DETERMINATION OF CROP WATER REQUIREMENT OF MAJOR CROPS UNDER SHALLOW WATER-TABLE CONDITIONS

Dr Muhammad Akram Kahlown
Dr Muhammad Ashraf
Abdur Raoof
Zia ul Haq

Pakistan Council of Research in Water Resources
P O Box 1849, Islamabad

2003

The Authors

Dr Muhammad Akram Kahlown is Chairman, Pakistan Council of Research in Water Resources, Islamabad

Dr Muhammad Ashraf is Director, Pakistan Council of Research in Water Resources, Islamabad

Abdul Raoof and Zia-ul-Haq are Regional Director and Director respectively, Pakistan

ISBN 969-8469-11-7

Acknowledgement

The authors would like to thank Mr. Naheed Ajaz and Mr. Javed Akhter for providing help in editing and formatting the report.

H/No.3, Street 17, F-6/2, Islamabad – Pakistan
Email: pcrwr@isb.comsats.net.pk

CONTENTS

CHAPTER 4

CHAPTER 5

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Due to increasing demand for food and fiber by ever-increasing population of the country, the pressure on fresh water resources is increasing. Optimum utilization of surface and groundwater resources is of paramount importance to fill the gap between water demand and supply. To investigate the effect of shallow water-table depths on crop water requirements and crop performance, Pakistan Council of Research in Water Resources (PCRWR) initiated, two lysimeter schemes, one in the province of Punjab and the other in Sindh. Eighteen concrete lysimeters of the size 3.05 m x 3.05 m and 6.1 metre deep were constructed in Lahore. In Tando Jam Sindh, 12 lysimeters, with dimensions of 3 m x 3 m x 5 m were constructed with RCC. Tensiometers and gypsum blocks were installed in the lysimeters to measure soil matric potential/water contents. The lysimeters were connected to Marriotte Bottles to maintain groundwater level at the desired depth. The amount of water percolated deep into the sub-soil was measured through a rubber tubing of 2 mm dia, connected to an outlet pipe fitted at the bottom of each lysimeter. Regular experiments were started in Punjab and Sindh in 1975 and 1985, respectively. The results of these studies show that irrigation scheduling according to needs of the crops can make most efficient and productive use of available surface and groundwater resources. In the areas with shallow water-table (generally less than 3 m), crop yield can be enhanced and the amount of irrigation applied can be reduced significantly. Under very shallow watertable conditions (0.5 m depth), wheat extracted almost all its required water from the groundwater, whereas sunflower extracted more than 80% of its requirement. Maize and sorghum were found to be water sensitive crops since their yields were reduced with decrease in water-table depth. Maximum sugarcane yield (over 70 t/ha) was found at 1.0 m depth however, there was drastic decrease in sugarcane yield with decrease in water-table depth (less than 15 ton/ha). Water-table depth of 1.5-2.0 m was found to be optimum depth for all the crops studied except sugarcane. Therefore the present system of irrigation supplies especially in the areas, where water-table is shallow, needs modification to avoid in-efficient use of water. Due to reduction in surface irrigation water under shallow water-table conditions, and due to groundwater contribution, salts may accumulate in the root zone. Periodic flushing of such salts after harvesting the crops may be necessary for sustainable crop production. The following is the summary of irrigation requirements (mm) of different crops under varying water-table depths.

Crop	*Water-table Depth (m)*					
	0.5	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*
Wheat	35	75	150	225	300	375
Maize	35	50	75	150	150	225
Sugarcane	-	225	450	525	600	675
Sunflower	75	125	225	300	375	450
Berseem	-	330	450	480	630	630
Sorghum	-	75	75	75	75	100

CHAPTER 1

1. INTRODUCTION

Currently agriculture contributes about 25 percent of the Gross Domestic Products (GDP) and together with agro-based product fetches 75 percent of the national merchandise export earnings. Over half of the labour force is absorbed by the agriculture sector. Agriculture sector comprises crops, livestock, forestry and fisheries sub-sectors, of which crop sector accounts for almost 69 percent of agriculture's GDP, while the livestock accounts for nearly 30 percent. Forestry and fisheries make up less than 2 percent of the total. Agriculture is, therefore, a leading sector and backbone of the economy. Providing sufficient food, fiber and fuel for the growing population and raw materials for the expanding industry is a major challenge being faced today by the agriculture sector. Irrigated agriculture in the Indus basin is the major user of water in Pakistan. There is a dire need to optimize the limiting resources/input particularly, water – the precious resource. For this purpose it is important to know what quantity of water is required as well as when and where it is needed. Moreover, reliable agricultural water use estimates are necessary for water resources planning, development and management of many other multipurpose water projects. This information is also required for better soil and water management practices for increased agricultural production. Determination of crop coefficient is necessary for proper irrigation scheduling. These help in determining the water requirements.

Availability of adequate good quality water is one of the most dominant input in successful crop production. Due to increasing demand for food and fiber, the pressure on fresh water resources is increasing. The time has now reached to review, evaluate and reorganize all our activities in water sector and take appropriate steps to ensure enhanced crop production with optimal utilization of available surface and groundwater resources. Canal water supply in Pakistan is rigid and does not consider crop water requirements, water-table depth, and soil physico-chemical conditions. Water allowance was fixed for different canals depending upon the surface water availability and the area to be covered about a century ago. The water use efficiency however, can be enhanced many - fold through demand-based irrigation scheduling as compared to rotational system.

Due to seepage from irrigation network and ineffective drainage system, water-table in many areas reached near the soil surface. Rafique (1990) reported that in Pakistan 1.47 million hectare (Mha) area has a water-table within 1.5 m of the surface. Out of this, 0.13 Mha is covered by severely saline, uncultivated soils. In non-saline soils 0.32 m ha have water-table at 1.0-1.5 m, 0.28 Mha at 0.5-1.0 m depth and 0.74 Mha within 0.5 m. By the end of dry season, 13% of irrigated land has water-table of less than 1.5 m. However, after the monsoon, 26% of the irrigated area has the water-table of less than 1.5 m (Qureshi and Barrett-Lennard, 1998).

Seepage of water from irrigation canals and watercourses to underlying aquifers however, is not always a loss because the water can be recovered by pumping or can be used directly by the plants. High water-table is also a boon for the residents of Indus plain and has many advantages. The water is within easy reach for extraction. Pumping lift is small which reduces pumping cost and the cost of the tubewell installation. Moreover, it is a flexible and reliable source of water that can be used in any amount and at any time (Nazir, 1993). Public and private deep tubewells are nevertheless, pumping saline water from deeper horizons thereby increasing the hazards of salinization at the soil surface and in the root zone. Thus the shallow fresh groundwater remains unexplored and its quality deteriorates without any use. Hence there is a need for the use of this precious water judiciously. Shallow groundwater could also be used as subirrigation by adopting proper irrigation scheduling to bridge gap between water demand and supply.

For proper irrigation scheduling knowledge of crop water requirement is essential. Evaporation from soil surface and transpiration by plants are generally combined into one term evapotranspiration as it is difficult to separate these two losses in cropped fields. The relative amounts of direct evaporation from land and water surfaces, transpiration depend usually on the ground cover. The average crop water requirement of some major crops are given in Table 1.

Table 1: *Average Crop Water Requirement of Major Crops in Pakistan*

Crop	*Crop Water Requirement (mm)*
Wheat	480
Berseem	1050
Sugarcane	1800
Rice	1500
Cotton	620
Maize	550
Sorghum	500

Source: Riaz (2001).

The above values represent the total water requirement of crops. The actual requirement of irrigation may be less, depending upon the effective rainfall and groundwater contribution. Moreover, these values also include evaporation and percolation losses.

Irrigation scheduling is the procedure used to determine the time and depth of water application for each irrigation event. The time of water application is normally based on fixed depletion of stored soil water, whereas the depth of application is equal to the value of soil water depletion plus some additional water to account for non-uniformity in water application and leaching fraction. Therefore, the time and depth of water application will also depend on the root zone depth and the salt concentration in the root zone. For proper irrigation scheduling, knowledge of water and salt balance of the root zone is of crucial importance.

