*Pak. J. Agri. Sci., Vol. 55(4), 971-xxx;2018*
*ISSN (Print) 0552-9034, ISSN (Online) 2076-0906*
*DOI:10.21162/PAKJAS/18.3544*
http://www.pakjas.com.pk

# DETERMINING WATER REQUIREMENTS OF MAJOR CROPS IN THE LOWER INDUS BASIN OF PAKISTAN USING DRAINAGE-TYPE LYSIMETERS

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The crop water requirements of three major crops grown in the Lower Indus Basin namely wheat, cotton and sugarcane were determined at different water-table depths and the groundwater contribution to the total water requirement was quantified. The study was conducted in drainage type lysimeters of size 3.05 m x 3.05 m x 5.18 m constructed at the Drainage Research Centre Tandojam, Pakistan. Three different water-table depths of 1.5, 2.25 and 2.75 m were maintained during the study. The evapotranspiration (ET) was more at shallow water-table depths and it decreased with increase in water-table depths. The maximum wheat yield was obtained at water-table depth of 2.25 m whereas the maximum cotton and sugarcane yields were observed at 1.5 m depth. The groundwater contribution to wheat crop was, 19, 6 and 4%, to cotton crop, 20, 4 and 1% and to sugarcane crop, 21, 5 and 1% at the three water-table depths, respectively. At 1.50 m depth, the water productivity of wheat was 8-22%, cotton 27-30% and sugarcane 34-57% higher than at 2.25 and 2.75 m depths. Therefore, there is a need to exploit the shallow water table to reduce the surface water applications and to improve the water productivity.
**Keywords:** Evapotranspiration, groundwater contribution, crop yield, water productivity.

## INTRODUCTION

Water demand for domestic, industrial and agricultural sectors is increasing day by day mainly because of ever increasing population. Pakistan has one of the largest surface irrigation systems in the world. Due to seepage from canals and watercourses and over irrigation, not only a huge quantity of irrigation water is lost but also results in waterlogging. In the Lower Indus Basin, the problem of waterlogging has become severe due to mismanagement of water resources. In the Sindh province, out of the gross command area of 5.74 million hectare (Mha), 1.35 Mha (23.6%) has water table less than 1.5 m and 3.35 Mha (54.5%) between 1.5 to 3 m (Sufi *et al*., 2004). Nevertheless, seepage of water from irrigation canals and watercourses to underlying aquifers is not always a real loss, because the water can be recovered by pumping or can be used directly by the plants, and therefore, is also a boon for the residents of Indus plain (Nazir, 1998). This water is relatively fresh as compared to deep water, is a flexible source of water and can be used at any time and in any quantity. The water is within easy reach for extraction and pumping lift is small which reduces the operational and installation cost of tubewell. However, proper knowledge of crop water requirement is a prerequisite for the optimum use of shallow groundwater.

In Pakistan however, farmers normally over irrigate their fields due to (i) lack of proper knowledge about crop water requirement and (ii) with the intention that more water will produce more yield. More water applications nevertheless, not only result in low water productivity but also leach the nutrients out of the root zone, consequently decreasing the crop yield. Particularly, under skimmed water (freshwater overlying saline water) applications, more water applications, more cost, more danger of salinity build up in the root zone and less net income (Ashraf *et al*., 2001). The lack of farmer's knowledge about correct irrigation scheduling is a major constraint in efficient use of irrigation water.

Wheat, cotton and sugarcane are the major crops grown in the Lower Indus Basin. However, their crop water requirements under high water-table conditions have not been determined. The crop water requirement depends on agro-climatic conditions, soil type, crop grown, water-table conditions and to some extent on cultural practices. There is a controversy in literature on the crop water requirements of these crops. Ali and Sabir (1975) concluded that conventional practice of applying 48 and 64 cm of water to wheat and cotton crops, respectively is unproductive and wasteful particularly under shallow water-table conditions. Sabir and Iqbal (1979) concluded that applying of 160 cm water to sugarcane crop during growth period is wasteful and unproductive on soils where water table is less than 3 m deep.

