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IRRIGATION PRACTICES AND APPLICATION EFFICIENCIES IN PAKISTAN

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Fort Collins, Colorado
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IRRIGATION PRACTICES AND APPLICATION EFFICIENCIES IN PAKISTAN[1]

Wayne Clyma, Arshad Ali and Mein Mohammad Ashraf[2]

The effectiveness of water use and benefits in terms of crop yield are determined to a large extent by when the farmer irrigates, how much water he applies and how he applies it. Farmer irrigation practices in the Mona Project area of Pakistan have been studied for approximately one year. The results of this study are presented to document the problems of on-farm water management in Pakistan. Some suggested solutions to these problems are also discussed.

Background of the Study

Most of the data presented in this study were collected in SCARP areas where canal supply is augmented with tubewell water to provide about one cusec per 150 acres. Some of the unaugmented watercourses are supplemented by private tubewells.

Data collected on SCARP watercourses may be different in several respects from non-SCARP areas. Conclusive data have not been obtained that demonstrate these watercourses

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[1]Review draft prepared for publication as Field Party Report No. 3, Colorado State University, Water Management Research Contract/Pakistan.

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to be different. The following discussion applies primarily to SCARP watercourses. Where significant differences are expected on non-SCARP watercourses, these differences will be explained and documented as well as possible.

A discussion of how farmers manage water on their fields is worthwhile. Some of the conclusions presented have been deduced from visual observation and interviews; others have been documented many times by carefully collected data. Some conclusions are generalized for Pakistan even though generalized geographic data are not available. A very narrow interpretation of this report would permit its application only to the watercourses where the data have been collected. However, these data can be related to general principles, and these principles can be used to suggest whether the data have applicability over much of Pakistan.

The general conclusions should be considered applicable to Pakistan. Farmers use water very ineffectively. Whether farmers have an overall efficiency of 10, 20 or 30 percent in field applications of water can be answered only after collecting much more data. Whether more water is wasted on SCARP watercourses than on non-SCARP watercourses can only be established through careful collection of comparative data. An unleveled field requires over-irrigation anywhere in Pakistan. Farmers adjust the area irrigated and the resulting cropping intensity to the water supply available. A poor job can be done whether the water supply is short or whether there is a surplus.

To remove some of the difficulties of discussing only water management practices for which there are adequate data to document the practices, first we will give a description of the farm water management practices in Pakistan as we have observed them; a sort of hypothesis of farmer irrigation practices. Then we will document these practices with the data that have been collected.

Hypothesized Water Management Practices

Some irrigation practices in Pakistan are general in that they are the same for every crop whether grown during rabi or kharif. These practices are well documented by interview and by data. Probably the practice most universal and uniform is that farmers apply water to a field until all of the field is covered with water including any high spots. This procedure has been observed both on research plots as well as on farmer fields and has been described repeatedly in answer to carefully worded questions. Once the criteria of how long to irrigate a field is established, it is quite simple to establish specific circumstances where this criteria on results is substantial overirrigation.[3]

The amount of time required to apply a unit amount of water, 3 acre in/acre for example, to a given area depends only upon the rate (discharge in cusecs) at which it is applied. The time required to cover a given area with

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[3]Overirrigation as used here means that repeated application of amounts of irrigation water that exceeds the amount that can be stored in the soil by at least twice and generally 5 times more.

water depends primarily on the surface topography (levelness and slope) infiltration rate, size of field, discharge, and surface roughness. Since these factors vary widely from field to field and area to area in Pakistan, the time to irrigate a given area and the amount of water applied will also vary widely. The fact that farmers and researchers assume that the amount of water applied in covering a given area results in a constant amount of water applied is responsible for much overirrigation.

The surface topography of a field affects the amount of water applied in covering the field. Extra water is required to fill the low areas of the field and extra time is required to cover high areas. In a number of instances the time required to cover a high spot doubles the irrigation time and the amount of water applied to a field. Level basins are assumed to be the irrigation system used in Pakistan. In addition to not being level because of high and low areas, fields frequently have a slope. When the slope is away from the nucca, the farmer still applies water until the field is covered and much of the water is ponded on the lower end. Several times fields were measured with the slope towards the nucca. When the farmer irrigates uphill excess water is required to cover the field and the high portion is underirrigated.