To investigate the effect of shallow water-table depths on crop water requirements and crop performance and other related parameters, PCRWR initiated two lysimeter schemes, one in Punjab and the other in Sindh. Regular experiments were started in 1975 and 1985 in Punjab and Sindh, respectively. The main objectives of these lysimeter studies were to study:

- Irrigation requirement and evapotranspiration of various crops under different water-table depths;
- Groundwater contribution to the crop water requirement under different water-tables depth;
- Effect of different water-table depth on re-distribution of salts in the root zone;
- Effect of different water-table depth on crop yield;
- Determination of optimum water-table depth for various crops; and
- Computation of crop coefficients for major crops.

The crops studied include wheat, maize, sorghum, berseem, sunflower and sugarcane. This report present the results of the various studies conducted in Punjab. This report provides guidelines to farm managers for the optimum utilization of their existing water resources for maximum crop production.

CAHPTER 2

2. REVIEW OF LITERATURE

2.1 Consumptive Use of Water for Various Crops

2.1.1 *By Computation*

Blaney and Criddle (1957) calculated the evapotranspiration for wheat to be 400 mm. Similarly, Asghar and Ahmad (1962) and Revelle (1964) reported evapotranspiration for wheat as 350 and 330 mm, respectively. The M/s Hunting Technical Services Ltd. (1966) calculated consumptive use of water for wheat in Hyderabad area to be 414 mm. Dastane (1966) worked out correlations between values of actual consumptive use and those computed by using various empirical equations under optimum moisture regimes. In case of wheat the correlation values for Penman, Thornthwaite and U.S. Open Pan Evaporation Methods were 0.982, 0.939 and 0.998, respectively. For wheat he reported 330 mm as total evapotranspiration.

The M/s Harza Engineering Company, Int. (1968) determined the consumptive use of water for various crops using the evaporation index method. The findings were based on studies carried out in USA. These computations were modified to determine crop coefficients to made them applicable for conditions in Pakistan. Based on hypothetical calculations, the consumptive use of water for wheat was found 403 mm. Clyma (1973) advocated the Jensen-Haise Method for estimating evapotranspiration for crops. He estimated mean annual potential evapotranspiration for Sargodha to be near 1830 mm per year. With wheat during *Rabi* and cotton during *Kharif*, evapotranspiration ranged from 1100 mm in a wet year to 1200 mm in a dry year. He calculated net irrigation requirements for wheat grown in Sargodha under wet and dry seasons as 173 and 410 mm, respectively. Ahmad (1985) presented prediction models for reference crop evapotranspiration in Punjab for eight selected crops. He further reported basal crops coefficients for eight crops. Hargreaves and Samani (1985) presented monthly crop evapotranspiration for a number of locations in Pakistan. This method required only mean temperature. Azam *et al. (*1999) divided the country into nine cropping zones. The crop water requirements for wheat, sugarcane, cotton, rice and maize were determined through empirical methods. The average water requirements for these crops came out to be 317, 1415, 631, 960 and 354 mm, respectively. They used Kc values already developed by Pakistan Council of Research in Water Resources and Pakistan Agriculture Research Council.

2.1.2 *Field Studies*

Khan *et al. (*1968) while comparing the effect of varying quantities of water on yield of wheat (Maxi-Pak) found water requirement of wheat 523 mm. These findings were however, not based on actual consumptive use estimation. Hussain and Asghar (1969) reported that water requirements of wheat grown at various places in Pakistan vary from 343 mm to 606 mm, whereas Assifi (1970) estimated that consumptive use of wheat grown in Helmand Valley Shamalan was 510 mm. He tabulated the monthly requirement and concluded that the minimum requirement was in the month of January and maximum in the month of May.

Droogers (2000) estimated actual evapotranspiration using detailed agro-hydrological model for cotton crop in Gediz Basin, Turkey. The results show a distinction between actual crop transpiration and soil evaporation. The precipitation only occurred during the first month of growing season *i.e*. May and the last month September, 400 mm of irrigation was given as border irrigation with four applications. The feasibility of supplemental irrigation of sugarcane in the state of Sao Paulo, Brazil, was examined, focusing on irrigation scheduling. Sugarcane basal crop coefficients were determined from field experiments in a steady state water-table lysimeter. Crop response to water deficits at selected growth stages were evaluated to obtain an additive relative yield model. Optimal irrigation scheduling for various growth stages and corresponding optimized yields were determined for each planting season. Results showed that the elimination or partial reduction of irrigation application was possible without affecting economic return. Simulation models also confirmed that the optimal irrigation programme produced higher economic yields than non-optimized application strategies.

PARC (1982) reported results of consumptive use of water, moisture stress-yield functions and crop coefficients for wheat, maize, cotton, sugarcane and soybeans for six agro-climatic regions of Pakistan under field conditions, where water-table was below 6 metre (Table 2). The studies were conducted using irrigation scheduling criteria based on soil moisture depletion.

Table 2: *Results of the Consumptive Use Studies Conducted by PARC (1982)*

Crop	*Crop water Requirement Range (mm)*	*Crop Water Requirement for Maximum Yield (mm)*	*Maximum Yield (kg/ha)*	*Station*
Wheat	353-562	401	5710	Bhalwal
Maize	431- 715	610	5585	Bhakkar
Cotton	587-797	587	1429	Bhalwal
Sugarcane	1195-1482	1482	131000	Mianchannu

PARC (1993) further reported results of consumptive use of water, moisture stress yield functions and crop coefficients for 12 crops grown in various climatic zones of the country. The moisture stress yield function indicates that most of the grain crops like wheat, maize, sorghum and millets can be irrigated at 75% depletion of available soil moisture without loosing any significant yield. Thus management allowed deficit for these crops should range between 50-75%. Cotton crop behaved differently where further stress did not affect the yield rather it helped to maintain the yield.

2.1.3 *Lysimeter Studies*

In a Iysimeter study Asghar *et al*. (1962) found that wheat crop used 505 mm of water during its growing season, when the water-table was kept at 3.2 m. Hussain (1970) calculated the consumptive use for wheat (indigenous) and wheat (Maxi-Pak) as 339 and 522 mm, respectively. Using Climatological data, the author worked out the Blaney-Criddle crop coefficient (Kc) for wheat to be 0.50. In a similar study, Ali *et al. (*1973) calculated the consumptive use of common crops in Iysimeters keeping the groundwater table at various depths. They used climatological data to work out empirical consumptive use coefficients. They found the consumptive use of wheat (Maxi-Pak) with water-table depths at 1.5, 2.1 and 2.75 metre and there were 546, 483 and 488 mm, respectively. The average measured seasonal crop evapotranspiration was of 336 mm for wheat and 495 mm for sorghum in Karala, India. Tyagi *et al. (*1999) conducted experiments on sunflower during summer season (March-June) in a set of two electronic weighing type lysimeters to measure the hourly evapotranspiration of these crops from 1994 to 1995 at Karnal, India. The estimated Kc values during the first, second, third and fourth growth stages were 0.52, 1.1, 1.32 and 0.41, respectively. The estimated Kc values of sunflower were 11.6-74.2% higher than the values suggested by FAO.

2.2 Groundwater Contribution to Crop Growth

Estimation of groundwater contribution to crop growth is of vital importance in consumptive use experiments conducted under shallow water-table conditions. Rehman *et al*. (1977) showed that for wheat crop, the groundwater contribution was about 83, 24, 8, 4 and 3% of the total evapotranspiration with water-table at 0.91, 1.83, 2.74, 3.66 and 4.57 m depths, respectively. Chaudhry *et al. (*1974) studied the response of wheat to depth and salinity of groundwater maintained at the depths 60, 90, 120 and 150 cm from the soil surface. It was observed that different amounts of supplemental irrigation were required to keep a favourable soil moisture condition in the root zone. Amount of surface irrigation applied varied from 8 cm to 34.5 cm as water-table depth increased from 60 cm to 150 cm. Groundwater contribution was 70, 53, 23 and 20% of the total water used with respect to water-table depth 60, 90, 120 and 150 cm, respectively.

Asad (2001) concluded that good yields of cotton and wheat could be obtained with 1-2 irrigations (where each irrigation measures about 7.5 cm) at water-table depth of 1-2 m, 2-3 irrigations at water-table depth of 2-3 m and 3-4 irrigations at water-table depth of 3-4 m provided groundwater quality is within safe limits. Sadiq *et al. (*1973) found that for major crops of Pakistan, 2.74 metres depth of water-table is optimum, provided the water is of usable quality.