Several studies indicated that the shallow groundwater contributes significantly to crop water requirements and irrigation should be terminated earlier where a high water table exists (Wallender *et al*., 1979; Ayers and Schoneman 1986; Benz *et al*., 1984; Pratharpar and Qureshi 1998; Soppe and Ayars 2003; Stampfli and Madramootoo 2006; Babajimopoulos *et al*., 2007). Javaid and Solangi (1987) found that in a fresh groundwater zone where the average water-table depth was 0.5 m, only 10 cm pre-sowing irrigation was required for normal yield of wheat. At a water-table depth of 1.3 m, high yield of cotton was obtained with only a 10 cm pre-sowing irrigation. They found 2.75 to 3.21 m water-table depth optimum for production of wheat and cotton, respectively whereas, Kahlown *et al*. (2004) found 1.5 to 2.0 m as the optimum depths for wheat, maize, sunflower, sorghum, berseem and sugarcane crops in the Upper Indus Basin.

The above discussion shows that high water table is a valuable agricultural resource that can be used as sub irrigation. The sub irrigation reduces the volume of effluent, saves labour, water and energy and helps control waterlogging. This study was conducted in the Lower Indus Basin to determine water requirements, groundwater contribution, crop yields and water productivity of three major crops at different water-table depths.

## MATERIALS AND METHODS

Pakistan Council of Research in Water Resources (PCRWR) constructed 12 drainage type lysimeters at Drainage Research Centre, Tando Jam in 1985 (latitude 25° 26' N, longitude 68° 25' E and altitude of 120 m). The area falls in arid zone where average summer minimum and maximum temperatures are 30.5 and 33.8 °C, respectively and average winter minimum and maximum temperatures are 17.2 and 18.8 °C, respectively. The size of these lysimeters is 3.05 m x 3.05 m and 5.18 m depth. Each lysimeter is provided with filter screens, non-calcareous spawls and graded gravel filter material, drainage outlet and water feeding arrangement. In each lysimeter, polyvinyl chloride (PVC) screens of 50.8 mm diameter and 2.43 m long were imbedded in the gravel filter and connected with 2.54 cm pipe for water supply system. Piezometers were also installed with each lysimeter to monitor the water table. Marriotte bottles were installed on all lysimeters to maintain water table at the desired level and to measure the groundwater contribution. Figure 1 shows the schematic diagram of the lysimeter set up.

Two representative soil series of the Sindh Province namely; Sultanpur (silt loam) and Miani (silty clay loam) were filled layer wise in each of the six lysimeters. Both soil series were identified in the field upto a depth of 240 cm. Their dry bulk densities were determined in the field using auger method and the same were maintained in the lysimeters. To obtain the field conditions and to check the proper functioning of these lysimeters, the crops were grown for a year on non-experimental basis. The lysimeter studies were then started in 1986 and studies on wheat, cotton and sugarcane were completed. Four lysimeters were used for each water-table depth (4 replications). Three water-table depths of 1.5, 2.25 and 2.75 m were maintained during the study. The lysimeters were surrounded by the same crops (upto 3 m distance) as were experimented in the lysimeters to avoid the oasis effect. The average rainfall during the wheat and sugarcane seasons was 29 and 150 mm, respectively. There was however, no rainfall during the cotton growth period.

The surface irrigation was applied as per schedule depending on the type of crop and was based on potential evaporation. While determining crop water requirements, it is necessary to provide optimal conditions. Therefore, to avoid water stress to plants, a weekly irrigation of 7.5 cm was scheduled for each lysimeter planted with sugarcane. This was based on the previous experience as weekly application of 7.5 cm water to lysimeters maintained about 40-50% soil moisture storage.