The rate at which water enters a soil or the infiltration rate of a soil has a complex effect on the amount of water applied. Basic intake rates or the infiltration rate after several hours on many soils are low, approaching 0.1 inch per hour or less. This is probably related to the high silt content of the soil but may also be related to soil structure, lack of organic matter or salinity. Some areas of Pakistan have sufficient sand content in the soil to result in a much higher infiltration rate and this almost always results in overirrigation using traditional methods.

Two additional factors influence infiltration rates and the amount of water applied to a field. The first is the high infiltration rates that frequently exist at the beginning of a season. The high infiltration rates result from the practices of the farmer. Most farmers irrigate their fields in preparation for plowing and this irrigation will frequently fill the expected root zone with moisture. After plowing a number of times the field is again irrigated in preparation for sowing. This irrigation just before sowing is called the rauni irrigation. The rauni is primarily necessary to insure adequate moisture for germination and emergence. When the rauni irrigation is applied, the soil moisture deficiency is usually 1 to 1.5 inches.

The loose surface soil condition may result in 1.5 to 2 inches of infiltration during the first 10 seconds that water is applied to a field. It is not surprising that an additional 4 inches or more is required to cover all of the field. This results in much overirrigation.

The second factor influencing the amount of water applied is the seasonal changes in infiltration rate. Data collected in Pakistan and in the United States have shown that frequently the infiltration rates of soils decrease as the cropping season progresses from the time of planting. The amount by which infiltration decreases depends both on the initial and final rates and unknown management factors during the growing season. Whether farmers continue to overirrigate their fields depends on how the infiltration rate changes with time. The reduction in infiltration rates appears to at least reduce the amount of overirrigation.

As the crop grows, the rate at which the crop extracts water from the soil increases. Typically this may increase from 0.05 in/day early in the season to over 0.25 inches per day during periods of peak water use. Thus, a farmer who maintains the same interval between irrigations, or slowly reduces the interval, will have larger and larger soil water deficiencies at the time of each succeeding irrigation. This increased soil water deficit will tend to decrease the overirrigation as the season progresses.

A complicating factor that affects the tendency of a farmer to reduce his overirrigation as the season progresses is rainfall. Rainfall during rabi comes frequently when water use rates are low, and since water is usually still available from the canal, he continues to irrigate further contributing to overirrigation. During kharif rainfall comes after use rates are high but the frequency and amount of rainfall can equal and usually exceeds the crop requirements. Irrigation during this period will also generally exceed the amount that can be stored because of the rainfall.

Waterlogging is a serious problem in Pakistan with 17.4 million acres affected with the water table less than ten feet from the surface. Waterlogging also causes inefficient use of water because as the water table rises a crop draws increasing amounts of water from the high water table. This use of water from ground water reduces the amount of water use from soil moisture storage and the amount of water that needs to be supplied by irrigation. Ahmed (1972) has shown that as the water table varies from ten to 3 feet from the surface, from 0 to 80 percent, respectively, of the evapotranspiration can be met by water use from the high water table. Stated another way, with the water table at a depth of 3 to 10 feet the amount of water that must be supplied by irrigation ranges of 20 to 100 percent, respectively, of that needed without the high water table. If the water table is constant at the following depths and the consumptive use is assumed to be 16.4 inches for wheat, the amount needed from irrigation is:

Water Table Depth/Feet	Water Used From Water Table-Pct.	Water Required From Irrigation - in.
10	0	16.4
5	50	8.2
3	80	3.3

The primary point from this discussion is that a high water table reduces the consumptive use of crops that must be supplied from applications of irrigation water. This reduced requirement for water should result in reduced amounts of water applied and decreased frequency. When the farmer continues to apply large amounts of water at the prevailing frequency, a high water table results in more overirrigation.

Underirrigation is practiced in Pakistan at least seasonally on many fields. This occurs during the period of peak consumptive use in March for rabi and in July and September, before and after the monsoon during kharif. Some fields are underirrigated on a more consistent pattern and these fields have developed salinity problems.

On many soils where the infiltration rate substantially decreases during the season, the farmer underirrigates his field. The combination of reduced amounts of water applied caused by a reduction in infiltration rates, and larger and larger amounts of soil water extracted by the plant due to increased evapotranspiration can result in the development of severe moisture stress. Since crops are most sensitive to moisture stress or have the greatest reductions in yield from moisture stress during the periods of peak water use, one of the primary factors causing low yields of most crops in Pakistan is the severe soil moisture stresses that farmers and researchers allow to develop during this period. The circumstance largely results from assuming that a certain amount of water is applied to a field when the field is covered with water. Infiltration rate changes during the season can change the amount applied to the same field by a factor of four.