Khan *et al.* (1972) observed that on a sandy clay loam soil, having a groundwater table depth at 2.2 metre below the soil surface, the standard practice of providing 480 mm of water to the Mexican wheat, 640 mm to American cotton was unproductive and wasteful practice. High yield of both crops could be obtained without any irrigation after planting with 100 mm of *rouni* water, while only one further irrigation at tillering to wheat and at flowering to cotton was needed to obtain their maximum yield with reduced surface irrigation. No significant change in pH and salinity was observed. The above findings were further supported by Ali *et al. (*1973). They reported maximum yield of wheat and cotton without any subsequent irrigation after applying 100 mm irrigation as *rouni* and sowing on a soil with a water-table depth 1 m below ground surface. One 75 mm irrigation after sowing was needed to obtain maximum yield on soil with a water-table 2 m below the surface. Similarly, not more than two irrigations after planting were required to obtain maximum yield of wheat where the groundwater was 3 m below the surface, while a third irrigation was needed to obtain maximum yield of seed cotton on such a soil.

Sabir (1975) showed that the conventional practice of giving 1625 mm of water for raising sugarcane crop proved as wasteful practice on a soil with a groundwater table depth of 0.60 m as fairly high yield of this crop was obtained without any subsequent irrigation. Similarly, 1270 mm of irrigation water including 533 mm of rainfall gave significantly better yield of sugarcane on soil with a groundwater table depth up to 3 m. Subsequent irrigation of the crop may have to be adjusted according to the rainfall. However, beyond 3 m depth, the irrigation requirements of the crop may increase from 625 to 1778 mm depending upon the rainfall and soil type.

Pratharpar and Qureshi (1998) observed that in the areas where shallow water-table exists, the irrigation requirements can be reduced to 80% of the total crop evapotranspiration (ET) without reducing crop yield and increasing soil salinization. This practice not only produces reasonably good yields but also keeps the soil salinity and water-table depth within the acceptable limit. Ayara and Schoneman (1986) showed that during 3 years of cotton growth, for a water-table depth (EC_e =10 dS m^{-1}) of 1.7 m to 2.1 m, the percentage of ET contributed by the groundwater ranged from less than 0 to a maximum of 37%. Wallender *et al. (*1979) found that cotton extracted 60% of its ET from a saline (6.0 dS m^{-1}) water-table.

Kahlown *et al. (*1998) showed that there was a direct relationship between the water-table depth and the groundwater contribution despite the brackish nature of the groundwater. They found that groundwater contribution was maximum at depth shallower than 1 m and minimum for 2-3 m water-table depths. It is therefore, obvious from the above discussion that the groundwater contribution is an important component of water balance and should be operated as a system for effective water management. This will save water, energy, and labour and will also reduce the drainage effluent and help keep the water-table at the desired depth.

Javid and Solangi (1990) obtained high yields of wheat grown over a three years period on a soil with a water-table depth of 0.5 to 1.0 metre and 1.0 to 1.5 metre below the good surface in sweat water zone near Tando Adam, Sindh. The canal irrigation water was applied when the available soil-moisture depleted by 40-50 percent in the top 30 cm of soil. The average yield of wheat planted on was 2608 kg/ha on the soil with water-table depth of 0.5 to 1.0 metre, while it was 2242 kg/ha where water-table depth was 1.0 to 1.5 metre. The contribution of groundwater was 48 and 38 percent, respectively. Hameed and Solangi (1993) grew cotton and wheat on raised beds of different width on soils with water-table depth of 0.5 to 1.0 and 1.0 to 1.5 metre near Tando Adam in Sindh. The average groundwater contribution to the total irrigation requirement of cotton for 1 and 1.5 m depth was 60 and 35 percent respectively, while in case of wheat it was 52 and 44 percent, respectively. Iqbal and Bashir (1991) conducted experiments on wheat and maize crops on soil with water-table depths of 0.5-1.0 and 1.0-2.0 m in Mona area, Punjab. Wheat was sown on level basin and broad beds of different sizes, while maize was planted on ridges with different irrigation interventions. Irrigation was applied at 50 percent depletion of available soil moisture. Fairly high yields of both wheat and maize were obtained at both water-table depths. With water-table at 1-2 m depth, 75 percent of the total water requirements of wheat and 57 of maize were met from the water-table. Similar results on wheat were obtained by Iqbal (1993). He planted wheat on 95 cm wide beds on soils with water-table depths of 0.5-1.0 and 1.0-2.0 metre from the ground surface in Mona. However, irrigation was applied when the available soil moisture in the top 30 cm soil in the middle of the bed was exhausted by 50, 65 and 80 percent. Wheat planted on beds gave significantly higher yield than the traditional level basin planting, especially at shallow water-table depth. The average groundwater contribution towards the consumptive use of the crop was 72 and 57 percent, respectively. However Ahmad and Rahim (1990) obtained an average yield of 3087 kg/ha of wheat planted on a soil with a water-table depth of 0.1 to 0.6 metre and 4356 kg/ha on a soil with a water-table depth of 0.6 to 1 m. Crop was irrigated at 45 percent soil moisture depletion. The contribution of groundwater was 74 and 70 percent for each water-table depth, respectively. Therefore, it can be concluded that substantial part of crop water requirement is met from the groundwater if the water-table is high. The groundwater contribution will depend on soil characteristics, crop root system, water-table depth, rainfall and other climatic factors. Therefore, the water requirements of crops growing on soils with water-table depth of less then 3 m are significantly reduced. This results in considerable saving of water if proper irrigation and crop management practices are followed. Thus the saving of water can be utilized for increasing the cropping intensity or bringing more area under cultivation.

There are vast areas where groundwater is within 0.0-1.5 metre and 1.5-3.0 metre below the natural soil surface. In the Indus plain gross area under irrigation command is about 16.6 Mha. According to water-table appraisal carried out by WAPDA in April/June 1990, in 13 percent of the gross area, water-table is within 1.5 metre and in 36 percent area water-table is within 1.5-3.0 metre. The province wise distribution of high water-table condition is presented in Table 3.

Table 3: *Depth of Water-table in the Indus Plain Irrigation Command Area*

Province	*Depth of Water-table*			
	0.0-1.5 m		*1.5-3.0 m*	
	Area (Mha)	*%*	*Area (Mha)*	*%*
Punjab	0.710	7	2	24
Sindh	1.348	23	3.434	60
Balochistan	0.093	23	0.07	19
NWFP	0.049	9	0.176	24
Pakistan	2.200	13	6.028	36

Source: Riaz (2001).

2.3 Evapotranspiration for Various Crops

Evaporation of water from the surface of the plants and the adjacent soil is often termed as evapotranspiration or consumptive use of water. It is the total quantity of water consumed by evaporation and transpiration.

The Consumptive use mainly depends on:

- *The Climate:* In hot climate, crop need more water per day than in a cold climate.
- *The Crop Type:* Crop like rice or sugarcane need more water than crop like Sorghum or millet.
- *The Growth Stage of the Crop:* Fully grown crop need more water then they just have been planted.

The major climatic factors, which influence the crop water requirements are: (i) sunshine; (ii) temperature; (iii) rainfall; (iv) humidity; and (v) wind speed.

The reference crop evapotranspiration or potential evapotranspiration (ETO) is the rate of evapotranspiration from a large area. The ETO is usually expressed in millimetres per unit time *e.g.* mm/day, mm/month or mm/season. The average daily potential evapotranspiration of different locations in Pakistan is shown in Figure 1.

