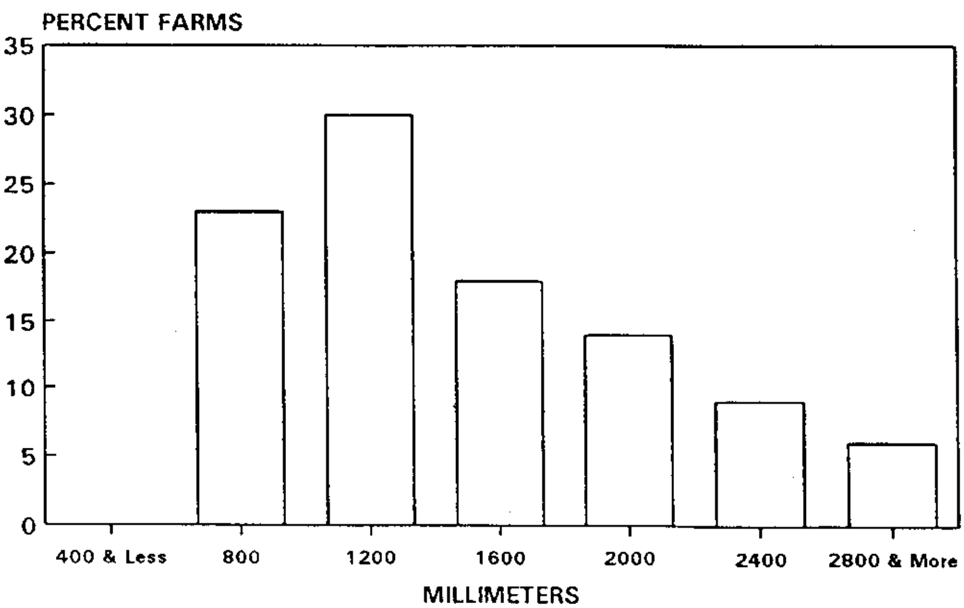

Figure 9. Water depth applied to rice crop during kharif 1989. (Source: Bhatti, 1992).

1.3) Poor Quality Irrigation Water

Another finding has been that the quality of tubewell water deteriorates towards the tail ends of distributaries. Due to persistent shortages and greater variability in canal water supplies, farmers, especially at the tail ends of the irrigation system, heavily depend on tubewell water for irrigation. Field observations reveal the structural decline of soils resulting from irrigation with saline/sodic tubewell water. In the Punjab Province, it has been found the that rice yield per unit water for about 67 percent of the farms is less than 0.1kg/m3, which is low compared with other countries in Asia, or elsewhere (Figure 10).

1.4) Salinity and Sodicity

Soil salinity/sodicity causes reduced rice yields in the Punjab Province. About 1.1mha of the canal command area of the Punjab Province (9.3 Mha) is salt-affected, established through a visual survey of the soils during 1985-86. Profile salinity was assessed at 38 percent of the cultivated canal irrigated areas. Rice is highly sensitive to salts during germination and in the early seedling stage, but it is also grown in saline soils as a reclamation crop, since it is moderately sensitive to salts once established. However, yields under those conditions are lower than those obtained from salt-free soils (Table 22).

Table 22. Effects of soil salinity on paddy yields in the Indus Basin.

Soils	Yields (kg/ha)	Decrease (%)
Normal Soil	2838	-
Slightly affected	1928	32
Moderately affected	1039	63
Severely affected	593	79

(Source: DRIP, 1985)

Based on the pattern of irrigation water use and rice yields, it has been found that irrigation water is managed better in the tail reaches where it is relatively scarce, than in the head reaches (Figure 11). Figure 12 presents the comparison of 10 percent of the farms with the highest yields, and 10 percent with the lowest rice yields. Clearly, the average seasonal water use did not differ greatly between the two sub-groups, but the yields are quite different. Unsuitable soils and marginal quality tubewell water cause low yields, regardless of the amount applied.

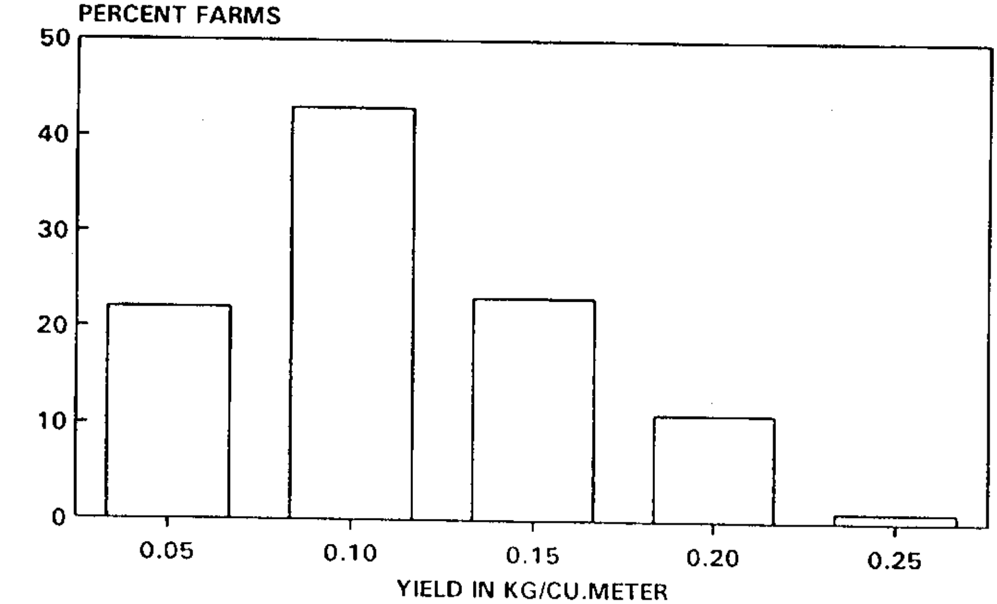

Figure 10. Water use efficiency of rice crop during Kharif 1989 (Source: Bhatti, 1992).

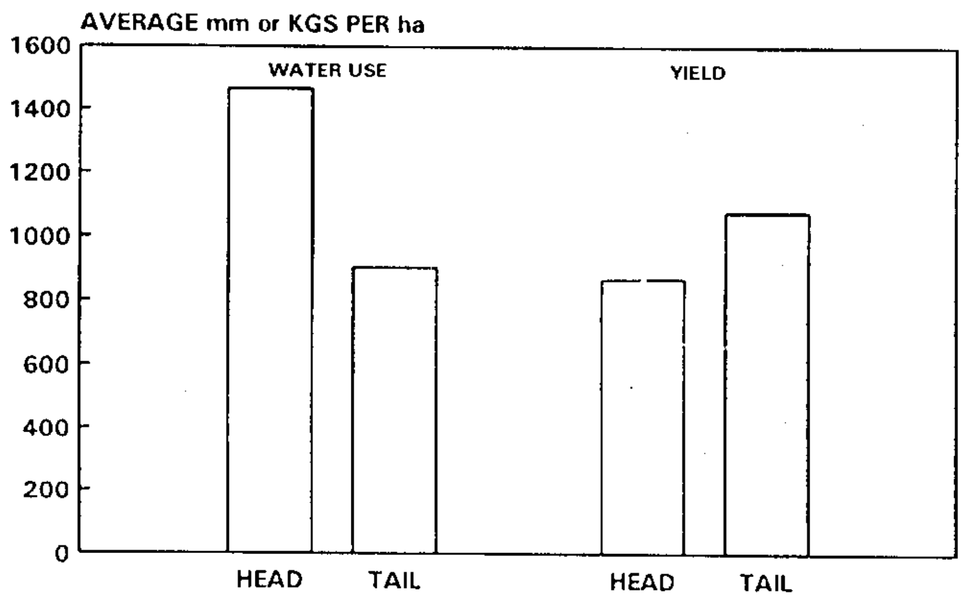

Figure 11. Comparison of water use and paddy yield at head and tail farms (Source: Bhatti, 1992).

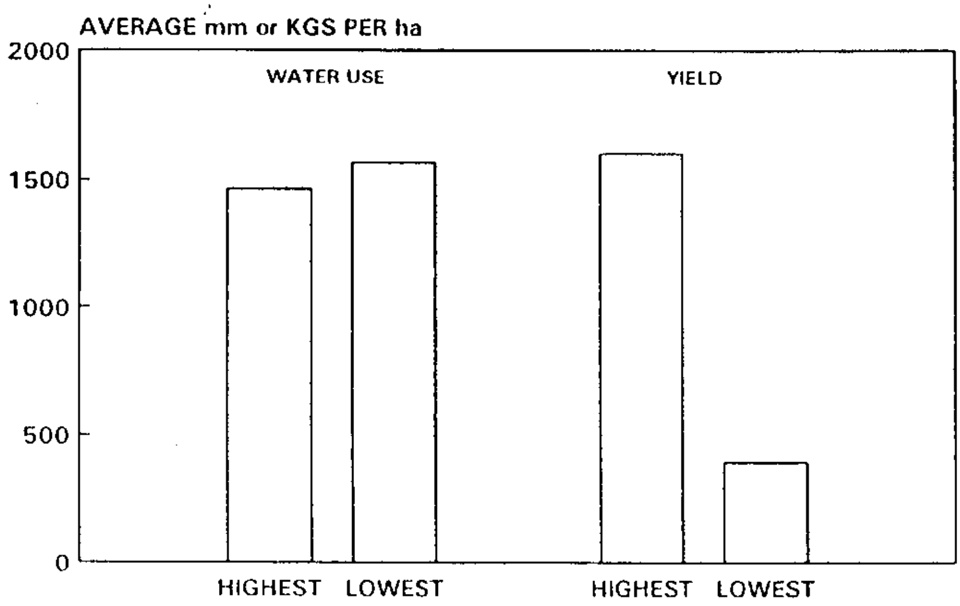

Figure 12. A comparison of the highest, and lowest, yields (Source: Bhatti, 1992).

2) Wheat

The water requirement for wheat ranges from 450 to 650mm, depending on the climate and the length of the growing reason (FAO, 33). Actual irrigation practices for the wheat crop are discussed below. Bhatti et al. (1989) reported that during the *Rabi* season of 1987-88, the amount of water applied to wheat varied from 200 to 750mm, including all the irrigation turns (*rauni*, plus crop irrigation turns) and rainfall during the growing period. Figure 13 shows the actual amounts of water received on the study farms. Consumptive use, the net requirement, was calculated as 335mm. The gross water requirement was 479mm, the net requirement plus 30 percent field application losses (considering an average field application efficiency of 70%). Twenty-five percent (25%) of fields received less than the gross requirement. In the Punjab Province, farmers deliberately over-plant and under-irrigate wheat with the hope that winter rainfall will bridge the gap between irrigation applications and the consumptive use requirement. In wet years, particularly if rainfall occurs in the months of March and April, this strategy causes maximized production, whereas, in dry years, the wheat yield decreases due to inadequate water supplies.

The recommended timing of the first irrigation varies from 20 to 30 days after sowing. The finding was that about 67 percent of the farmers apply the first irrigation later than the recommended time. This may be due to the canal closure for maintenance in January. The delay in the first irrigation causes an adverse effect on the wheat yield, as the majority of farmers apply nitrogen with the first irrigation. Yield is reduced by 25 percent when the first irrigation is applied 50 days after sowing, and the reduction from optimum is 33 percent if the first irrigation is delayed 60 days after sowing (Figure 14). The amounts of water applied during the first irrigation vary, from less than 50mm to about 250mm. A large number of farmers apply amounts in the range of 125 to 175mm (Figure 15). About 50 percent of the farmers applied the second irrigation as recommended (60 to 70 days after sowing). About 75 percent of the farmers applied the second irrigation from 50 to 100 days after sowing. The range in the number of days from sowing to the second irrigation varied from 35 to 125 days. The range in the amounts of water applied during the second irrigation varied from about 50 to 200mm. Another finding was that about 33 percent of the farmers (194) applied all the water in two irrigation turns, and over half applied more than 80 percent of water in two irrigation turns (Figure 16).

Also reported is that the majority of the farmers (42%) applied 3 irrigation turns. The number of irrigation turns given to wheat during the growing season varies from 1 to 6. About 34 percent of the turns provided two, or less, irrigation turns (Figure 17). Adequate water supply in March is critical to the wheat crop in the Punjab Province. Late irrigation at the soft dough stage helps to increase and ensure a good harvest. Farmers generally do not irrigate wheat during March, due to which an optimum wheat yield is not being obtained in the Punjab Province. An additional irrigation late in the wheat life cycle has a significant impact (increased yield) on the wheat yield. As long as the wheat crop is well watered in March/April, it can recover from earlier water stress (Bhatti, et al. 1989).