The time interval between irrigations appears to be a combination of how many turns are required to cover the area being cropped by an individual farmer and how much rainfall and borrowed or stolen water is available to supplement the turn. When a turn occurs and the water is not needed because rainfall has filled the soil moisture reservoir, his field is not ready for the rauni, or because of other factors it may be used to repay borrowed water or will be used to irrigate the field that "most needs" irrigation. During kharif, sugarcane and rice are usually irrigated with any surplus water that becomes available. During the fall, fodder crops appear to also fulfill this duty. On SCARP and non-SCARP watercourses, surplus water does occur and it must be used on a field that does not need irrigating. If the water requirement of a crop goes from near 0.05 in/day to 5 or more times the rate during the season while the supply is available at a constant rate,[4] then during the early stages of growth and after substantial rainfall water applied goes to overirrigation.

A review of the status of water demand on a watercourse during a year of observations suggests four periods when water is in short supply. The most obvious and traditional periods are the periods of peak consumptive use during the rabi and kharif seasons. Farmers appear to meet the demands of these periods by adjusting the frequency of their irrigations. Where water is short, and all or most

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[4]In SCARP this rate can be adjusted by operating or not operating tubewells.

watercourses are short at this time, severe moisture stress frequently develops. The other short supply periods are time of planting for the rabi and kharif crops. Kharif crop sowings for sugarcane, cotton, fodders, rice and vegetables are spread over such a long interval of time that no major peak demand was observed for kharif. Other factors such as harvesting of wheat and tillage may contribute, but a major factor affecting the acreage planted is the amount of water available for rauni irrigations. For wheat, the major factor limiting the acreage sown is probably the amount of water available for rauni. Once sown, the frequency of irrigation is adjusted to use the rigidly available supply. The sad aspect of water use at rauni for wheat is that the greatest wastage of water in Pakistan occurs with the rauni irrigation for wheat.

The size of the fields in relation to the discharge available for irrigation also affects the amount of water applied to a field. Design criteria for border or basin irrigation systems suggests that when a farmer irrigates a one-half acre field with 4 or 5 cusecs, he is using a flow rate that is from 2 to 30 times the recommended flow rate for irrigating that size of a field. Use of too large a flow rate to irrigate a field results in additional water being applied to the field. Farmers do commonly divide the flow when tubewell plus canal water is available and they irrigate more than one field at the same time, sometimes on more than one branch of the watercourse. The flow rate may still be excessive for the size of field because field size may frequently range from 0.1 to 0.25 acre.

Surface roughness caused by growing vegetation increases as the season progresses contributing to increased amounts of water applied. This partially offsets the usual reduction in amount of water applied caused by decreasing infiltration rates. The quantitative effects of vegetation on amounts of water applied is not known.

The Warabundi and Farmer Practices

Pakistan's irrigation system from the barrage to the mogha operates on a continuous flow, least cost principle. From the mogha to the farmer's field a turn system (warabundi) is instituted. The pacca warabundi (official warabundi) is assumed to operate strictly on a turn system with no deviations from the officially registered turn. The kacha warabundi has a turn system operated by the farmers and can be adjusted once agreement among the farmers of the watercourse has been reached. Otherwise, no provision for altering the warabundi has been provided.

As others have discovered previously (Hunting Technical Services and Sir M. MacDonald and Partners, 1966), a strict rotation system does not operate in Pakistan. On SCARP and non-SCARP watercourses farmers trade and make unauthorized diversions of water under a system that more nearly approaches water on demand than water use on a rotation basis. Since many factors operate to cause water needs to occur other than on a fixed schedule each week, water is used simultaneously by two farmers and out of turn probably more often than on the fixed schedule. When water is surplus it is readily available, apparently for the asking. Water should be used when needed by the farmer rather than when his turn makes it available. A number of irrigations were applied to sugarcane when the soil water deficiency was zero or no water was needed. In attempting to schedule observations of the irrigation of particular fields, frequently farmers would insist that such and such a field would be irrigated next. At the last moment another farmer would intervene and the water would go to another field. This procedure tends to maximize the benefits derived from the surplus water.

A condition of surplus water seems to be the general rule rather than the exception. This is caused by the cropping sequences, planting dates and staggered plantings of many crops. The greatest opportunities for improved water management are to reduce rauni irrigation requirements through precision land leveling and reduce soil moisture stress by more careful timings of irrigations during periods of peak water use.