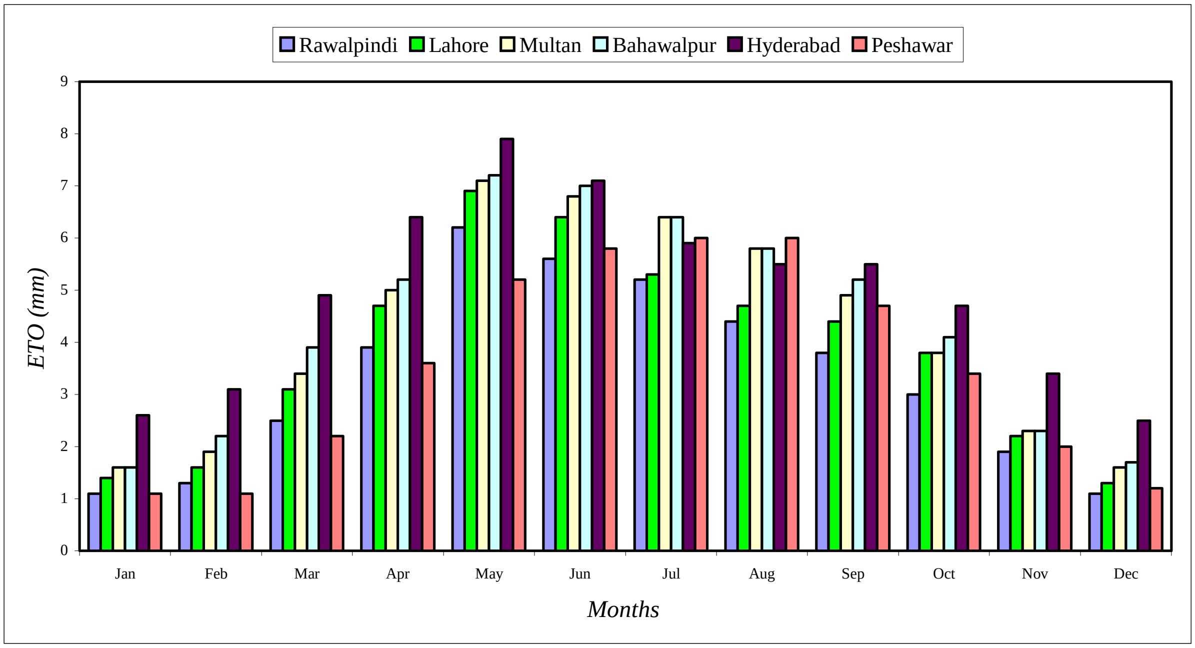

Figure 1: *Average Daily Potential Evapotranspiration of Different Locations in Pakistan*

Evapotranspiration (ET) is one of the most basic components of the hydrologic cycle. Consumptive use includes evaporation of water from land and water surfaces and transpiration by vegetation. As the water retained in plant tissues is minor relative to the amount used in ET, both the terms are used for the same meaning (Jensen *et al*., 1990). Rate of evapotranspiration under different evaporative conditions is actively governed by the moisture status of the soil. A reduction in rate of evapotranspiration occurs due to primarily increased diffusive resistance in the path of evaporating water. Relative decrease in evapotranspiration with respect to lowering of soil moisture contents is generally expressed as a ratio ET/EP. Many workers have drawn relationship between ET/EP and available soil water. Veihmeyer and Hendrickson (1955), and Pierce (1958), presented different forms of this relationship showing a regular decrease in the ratio ET/EP as soil moisture tension increases.

The potential requirements of the above crops from North to South of the basin are shown in Table 4.

Table 4: *Potential Water Requirement*

Sr.No	*Crop*	*Potential Requirement Range (mm)*
1	Wheat	271-515
2	Cotton	627-1161
3	Sugarcane	1278-1887
4	Rice	587-1323
5	Maize	289-367
6	Sorghum	370-537

The potential requirement for the wheat, cotton, sugarcane, rice, maize and sorghum have the variation of 52%, 54%, 68%, 44%, 79% and 69% respectively.

CHAPTER 3

3. MATERIAL AND METHODS

Lysimeter is the name of an experimental arrangement drawn from a Greek word '*Lysi*'; meaning 'water'. Lysimeters have been used for over 300 years to study the relations between soil, water and plant. The use of lysimeters has been extended to other scientific fields, for example to quantitative and qualitative studies of the leaching from waste products or contaminated soils in order to evaluate the environmental impact of these materials. Lysimeter experiments are often performed outdoor under "natural" conditions where the flow direction of the soil solution is downward. Lysimeter experiments may also be performed indoor where the formation of leachate will be due to irrigation, and in that case the flow direction can be upward as well as downward. The duration of lysimeter tests is typically one to several years.

3.1 Classification of Lysimeters

Lysimeters may be classified according to different criteria such as type of soil, block used (monolithic or reconstructed), drainage (drainage by gravity or vacuum or water). The lysimeter may be classified differently according to the criteria used. For example a zero-tension lysimeter can be performed either with an undisturbed core of test material (equal to a block lysimeter) or as a packed container of treated and homogenised test material. It may also be equipped with a water-lock to maintain a certain water-table within the lysimeter itself or in the drainage system. Some of the classifications of the lysimeters on the basis of its use are given in Table 5.

3.2 Design and Materials

Most commonly, Lysimeters are constructed with rectangular or circular surfaces, and they vary widely in sizes. A cylindrical container is often used for a "smaller" lysimeter, whereas rectangular shapes generally are more practical for very large lysimeters. Rectangular lysimeters are also recommended for studies involving crops at the surfaces of the lysimeters due to the row crop geometry. In general the size of the lysimeter should be chosen keeping in mind that the results of the lysimeter tests must be representative for the material investigated. This means that if the material is very heterogeneous or if the particle size is large the lysimeter must be large enough to contain a representative sample of the material.

3.3 Lysimeters in Pakistan

Asghar (1963) initiated first lysimetric investigations in 1943-44 in the Punjab Irrigation Department by setting up glazed pipes of 10 cm diameter, built-up in segments of 0.60 metre length and erected vertically. Provision of water-table was made at the bottom. Holes were made at regular intervals at a distance of 0.3 metre feet, each which were plugged with waxed bark corks. Artificial soil profiles were built-up in these tubes and surface application was given at various experiments. Soil samples were taken through the holes in the pipes and examined for moisture distribution from time to time as required. From these experiments conclusions were made for the surface application and the actual amount of moisture present in the soil profile. Mechanical composition and dry bulk density were the two variables, which were studied for various artificially prepared soil profiles.

Table 5: *Classification of Lysimeters*

Classification	***Short Description***
According to Drainage	
Zero-tension Lysimeter	A lysimeter with freely draining leachate
Equilibrium Tension Lysimeter.	A lysimeter designed to maintain equilibrium between the suction applied to the leachate collection system and soil matrix potential thus the suction applied may varies.
According to Packing of Test Material	
Block lysimeter	An undisturbed soil core is excavated and a casing is constructed around the block. Leachates can be collected with or without applying suction.
Ebermayer lysimeter (*In situ* lysimeter with no side walls separating a definitive soil block from adjacent soil).	Leachates can be collected with or without suction.
Filled-in lysimeter method	The test material is collected and potentially pre-treated, for example by homogenisation, before being filled into the lysimeter container. Leachates can be collected with or without applying suction.
According to Methods of Measuring Water Content	
Weighing lysimeter	The lysimeter is either placed directly on weighing equipment or can be moved and placed on weighing equipment periodically. This means that the lysimeter can be weighed constantly or periodically.
Non-weighing lysimeter	Lysimeters without weighing equipment available. This category falls potentially under any other category described in the table except from weighing lysimeter.

Source: Hansen *et al.* (2000).

3.4 Design of Lysimeter and Soil Profile

Pakistan Council of Research in Water Resources initiated a lysimeter research programme with the collaboration of Punjab Irrigation Department in the early 1970's. Eighteen large size concrete lysimeters of the size 3.05 m x 3.05 m and 6.1 metre deep were constructed. The layout of the lysimeters is shown in Figure 2.

All the lysimeters after their construction were first coated with bitumen and then tested for their imperviousness. When there were no signs of leakage, these lysimeters were filled with soil profile. The soil profile consists of two horizons. The horizons at the top are of silt loam texture extending from surface to 4.3 metres depth. The bottom horizon is 0.9 m thick and is of loamy fine sand. A 0.9 m thick calcareous graded gravel filter is provided at the bottom of each lysimeter to facilitate the flow of water into and out of the lysimeters (Figure 2). The mechanical analysis of the soil filled in the lysimeter is given in Table 6. A view of crop grown in lysimeter is shown in Figure 3.