In summary, irrigation water management practices for wheat cultivation in the Punjab Province are:

(i) Seasonally, insufficient water is applied. About 75 percent of the farmers apply less than the gross water requirement. Farmers tend to over-plant and under-irrigate, hoping that abundant rains will close the gap between evapotranspiration demands and irrigation supplies;

(ii) The first irrigation is applied too late. This is because canals are closed for maintenance during this period. The delay in the first irrigation has a double negative impact because the majority of the farmers apply nitrogen with the first irrigation. The delay in irrigation affects the uptake and utilization of nitrogen, in addition to the crop water condition;

(iii) Farmers terminate their irrigation turns in early to mid-March, when the wheat crop is at the grain-filling stages, when temperatures rise abruptly, and thus, when the wheat crop needs water badly due to high evapotranspiration. This practice had a detrimental effect on wheat yields during the years with no rainfall during that time period.

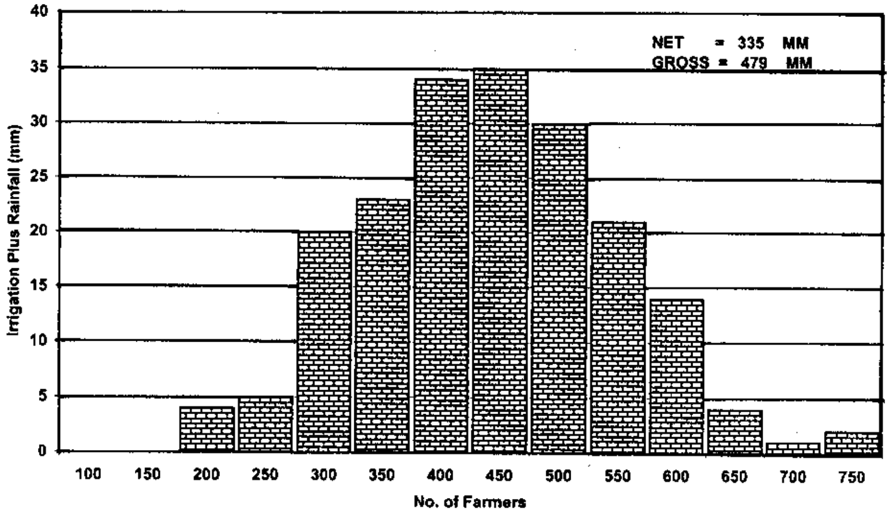

Figure 13. Water applied vs. wheat water requirements (Source: Bhatti et al., 1989).

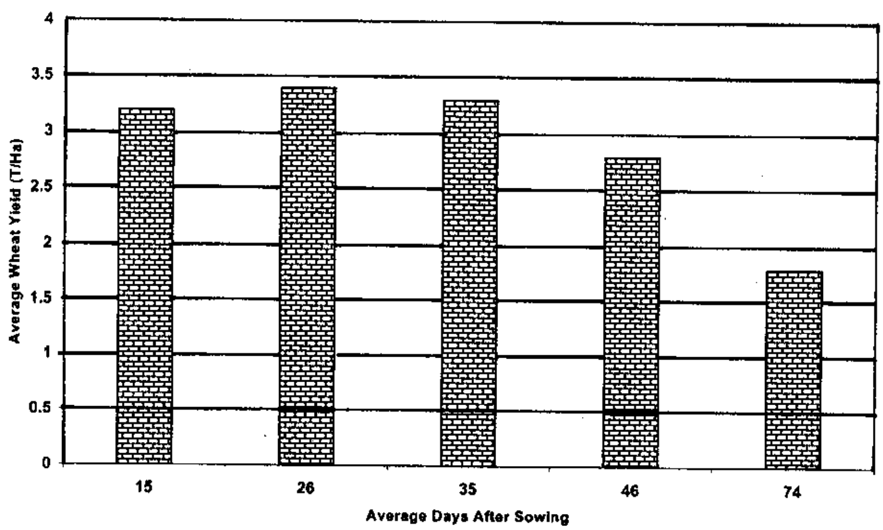

Figure 14. Impact of first irrigation timing on the wheat yield (Source: Bhatti et al., 1989).

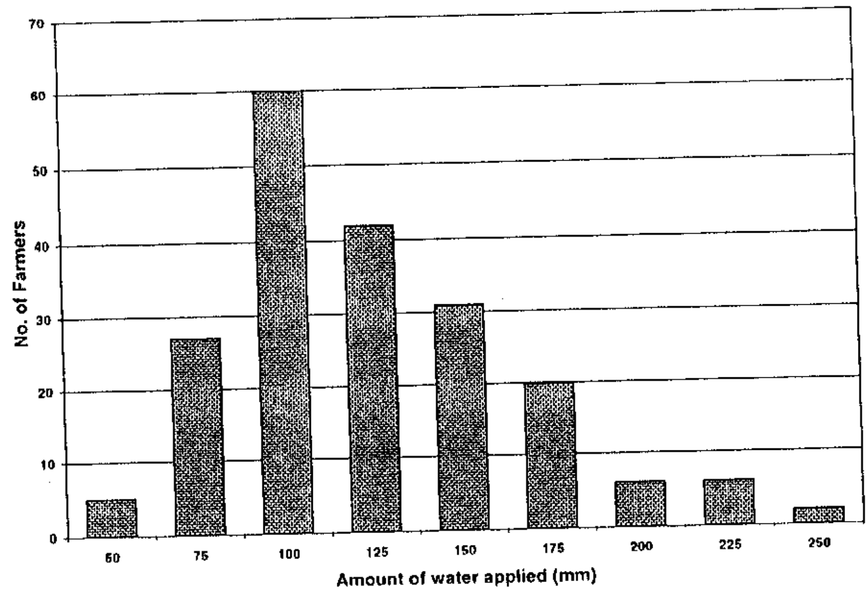

Figure 15. Water applied during the first irrigation (Source: Bhatti et al., 1989).

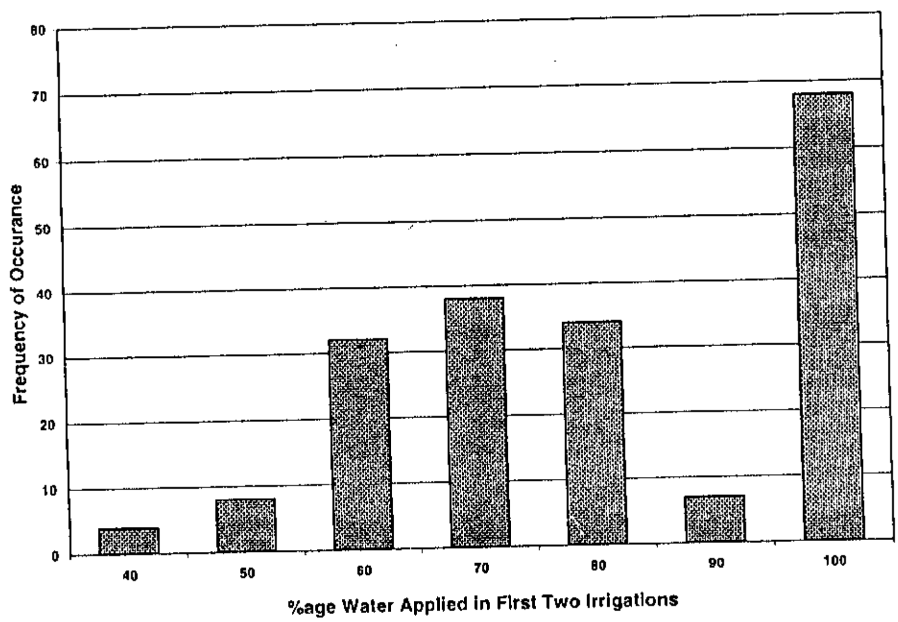

Figure 16. Water applied in the first two irrigation turns (Source: Bhatti et al., 1989).

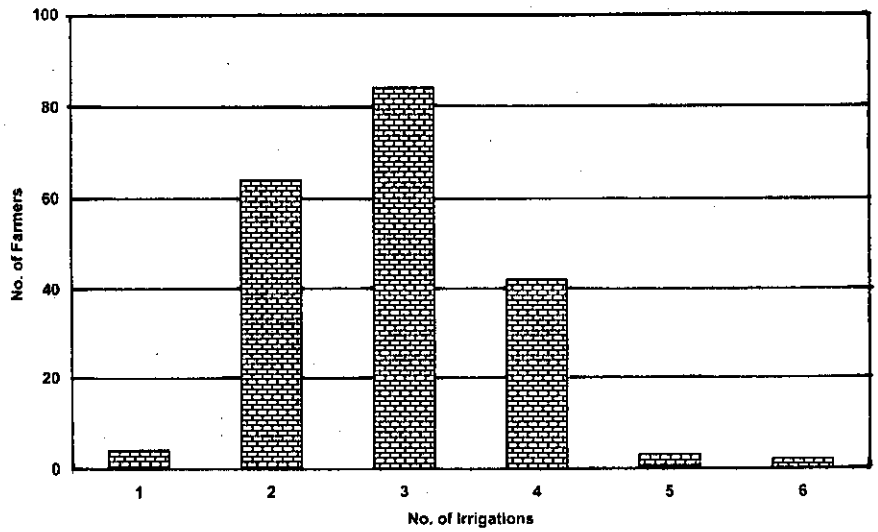

Figure 17. The number of irrigation turns applied to wheat (Source: Bhatti et al., 1989).

Azeem et al. (1990) reported that in the *Rabi* season, wheat occupies the major share of acreage after rice in the area. The late harvesting of rice leads to a major time conflict in the rice-wheat systems, resulting in the late planting of wheat. The mean wheat planting date on sample fields was the last week of November. A large number of farmers (37%) planted wheat later than the recommended time (30 November). Land preparation after rice for wheat planting is a very critical factor among the farmers in the area. The majority of the farmers (57%) planted wheat under "Wad Water" conditions, which mean irrigating rice late and preparing land for wheat on residual moisture. The remaining fields were planted after *rauni*, and watering after the rice harvest for land preparation for the following crop. On average, *rauni* was applied 11 days after the rice harvest. On average, the first irrigation was applied after 44 days of wheat planting on the sample fields.

Bhatti (1990) reported that the number of irrigation turns applied to sample wheat fields ranged from a minimum of 1 to a maximum of 6, with a mean value of 3. These irrigation turns were in addition to a pre-sowing (*rauni*) irrigation applied on 75 percent of the fields in order to ensure favorable soil moisture conditions for wheat germination. The seasonal amount of irrigation water, excluding rainfall, applied to wheat fields ranged from 89mm to 709mm with a mean of 356mm, which is considerably lower than the average gross water requirements of 580mm for wheat, taking into account:

- An approximate pre-sowing irrigation of 100mm;
- Consumptive water use requirements of 335mm; and

- Field application efficiency of 70 percent.

Only 15 percent of the sample fields (194) received irrigation water equal, or more, than the gross water requirements, whereas a vast majority of the fields remained within the range of 300-500mm (Table 23).

Table 23 shows that the fields with access to a combination of canal and private tubewell water performed better in terms of both, efficiency of water use (316mm average seasonal water applied) and productivity for yield per unit of water applied (0.94kg/cu.m). Fields with access to canal water only performed next best. Fields with canal plus public water remained the lowest. Theoretically, a normal irrigation for wheat is considered to be 76mm, and a heavy irrigation 102mm. In practice, an irrigation turn may vary from 51 to about 254mm, with high average amounts. Table 24 presents the average depth of water applied to wheat fields in individual irrigation turns during *Rabi* 1987-88.

Table 23. Irrigation and wheat yields.

Irrigation supply conditions	No. of cases	Average no. of irrigation turns	Average seasonal applications (mm)	Average Yield	
				t/ha	kg/cu. m
Canal only	47	3	378	3.58	0.84
Canal + Pub. TW	30	3	443	2.85	0.60
Pub. TW only	18	2	260	3.10	0.82
Canal + Pvt. TW	10	3	316	3.55	0.94
Pvt. TW only	89	3	340	3.08	0.81

Pub = Public
Pvt = Private
TW = Tubewell

Table 24. Depths of individual irrigation turns.

Irrigation supply conditions	Average depth of water applied (mm)			
	Pre-sowing Irrigation (*Rauni*)	1st Irrigation	2nd Irrigation	3rd Irrigation
Canal only	115	121	99	88
Canal + Pub. TW	163	143	122	104
Pub. TW only	72	111	93	91
Canal + Pvt. TW	110	85	84	84
Pvt. TW only	95	95	82	76

Clearly, the fields with access to canal plus public tubewell water received the highest amount of irrigation water, whereas fields with private tubewells received the lowest irrigation water amounts. These practices reflect that irrigation supplies from public sources were used with considerably lower efficiency than the private ones. Another finding was that the stream size significantly affects the depth of the irrigation water applied during individual irrigation turns. As the stream size increases there is a corresponding increase in the depth of the water applied, and a resultant decrease in the application efficiency. The large variations in stream sizes were found wherever more than one source of irrigation was available. The large diversity in the stream size appears to be a key obstacle in the efficient management of individual irrigation turns at the farm. This is also supported by the fact that in the case of canal irrigation only, and private tubewell use only, farmers have been successful in applying relatively smaller amounts of water during individual irrigation turns.