Water is short in Pakistan and the shortage has been documented in many ways by many people. The procedure used most generally is to cite acreages, water supply and annual potential evapotranspiration or evaporation. Water is short primarily in the sense that the total area can not be used for maximum production with the available water supply. As presently managed, the available water supply seems to be surplus on most fields for most of the year. Farmers in Pakistan use a very simple procedure to adjust water demand to water supply. They adjust the acres they plant and the frequency between irrigations as the water supply increases or decreases. Individual applications of water to a field are in excess even in water short, non-SCARP areas. There is no practical way a farmer can irrigate an improperly leveled field without overirrigating at least some area of the field. This is why precision land leveling is so valuable to farmers and why the farmers invest so much time and effort into getting their fields leveled. The farmer with a short water supply can spread the interval over which he plants and increase the interval between irrigations, but each application is still an overirrigation until moisture extracted and/or the infiltration rate brings the moisture deficiency and amount of water applied into a closer balance.

A factor that has not been evaluated is the effect of undependability of the water supply on farmer practices. Studies by consultants and WAPDA have documented many instances of water supplies in excess of the official flow. Inequitable distribution within the watercourse by unofficial modification of the turn has not been evaluated.

Other factors will be understood as contributing to poor use of water in Pakistan as more experience is gained and farmer practices are more clearly understood. Practices which enhance proper use of water will also be discovered as attempts to improve water use through research are continued. The quantitative method used to evaluate farmer practices in Pakistan was irrigation application efficiency. Irrigation application efficiency will now be defined and discussed.

Irrigation Application Efficiency

Water applied to a field during irrigation is primarily for storage in the root zone and subsequent consumptive use by a crop. Water may also be applied to a field to permit tillage, to provide water for germination, for temperature control and to reduce surface or soil salinity. When evaluating irrigation practices, consideration may be given to purposes for irrigation other than storing of soil moisture. In a number of instances irrigation of a fallow field is to permit cultivation and rauni irrigations are for the purpose of supplying moisture in the top foot of soil to permit germination and emergence of seed. However, moisture applied in a rauni irrigation above the amount needed to replenish soil moisture is excess and is wasted. Water applied for salinity control was not accounted for as the frequency of over irrigation is such that salinity control requirements have been grossly exceeded except for high spots on unleveled fields.

In this study of farmer irrigation practices, irrigation application efficiency is the primary criteria used to judge the adequacy of these practices. Irrigation application efficiency, E_a, is defined as:

$$E_a = \frac{\text{water stored in the root zone}}{\text{water applied to the field}}$$

Many other factors affect farmer irrigation practices other than amount of water stored or the application efficiency. Some of these factors are discussed and other data are presented to show the effects of these factors on irrigation practices and application efficiency.

Application efficiencies were evaluated based on water measurements in the watercourse near the particular field. The amount of water lost from the watercourse in transporting the water from the mogha to the farmer's field is not included in the measurement of the water applied to the field. The application efficiency reported herein therefore does not include delivery efficiency.

Worldwide Application Efficiencies

Application of irrigation water is not normally an efficient operation anywhere in the world. Jensen, Swarner and Phelan (1967) cited a U.S. Bureau of Reclamation study in which farm efficiencies ranged from 32 to 78 percent for 21 different irrigation projects. Langley and Robb (1969) studied sugar beets for a crop season in Colorado and showed that application efficiencies ranged from 8 to 71 percent during the season with an average of 40 percent for the season. Very low efficiencies occurred early and late in the season. In a Bureau of Reclamation (1968) study in Colorado, farm efficiencies ranged from 24 to 53 percent and the three farm, 4 year average was 33 percent. In another Bureau of Reclamation (1971a) study involving seven farms and five years in Idaho, the seasonal average application efficiency for particular crops ranged from 23 to 60 percent and seasonal farm efficiencies for all crops ranged from 31 to 60 percent. These efficiencies have been corrected to reflect application efficiencies as the distribution losses have been substracted. In a companion study in California for four farms and four years (Bureau of Reclamation, 1971b), application efficiencies ranged from 10 to 100 percent. The application efficiencies ranged as follows:

	Farm 1	Farm 2	Farm 3	Farm 4
Efficiency, Pct.	80-100	26-100	22-41	10-20

The high efficiencies measured on farms 1 and 2 may seem commandable. However, what these efficiencies reflect is inadequate watering and buildup of salinity which is resulting in lost production. The low efficiencies were caused by surface runoff and large amounts of deep percolation. Clyma and Corey (1974) have discussed the history of assumed farmer practices in Pakistan and showed that most studies have assumed field application efficiencies of 85 percent for Pakistan. This is contrary to measured performance in other countries of the world.