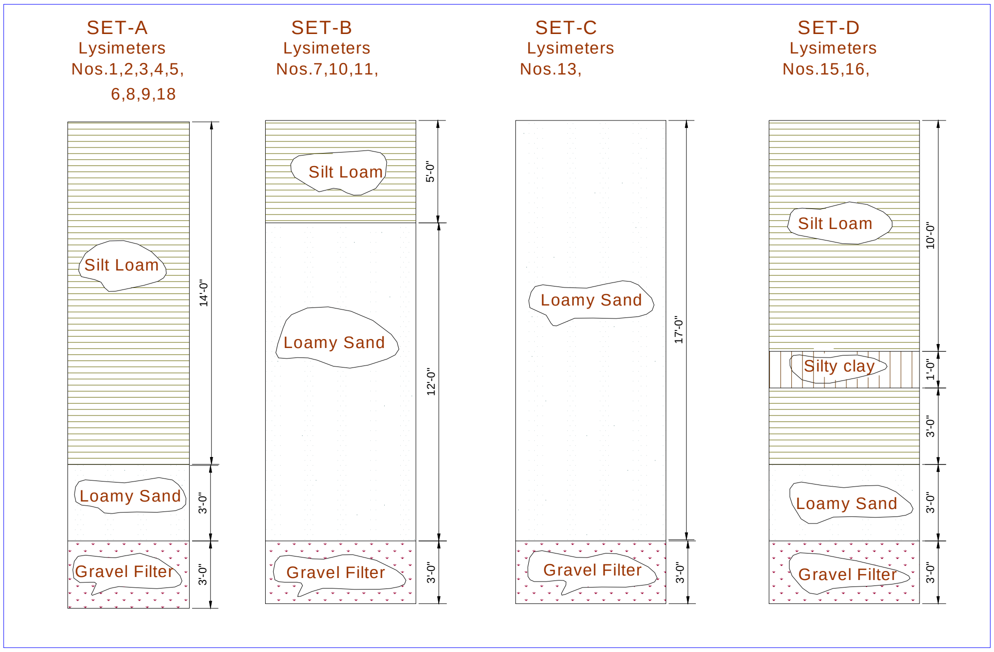

Figure 2: *Layout Plan of the Lysimeters at Lahore*

Figure 3: *A View of Crop Grown in Lysimeter*

Table 6: *Mechanical Analysis of Soil Profile*

Depth (m)	*Percentage of Soil Fractions*			
	Sand (%)	*Silt (%)*	*Clay (%)*	*Classification*
0.0-4.3	17	70	13	Silt loam
4.3-5.2	84	12	4	Loamy fine sand

Soil was compacted to bring it as close as possible to the natural field conditions. The soil was filled in steps in the lysimeters to form a compacted layer of about 8 cm thickness at each time. The stratification of soil was avoided by scratching the surface of the each compacted layer before filling next layer. After completion of soil filling, the soil profiles in the lysimeters were saturated and drained twice by raising and lowering the water-table from the bottom to attain a soil bulk density from 1.45-1.48 gm cm^{-3}.

3.5 Measuring Devices

3.5.1 *Water-table Maintenance*

The water-table at different depths was maintained using Mariotte Bottles. The Mariotte Bottle consists of about 16 litre capacity glass bottle having a tight two hole rubber cork fitted in its mouth. Two-glass tubing of 2 mm dia were passed through the cork as shown in the Figure 4. The upper end of one glass tube was opened to atmosphere and that of the second one connected to the inlet pipe of the lysimeter with rubber tubing. The water-table in the lysimeter adjusts itself at the level of bottom end of the glass tube opened to atmosphere. The water in the bottle above this level function as reservoir for the supply of water to the lysimeter as and when required. Whatever the amount of water is taken up from the groundwater in the lysimeter due to evapotranspiration is replenished from the Mariotte Bottle. This immediate supply of water from the bottle keeps the water-table at a constant level at all times. The bottles were placed on the wooden boards fixed along the walls of the lysimeters at the desired elevations.

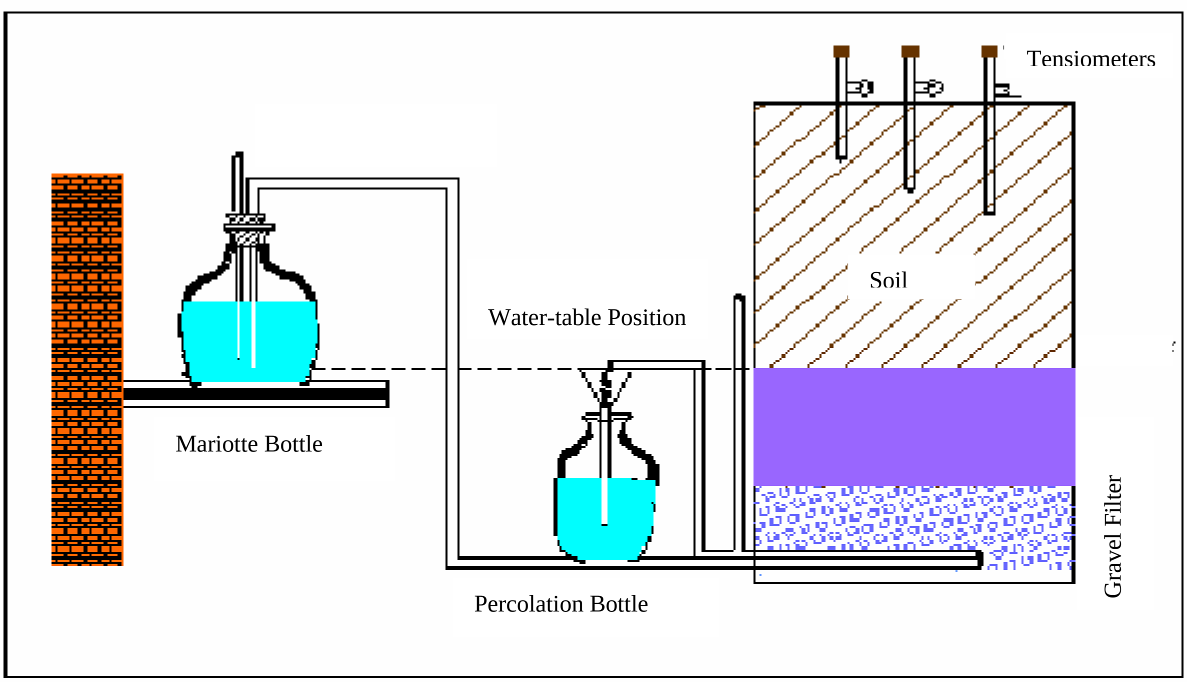

Figure 4: *Apparatus for the Measurement of Sub-irrigation and Drainage Surplus*

3.5.2 *Sub-Irrigation*

The amount of subirrigation *i.e*. the groundwater contribution was calculated from the daily loss of water from the Mariotte bottles connected to the lysimeters having different water-table conditions. The volume of the water taken up by the lysimeter was measured in litres but was converted to the units of length by multiplying with the surface area of the lysimeter. The calculated value of groundwater contribution (capillary rise) depends on the value of ET and water-table depth. Upward flow from the water-table is the contribution of water to crops. Upward flow is calculated as the difference between the total ET and the sum of the soil water depletion (SWD) and stored irrigation water (SIW). Stored irrigation water is calculated from the soil moisture data taken before and after irrigation with adjustments to account for crop water use during the interval between the measurements.

3.5.3 *Drainable Surplus*

Drainable surplus *i.e.* the amount of water percolated deep into the subsoil water was measured through a rubber tubing of 2 mm dia connected to an outlet pipe fitted at the bottom of each lysimeter (Figure 5). The open end of the tube was raised along the outer wall of the lysimeter to its water-table level. Percolation storage bottles were placed just below the raised open ends of the attached rubber tubing. The seepage water from surface irrigation or rainfall, if any, escaped from the bottom of lysimeter and was collected in the percolation storage bottles. The volume of the drainable surplus was also converted to the units of length.

Figure 5: *Collection of Drainable Surplus*

3.5.4 *Monitoring Soil Moisture and Scheduling of Surface Irrigation*

Soil moisture in the root zone was monitored daily by recording soil moisture tensions from the tensiometers and through the use of gypsum blocks. Two tensiometers were installed in each lysimeter at 20 cm and 50 cm depth. The gypsum blocks were embedded in the soil at 20, 50, 100, 150 and 200 cm depth.