Basin irrigation is used for irrigation applications to the wheat crop. There is a considerable variation in the sizes of basins employed under various water supply conditions. An observation has been that relatively large basins are employed when access to public tubewell water is provided. The presence of a large diversity in stream sizes, and basin sizes, results in a wide range of application efficiencies and distribution uniformity.

B. Sindh Rice-Wheat Zone

The irrigation and drainage practices for rice and wheat cultivation in the Sindh rice-wheat zone are presented in the following sections.

1) Rice

Rice, being an aquatic crop, needs an adequate supply of water for its proper growth and development. The important factor in determining the production of rice is the level of water supply to the crop. Rice grows under a wide range of water management conditions. This may be continuously flooded, intermittently flooded, or upland. The average requirement for early maturing varieties is about 60 acre–inches, and of late maturing varieties about 70 acre–inches. This water needs to be supplied in a continuous flow in order to maintain the constant flooding of the soil to 2-3-inch depths of water during the growth of the rice crop. The water requirement for the rice crop is the highest during:

(1) The initial seedling period, covering about 10 days;

(2) The pre-flowering and flowering period, covering about 25 days; and

(3) The grain formation period covering about 5-7 days. The rice crop is adversely affected in the case of any water deficiency water during these critical periods.

The strategy for increasing rice production should be to increase the vertical yield rather than the horizontal yield. The horizontal yield can be increased in the case of rice, by bringing more area under cultivation. A large area is lying uncultivated and has a varying degree of salinity and alkalinity, and which can be brought under rice cultivation. However, the major constraint in achieving this objective is the non-availability of irrigation water. The water is very limited and is said to be insufficient for the area being cultivated at present. Though the water availability is limited, water to irrigate more area could be made available by making efficient use of the available irrigation water, and practicing proper water management. That 33 percent of irrigation water is lost, or wasted, during its course of flow from the canal to the farm gate has been found. In addition, there is 17 percent loss of water in the field due to poor water management. Water management covers the supply of a proper and adequate amount of water according to the need of the crop at the proper stages of the crop growth. Also, it aims at minimizing water losses through efficient irrigation and cultural practices. Therefore, the water loss of 17 percent in the field can be saved through proper water management. Water management is more important to the rice crop as it consumes comparatively more water during its life cycle than other crops.

1.1) Rice Crop Water Requirements

The total water requirement for the rice crop could be calculated by the following relationship:

$$\mathbf{TWR = E + T + P - PPT}$$

Where:

TWR = Total irrigation water requirement
E = Evaporation
T = Transpiration
P = Percolation
PPT = Precipitation

Evapotranspiration is affected by climatic conditions. In the rainy season, evapotranspiration occurs less than during the dry season. The percolation rate depends on the soil type and the groundwater table depth. In the case of light-textured soils and deep groundwater tables, percolation losses may be 10 times more than in heavy soils with shallow watertables.

The work on the water requirements of the rice crop in the Sindh Province was done after the Sukkur Barrage was inaugurated in 1936. The delta, at that time, was estimated 55-60 acre-inches. The duty was found to be 50 acre-cusecs (with one cusec of water, 50 acres can be brought under rice cultivation). Due to water supply conditions and new rice varieties, the water need has become 60-70 acre-inches. The early maturing varieties need 60 acre-inches and medium maturing varieties, 70 acre-inches. On the basis of a delta of 60-70 acre-inches and the area covered under different varieties of rice, the total annual requirement for irrigation water for the Sindh Province is about 10 million acre-feet.

The rice crop requires water right from when the field is soaked until the maturity of the crop. The water requirement varies at different stages of the crop growth. Very little water is required for nursery raising as the area is covered at the ratio of 1:40 i.e., seedlings grown on one acre of nursery are sufficient to transplant 40 acres. The nursery period is about one month, during which about one inch of water is sufficient for the growth of seedlings, except at the time for sowing when soil is kept under saturated conditions for about one week.

In soaking the field to transplant seedlings, a heavy dose of 6-8 acre-inches is required. During the seedling establishment stage (10-15 days after transplanting), the water availability for the rice crop is very necessary. The optimum water level at the transplanting stage is about one inch deep, which is to be maintained even after transplanting.

The production of tillers is of varietal character, but is excessively affected by the water level of the rice field. That the water level at this stage is shallow is essential. Light irrigation turns are required at this stage to allow the plant to produce the maximum number of tillers.

During the reproductive phase (panicle initiation, booting, heading and flowering) of 25-30 days depending on variety, the water requirement is very critical. The water depth may be 3-4 inches until thel seed formation and development. The water is drained out 10-12 days before maturity. More than 60 percent of the total water required for growing rice is consumed during the reproductive phase (panicle initiation, booting, heading and flowering).

1.2) Water Supply Pattern

Based on different climatic conditions, the area of 0.77 million hectares(Mha) under rice cultivation in the province of Sindh has been divided into three rice cultivating zones, namely, (i) Guddu Barrage Command Rice Zone; (ii) Sukkur Barrage Command Rice Zone; and (iii) Kotri Barrage Command Rice Zone. Actually, the Guddu rice zone is included in the Sindh Rice-Wheat North zone. The water supply pattern in these zones is provided below.

In the Guddu Barrage Command Rice Zone, irrigation water for rice cultivation is supplied from two non-perennial canals (S. B. Feeder and Pat Feeder) off-taking from the Right Bank of the Guddu Barrage. On the left side, the Ghotki Feeder mostly feeds dry crops, with some patches of rice cultivation. Under this rice zone, 40 to 50 acre–cusecs discharge is sanctioned for rice cultivation and covers about 251,417 hectares of the entire Jacobabad District, and a major part of the Sukkur District.

The Sukkur Barrage Command Rice Zone consists of part of the Sukkur District, the entire Larkana District and part of the Dadu District, and covers about 276113 hectares of rice in these districts. In this zone, the water supply is sanctioned at the rate of 50 acre–cusecs for rice cultivation and 360 acre-cusecs for dry cultivation. In the commands of the Northwest and Dadu Canals, due to waterlogging and salinity, most areas have become unfit for dry crop cultivation and the farmers are obstinate to grow rice only during the *Kharif* season.

The Kotri Barrage Command Zone comprises part of the Hyderabad District and the entire Thatta District. Irrigation water is provided for rice cultivation on an area of about 240,891 hectares through the Kalri Canal (non-perennial) on the right side, the Fuleli and Pinyari Canals (non-perennial) on the left side of the barrage. In this zone, the water supply for rice cultivation is sanctioned at the rate of 40 acre/cusecs.

1.3) Irrigation Practices

In the rice-wheat zone of the Sindh Province, all rice is grown in flooded fields (Basin Irrigation), which are initially irrigated individually, and later on, with the increase in water depth, a largely uncontrolled water flow takes place from field to field. This will result in some kind of continuous flow irrigation, called the Pancho System. In low-lying areas, rice may be grown in stagnant water caused by poor drainage conditions.

The necessary irrigation and drainage control for intermittent irrigation is not usually present. Irrigation practices for broadcast and transplanted rice differ in the initial stages, but once the seedlings are established, the same irrigation method is used for both, broadcast and transplanted rice. For broadcast rice, fields are normally flooded as soon as water becomes available and seed is broadcast into the standing water. The next irrigation is given after germination, when seedlings are about 5cm high (7 to 10 days after sowing). Additional irrigation turns are aimed at flooding the field and keeping the water surface just below the growing tips of the rice. Once a depth of about 30.5cm is attained, further water applications are provided to maintain this depth. The levelness of the fields is rarely, if ever, up to the standard required for efficient water control in broadcast rice. In the case for transplanted rice, one, or more, pre-irrigation turns are provided in order to have some soil moisture before transplanting. This is done when the seedlings are in the nursery. An additional irrigation is given just prior to transplanting. Once the seedlings are established, normally a few days after transplanting, water is again applied and the field kept permanently flooded in a way similar to broadcast rice. Irrigation is discontinued about 15-20 days before harvesting in order to aid maturity, and also to have fields free of standing water at the harvest time. Drainage is often difficult and water is allowed to subside rather than run off.

From a study on the effect of farm area location on transplanting dates conducted in the Rice Canal Command, it was discovered where the full water supply was reached early, i.e., at the head of a distributary, rice planting was early and finished in a short period. Where the water supply was low for the first few weeks, but increased rapidly afterwards, like in the middle reaches, planting started before the full supply was obtained and continued over a longer period. Where full supplies were received late, planting was delayed, the amount of water applied per hectare was less and the proportion of rice in the cropping pattern was lower than in the cases for either, the head or middle reaches (Lower Indus Report (LIR), Vol. 10, 1965).

Table 25 presents the amounts of water applied at study areas in the commands of various canals. This table reveals that the highest quantities are associated with more water received than is actually required in all the study areas. Water in excess of that required for the cropped area is received and is allowed to flow through the rice fields onto adjacent uncultivated land. In the Sukkur Right Bank, two study areas on the Northwest Canal have high amounts recorded.

Table 25. Water amounts applied to rice fields during *Kharif* 1964.

Command	Watercourse Group	Assessed hectares on each study area	Water applied	
			Total hectare-mm	Average per hectare (mm)
Kotri Barrage	Perennial	40	53,640	1341
		5	8380	1676
	Non-perennial	33	47,256	1432
		56	163,856	2926
		91	208,026	2286
Total		225	479,475	2134
Sukkur Right Bank	Rice Canal	36	51,552	1432
		54	46,062	853
		66	48,246	731
	Northwest Canal	17	43,520	2560
		71	45,440	640
		24	57,792	2408
	Dadu Canal	37	63,159	1707
Total		305	353,190	1158
Both Barrages		530	840,050	1585

(Source: LIR, Vol 10, 1965)

The average amount of water applied per hectare of rice grown in each group of the study area, and the minimum and maximum applications recorded on individual study areas within each group for a total assessed area of 530 hectares are presented in Table 26.

Table 26. Average minimum, and maximum, water amounts applied to rice fields during *Kharif* 1964.

Watercourse Group	Delta to cropped average		
	Average (mm)	Minimum (mm.)	Maximum (mm)
Sukkur Right Bank			
Rice Canal	945	731	1432
North West Canal	823	640	2560
Dadu Canal	1707	1707	1707
Kotri Barrage			
Non-perennial	2316	1432	2926
Perennial	1372	1341	1753
All groups	1311	640	2926

(Source: LIR, Vol. 10, 1965)

Clearly, more water is applied to rice in the Kotri Barrage Command than in the Sukkur Right Bank rice growing areas. This is a result of more per haectare water available in the Kotri Commands.

The calculated water requirements and the actual supplies given to rice in the study watercourse groups of the Northwest, Rice and Dadu Commands (Figure 18) are presented in Figure 19. The comparison of water requirements and supplies in the rice areas clearly reveals the impact of the crop calendar. Transplanting rice takes 2-2.5 months, against the proposed month. This causes the curves to rise to its peak more gradually, which comes much later. The total amount of water used is the same. The Northwest and Dadu curves show this, but not the Rice Canal curve. The watercourses under study in the Rice Canal Command were not a typical example from an irrigation point of view.