Observations of Farmer Irrigation Practices

Irrigation practices were evaluated from the following data which were collected before and during the time water was applied to the field.

1. Watercourse discharge and amount of water applied.
2. Soil moisture deficiency or date of last irrigation.
3. Two or more profiles of the basin (field).
4. Advance and recession times of water at marked stations in the basin.
5. Infiltration from infiltrometers during the time of irrigation.

The procedures followed were generally those given by Criddle et al (1958) for evaluation of border irrigation systems. Soil moisture deficiency was estimated using procedures described by Halderman (1966) by estimating texture and soil cohesion. Soil moisture depletion was also estimated using the Jensen-Haise (1963) method of estimating evapotranspiration. During some irrigations less detailed measurements were obtained consisting only of items (1) and (2). This permitted more numerous observations with the reduced detail of measurements.

The first preliminary observations of farmer irrigation practices began in the fall of 1972 and organized, detailed evaluations began with the rabi 1972-73 season. The majority of observations were for wheat during rabi. A summary of these observations is presented in Table 1. Only three of the fourteen measurements of irrigation applications for wheat consisted of amounts less than four inches. The maximum amount was 9.5 inches. Application efficiencies range from ten to forty percent of the measurements less than or equal to 20 percent.

Sugarcane is a major kharif crop and measurements of irrigation were obtained for most months from May through

Table 1. Evaluation of field application efficiencies for wheat on traditionally farmed land for rabi 72-73 and 73-74 at Mona.

Date	Crop Height	Date of Last Irrigation	Deficiency (in.)	Amount Applied (ac-in/ac.)	Efficiency (Pct.)
		Rabi 72-73			
Nov. 1	Rauni	-	1.5	8.5	20
Nov. 2	Rauni	-	1.0	9.5	10
Dec. 14			1.2	4.5	25
Dec. 14		Nov. 2	1	6.0	15
Dec. 14			1	4.5	20
Dec. 14			1	7.5	15
Dec. 14			1	8	10
Jan. 10			1.0	3.8	25
		Rabi 73-74			
Oct. 18	Rauni	-	1.4	3.7	40
Oct. 22	"	-	1.0	5.1	20
Oct. 22	"	-	1.0	5.1	20
Nov. 3	"	-	1	6.2	15
Nov. 6	"	-	1.0	2.5	40
Nov. 6	"	-	1.0	5.3	20

October (Table 2) during 1973. Only one observation was obtained in August because monthly rainfall was 12.9 in. and canals and tubewells were closed. Irrigation of sugarcane follows the pattern of inefficient early irrigations for the period of low soil moisture depletions because of a low actual evapotranspiration rate even though the potential evapotranspiration rate during May exceeds 0.3 in./day. By July the sugarcane is approaching full effective cover and is using water at the potential evapotranspiration rate but monsoon rainfall limits the soil moisture depletions. By the last of July, the fields are used to dispose of surplus irrigations water as several irrigations were applied where the soil moisture deficiency was near zero. In September and October greater soil moisture depletions and resulting higher application efficiencies were observed. Two instances of underirrigation were observed i.e. the soil moisture deficiency was greater than the amount of water applied so the application efficiency was 100 percent. Application efficiencies in Table 2 for sugarcane ranged from 0 to 100 percent with 36 percent of the efficiencies less than or equal to 20 percent. Amount of water applied ranged from near 2 in. to near 11 with 45 percent of the measurements exceeding 4 in. The preponderance of amounts less than 4 inches occurred after September 1, except for the amounts inaccurately

Table 2. Evaluation of field application efficiencies for suga-cane for traditionally farmed land for kharif 73 at Mona.