3.5.5 *Measurement of Soil Moisture Tension by Using Tensiometer*

Tensiometer essentially consists of rigid glass or plastic tube sealed at the bottom and by a ceramic porous cup and the other end connected to a mercury manometer. The tensiometer can be used reliably up to 0.85 bars of soil suction (Figure 6). The range is very limited but according to the soil characteristic curve, most of the available water is used below this level of tension in the range of optimum growth for most crops.

Scheduling of irrigation on the basis of soil moisture tension depends on crop, soil, water-table depth, and climatic conditions. The irrigation to the crop under experiment was however, given when the soil moisture tension reached 0.60-0.65 bar. A few days before harvesting, when the irrigation was stopped, the soil moisture tension increased above the working range of tensiometers and readings at that stage were discarded. All the observations of soil moisture tension were plotted immediately on a chart showing daily variations with respect to the growth period. The chart lines showed not only the past history but also enabled to predict the irrigation timing for planning and preparation for the next irrigation. All the tensiometers worked quite satisfactorily up to the time of maturity. Occasionally when the tensiometers were under operation, air diffused into the tensiometers through the tensiometer cups particularly at a time of high soil moisture tension. The diffused air was removed immediately as soon as air bubbles were seen in the tensiometers.

Figure 6: *Tensiometers Installed in the Lysimeter*

3.5.6 *Measurement of Soil Moisture Tension with Gypsum Blocks*

Soil moisture tension was also measured by using gypsum blocks. All the blocks were calibrated with the pressure membrane apparatus before their use in the lysimeter. The blocks were saturated in water and then placed in the holes at 20, 30, 50, 100, 150 and 200 cm depths in each lysimeter. The measurements of the electrical resistance of the moisture blocks were made by connecting their leads to the resistivity bridge through the switching box placed at one side of each lysimeter. Electrical resistance given by the meter was converted to soil moisture tensions from the calibration charts showing the moisture tensions in relation to the electrical resistance of the respective moisture block.

3.5.7 *Moisture-Retention Curve*

The soil moisture retention curve shows the volume of water retained by soil at different soil moisture tensions from saturation to air dryness. The curve is useful in estimating the available water, pore size distribution and capillary fringe *etc*. In addition, knowing the soil moisture tension, volume of water in the root zone at any time can fairly be estimated from this curve without disturbing the soil column. For practical purpose two points on the curve against 1/3 bar and 15 bar tensions are important to estimate available moisture for the plants. Soil moisture-retention curve up to 1 bar tension was determined in the temp cell by weighing the complete cell at pressure equilibrium points. Pressure plate apparatus was used to determine moisture retention curve from 1-15 bar tension. Figure 7 shows moisture retention curve of the lysimeter for silty loam soil.

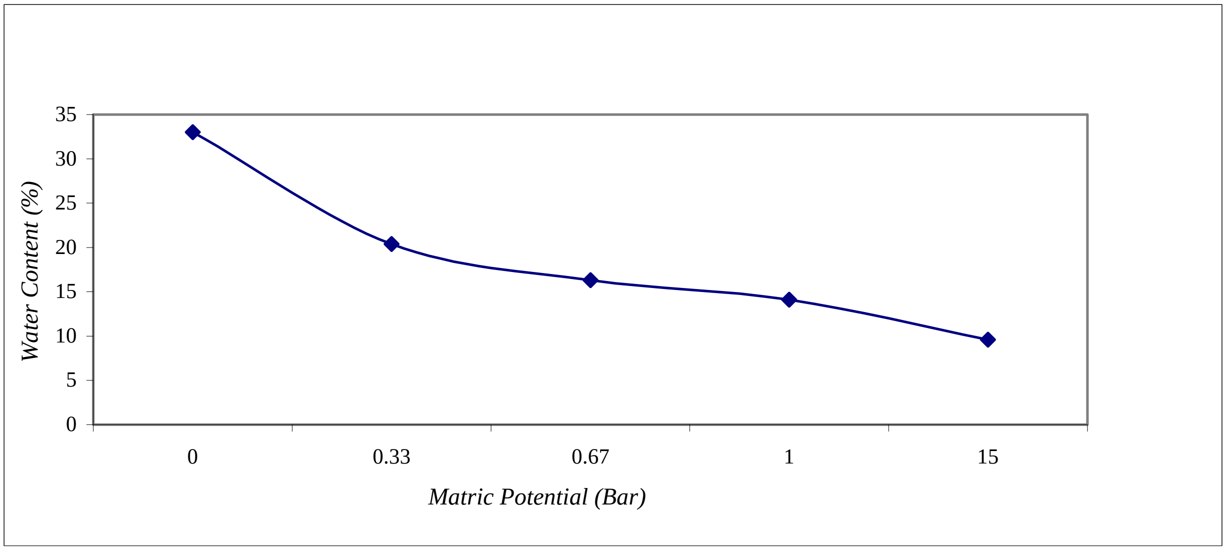

Figure 7: *Moisture-Retention Curve*

3.5.8 *Electrical Conductivity of Saturation Extracts*

Electrical conductivities of the saturation extracts of soil samples were determined before and after crop for the appraisal of soil salinity build up in the root zone under different water-table conditions. The soil samples were taken from 0-5, 5-15, 15-30, 30-45, 45-60 and 90 cm depths. The measurements of the conductivities of the saturation extracts were made with Backman Electrical Conductivity Bridge. The method of soil moisture extraction was used as described in the U.S. Salinity Hand Book 60.

3.5.9 *Meteorological Observations*

The meteorological data were regularly collected at the site using standard instruments. These data included maximum and minimum temperature, relative humidity, wind speed, pan evaporation and rainfall. Sunshine hour data were collected from the Meteorological Department, Lahore.

3.5.10 *Crops and Crop Husbandry Practices*

Wheat, maize, sugarcane, sunflower, berseem, sorghum and rice crops were studied in the lysimeters. Chemical Fertilizers such as nitrogen, phosphorous and potassium were applied in the form of Di-ammonium Phosphate (DAP) and other cultural practices were followed according to general recommendations of the agriculture department. Pesticides and insecticides were also used necessary. Pre-irrigation of about 7.5 cm for the seed bed preparation was applied to all the lysimeters. The crops were protected from diseases by applying suitable pesticides/insecticides.

3.5.11 *Computation of Evapotranspiration of Crops and Crop Coefficient*

Actual evapotranspiration of the crop was computed using water balance equation:

$$ET = I + S + R - D \pm \Delta SM$$

where ET represents evapotranspiration, I, S, R, D, and ΔSM denote irrigation, subirrigation (groundwater contribution), rainfall, drainage surplus and changes in soil moisture storage, respectively. Crop coefficients have been worked out using Blaney-Criddle and Modified Penman Method.

CHAPTER 4

4. RESULTS AND DISCUSSIONS

4.1 Effect of Different Water-table Depths on Surface Irrigation Requirements of Crops

Over irrigation can lead to excessive water loss through high rate of evapotranspiration and excessive water seepage/percolation can also cause severe drainage problems like water logging *etc.* Where water-table is shallow, the surface irrigation requirements can be reduced significantly. However, groundwater contribution to crop consumptive use depends mainly upon soil type, crop root system and water-table depth.

The surface irrigation requirements of crops with respect to different water-table depths have been presented in Figures 8 to 13. It is obvious from these figures that, for wheat and maize, one irrigation of 7.5 cm may be sufficient to get successful crops if water-table is situated within 1 m depth. However, with an increase in water-table depth, surface irrigation requirements increase. This is mainly due to the fact that at shallower water-table depths groundwater contribution is higher which consequently reduce the surface irrigation requirements. It can also be noted that all water demands of the crops has to be supplied from surface irrigation if water-table is situated at 3 m depth or beyond.