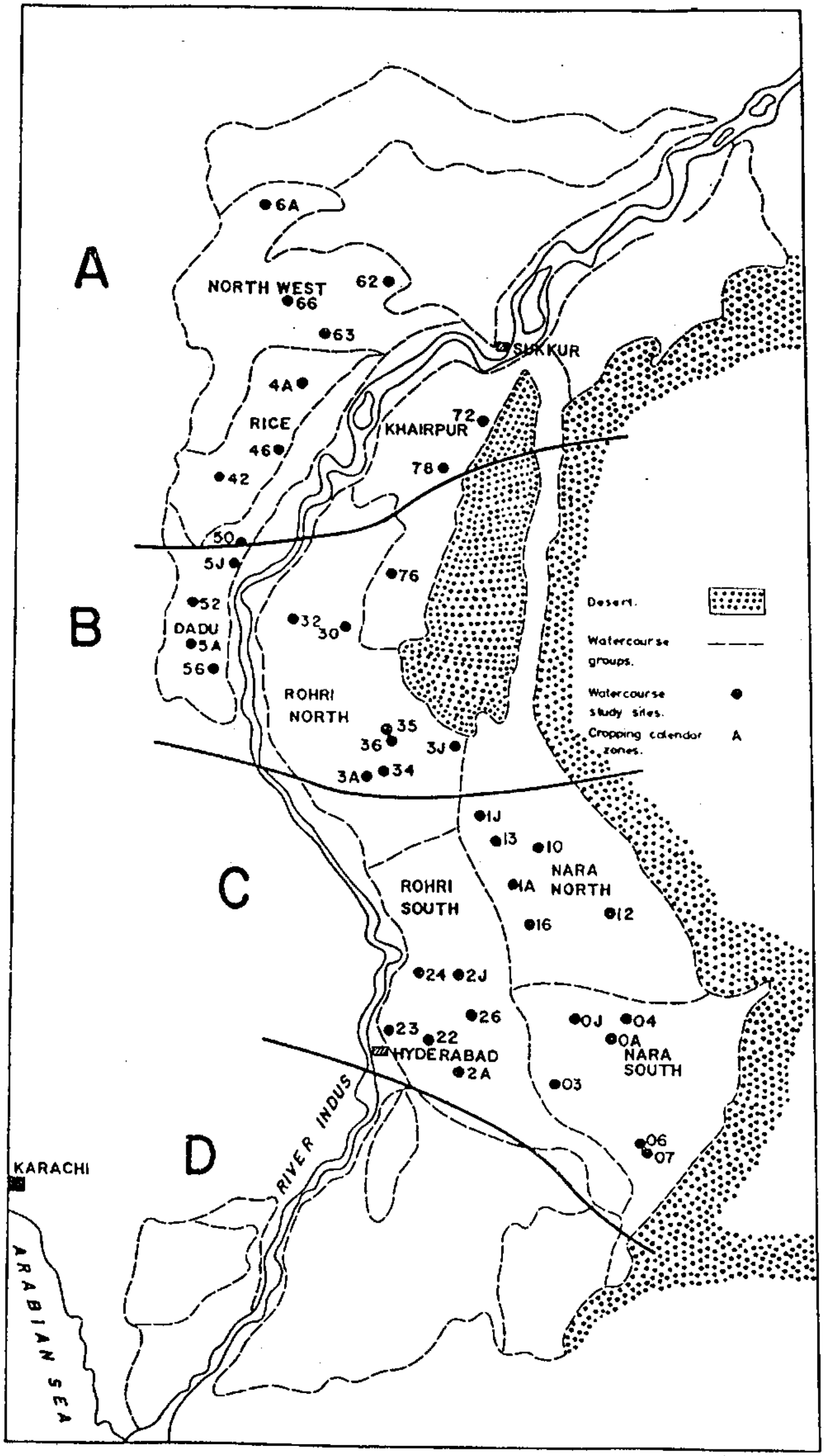

Figure 18. Locations of watercourse study sites (Source: LIR, Vol. 18, 1965).

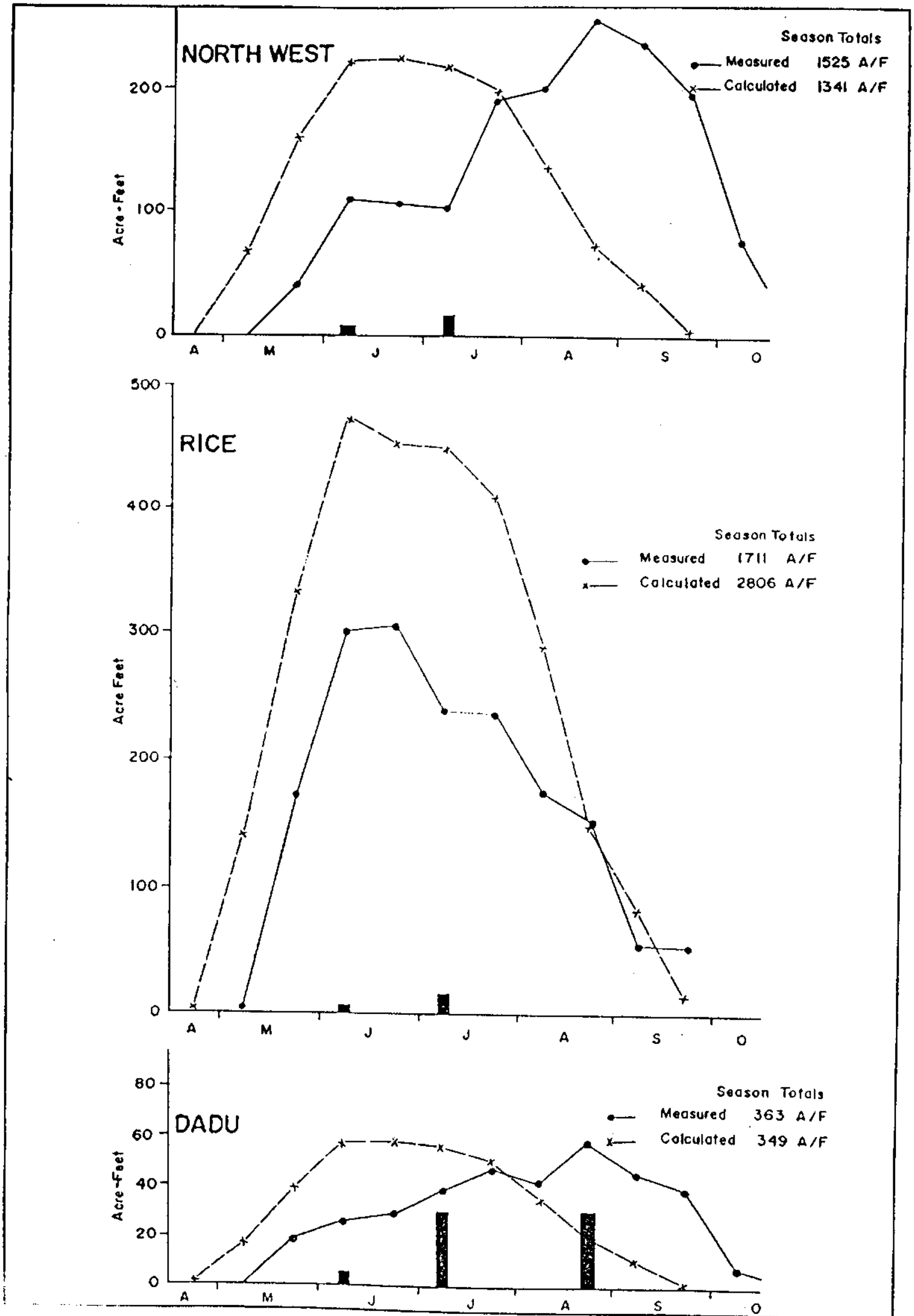

Figure 19. **Comparison of water supplies and water requirements for the rice crop (Source: LIR, Vol. 18, 1965).**

1.4) Water Losses in Rice Fields

Water losses and wastage in rice fields occur due to the following reasons:

- Rice farmers in the Sindh Province practice continuous irrigation of the field where water is always available. At other places, particularly at the tail ends of water channels, the fields are irrigated whenever water is available. This results in the over-flooding of rice fields due to the feeling that water may not be available again for some time;

- The fields are irrigated in such a way that water flows from one field to another, as there are no separate inlets for different fields;

- The fields are not properly leveled, therefore, in order to irrigate the high areas, fields are over-irrigated, which results in extremely deep water at lower spots; and

- Some farmers in the Sindh Province practice the Pancho System, which causes waterlogging.

1.5) Drainage of Rice Fields

Drainage requirements for rice are quite different from other crops. The saturation of the root zone and the maintenance of a controlled depth of water on the field are essential for paddy rice production. With fine-textured soils, this may be achieved by puddling the surface horizons, restricting infiltration and trapping ponded water above a deeper watertable. In general, soils on the Right Bank of the Indus River are too coarse-textured for this method of rice cultivation. The Indus alluvials, which occur over 70 percent of the Right Bank area, have medium to fast infiltration rates, whereas finer-textured soils occur in Piedmont alluvials, which are found in 30 percent of the area. Generally, conditions favorable for rice cultivation are achieved by raising the watertable to the surface. In these conditions, the provision of sub-surface drainage to lower the watertable would be counterproductive. For crops other than rice, good watertable control is required, maintaining well-aerated root zone. The desired watertable depth varies according to the rooting depth of crops and in general, from one meter for shallow-rooted crops, like wheat, to two meters for deep-rooted crops, like cotton. In this situation, it is also important to keep the water table low in order to avoid the hazard of salinization by capillary rise. Surface flooding due to rainfall is also critical for most non-rice crops. *Rabi* crops cannot be planted in rotation with rice in *Kharif* until the land is sufficiently dry for land preparation to be carried out.

Major constraints in achieving increased agricultural production are the inadequate drainage system in the area, combined with inadequate outfall arrangements. A drainage strategy has to be developed in order to maximize production, and the performance of each type of drainage has to be assessed with respect to the major crops being grown in the area. To provide an adequate drainage system in the area is essential to enhance control of water in low-lying areas, bring marginal areas under cultivation, reduce storm water drainage and promote early planting of the *Rabi* crop.

The Pancho System of irrigation implies changing water from the field at intervals, and applying a fresh irrigation to rice fields. The standing water in the rice fields is drained out to adjacent low-lying areas and fresh water is applied. This practice results in waterlogging. Draining rice fields may be by either, percolation or lateral drainage. The increase in the rice yield is attributed to percolating, as it helps the oxygen supply to the rhisophere of the rice plant, as well as removes toxic substances. Another finding has been that the amount of CO_2 decreased due to percolation; the decrease being proportionate to the increase in percolation, the water from canals and rice fields, coupled with Pancho water (water drained from rice fields during the periodic replacement of the standing water. Farmers release water from fields by either, small continuous trickles or emptying rice basins and refilling these with fresh water) either percolate into the groundwater, or stand in the depressions. These pools of water remain filled throughout the year because only a portion seeps down to the groundwater, or is lost due to evaporation. These pools of water continue to expand every year as a result of which valuable agricultural land is lost. An efficient drainage network is very essential for the rice area for sustained crop productivity.

In *Kharif*, during the rice-growing season, the watertable is generally at, or near, the surface, with a negligible component of deep percolation. The consequent removal of excess water is only by evaporation, leaving the concentrated salts behind. The existing drainage system has an inadequate capacity, and at present there is a dire need to remodel and rehabilitate the existing drainage works, and provide new drainage facilities to cater for the drainage requirements of the rice areas of the Sindh Province.

In the low-lying areas of the Sindh Province, water accumulates in excessive depths, and damages the rice crop. The situation is further aggravated during storm water runoff, resulting in a reduction of rice area. In the absence of drainage, surface water accumulated during the *Kharif* season is not drained off in time, with the result that the area for the *Rabi* crop is substantially reduced. In some of the low-lying areas, surface drainage only cannot provide favorable conditions for *Rabi* crops, and has to be substantiated by small pumping stations in order to pump the accumulated water into the surface drainage network. Thus, in line with the cropping pattern of the area, i.e., growing rice in the *Kharif* followed by wheat in the *Rabi* season, surface drainage is the most attractive solution. That will help to improve the time lines for the *Rabi* planting due to improved water control and reduced flooding, leading to the rapid drying of fields at the end of the *Kharif*.

2) Wheat

Wheat is grown as *dubari* (growing crops in the *Rabi* season on residual moisture from *Kharif* irrigation. This practice usually occurs in non-perennial areas) and *bosi* (growing crops in the *Rabi* season on water supplied at the end of the *Kharif* season. This practice is also used in the non-perennial areas) crops, mainly in the non-perennial areas, but is usually grown under the normal basin flood irrigation method in the perennial areas. Table 27 presents the percentage of wheat area with the average yield per hectare grown under *dubari*, *bosi* and basin flood irrigation methods in each watercourse group. This table reveals that the majority of wheat in the region is grown under the basin flood irrigation method. Only in the non-perennial Rice Canal and Kotri commands, the *dubari* and *bosi* methods are used. The average yield from normally irrigated fields is about double that from the other two methods. In general, *dubari*-grown wheat yields more than *bosi*-grown wheat.

Table 27. Different irrigation methods vs. wheat yields.