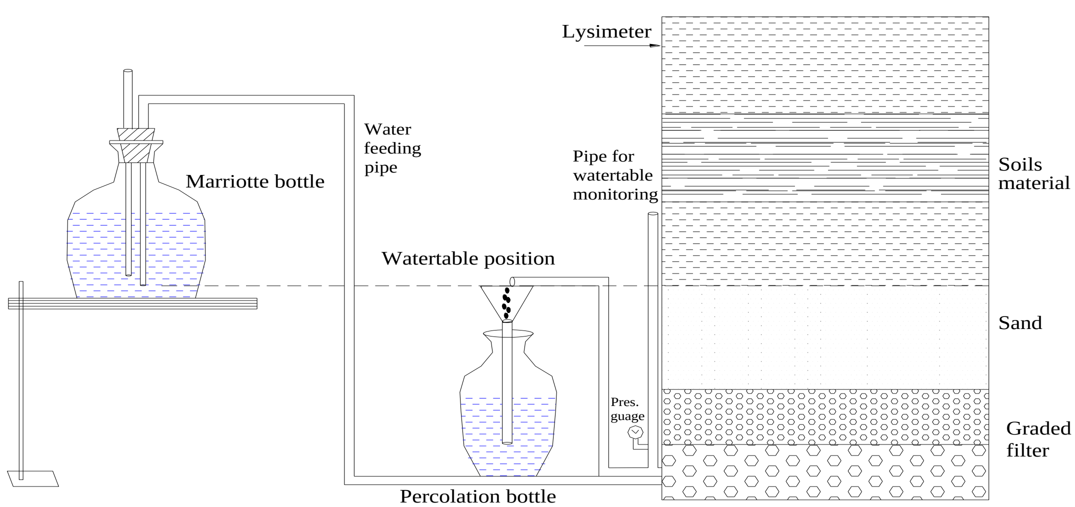


**Figure 1. Schematic diagram of the experimental set up.**

Any excess water was percolated down that was collected as a drainage surplus. For wheat and cotton, each irrigation was 2.5 cm and 7.5 cm, respectively which was applied at suitable time intervals based on the potential evaporation. The irrigation interval was increased in case of rainfall. The excess or percolated water was collected in a percolation bottle and was subtracted from the amount of water supplied through Marriotte bottles in order to determine net groundwater contribution. The canal water was collected in a reservoir from where it was pumped to an overhead water tank (2 m high). From this tank, irrigation was applied to lysimeters through a pipeline. A water meter was fitted on the main inflow pipeline to measure the amount of water applied.

Wheat was sown on November 17, 1986 and harvested in March 20, 1987. The row-to-row distance for wheat was 20 cm. On April 29, 1987, cotton crop was sown in the lysimeters. The row-to-row and plant-to-plant distances were 75 and 25 cm, respectively. The cotton picking was completed by August 31, 1987. Cane stalks were cut into sections with each section having two to three buds and were planted at row to row distance of one meter on September 25, 1987 and was harvested on September 29, 1988. The budded sets were sown in the rows prepared manually. Recommended doses of fertilizers were applied at suitable time intervals (Table 1). When the sugarcane crop was matured to its full growth period, (after one year) it was harvested and weighed. The yield was recorded separately for each lysimeter. The average yield under each water-table depth was determined which was then converted to kg/ha. Table 1 shows the salient features of the crops studied. The crop ET was calculated using the following formula:

$$ET = I + S + R - D \pm SMS \qquad (1)$$

where ET is the crop evapotranspiration (cm), I is the surface irrigation (cm), S is the sub irrigation or groundwater contribution to crop (cm), R is the rainfall (cm), D is the drainage effluent (cm) and SMS is the soil moisture storage i.e. difference in soil moisture storage before sowing and after harvesting of crop. A meteorological observatory has been installed at about 50 m from the lysimeters that provided data on maximum-minimum temperatures, relative humidity, wind speed, sunshine hours, pan evaporation and rainfall. Soil samples were collected at an interval of 15 cm upto 150 cm depths before sowing and after harvesting of crops and soil moisture was measured gravimetrically.

## RESULTS AND DISCUSSIONS

***Evapotranspiration as a function of water-table depth*:** Figures 2-4 show the evapotranspiration obtained from lysimeters for the crops studied. In general the ET was 3-6% higher with shallow water tables as compared to deep water tables and decreased with an increase in the water-table depth. Figure 2 shows that the peak evapotranspiration of wheat crop occurred in the month of December. This was actually the booting stage of the wheat when its water requirement increased. During December, there was a difference of about 2 cm between the ET at 1.5 m and 2.75 m water-table depths. The ET was the minimum during the month of January, increased in February and again decreased in March towards crop maturity. The cumulative water consumption for wheat was 41.4, 40.2 and 38.8 cm at 1.5 m, 2.25 m and 2.75 m water-table depths, respectively (Table 2). Kalwar and Abbasi (1982) however, found 56.2, 46.7, and 37.7 cm at soil moisture depletion levels of 70, 80 and 90%, respectively at Sindh Agriculture University, Tando Jam, Pakistan. This was