Date	Crop Height (ft.)	Date of Last Irrigation	Deficiency (in.)	Amount Applied (ac-in/ac.)	Efficiency (Pct.)
May 8	1		1.0	6.7	15
May 8	1		1.0	6.8	15
May 8	1		1.0	6.1	15
May 8	1		1	7.4	15
July 12	5	July 6	1.7**	4.1	40
July 12	5	July 6	1.7**	4.5	40
July 15	4.5	July 8	2.0**	2.8*	70
July 19	4.5	July 12	0.7**	2.4*	30
July 19	5.0	July 12	0.7**	2.5*	30
July 19	4.5	July 5	0.7**	2.4*	30
July 19	5.0	July 12	0.7**	2.3*	30
July 20	5.0	July 5	0.8**	3.4*	25
July 22	4.5	July 15	0.2**	2.5*	10
July 26	4.5	July 19	0.3	3.5	10
July 31	5	July 24	0.2	10.7	0
August 2	5	July 26	0	4.8	0
Sept. 24	6-7	1st week Aug.	5.6**	3.1	100
Sept. 27		Before rains	1.7	3.8	45
Oct. 18		Sept. 20	5.1**	5.5	95
Oct. 18	7-8	Sept. 20	1.0	3.6	30
Oct. 18		Sept. 20	5.1**	4.7	100
Oct. 20			0.5	1.9	25
Oct. 20			0.5	2.2	25
Oct. 20	7-8	Sept. 28	3.8**	3.8	100
Oct. 22			1	5.1	20

*Amount of water applied probably low because time of irrigation and area of field obtained from farmer interview.

**Soil moisture deficiency estimated by estimating evapotranspiration.

measured[5], when reduced infiltration rates would be expected to have reduced the amount of water applied significantly.

Rice irrigations observed are shown in Table 3. Application efficiencies have little meaning since the objective in the irrigation of rice is to submerge the soil surface. Rice fields can experience moisture stress. The stress can result from inadequate amounts of water applied during the weekly irrigation or excessive infiltration rates and most of the water applied going to deep percolation. The limited data collected do not suggest a seasonal pattern nor a seasonal application amount. Rice does appear to be irrigated at least once each week and is also irrigated when any surplus water is available. Since the objective is to pond water on the soil surface the limited number of observations suggest individual applications in excess of 100 inches while seasonal evapotranspiration will be only a fraction of the amount applied. The deep percolation losses of rice can be an important factor causing the prevalent high water tables. Use of rice growing to reclaim salinized land can be easily understood when so much excess water is used which does provide leaching.

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[5]The data in July in Tables 2 through 5 identified with the asterick (*) is used even though comparison with other data collected in the same month on the same branch of the watercourse suggest that the amounts of water applied may be low by as much as 100 percent. The efficiencies obtained from these data are thus as much as double what would otherwise be expected. The maximum efficiency obtained for these data was 70 percent and the minimum was 10 percent. The data are important for showing how the initiation of monsoon rainfall in July complicates the farmer's ability to use water effectively on a rotation basis.

Table 3. Evaluation of application amounts and deficiencies for rice on traditionally farmed land for kharif 73 at Mona.

Date	Crop Height (ft.)	Date of Last Irrigation	Deficiency (in.)	Amount Applied (ac-in/ac.)
July 12	1	July 6	0.8	4.1
July 15	.75	July 8	1.0	3.4*
July 19	1	July 12	0	2.6*
July 20	1	July 12	0	2.7*
July 22	1	July 15	0	2.5*
July 25	Rauni	-	0.4	7.2
July 26	Rauni	-	0	3-4
July 25 & 26			0.4	10.2 - 11.2

*Amount of water applied is probably low because time of irrigation and area irrigated were obtained from farmer interviews.

Fodder crops are grown throughout the year with planting of some fodder during almost every month. The authors suspect that the staggered dates of planting fodder crops in Pakistan serve a very important function. It allows farmers to adjust their cropped acreages to the available water. During wet, full water supply years, additional acreages are planted. During water short years when water is unavailable for the rauni, the planting is delayed to adjust for the shortage of water.

The results from the observations of fodder irrigations are given in Table 4. The amount of water applied varied widely from 2.4 in. to 9.5 in. In a significant number of the observations the amount of water applied was assumed to be underestimated. It should be noted that in many of the instances the soil was near field capacity at the time of irrigation and the additional water went to deep percolation. Of the additional irrigations, all but two were greater than 4 inches and all but four were greater than 5 inches. During September, however, one underirrigation was observed illustrating again that large soil moisture deficiencies do develop during periods of peak water use. This represents a nearly 80 percent soil moisture depletion based on the expected water holding capacities of the soil, a definitely excessive soil moisture stress for good fodder yields.

A limited number of observations of irrigations were obtained for several different crops and these results are summarized in Table 5. The number of observations

Table 4. Evaluation of field application efficiencies for fodders on traditionally farmed land for kharif 73 at Mona.