Watercourse Group	Assessed Hectares	Method of irrigation: Normal		*Dubari*		*Bosi*	
		% of assessed hectares	Average yield kg/ha	% of assessed hectares	Average yield kg/ha	% of assessed hectares	Average yield kg/ha
Kotri Barrage:							
Perennial	127	93	731	7	548	0	-
Non-perennial	39	27	183	17	274	56	183
Nara South	150	100	914	0	-	0	-
Nara North	204	100	1097	0	-	0	-
Rohri South	161	100	1188	0	-	0	-
Rohri North	241	100	1462	0	-	0	-
Rice Canal	42	0	-	100	640	0	-
Dadu Canal	194	99	1005	0	-	1	822
Northwest	155	95	640	4	457	1	91
Gudu Left Bank	51	51	1097	22	914	27	1188
All areas	1364	91	1005	6	640	3	457

(Source: LIR, Vol. 10, 1965)

Under the basin flooded irrigation watercourse groups, more than 75 percent of the wheat received only a single pre-planting irrigation in all the areas. The average interval between sowing and the first irrigation is approximately 4 weeks in perennially irrigated areas, and is between 5 and 7 weeks in the non-perennial areas. Generally, more irrigation turns are applied in the perennial than in the non-perennial areas (Table 28). The average maximum interval between successive irrigation turns is 6 weeks in the perennial areas where there is a canal closure during January. The interval is a little shorter in the non-perennially irrigated areas.

Table 28. Number of irrigation turns applied to wheat.

Watercourse group	Assessed hectares	The percentage of assessed hectares receiving varying number of crop irrigation turns									Average number of irrigation turns
		1	2	3	4	5	6	7	8	9 or >	
Kotri Barrage											
Perennial	104	5	33	32	26	0	2	2	0	0	3
Non-perennial	10	84	16	0	0	0	0	0	0	0	1
Nara South	146	1	2	21	25	24	7	9	6	5	5
Nara North	150	1	3	13	20	19	20	10	6	8	5
Rohri South	155	0	3	17	31	24	9	9	2	5	5
Rohri North	187	0	2	6	38	15	22	8	8	4	5
Rice Canal	41	0	0	0	0	0	0	0	0	0	0
Dadu Canal	88	2	12	41	24	12	5	2	2	0	4
North West Canal	138	22	37	29	7	3	2	0	0	0	2
Gudu Left Bank	18	31	14	32	7	2	0	14	0	0	3
Total	996	6	12	20	24	15	10	6	4	3	-

Bhatti et al. (1987), based on a field survey for 100 farmers who actually grew irrigated rice and wheat on the same field in the 1986-87 crop year in the Dadu Canal command (Upper Sindh), reported that the rice is continuously flooded, unlike wheat, an upland crop, and is quite sensitive to waterlogging. Unlike the common practice in the Punjab Province, only two of the sampled farmers irrigated their wheat land, pre-sowing after the rice harvest. All farmers irrigated their wheat crop post-sowing: 28 percent irrigated twice; 60 percent irrigated three times; and 12 percent of the sampled farmers irrigated their wheat crop four times. Thus, the most frequent number of post-sowing irrigation turns for wheat was three, with the range from two to four. In general, farmers who seeded their wheat crop late, irrigated more often.

C. Summary

In the Punjab Province, rice is grown mainly in rotation with wheat, on about 1.3 Mha out of the total 9.3 Mha of canal commanded area. The main sources of irrigation water are perennial and non-perennial canals, supplemented by electric and diesel tubewells. Water requirements for rice cultivation vary and depend largely on the soil types. The average requirement in the Punjab rice-wheat zone is considered to be about 1600mm, which includes water that is needed for land preparation, intentional drainage and deep percolation. However, the mean irrigation application was found to be about 1300mm during actual measurements on a fairly large number of farms in the Punjab rice-wheat zone. The mean irrigation application of about 1300mm is considerably lower than paddy's gross water requirements of about 1600mm considering the consumptive water use of 650mm, land preparation of 450mm and seasonal seepage and percolation losses of 500mm in the case of fine-textured soil. But, there is a large variation around the mean water application.

The majority of the farmers do not have sufficient irrigation water for land preparation, which leads to a delay in land preparation and transplantation until the monsoon starts. This is especially the case in tail watercourses that are usually well in time with wheat sowing, but fall behind in paddy cultivation. Irrigation water available for a short duration simply cannot be managed efficiently considering the distribution network at the tertiary level and surface irrigation practices employed at the farm. A major cause for the short turn is the continuing fragmentation of farm holdings when the land is distributed among male family members. The decrease in farm size directly affects the water rights, and therefore, the duration of the turn in the same proportion. To manage weekly irrigation supplies more efficiently, some farmers trade their turns by borrowing, lending, selling and buying among themselves according to their needs and/or convenience.

Imperfectly drained clay and silty-clay soils are quite suitable for paddy. Well-drained loams and silt-loams are suitable for all types of crops, but their lighter texture makes them less appropriate for rice cultivation. Saline-sodic soils are unsuitable for nearly all crops. In practice, farmers use just about all kinds of soils for rice cultivation without considering their suitability, which results in large percolation losses in land preparation and from irrigation turns during the paddy-growing season. Infiltration rates measured on selected fields range from less than 1 to more than 10mm/day (in some cases as high as 20mm/day), which result in losses as high evapotranspiration. On most of these fields, water applications were higher than average, while yields were low (low water use efficiency).

Shortages and variability in canal water supplies force the farmers, especially at tail ends of the irrigation system, to depend heavily on tubewell water for irrigation, which results in soil degradation due to saline/sodic tubewell water. In the Punjab Province, it has been found that the rice yield per unit water on the majority of farms is less than 0.1kg/m^3, which is low when compared to other countries in Asia, or elsewhere. Soil salinity/sodicity causes reduced rice yields in the Punjab Province. Based on the pattern of irrigation water use and rice yields, it has been found that irrigation water is managed better in the tail reaches where it is relatively scarce, than in the head reaches. In a comparison of 10 percent of each, farms with the highest and the lowest rice yields, it was found that the average seasonal water use was the same for the two farm groups, but the yields were considerably different. Unsuitable soils and marginal quality tubewell water cause low yields, regardless of the amount applied.

Irrigation water management practices for wheat cultivation in the Punjab Province are:

- Seasonally, insufficient water is applied. About 75 percent of the farmers apply less than the gross water requirement. Farmers tend to over-plant and under-irrigate, hoping that abundant rains will close the gap between evapotranspiration demands and irrigation supplies;

- The first irrigation is applied too late. This is because canals are closed for maintenance during this period. The delay in the first irrigation has a double negative impact because the majority of farmers apply nitrogen with the first irrigation. The delay in irrigation affects uptake and utilization of nitrogen, in addition to crop water conditions;

- Farmers terminate their irrigation turns in early to mid-March, when the wheat crop is at the grain filling stages, when temperatures rise abruptly, and thus, when the wheat crop needs water badly due to high evapotranspiration. This practice has a detrimental effect on wheat yields during the years with no rainfall during that time period. The late harvesting of rice leads to a major time conflict in the rice-wheat systems, resulting in the late planting of wheat.

The fields with access to a combination of canal and private tubewell water perform better in both, efficiency of water use (316mm average seasonal water applied) and productivity, i.e. the yield per unit of water applied (0.94kg/cu.m). Then, fields with access to canal water only follow. Fields with canal plus public water remained the lowest. Theoretically, a normal irrigation for wheat is considered to be 76mm and a heavy irrigation 102mm. In practice, an irrigation turn may vary from 51mm to about 254mm, with high average amounts.

In the Sindh Province, the average requirement of early maturing varieties is about 60 acre–inches and of late maturing varieties is about 70 acre–inches. This water needs to be supplied in a continuous flow in order to maintain the constant flooding of the soil to 2-3 inch depths of water during the growth of the rice crop. In the rice-wheat zone of the Sindh Province, all rice is grown in flooded fields, which are initially irrigated individually, and later, with the increase in water depth, a largely uncontrolled water flow takes place from field to field. Thereby, the result is some sort of continuous flow irrigation, called the Pancho System. In low-lying areas, rice may be grown in stagnant water caused by poor drainage conditions.

The necessary irrigation and drainage control for intermittent irrigation is not usually present. Irrigation practices for broadcast and transplanted rice differ in the initial stages, but once the seedlings are established, the same irrigation method is used for both, broadcast and transplanted rice. For broadcast rice, fields are normally flooded as soon as water becomes available and seed is broadcast into the standing water. The next irrigation is given after germination when seedlings are about 5cm high (7 to 10 days after sowing). Additional irrigation turns are aimed at flooding the field and keeping the water surface just below the growing tips of the rice. Once a depth of about 30.5cm is attained, further water applications are provided to maintain this depth. The levelness of the fields is rarely, if ever, up to the standard required for efficient water control in broadcast rice. In the case of transplanted rice, one, or more, pre-irrigation turns are provided to have some soil moisture before transplanting. This is done when the seedlings are in the nursery. An additional irrigation is given just prior to transplanting. Once the seedlings are established, normally a few days after transplanting, water is applied once more, and the field kept permanently flooded in a way similar to broadcast rice. Irrigation is discontinued about 15-20 days before harvesting in order to aid maturity, and also, to have fields free of standing water at the time of harvest. Drainage is often difficult and water is allowed to subside rather than run off.

From a study on the effect of farm area location on transplanting dates, conducted in the Rice Canal Command, it was found that where a full water supply was reached early, i.e., at the head of a distributary, rice planting was early and finished in a short period. Where the water supply was low for the first few weeks, but increased rapidly afterwards, as in the middle reaches, planting started before full supply was obtained and continued over a longer period. Where full supplies were received late, planting was delayed, the amount of water applied per hectare was less and the proportion of rice in the cropping pattern was lower than in the cases for either, head or middle reaches.

Major constraints in achieving increased agricultural production are the inadequate drainage system in the area, combined with inadequate outfall arrangements. A drainage strategy has to be developed to maximize production and the performance. Drainage has to be assessed with respect to the major crops that are grown in the area. Providing an adequate drainage system in the area in order to enhance the control of water in low-lying areas is essential to bring marginal areas under cultivation, reduce storm water drainage and promote early planting of the *Rabi* crop. The Pancho System of irrigation implies changing water from the field at intervals, and giving fresh irrigation to rice fields. The standing water in the rice fields is drained out to adjacent low-lying areas and fresh water is applied. This practice results in waterlogging. The drainage of rice fields may be by either, percolation or lateral drainage. The water from canals and rice fields coupled with the Pancho water flow, either percolate into the groundwater or stand in the depressions. These pools of water remain filled throughout the year because only a portion seeps down to the groundwater, or is lost due to evaporation. These pools of water continue to expand every year, as a result of which valuable agricultural land is lost. An efficient drainage network is very essential for the rice area for sustained crop productivity. The existing drainage system has an inadequate capacity, and at present, there is a dire need to remodel and rehabilitate existing drainage works and the provision of new drainage facilities to cater for the drainage requirements of the rice areas of the Sindh Province.

In the Sindh Province, wheat is grown as *dubari* (growing crops in the *Rabi* season on residual moisture from *Kharif* irrigation. This practice usually occurs in non-perennial areas) and *bosi* (growing crops in the *Rabi* season on water supplied at the end of the *Kharif* season. This practice also is used in non-perennial areas) crops, mainly in the non-perennial areas, but is usually grown under the normal basin flood irrigation method in the perennial areas. The majority of wheat in the region is grown under the basin flood irrigation method. Only in the non-perennial Rice Canal and Kotri commands, the *dubari* and *bosi* methods are used. The average yield from normally irrigated fields is about double that from the other two methods. In general, *dubari*-grown wheat yields more than *bosi*-grown wheat.

IV. IMPROVED IRRIGATION WATER MANAGEMENT FOR THE RICE-WHEAT CROPPING SYSTEMS IN THE SINDH PROVINCE

A. Overview

Rice and wheat are Pakistan's most important cereal crops, extensively grown IN large areas on rotation with rice in the *Kharif* season and wheat in *Rabi* season. Pakistan grows wheat on an area of about 8.22 Mha with a production of 16.4 Mtons of wheat, with yield of 1.99tons/ha. Rice, after wheat, is grown on about 1.93 Mha, with a production of 3.08 Mtons of rice yielding 1.59tons/ha (Altaf, 1994). In the Sindh Province, rice is grown on about 0.75 Mha with production of about 1.5m tons of rice yielding about 2tons/ha, whereas area under wheat is over 1.0 Mha with the average irrigated wheat yielding 2.1tons/ha. This reflects that areas of rice and wheat in the Sindh Province are 39 percent and 12 percent of the country's rice and wheat areas, respectively. The Sindh Province's rice and wheat productions are 49 percent and 13 percent of the national rice and wheat production, respectively. Generally, in the Sindh Province, the area under rice has been about 36 to 42 percent of the total rice area of Pakistan, whereas the production has been from 40-50 percent of the total production.