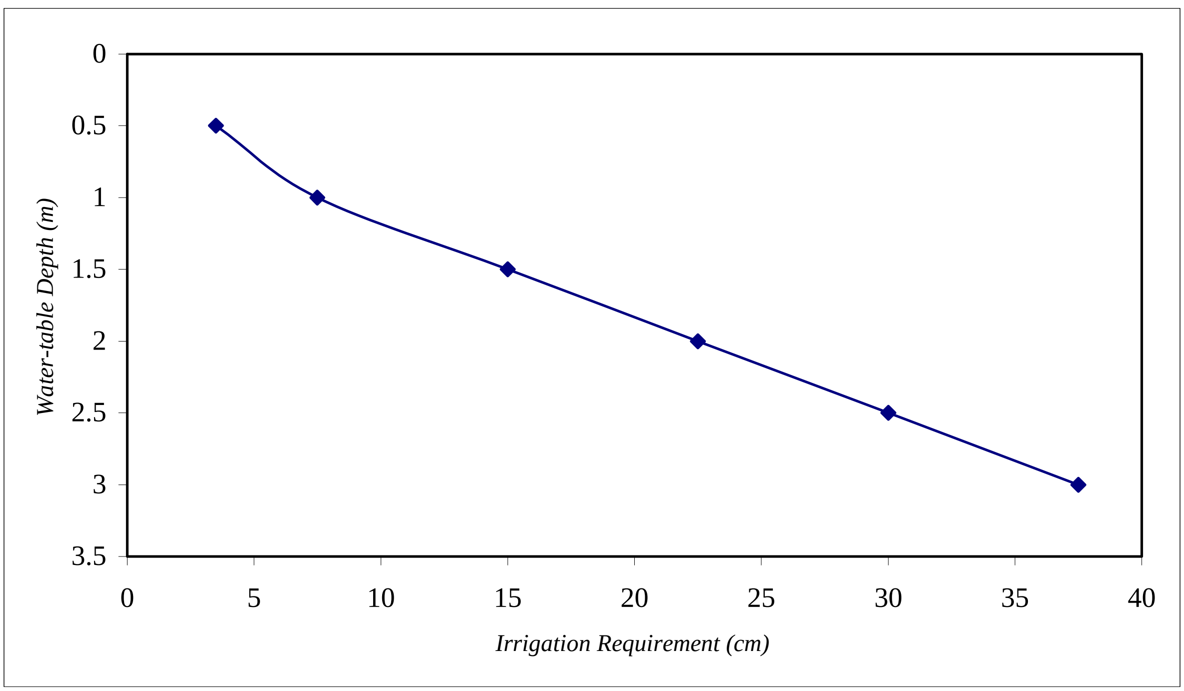

Figure 8: *Irrigation Requirement as a Function of Water-table Depth for Wheat*

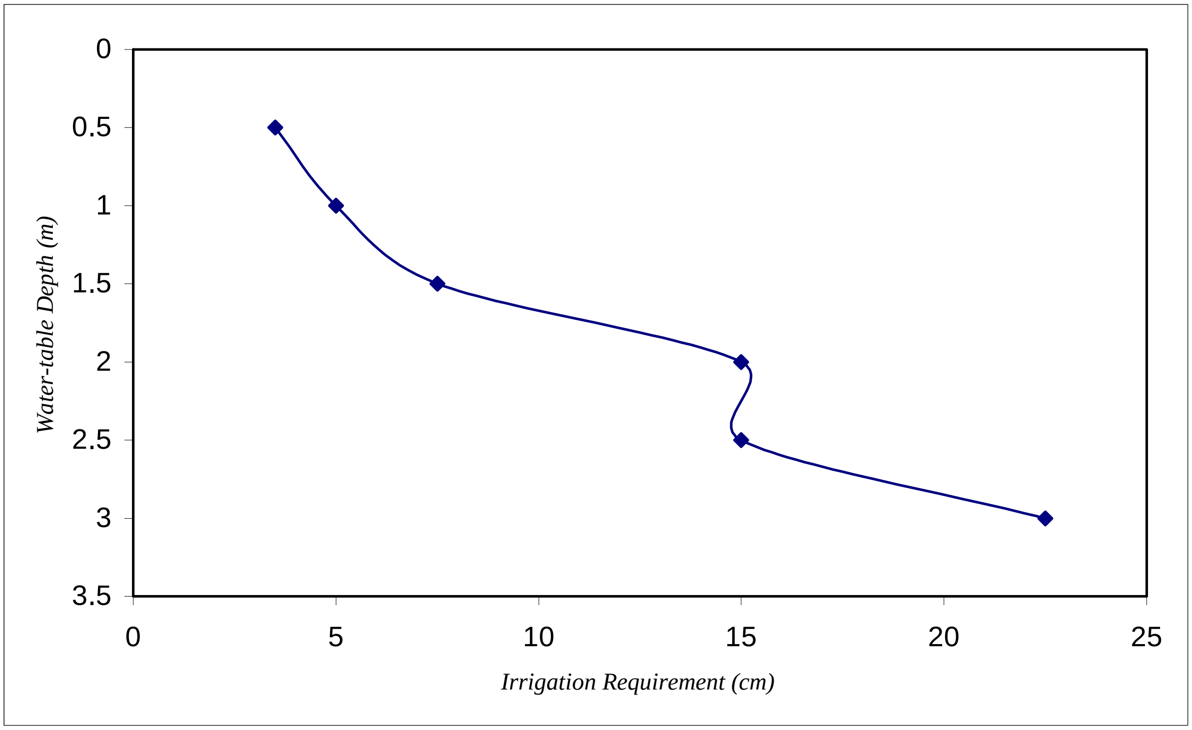

Figure 9: *Irrigation Requirement as a Function of Water-table Depth for Maize*

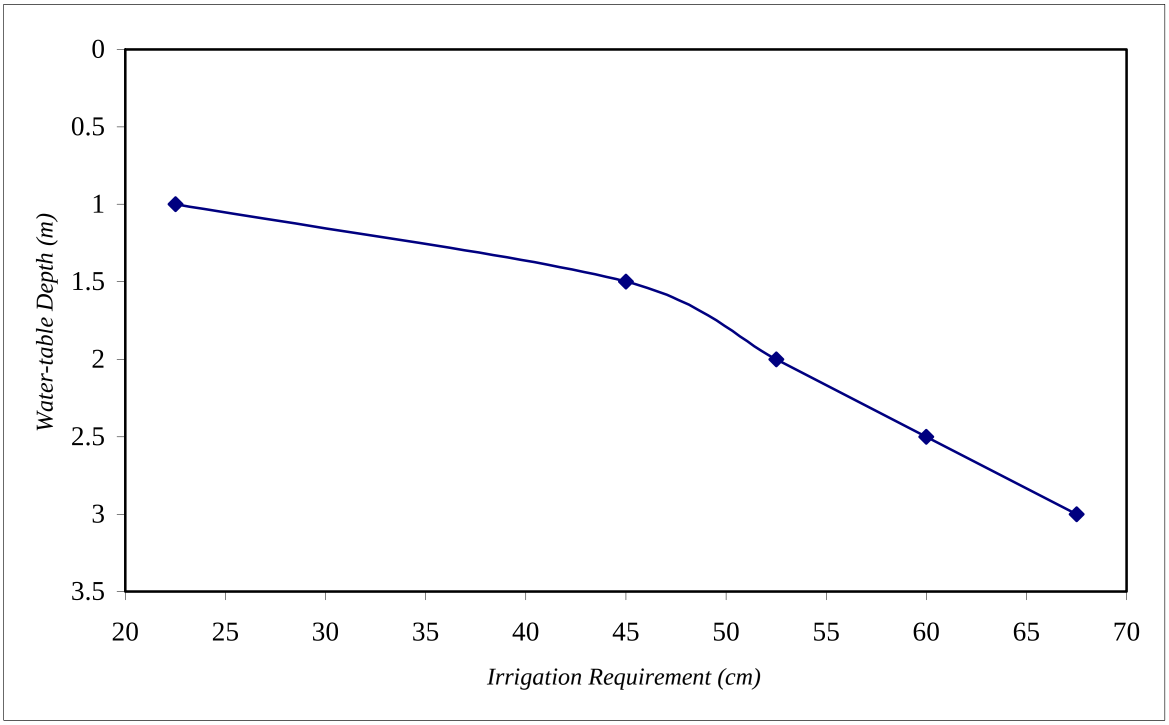

Figure 10: *Irrigation Requirement as a Function of Water-table Depth for Sugarcane*