**Table 1. Salient features of the crops studied.**

| Name of crop | Botanical name | Variety | Rooting depth (cm) | Sowing time | Harvesting time | Fertilizer applications (kg/ha) |
|---|---|---|---|---|---|---|
| Wheat | *Triticum aestivum* | Johar-78 | 90-150 | November | March | Nitrogen = 142<br>Phosphorous = 73 |
| Cotton | *Gossypium hirsutum* | NIAB-78 | 90-150 | May | October | Nitrogen = 200<br>Phosphorous = 125<br>Potassium = 50 |
| Sugarcane | *Saccharum officinarum* | BL-4 | 60-150 | October | November | Nitrogen = 250<br>Phosphorous = 100<br>Potassium = 150 |

**Table 2. Groundwater contribution to crop water requirements from different water-table depths** .

| Water-table | Wheat | | Cotton | | Sugarcane | |
|---|---|---|---|---|---|---|
| depth (m) | ET (cm) | GWC* (cm) | ET (cm) | GWC (cm) | ET (cm) | GWC (cm) |
| 1.50 | 41.4±0.90 | 7.7±0.97 | 88.3±0.90 | 17.2±0.93 | 210±0.92 | 44.1±0.85 |
| 2.25 | 40.2±0.88 | 2.4±0.84 | 89.6±1.01 | 3.1±0.89 | 199±0.91 | 8.8±0.88 |
| 2.75 | 38.8±0.60 | 1.4±0.44 | 85.2±0.38 | 0.9±0.40 | 179±0.40 | 2.2±0.39 |

*GWC: Groundwater contribution that was measured through Marriotte bottles for growth period of 140 days however, the wheat sown in the lysimeters was harvested after 128 days.

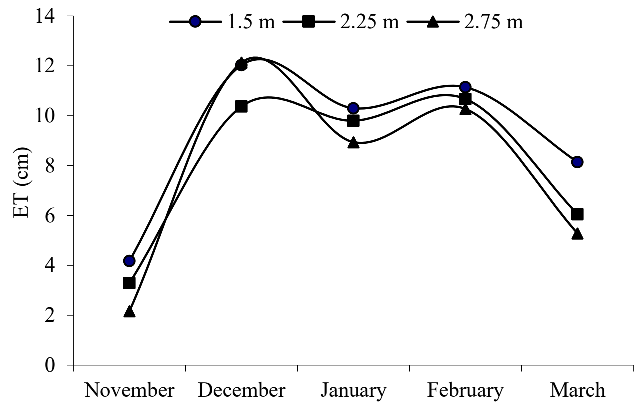


**Figure 2. Monthly evapotranspiration for wheat, grown in the lysimeters at different water-table depths.**

For cotton, there was no difference between ET at 1.5 m and 2.25 m depths during the period of high evaporative demand period i.e. in July (Fig. 3). This might be due to the drying of the soil surface due to high evaporation and movement of drying front down the soil profile. However, during the same period, there was a difference of about 5 cm at 1.5 m and 2.75 m water-table depths. During the period of early crop and towards crop maturity however, there was a significant difference at 5% significance level in ET at 1.5 m and 2.25 m depths.