The 0.75 Mha of rice and over 95 percent of the 1.0 Mha of wheat grown in the Sindh Province is irrigated. Rice dominates on the Right Bank of the Indus River (Larkana, Jacobabad, Shikarpur, Sukkur and Dadu Districts), partly because of high watertables that make the land unsuitable to grow other crops in the *Kharif* season. In contrast, most wheat in the Sindh Province is grown on the Left Bank of the Indus River (Nawabshah, Sanghar, Tharparkar and Hyderabad Districts). Rice-wheat rotations occur most widely in Upper Sindh. The estimate is that 32 percent of the rice area is in Lower Sindh (Thatta, Badin and Hyderabad Districts), whereas 68 percent is in Upper Sindh. The IRRI varieties are cultivated on about 90 percent of the total rice area in the Sindh Province, and on the remaining 10 percent area, traditional tall scented varieties are grown. Due to high levels of solar radiation, water control, and low pest infestation in the Sindh Province, IRRI6 has a yield potential of over 9tons/ha when grown under farm conditions, using the recommended practices. Among the highest farm yields of rice reported, over 13tons/ha of IRRI6 was recorded in Upper Sindh. Yet, average yields for IRRI6, across the province, are about 4tons/ha, less than half the yield potential. Rice (paddy) yields are substantially higher in Upper (4.3tons/ha) than in Lower Sindh (2.2tons/ha).

Wheat is also a traditional cereal crop in the Sindh Province. The area of wheat increased sharply in the mid-70s to over 1 Mha with the introduction of short-duration modern varieties of wheat. Wheat yields increased steadily from a provincial average of less than 1ton/ha in the mid-60s to 2.1tons/ha in the mid-80s. Wheat yields in Upper Sindh (2tons/ha) are slightly, but consistently, below those of Lower Sindh (2.2tons/ha). Mean wheat yields in irrigated areas (2.1tons/ha) are double those of the non-irrigated wheat tracts (1.0tons/ha). Thus, about 98 percent of wheat production in Sindh are from irrigated areas. The low wheat yields in Upper Sindh, in part, are due to the problems related to growing upland crop as wheat after rice. These problems include:

(i) Establishing a wheat crop on land that had previously been puddled for rice; and
(ii) A high temperature constraint during the grain filling period, which reduces the yield of late-planted wheat.

B. Irrigation Water Availability

Two important basic requirements for the rice-wheat production system are:

(i) Availability of irrigation water; and
(ii) Availability of good land.

Of course, rice and wheat yields depend not only on water quantity and quality, but also on a number of other inputs. Yet, irrigation is the single-most important factor also expected to stimulate the application of other inputs like fertilizer, etc.. Thus, any improvement in water supply is likely to improve the use and efficiency of other inputs as well. In the Sindh province, in rice-wheat zones, rice is grown during summer followed by the winter crop, wheat, under irrigated or non-irrigated conditions. Wheat is mostly grown on land where water is available for irrigation. In those areas where irrigation water is not available, wheat is grown on the residual moisture left from the rice crop. All of the rice-wheat area is irrigated through canals. The irrigation canals may be perennial with water available throughout the year, or non-perennial with water availability for about 6-7 months during May to November. In the non-perennial canals, the start of the supply of irrigation water is late, which delays transplanting the rice seedlings. Moreover, the water supply is stopped abruptly, without any prior information to the farmers. Such discontinuity in the supply of irrigation water, even for a short time, at critical stages such as the panicle initiation and flowering stages, cause significant reduction in the paddy yield. The rice crop is irrigated with one cusec of canal water for each 250-acres of land. This is not sufficient, as rice needs one cusec for each 60-acres of land. Thus, there is a general cry for the shortage of irrigation water, especially at the tail end of the irrigation system.

The water scarcity problem is further aggravated by high water losses in the water distribution system. That the total water losses from the canal head to the farm gate were about 40 percent (25% at the canal head and 15% at the watercourse level) of the total water available at the canal head has been reported. These high losses not only created water shortages for crops, but also cause waterlogging and salinity (Chaudhray et al., 1987). There are poor physical conditions of irrigation channels due to the lack of effective maintenance inputs, causing poor hydraulic performance of the canal system, inequity and unreliability in water distribution, outlet tampering and water theft activities in the upper reaches of irrigation channels. Thus, water shortage, poor operation and maintenance of the irrigation system, weak institutions, and illegal cuts and breaches by the farmers with large land holdings cause inequity and unreliability in canal water distribution. The increased rice-wheat production needs an equitable and reliable water distribution and improved irrigation management at the farm level. The improved irrigation system management would increase equity, reliability, and reduce the variability in canal water distribution in the irrigation system.

C. Farmers' Present Irrigation Practices

The variability and unreliability in water distribution cause inefficient water use at the farm. Poor irrigation management practices at the farm level cause wastage of limited irrigation water. Much water is wasted due to the farmers' negligence and the bad layout of water channels, resulting in low irrigation efficiency. These channels follow a zigzag pattern, which slows down the water speed and causes siltation that necessitates cleaning the water channels frequently. Paddy farmers in the Sindh Province practice continuous irrigation at fields where water is always available. At other places, particularly at the tail end of water channels, the fields are irrigated whenever water is available. This results in the over-flooding of rice fields because of the uncertainty about the availability of water for some time afterwards. The fields are irrigated in such a way that water flows from one field to another, as there are no separate inlets for different fields. Also, fields are not properly leveled. Consequently, in order to irrigate the high spots, the fields are over-irrigated, resulting in extensive depths of water at the lower spots.

In general, the water control is poor. The *bunds* of most of the fields and water channels are not properly maintained. When one field is irrigated, water also flows to other fields. The adjoining low-lying fields are flooded and sometimes the depth of water exceeds 60cm. In low lying fields, the excess supply of water and in other fields, the shortage of water, affect the growth of the rice crop adversely. Immediately after rice transplantation, the water shortage hampers early rooting. At the reproductive stage, especially from the panicle initiation to the flowering stage, the shortage of water causes panicle sterility and adversely affects panicle formation, flowering and fertilization. Excessive water supplies at the early growth stages of the rice plant suppress the tillering capacity and hamper rooting. However, the low water level enhances the tillering and promotes root anchorage in the soil. Over-irrigation at the booting stage causes decreases in culm strength and the lodging of rice plants.

Clark and Aniq (1993) reported that on the Right Bank of the Indus River in the Sindh province, rice is the major *Kharif* crop where the watertable is raised about 1.6m above the ground surface in summer, over 52 percent of the CCA during the entire growing period. A total of 1.2-1.7m of water is applied, of which only

0.9m is for consumption, which results in an application efficiency range of 53-75 percent only. Yaseen et al. (1995) reported that the total water requirement, including the soaking dose for wheat, is 375mm for Lower Sindh, whereas farmers apply about 450mm of irrigation water to the wheat crop. Thus, farmers apply about 17 percent more water than the crop water requirement. Also, water use efficiency was low (8.11kg/mm/ha) in cases where farmers' conditions were against wheat scheduling (9.97kg/mm/ha). This reflects more water use than required, but the reduced yield (3.65ton/ha) against the yield (3.74tons/ha) obtained by applying 375mm of irrigation water. By better management of irrigation water, application and water use efficiencies could be increased, which would result in water savings as well as minimum drainage effluent (reduced drainage requirements).

D. Pancho System of Irrigation

In the Sindh Province, some of the rice farmers, especially on the Right Bank of the Indus River, practice a Pancho System of irrigation, which causes waterlogging. The Pancho System of irrigation implies changing water from the field at intervals (every 4 or 5 days) and applying fresh irrigation turns to the rice fields. The standing water in the rice fields is drained out to adjoining low-lying areas and fresh water is applied. Though some Pancho water (let out of rice fields) is lost through evaporation and percolation, this practice (Pancho System) ultimately results in waterlogging, thereby creating acute drainage problems in the rice-growing areas. In the Sindh Province, in most rice fields, the groundwater table rises to an extent in some areas that reaches the surface layer of the soil. Under this condition, either the percolation does not take place or it is very slow. The only way to change water in such conditions is through lateral drainage. However, there is an artificial drainage system prevailing in the rice area in the Sindh Province. The farmers practice the Pancho System, which seems to be helpful towards increasing rice production, but in the absence of a drainage system, the water is drained to low-lying areas. As there is a further flow of drained water, there is some percolation achieved beyond which the drainage is not possible, therefore, the result is waterlogging. The factors that encourage the Pancho System irrigation are:

(i) Long watercourses and the continuous flow of water. The farmers are forced to use their irrigation turns, whether they need water or not;

(ii) Irrigation by block of fields. There is one water inlet for a number of fields from the irrigation ditch; water is let into one field and through it, to the next, and so on. Often, water is kept moving slowly through the paddy fields; and

(iii) Control of salinity. In newly reclaimed saline land, water is let out of the field to wash the salts from the land.

E. Drainage Problem

In the Sindh Province, the rice-wheat areas have serious drainage problems. The presence of extensively depressed areas, clayey soils and slowly permeable deep strata are mainly responsible for the impeded drainage, which has further deteriorated due to improper irrigation practices and the over use of irrigation water. Consequently, there are widespread problems of waterlogging and salinity, which cause considerable reduction in the rice and wheat yields. According to an estimate (Ansari and Khanzada, 1995), about 3.13 Mha out of the total Sindh Province's irrigated area of about 3.15 Mha is affected by waterlogging and salinity/sodicity. Table 29 presents the soil salinity situation in the Sindh Province. Clearly, about 30 percent of land is not favorable for the optimum growth of most crops.

Table 29. Soil salinity status of the Sindh Province (total cultivated area = 5.5 Mha).

Salinity Class	EC (ds/m)	Affected (% of total)	Visible symptoms	Crop growth
Non-saline	<4	52	Salts not visible	Unaffected
Slightly saline	4-8	19	Some salts visible	Uneven or patchy
Moderately saline	8-5	11	Scattered patches	Generally stunted
Highly saline	>15	18	Salts widespread	None or very poor

Source: (Ansari and Khanzada, 1995)

The problems of waterlogging and salinity are more pronounced in the Right Bank area, which is due to the topography of land, as the Right Bank area is at a lower level than the Left Bank.

Based upon the above discussion, it may be concluded that in the Sindh Province, increased rice-wheat production is greatly constrained by water shortage in certain areas, while over-irrigation in others depresses crop yields and creates problem of drainage. There is low irrigation efficiency due to considerable losses of water. In other words, there is poor drainage and improper management of irrigation water; therefore, e rice and wheat yields in the province are less than potentials. Under these circumstances, the improved management of irrigation water is the prime need of the Sindh Province to sustain its rice-wheat production system. In order to increase rice-wheat production, the vertical yield rather than the horizontal yield needs to be improved. Bringing more area under cultivation could increase the horizontal yield. A large area, with a varying degree of salinity and sodicity, remains uncultivated, which can be brought under rice and wheat cultivation. However, the major constraint in achieving this objective is the non-availability of irrigation water, which is very limited. Though it is true that the water availability is limited, water for more area can be made available, by making efficient use of available irrigation water and practicing proper water management. This reflects that because of the low probability of developing additional irrigation supplies, high priority has to be given to improve the management of present irrigation supplies. This implies that a substantial increase in rice-wheat yields had to be generated from the more efficient and economic use of available water supplies.

F. Efficient Water Management

Efficient water management refers to the supply of adequate amounts of water according to the need of the crop, and at the proper stages of the crop growth. Another aim is to minimize water losses through efficient irrigation and cultural practices. Management improvements can be made in the conservation of water by better irrigation scheduling, thereby improving crop yields. Inadequate or ill-timed applications of irrigation water can result in lowered crop yields. Efficient crop water management requires knowledge of crop water needs, rates at which water is extracted from the soil by the crop, characteristics of the soil, and the irrigation system used to apply water to the crop. Decisions concerning crop water requirement are made during the year, which require crop water availability and demand information. When irrigation is delayed, the crop will show signs of stress, but yield reductions are probably underway before the stress is visible. Irrigating more frequently than required can avoid the stress, but may not be an efficient use of a limited water supply. Successful water management requires achieving a balance between the amount of water used by the crop and the water made available to it by irrigation and rainfall.

G. Improved Irrigation Water Management for the Sindh Province

Based upon the literature review provided in Chapter II, the following improved irrigation water management practices, both at the system as well as the farm level, for the rice-wheat cropping systems in the Sindh Province are identified, which are considered most appropriate to sustain the rice-wheat cropping systems.