Date	Crop	Crop Height (ft.)	Date of Last Irrigation	Deficiency (in.)	Amount Applied (ac-in/ac.)	Efficiency (Pct.)
May 8	Fodder			1	7.4	15
May 8	Fodder		Rauni	1	7.4	15
July 12	Maize	1.5	July 6	1.7**	5.3	30
July 15	Sorghum	1.5	July 8	2.0**	3.4*	60
July 15	Maize	1.5	July 8	2.0**	3.4*	60
July 19	Maize	3	July 12	0.7	2.4*	30
July 20	Fodder	3	July 12	0.8**	3.0*	25
July 22	Sorghum	2	July 15	0.2**	2.5*	10
July 22	Maize	4.5	July 15	0.2**	2.5*	10
Sept 24	Alfalfa	.3	1st week Aug.	5.0	4.1	100
Sept 24	Maize	Rauni	-	1.3	4.1	30
Sept 25	Maize	Rauni	-	0	2.6	0
Oct. 10	Fodder		Sept. 23	3.3	9.2	35
Oct. 18	Alfalfa		Sept. 27	3.3	9.5	35
Oct. 18	Alfalfa			1.4	3.7	40
Nov. 6	Berseem			0.3	5.6	5

*Amount of water applied is probably low because time of irrigation and area irrigated were obtained from farmer interview.

**Soil moisture deficiency was estimated using estimates of evapotranspiration.

Table 5. Evaluation of field application efficiencies for miscellaneous crops on traditionally farmed land for Kharif 73 at Mona.

Date	Crop	Crop Height	Date of Last Irrigation	Deficiency (in.)	Amount Applied (ac-in/ac.)	Efficiency (Pct.)
July 15	Vegetables	1.5	July 8	2.0**	3.4**	60
July 19	Vegetables		July 12	0.7**	2.6**	25
July 22	Vegetables		July 15	0.2**	2.5**	10
Sept 29	Cotton	4		1.1	4.6	25
Oct 20	Oilseed			1.6	10.0	15
Nov 1	Cotton			0.6	7.2	10
Nov 1	Cotton			0.8	4.2	20
Nov 3	Oilseed			1.6	3.7	45
Nov 6	Cotton			0	1.8	0

*Amount of water applied is probably low because time of irrigation and area irrigated were obtained from farmer interview.

**Soil moisture deficiency was estimated using estimates of evapotranspiration.

restrict the general applicability of the results, but several comments seem warranted. Normally early in July, large soil moisture deficiencies do not occur because of low water use by seedling crops. The vegetables irrigated on July 15 were probably significantly stressed because of their relatively shallow roots and the higher evapotranspiration rates. Other vegetables were irrigated immediately after a substantial rain when the soil was at field capacity.

Cotton irrigated on November 1 and 6 had low deficiencies and overirrigation resulted. During the fall when evapotranspiration rates are low farmers still irrigate fields at regular intervals with too much water. Many cotton fields are inter planted to berseem during this time and some of the irrigations are to insure germination of the berseem or to facilitate its emergence. Including the three observations on vegetables which are assumed to be low, only two observations were less than 4 inches. Seven of the efficiencies were less than or equal to 25 percent.

Perhaps a better understanding of the distribution of measure application efficiencies can be obtained from a summary of observations for all crops for both rabi and kharif (Table 6). Seventy-one percent of the measured efficiencies were less than or equal to 30 percent with 46 percent less than or equal to 20 percent. Irrigation of all crops was inefficient as nearly half of the efficiencies measured were less than or equal to 20 percent.

Table 6. Distribution of irrigation application efficiencies observed at Mona on traditionally farmed fields for all crops for both rabi and kharif.

Application Efficiency Interval (Percent)	Crop				Total for Interval	Percent Of Total Number of Observations Interval	
	Wheat	Sugarcane	Fodders	Misc.			Accum.
0≤10	2	4	4	3	13	20	20
10≤20	8	5	2	2	17	26	46
20≤30	2	8	4	2	16	25	71
30≤40	2	2	3		7	11	82
40≤50		1		1	2	3	85
50≤60			2	1	3	5	90
60≤70		1			1	2	92
70≤80							
80≤90							
90≤100		4	1		5	8	100
Total	14	25	16	9	64		

Wheat, for example, had a preponderance of measurements made at rauni or the first irrigation after emergence and these irrigations are frequently highly inefficient. However, sugarcane irrigations were observed throughout the season and several observations were obtained where efficiencies were very high or underirrigation occurred. For the season, nearly 70 percent of the observed efficiencies were less than 30 percent and the median was near 25 percent. These results were obtained even though more than one-fourth of the efficiencies are assumed to be high.