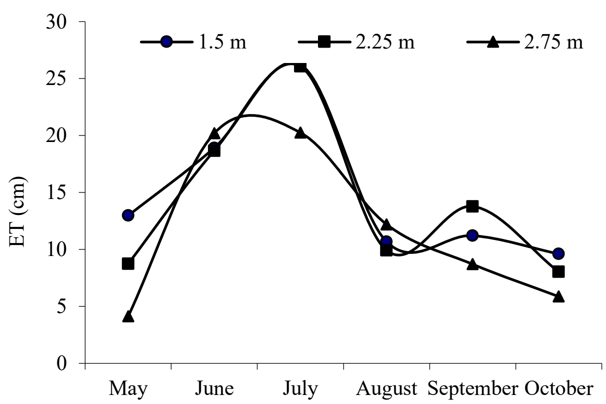


**Figure 3. Monthly evapotranspiration for cotton grown in the lysimeters at different water-table depths.**

During the first month of sowing when most of the soil surface did not have canopy cover, surface evaporation was the highest from areas with the highest water tables due to availability of more soil moisture. The total water consumed by the cotton was 88.3, 89.6 and 85.2 cm at 1.5, 2.25, and 2.75 m depth, respectively. However, Kalwar and Abbasi (1982) reported it to be 77.8 cm at 70% soil moisture depletion. The ET measured in lysimeters was relatively higher than for field experiments, because a large amount of moisture is available in the deeper root zone in the fields.

The ET of sugarcane, at three water-table depths, started to increase from November, became the maximum in June and decreased continuously till January (Fig. 4). The difference in ET at 1.5 m and other depths was comparatively small. This might be due to the long roots of the sugarcane which were able to extract water from the deeper depths. The ET of sugarcane was almost constant from October to March. The highest ET was observed in the month of June (the warmest month) at all the three water-table depths whereas, the lowest values of ET were observed in the month of January (the coolest month). The annual average ET (from October to October) at the three depths was 210, 199 and 179 cm, respectively.

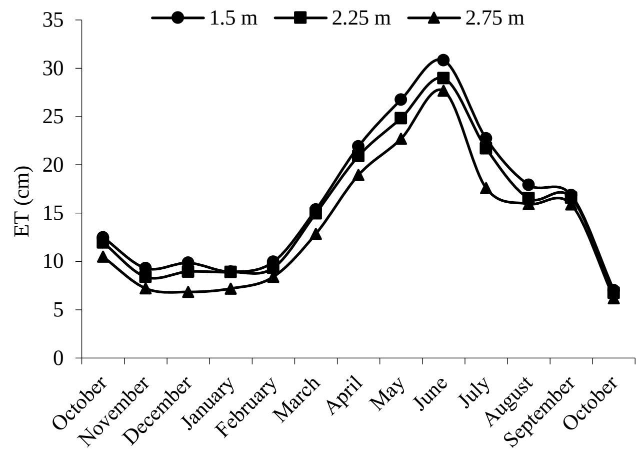


**Figure 4. Monthly evapotranspiration for sugarcane grown in the lysimeters at different water-table depths.**

***Groundwater contribution as a function of water-table depth*:** Groundwater contributions to the crops at the three water-table depths are presented in Table 2. At shallow water tables, the contribution to crops was more than from deeper ones. The groundwater contribution to wheat was 19, 6 and 4%, to cotton 20, 4 and 1% and to sugarcane was 21, 5 and 1%, at the three water-table depths, respectively. Therefore, the shallow groundwater (1.5 m depth) contributed about 20% of the total water requirements for all the crops studied. Grismer and Gates (1988) found that the groundwater can contribute as much as 60-70% of the crops water requirements. The groundwater contribution however, depends on soil type, crop grown, water-table depth, agro-climatic conditions. The shallow groundwater therefore, should be taken into consideration while devising irrigation scheduling. This would reduce surface irrigation requirements and would save labour, water, energy and would help control water logging and salinity.

**Table 3. Yield and water productivity of crops under different water-table depths.**

| Water-table depth (m) | Yield (kg/ha) | | | Water productivity (kg/m$^3$) | | |
|---|---|---|---|---|---|---|
| | Wheat | Cotton | Sugarcane | Wheat | Cotton | Sugarcane |
| 1.50 | 4,040±1,236 | 3,920±313 | 206,950±9,696 | 1.20 | 0.55 | 12.47 |
| 2.25 | 4,170±978 | 3,480±844 | 103,050±8,804 | 1.10 | 0.40 | 5.42 |
| 2.75 | 3,520±780 | 3,260±1,347 | 145,280±7,406 | 0.94 | 0.39 | 8.22 |