1) System Level Management Measures

In Pakistan, the Provincial Irrigation Departments are responsible for operations of primary (main) and secondary canals to deliver water to watercourse heads, maintenance of all channels in the main and secondary system and assessment for the collection of water fees. The Irrigation Departments are operating in the context of relatively rigid physical systems, organizational structures and administrative rules devised over 100 years ago. There have been considerable changes in sources, quantities and qualities of the water supply, agricultural technology changes, and needs for increased food and fiber production. Due to physical system rigidities and increased needs for water, there are substantial discrepancies between managerial actions and needs. Under these circumstances, there is a dire need to identify opportunities for effective management interventions. For the Sindh Irrigation Department, three potential management interventions are identified. The adoption of these would improve the performance of the irrigation system in terms of supplying equitable and reliable irrigation water supplies in amounts proportionate to command areas, to watercourse outlets that serve individual farmers in strict accordance with timed turns. This will help farmers to make irrigation decisions with confidence, on assured and timely irrigation water supplies. Any improvement in the reliability of the system operation would increase the productivity of available water supplies. The management interventions to strengthen the management capabilities of the Sindh Irrigation Department to improve the hydraulic performance of the irrigation systems, which currently causes inequity in surface canal water supplies, are:

2) Irrigation Water Delivery Accountability

Generally, Irrigation Departments suffer from the lack of accountability and changes in institutional arrangements that provide for greater individual and technical accountability. Actually, system operators are influenced by other factors than efficiency and equity of distribution, such as accommodating influential farmers and rent seeking. The irrigation system manager should be held accountable for water deliveries. In order to achieve this objective, all the control structures should be calibrated, flow measuring rating tables should be developed, or updated if already existent, and irrigation department (ID) field staff should be trained to carry out the necessary discharge measurements.

3) Management of Decision Support System

The overall aim of the *Management Support for Canal Operation and Maintenance* management intervention is to enable IDs to optimize the benefits of limited maintenance resources to improve canal system performance. This includes computer modeling of canal hydraulic conditions to accurately predict the impact of differential operational and maintenance inputs on water distribution equity and reliability. Irrigation system managers should be made familiar with the use and application of the hydraulic models to improve operations and maintenance of the irrigation channels.

4) Irrigation Management Information System

The IMIS would also improve the canal water distribution performance. The components of this intervention would consist of:

(i) Field data collection by the ID staff;

(ii) The timely flow of data from the field to the system manager; and
(iii) Daily processing of the data by the system manager and his feedback to the operating staff.

5) Performance Indicators

Without proper techniques for monitoring the performance of irrigation systems, it is impossible to evaluate the potential benefits that might come from further investments to improve them. Various performance indicators, which are practical, useful, and generally applicable, have been identified and evaluated. Irrigation managers should use these indicators to assess the performance of the irrigation system, as well as to evaluate the potential for further investments to improve the performance of an irrigation system. The performance indicators may include those dealing with hydraulic performance. Water delivery performance measured by the delivery performance ratio (DPR), which is the ratio of the actual discharge to intended discharge, efficiency, maintenance and the adequacy of supply *vis-à-vis* the need for water.

6) Farmers' Participation

Active farmers' participation in irrigation system management results in the improved equity and reliability of water distribution, which, in turn, result in timely planting for rice and wheat, and consequently, increased rice-wheat yields (Magliano et al., 1990). For Sindh situation also, farmers should be organized in order to participate in decision making and ID should consider them active partners in decision making process.

7) Reuse of Drainage Effluent

The reuse of drainage water offers another potential opportunity to improve irrigation water management for rice-wheat lands of water shortage areas in the Sindh Province. Depending upon the quality of the drainage effluent, the water reuse component can contribute significantly to the total irrigation water supply for the rice-wheat irrigated areas. Apart from meeting the water needs at peak demand periods, drainage water reuse would be a quick response water supply solution during water shortage periods, increasing both, the water reliability and rice-wheat crop security. Because drainage water within the irrigation area would be used for irrigation, the water intake from the headwork (the system fresh water requirements) could be reduced without sacrificing productivity and reducing cropped area. In Japan, it has been proved that coupled with efficient water usage methods, drainage water reuse has a high potential to improve irrigation water management in rice-wheat areas (Zulu et al., 1996). In the Sindh Province, future irrigation system improvement works should be planned in consideration of a possible drainage recycle technique as a means of water conservation.

8) Physical Rehabilitation

Technical inadequacy, improper operation and maintenance of the system, excessive, or inadequate flows, insufficient control structures, heavy seepage losses and the undisciplined use of water undermine the performance of most irrigation systems (Ali, 1983). Irrigation system infrastructures deteriorate with time, without sustained maintenance inputs by the Irrigation Department. Daily water level observations and adjustments on gate settings are needed to obtain a proper water distribution. But, currently, these observations and operations are lacking in the irrigation system and many control structures originally designed for free-flow conditions are operating under submerged flow conditions, which makes the flow measurements and operation of the structures difficult. Moreover, the use of old rating tables (not present in most irrigation systems) for flow measurements along the main and secondary canals, and also the poor physical conditions (the dimensions of structures are often different from the design values) of the control structures and channels, result in inaccurate flow measurements.

Investments should be made to restore irrigation system infrastructures to their original form to improve the adequacy, equity, and the carrying capacity of the channels to carry design flows without breaches, and the reliability of irrigation water supplies, thereby increasing the potential for agricultural production. A rehabilitation program should include the improvement of the physical conditions of diversion, and control structures, and the implementation of a selective maintenance program by the ID using its limited financial resources meant for maintenance and repair. There should be regular maintenance of irrigation infrastructure to sustain the initial benefits from a rehabilitation program. The sustainable improvements in operation and maintenance are not possible without the involvement and participation of the farming community in the management of the irrigation system (effective communication and cooperation between the ID and farmers).

H. Farm Level Management Measures

Poor irrigation management practices at the farm level cause wastage of limited irrigation water, whereas increased rice-wheat production needs improved irrigation management at the farm level. Moreover, sustained rice-wheat production systems require improved irrigation water management at both, the system as well as the farm level. The improved irrigation water management measures for rice-wheat systems at the farm level identified for the Sindh Province are discussed below.

1) Water-saving Irrigation Regimes

To improve water-use efficiency of the rice crop, farmers in the Sindh Province should adopt water-saving practices by maintaining a thin layer of standing water in the rice field, saturated, or alternate wet and dry soil regimes in place of the traditional practice of continuos submergence. These irrigation regimes cause savings of about 20-70 percent of irrigation water without a significant yield loss. In clay loam soils, high rice yields could be obtained with a saturated soil regime maintained continuously in the field to allow ET to take place at the potential rate. However, if weed growth is a problem, submergence up to the panicle initiation and continuous saturation after that, could be an effective technique of efficient water irrigation without a yield reduction. Thus, these regimes offer a major opportunity to improve the water use efficiency of rice. The adoption of these irrigation practices would require good control of irrigation water (reliable water supplies and effective water distribution).

2) Irrigation Scheduling

The technology for using available water supplies most efficiently should be adopted for improving on-farm irrigation water management practices. Irrigation scheduling techniques that answer the questions of when to irrigate and how much irrigation water to apply are very important to assist management in the efficient use of irrigation water on the farm, especially in the areas of limited water supply. By managing other production inputs too, the maximum crop yield could be achieved. Improved irrigation scheduling and irrigation practices, like land leveling by laser technology and appropriate irrigation methods, could result in reduced seasonal irrigation water requirements, and consequently, help to control waterlogging and salinity conditions in irrigated areas.

Thus, the adoption of efficient irrigation schedules developed by the research institutions, like DRIP, LIM, etc., offers another greater opportunity for improving water use efficiency of the rice-wheat farming systems in the Sindh Province. However, farmers over-irrigate because of the lack of awareness about crop water requirements and a fixed *warabandi* system of water distribution. Over-irrigation not causes only waterlogging and salinity problems, but also reduces the crop yield. In order to prevent agricultural land from waterlogging and salinity, to obtain the maximum crop yield, and also, to save irrigation water, the optimum water should be applied to crops in accordance with their requirements through irrigation scheduling of the crops. By adopting irrigation scheduling of wheat, about 17 percent of irrigation water could be saved, against farmers' practices. The irrigation scheduling adjusts water application to climatic evaporative demand and allowable soil water depletion, particularly for wheat grown on high water-storage soils, thereby causing a considerable reduction in irrigation requirements for the growing season; and also improving the productivity of water.

3) On-Farm Drainage System

In order to grow wheat after rice and to obtain appropriate soil and working conditions for farm machinery in the paddy fields, the installation of a sub-surface drainage system should be intensified, supported by the government's subsidies. There should be participatory drainage management in which farmers should share the capital cost and be responsible for operation and maintenance costs. As the sub-surface drainage system is operated and maintained by the government, it performs poorly due to management and financial resource constraints. The collaborative tile drainage system with capital cost sharing, along with operation and maintenance by the beneficiaries (farmers), is the key towards sustaining the on-farm drainage system for the rice-wheat cropping systems.

4) Rice Establishment Method

In the Sindh Province, the traditional practice of rice establishment is through the rice transplanting (TPR) of young rice seedlings from the rice nursery. The adoption of the direct-seeded rice (DSR) method of rice crop establishment offers another major opportunity for the improved management of irrigation water. The direct-seeding technique (saving the seeds directly on the paddy fields) uses less water for both, land preparation and crop irrigation, than for the transplanted rice technique. This is due to the reduced period of land preparation, and also, farmers do not have to wait for approximately one month (when seedlings are ready for transplanting) to transplant seedlings to the rice field. Further, direct seeding require a shallow water depth to be maintained in the rice field when compared to transplanted rice fields. DSR performs better than transplanted rice in water-short areas. Land leveling and good drainage are two important requirements for the adoption of direct seeding for the rice establishment. Drainage is required to drain out on-farm excess water during crop establishment and early growth periods, whereas land leveling causes better germination and crop establishment by the gradual rising of a uniform water layer. Poor germination and tremendous weed growth occur from direct seeding on unleveled land.

Direct seeded rice yields more in both, water sufficient and water short situations, requires less labor (because it eliminates nursery preparation, care of seedlings in seedbed, pulling seedlings, hauling and transportation) and produces a better return on investment than transplanted rice. There are two different systems of direct seeding rice, namely, the wet and dry systems. Under the wet direct seeding system, pre-germinated seeds are sown on the saturated land that has been prepared under wet conditions. In the dry direct seeding method, land preparation is done under dry conditions, immediately followed by seeds sown before either, irrigation water is supplied or rainfall to enable germination and seedling establishment. Under this system, the total cropping season could be reduced by about two weeks, avoiding the nursery preparation and transplanting phase. Thus, the overall irrigation supply schedule could be considerably shortened, resulting in significant water savings. A finding has been that transplanting rice requires more water and causes more wastage than the dry direct seeding system, due to which water savings of 25 percent could be achieved.

5) Discontinuation of the Pancho System

As mentioned earlier, in rice areas, especially on the Right Bank of the Indus River, farmers practice the Pancho system of irrigation (by which old water in rice fields is drained before applying fresh irrigation water), which causes waterlogging and the formation of marshes. In order to improve the drainage of rice areas, the practice of the Pancho system should cease, and could be achieved by:

(i) Reducing the length of the watercourses and
(ii) Farmers should irrigate each field separately from the irrigation ditch.

To achieve these objectives, there is a need for the ID to construct additional minor channels and irrigation ditches, so that each field has a separate water inlet from a watercourse, and irrigation is field by field. There should also be an efficient drainage system to drain water from the marshes.

6) Land Leveling

Farmers should be encouraged to carry out land leveling in order to improve rice-wheat systems and also water conservation. Land leveling effectively facilitates on-farm water control and management. The basic requirement at the field level is to avoid over- or under-irrigation due to the micro-ground surface undulations. In order to facilitate this activity, the local government agencies should provide subsidies, technical assistance and training to the farmers. As the scope of land leveling by bullock and manual labor is very limited in the Sindh Province due to the clayey nature of soils and tremendous work, farmers can benefit from laser technology for land leveling, as currently, laser equipment is locally available from the private sector. In general, farmers have a tendency to over-irrigate. Poorly leveled fields are considered a major factor causing over-irrigation. The provision of more, or less, than the desired quantity of water to the fields results in inefficient irrigation practices, and also give rise to waterlogging and salinity problems.

7) Improved Layout of Irrigation Ditches and Fields

Problems of water wastage, over-irrigation and shortage of water could be solved by the improved layout of water channels and fields, and keeping the water channels straight and clear. Also, in order to improve the irrigation efficiency, leveling individual fields and converting *bunds* into water channels and fields are very important. Farmers should be advised to construct proper field *bunds* to efficiently retain and control water to the standing depth required and prevent, or minimize, draining water losses (reduced drainage effluent).

8) Farmers' Awareness of Land Reclamation

In general, farmers are aware of the adverse effects of salinity on agricultural productivity and many farmers have the capacity to manage successful field-level salinity by modifying their farming and irrigation management practices, keeping in view the inequity in canal water distribution and the resulting effects on soil salinity. Sodicity is a main concern in many places, which needs chemical amendment and leaching for reclamation. For this purpose, the farmers should be made well aware of employing chemical amendments, like gypsum, and biological techniques to reclaim salt-affected lands, besides lowering the watertable through drainage measures.