Another characteristic of farmer irrigation practices can be obtained by a study of Table 7. The application efficiencies measured are distributed by the months in which they were measured. All months for which measurements were made had low efficiencies. The only months which had high efficiencies or underirrigation were September and October when low rainfall and relatively high evapotranspiration rates resulted in larger soil moisture deficiencies and higher application efficiencies. No data were obtained for the period of peak water use for wheat, but higher application efficiencies would have been expected for that period. The data in Table 7 do support the previous hypothesis that generally low efficiencies occur during periods of low evapotranspiration requirements or high rainfall. Only during September-October for kharif crops and in March-April for wheat will the higher efficiencies be obtained. These high efficiencies suggest soil moisture deficiencies that would result in stress levels that would reduce crop yield.

Table 7. Distribution of irrigation application efficiencies by months.

Efficiency Interval	Jan.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0 10				6	1	1		4	1
10 20		6					4	4	3
20 30	1			9		2	3		1
30 40				2			4	1	
40 50						1		1	
50 60				3					
60 70				1					
70 80									
80 90									
90 100						2	3		
Total	1	6		21	1	6	14	10	5

Cursory thought about the seasonal distribution of irrigation efficiencies might suggest that one or two irrigations near 100 percent would appreciably offset several efficiencies near 10 percent. However, the average seasonal efficiency is computed by summing the deficiencies and the amounts applied to obtain a new ratio for the season. The result is that excessive applications early and late in the season weight the totals more toward a low average than one or two effective irrigations toward a high efficiency.

The seasonal pattern of irrigation for wheat suggests that a mean of more than 30 inches is common. As previously estimated by Clyma (1974) the seasonal evapotranspiration for wheat is near 16 in. When wheat is stressed during the period of peak consumptive use, the actual consumptive use may be nearer 14 in. This amount must be reduced by effective rainfall and for the Mona area may average near 2.5 inches. For nearly 17 million acres water use from the water table will be significant and this will vary depending on the depth of roots and exact position of the water table. The result suggests that seasonal irrigation efficiencies will not frequently exceed 50 percent, will average between 20 and 30 percent, and with a high water table may be even less. Rabi supplies of water are considered to be most inadequate, so kharif application efficiencies will not be higher and may be less due to increased rainfall and increased canal supplies. The authors conclude that annual irrigation application efficiencies are near 20 percent based on the presently available data. This suggests that improvement of on-farm water management has the greatest potential for increasing water supplies in Pakistan.

A "normal" irrigation in Pakistan is considered to be 3 in. and a "heavy" irrigation is equal to 4 in. Table 8 was prepared to give data on amount of water applied in an irrigation. Only ten percent of the amounts were less than or equal to 3 in. and only 29 percent or one-third were less than or equal to 4 in. The median irrigation application for all the measurements was more than 5 in. and 27 percent of all measurements were greater than 7 in.

Summary and Conclusions

Farmer irrigation practices have been studied for approximately one year in Pakistan. The method used was to qualitatively evaluate practices and circumstances that cause ineffective use of irrigation water. Effectiveness of irrigation water use was quantitatively evaluated in terms of irrigation application efficiency.

Farmer application efficiencies are not generally high many places in the world. In the United States seasonal application efficiencies are frequently between 30 and 40 percent. Previous studies in Pakistan have assumed application efficiencies of near 85 percent.

Factors which contribute to ineffective use of water in Pakistan are:

Table 8. Distribution of amount of water applied per irrigation for all crops and all months.

Amount Inches	Number for Interval	Percent Interval	Total Accumulated
0≤1	0	0	0
1≤2	2	4	4
2≤3	3	6	10
3≤4	10	19	29
4≤5	11	21	50
5≤6	8	15	65
6≤7	4	8	73
7≤8	7	13	86
8≤9	1	2	88
9≤10	4	8	96
≥10	2	4	100
Total	52	100	

1. Lack of water measurement and the assumption by researchers and farmers that a certain depth of water on the field means a given amount of water has been applied.
2. Inadequately leveled and improperly designed fields.
3. Infiltration rates that cause excessive applications when water use rates are low and underirrigation when water use rates are high.
4. The inability to adjust frequency of irrigation to crop water requirements due to the fixed warabundi.

Irrigation application efficiencies measured on farmer fields ranged from zero to 100 percent. The median application efficiency measured was near 20 percent based on 64 individual observations. Improvement of on-farm water management has a great potential for increasing the effective irrigation water supply.

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