***Crop yield and water productivity as a function of water-table depth*:** Table 3 shows that the wheat yield was the maximum at water-table depth of 2.25 m whereas the cotton yield was maximum at 1.5 m and decreased almost linearly with an increase in water-table depth. Similarly, the yield of sugarcane was the maximum at 1.5 m, decreased at 2.25 m and again increased as the water table was lowered. The average sugarcane yield at 1.5 m depth was 50% higher than at 2.25 m and 30% higher than at 2.75 m. Since sugarcane is a high water requirement crop, therefore, it met most of its water requirements from the shallow water table. The 't' test was applied to see the significance of difference. There was no significant difference in the yields of cotton and wheat for different treatments (Table 4). However, sugarcane indicated significant yield difference for different treatments (Table 4). Asad (2001) found a water-table depth of 1 to 1.5 m optimum for wheat and cotton. Therefore, cotton and sugarcane crops can be grown at a water-table depth of 1.5 m from the ground surface with relatively good yields. Kahlown *et al*. (2004) also reported the maximum sugarcane yield at 1.5 m water-table depth in the Upper Indus Basin.

**Table 4. Significance of difference between the crops yield at different water-table depths.**

| Treatments | `t' calculated | P | Significance at 5% level |
|---|---|---|---|
| $T_1$ & $T_2$ | 0.165 | 0.874 | N.S |
| $T_2$ & $T_3$ | -1.035 | 0.341 | N.S |
| $T_1$ & $T_3$ | -0.708 | 0.505 | N.S |
| $T_1$ & $T_2$ | -0.966 | 0.371 | N.S |
| $T_2$ & $T_3$ | 0.569 | 0.589 | N.S |
| $T_1$ & $T_3$ | 0.025 | 0.981 | N.S |
| $T_1$ & $T_2$ | -15.86 | $3.97x10^{-6}$ | S |
| $T_2$ & $T_3$ | 7.29 | $3.40x10^{-4}$ | S |
| $T_1$ & $T_3$ | -10.15 | $5.31x10^{-5}$ | S |

$T_1$ = 1.5 m, $T_2$ = 2.25 m, $T_3$ = 2.75 m, S = Significant, NS = Non significant

Table 3 also shows that water productivity of wheat, cotton and sugarcane was higher for shallow water tables as compared to the deeper ones. At shallow depth (1.50 m), the water productivity was more by 8-22% for wheat, by 27-30% for cotton and by34-57% for sugarcane than for the deep water-table depths. Water productivity is a measure of how efficiently water has been used in crop production. It is measured as crop yield in kg per cubic meter of water used. The water productivities at the shallow depths were reasonably well compared with those found in the literature. Ashraf and Saeed (2006) obtained wheat yield of 5,091 kg/ha and water productivity of 1.20 kg/m$^3$ with bed and furrow irrigation in the Chaj Doab (the area between the rivers Chenab and Jhelum). Singh *et al*. (2007), in a field trial in the northern India, obtained mean water productivities of 7.1 kg/m$^3$ and 6.3 kg/m$^3$ for plant and ratoon sugarcane crops, respectively. In our study, it is 12.47 kg/m$^3$ at a water-table depth of 1.5 m. Under shallow water-table conditions, the surface irrigation requirements are significantly reduced, without compromising the crops yields, and the groundwater contribution to crop water requirements should therefore, be considered while devising the irrigation scheduling. This would not only save precious surface water but would also help manage the groundwater resources, reduce the waterlogging and increase the water productivity. Those packages and others are not within the reach of most farmers. Any improvement requires that effective extension services together with proper policies be implemented (Mahmood *et al*., 2015).

***Conclusions*:** The ET was more at shallow water-table depths and it decreased with increase in water-table depths for all the crops studied. The wheat yield was maximum at a water-table depth of 2.25 m whereas for cotton, it was maximum at 1.5 m and decreased almost linearly with an increase in water-table depth. The yield of sugarcane was maximum at the 1.5 m water-table depth. At 1.5 m water-table depth, the groundwater contribution was 19, 20 and 21% for wheat, cotton and sugarcane, respectively as compared to 2.75 m depth. At 1.50 m depth, the water productivity of wheat was 8-22%, cotton 27-30% and sugarcane 34-57% higher than at 2.25 m and 2.75 m depths. Therefore, the irrigation system (depth and frequency) needs to be modified where water table is shallow to make best use of the shallow water and to avoid wastage of precious irrigation water. For this purpose, planting on beds and ridges can help great to improve the water productivity.

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