I. Comparison of Water Management Practices for the Rice-Wheat Systems of Pakistan, with other Countries of the World

In Sindh, rice is grown on about 0.75 Mha with production of about 1.5 Mt of rice yielding about 2tons/ha, whereas area under wheat is over 1.0 Mha with an average irrigated wheat yield of 2.1tons/ha. In comparison with Pakistan, areas of rice and wheat in the Sindh Province are 38 percent and 12 percent of the country's rice (about 2 Mha) and wheat (about 8 Mha) areas, respectively. The Sindh Province's rice and wheat productions are 50 percent and 13 percent of the national rice (3 Mt) and wheat (16 Mt) production, respectively. Generally, in the Sindh Province, the area under rice has been about 36-42 percent of the total rice area of Pakistan, whereas the production has been from 40-50 percent of the total production.

Rice dominates on the Right Bank of the Indus River, partly because of high watertables that make the land unsuitable for other crops grown in the *Kharif* season. In contrast, most wheat in the Sindh Province is grown on the Left Bank of the Indus River. Rice-wheat rotations occur most widely in Upper Sindh. The estimate is that 32 percent of the rice area is in Lower Sindh, whereas 68 percent is in Upper Sindh. The IRRI varieties are cultivated on about 90 percent of the total rice area in the Sindh Province, and traditional varieties are grown on the remaining 10 percent. IRRI6 has a yield potential of over 9tons/ha when grown under farmers' conditions, using recommended practices. Among the highest farm yields of rice reported, over 13tons/ha of IRRI6 has been recorded in Upper Sindh. Yet, average yields for IRRI6, across the province, are about 4tons/ha, less than half the yield potential. This may be due to inadequate levels of inputs, cultural practices and environmental constraints.

Wheat yields increased steadily from a provincial average of less than 1ton/ha in the mid-60s to 2.1tons/ha in the mid-80s. Wheat yields in Upper Sindh (2tons/ha) are slightly, but consistently, below those of Lower Sindh (2.2tons/ha). Mean wheat yields in irrigated areas (2.1tons/ha) are double those of the non-irrigated wheat tracts (1.0ton/ha). Thus, about 98 percent of wheat production in the Sindh Province are from irrigated areas. The low wheat yields are partly due to the problems of growing upland crop as wheat after rice. Those include:

(i) Establishing a wheat crop on land that had previously been puddled for rice; and
(ii) A high temperature constraint during the grain filling period, which reduces the yield of late-planted wheat.

In summary, in the Sindh Province, increased rice-wheat production is greatly constrained by water shortages in certain areas, while over-irrigation in others depresses crop yields and creates drainage problems. There is low irrigation efficiency due to considerable losses of water. In other words, poor drainage and improper management of irrigation water are to blame for rice and wheat yields in the Sindh Province attaining less than their yield potentials.

Though in the past several efforts have been made to increase the rice-wheat yields, unfortunately, per hectare yields of these crops are still far lower than their potential. In Pakistan, present national yields of *basmati* rice and wheat are 1.567 and 1.88tons/ha, respectively. Their potential yields are 5.2 and 6.4tons/ha, respectively, which reflect the yield gap of 3.633tons/ha for rice and 4.51tons/ha for wheat.

Table 30 presents a comparison of production, yield and area of rice and wheat in the rice–wheat countries of the Asia-Pacific Region for the 1991-1992 period. Though the area of rice and wheat in Pakistan is less when compared to other countries, the yield per hectare of these crops is also lower than those obtained in other rice-wheat countries of the world. Consequently, rice and wheat productions in Pakistan are considerably lower when compared to Asian rice-wheat countries (Table 30).

The lower yields of rice and wheat can be attributed to the constraints in achieving the potential production of rice and wheat. These constraints are generally due to inadequate levels of vital inputs, cultural practices, i.e.:

- Seedbed preparation
- Seed quality
- Seeding rates and depths
- Planting dates
- Times
- Methods and amounts of fertilizers and irrigation water applied
- Pesticide use, etc.

Also, environmental constraints include:

- Soils (soil salinity/sodicity)
- Waterlogging
- Irrigation water supplies (quantity and quality)
- Drainage problems

Table 30. Rice and wheat production, yield and area in rice-wheat countries of the Asia-Pacific Region, 1991-92.

Countries	1991-92	
	Rice	Wheat
Bangladesh		
Production (Mt)	27.30	1.04
Yield (tons/ha)	2.68	1.76
Area (Mha)	10.20	0.59
China		
Production (Mt)	134.90	98.50
Yield (tons/ha)	5.73	3.20
Area (Mha)	32.30	30.80
India		
Production (Mt)	110.00	54.80
Yield (tons/ha)	2.61	2.33
Area (Mha)	42.10	23.18
Nepal		
Production (Mt)	2.90	0.81
Yield (tons/ha)	2.27	1.39
Area (Mha)	1.30	0.58
Pakistan		
Production (Mt)	4.70	15.10
Yield (tons/ha)	2.41	1.92
Area (Mha)	2.00	7.90

(Source: Singh and Paroda, 1994)

Water use efficiency in the rice-wheat system is generally low. There are also problems of widespread waterlogging and salinity in poorly managed irrigated rice. For wheat cultivation following that of rice, poor rice-phase water management results in delayed and sub-optimal wheat establishment and consequently, lowers productivity. Various research studies on irrigation water management have shown that during the rice crop-growing season, intermittent flooding to keep the soil continuously saturated without standing water can save 40 percent of irrigation without experiencing any significant yield loss. Such technological solutions should be coupled with non-technological solutions, such as farmer-participatory management of the irrigation system, and charging for irrigation on the basis of the water quantity used.

Under these circumstances, adequate levels of agricultural inputs and improved cultural practices, and the improved management of irrigation water are the prime needs of the country in order to increase and sustain rice-wheat productivity. In order to increase rice-wheat production, the vertical yield rather than the horizontal yield needs to be improved. Bringing more area under cultivation could increase the horizontal yield. A large area with varying degrees of salinity and sodicity remains uncultivated, which can be brought under rice and wheat cultivation. However, the major constraint in achieving this objective is the non-availability of irrigation water, which is very limited. Though it is true that the water availability is limited, by making efficient use of available irrigation water and practicing proper water management, water for more area can be made available. This reflects that due to the low probability of developing additional irrigation supplies, high priority has to be given to improve the management of present irrigation supplies, which implies that a substantial increase in rice-wheat yields had to come from more efficient and economic use of available water supplies.

Irrigation water management at both, the irrigation system and farm level, is an important determinant of rice-wheat productivity. The growth stages at which water shortage is most damaging are well known for both, rice and wheat. Unfortunately, and for well-founded reasons of pre-planned water allocations by irrigation system managers, the delivery of irrigation to every farmer at the required time is not possible. Constraints of water shortage, thus, occur, and can be intense in fields with high rates of water seepage and percolation in the rice season. To counter these constraints, many rice-wheat-practicing countries have large numbers of public and private tubewells. Tubewell irrigation can significantly improve on-farm water management. Also, the conjunctive use of canal water and groundwater is the best method to control the emerging problem of waterlogging and soil salinization.

J. Summary

In the Sindh Province, rice is grown on about 0.75 Mha with production of about 1.5 Mt of rice yielding about 2tons/ha, whereas area under wheat is over 1.0 Mha with an average irrigated wheat yield of 2.1tons/ha. This reflects that areas of rice and wheat in the Sindh Province represents 39 percent and 12 percent of country's rice and wheat areas, respectively. The Sindh Province's rice and wheat productions are 49 percent and 13 percent of the national rice and wheat production, respectively. The 0.75 Mha of rice and over 95 percent of the 1 Mha of wheat grown in the Sindh Province is irrigated. Rice dominates on the Right Bank of the Indus River, partly because of high watertables that make the land unsuitable for the other crops grown in the *Kharif* season. In contrast, most wheat in the Sindh Province is grown on the Left Bank of the Indus River. Rice-wheat rotations occur most widely in Upper Sindh. The IRRI varieties are cultivated on about 90 percent of the total rice area in the Sindh Province. IRRI6 has a yield potential of over 9tons/ha when grown under farmers' conditions, using recommended practices. Among the highest farm yields of rice reported, over 13tons/ha of IRRI6 was recorded in Upper Sindh. Yet, average yields of IRRI6, across the province, are about 4tons/ha, less than half the yield potential. Rice (paddy) yields are substantially higher in Upper (4.3tons/ha) than in Lower Sindh (2.2tons/ha).

The area of wheat increased sharply in the mid-70s to over 1.0 Mha with the introduction of short-duration modern varieties of wheat. Wheat yields increased steadily from a provincial average of less than 1.0ton/ha in the mid-60s to 2.1tons/ha in the mid-80s. Wheat yields in Upper Sindh (2tons/ha) are slightly, but consistently, below those of Lower Sindh (2.2tons/ha). Mean wheat yields in irrigated areas (2.1tons/ha) are double those of non-irrigated wheat tracts (1.0t/ha). Thus, about 98 percent of wheat production in the Sindh Province are from irrigated areas.

The variability and unreliability in water distribution cause inefficient water use at the farm. Poor irrigation management practices at the farm level cause wastage of limited irrigation water. A lot of water is wasted due to farmers' negligence and bad the layout of water channels, resulting in low irrigation efficiency. These channels follow a zigzag pattern, which slows down the water speed and causes siltation that necessitates cleaning the water channels frequently. Paddy farmers in the Sindh Province practice continuous irrigation of fields where water is always available. At other places, particularly at tail ends of water channels, fields are irrigated whenever water is available. This results in over-flooding of rice fields because of the uncertainty of the availability of water for some time afterwards.

The fields are irrigated in such a way that water flows from one field to another, as there are no separate inlets for different fields. Also, fields are not properly leveled. Consequently, in order to irrigate the high spots, fields are over-irrigated and result in extensively deep water at the lower spots. In general, water control is poor. The *bunds* and water channels of most fields are not properly maintained. When one field is irrigated, water flows to other fields as well. The adjoining low-lying fields are flooded and sometimes the depth of the water exceeds 60cm. In low-lying fields, the excess supply of water and in other fields, the shortage of water affect the growth of the rice crop adversely. Immediately, after rice transplanting, water shortage hampers early rooting. At the reproductive stage, especially from the panicle initiation to the flowering stage, the shortage of water causes panicle sterility and adversely affects panicle formation, flowering and fertilization. Excess water supplies at early growth stages of the rice plant suppress the tillering capacity and hamper rooting. However, the low water level enhances the tillering and promotes root anchorage in the soil. Over-irrigation at the booting stage causes a decrease in culm strength and lodges rice plants.

For rice, on the Right Bank of the Indus River in the Sindh Province, it has been reported that for over 52 percent of the CCA during the entire growing period, a total of 1200mm to 1700mm of water is applied, of which only 900mm is for consumption. This results in an application efficiency range of 53-75 percent only. Also reported, is that the total water requirement, including the soaking dose for wheat, is 375mm for Lower Sindh, whereas farmers apply about 450mm of irrigation water to the wheat crop. Thus, farmers apply about 17 percent more water than the crop water requirement. Also, the water use efficiency is low (8.11kg/mm/ha) in the case of farmers' conditions against that of scheduling wheat (9.97kg/mm/ha). This reflects more water use than required, but the reduced yield (3.65tons/ha) against the yield (3.74tons/ha) obtained by applying 375mm of irrigation. By better management of irrigation water, application and water use efficiencies could be increased, which would result in water savings, as well as minimum drainage effluent.

In the Sindh Province, the rice-wheat areas have serious drainage problems. The presence of extensive depressed areas, clayey soils and slowly permeable deep strata are mainly responsible for the impeded drainage, which has further deteriorated due to improper irrigation practices and the over use of irrigation water. Consequently, there are widespread problems of waterlogging and salinity, which cause considerable reduction in the rice and wheat yields. About 3.13 Mha out of the total Sindh Province's irrigated area of about 3.15 Mha is affected by waterlogging and salinity/sodicity. Problems of waterlogging and salinity are more pronounced in the Right Bank area, which is due to the topography of the land, as the Right Bank area is at a lower level than the Left Bank.

The improved irrigation and drainage practices identified for the Sindh Province at the system level include irrigation water delivery accountability, management decision support system, irrigation management information system, performance indicators, farmers' participation, reuse of drainage effluent and physical rehabilitation. The farm level water management measures consist of water-saving irrigation regimes, irrigation scheduling, on-farm drainage system, rice establishment method, discontinuation of the Pancho system, land leveling, improved layout of irrigation ditches and fields, and farmers' awareness of land reclamation. The adoption of these irrigation and drainage management measures and practices would offer a greater opportunity to improve water use efficiency for the sustainability of the rice-wheat cropping systems in the Sindh Province.

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Report No.	Title	Author	Year
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Report No.	Title		Author	Year
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