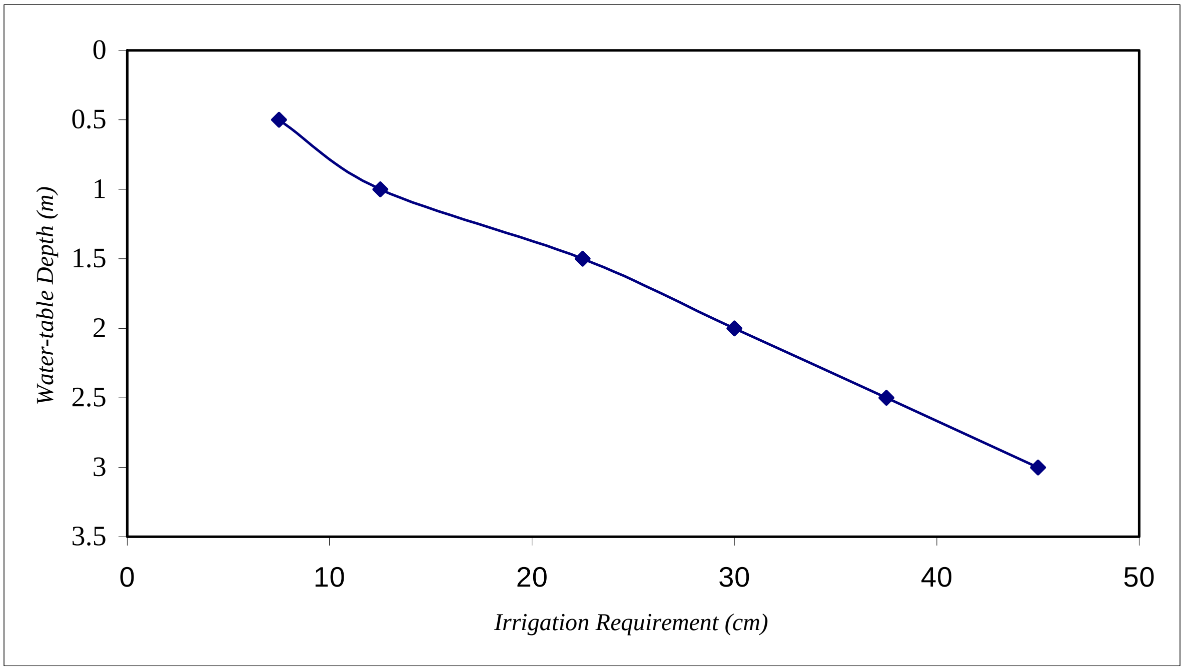

Figure 11: *Irrigation Requirement as a Function of Water-table Depth for Sunflower*

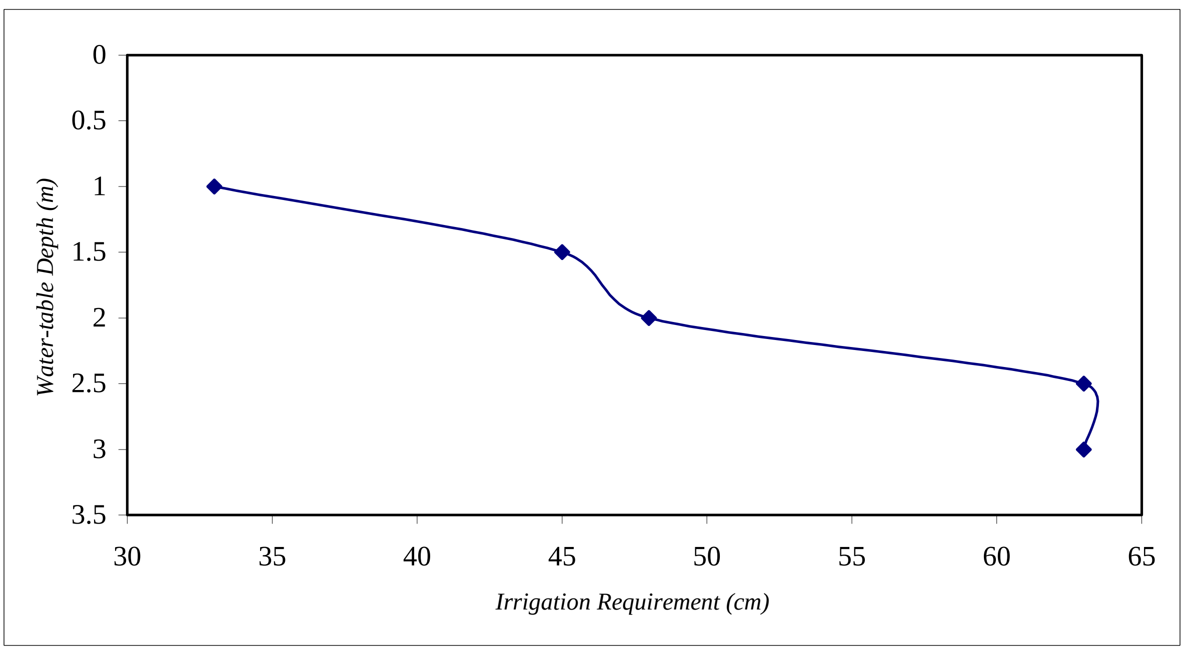

Figure 12: *Irrigation Requirement as a Function of Water-table Depth for Berseem*

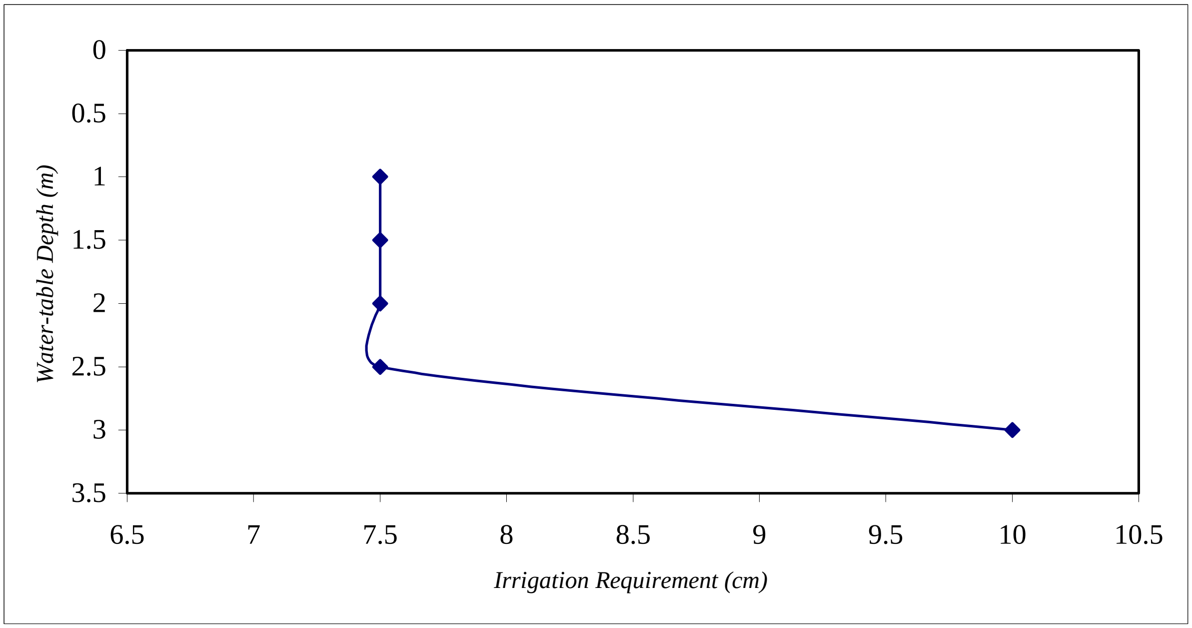

Figure 13: *Irrigation Requirement as a Function of Water-table Depth for Sorghum*

Figure 8 to 13 also show surface irrigation requirements decrease almost in a linear fashion with an increase in water-table for all the crops except for sorghum. Moreover, sugarcane and berseem have almost the same irrigation requirement under the same water-table depth. Figure 15 also shows that sugarcane extracted maximum water at 1.0 m depth more probably due to its long roots. The irrigation requirement of sugarcane reduced drastically with decreasing water-table depth indicating that shallow water-table can contribute significantly to crop water requirement. It can also be seen that there was no effect of water-table depth on irrigation requirement of sorghum and its crop water requirement was minimum as compared to the crops studied (Figure 13). The sunflower shows similar trend of irrigation requirement as that of wheat with relatively greater magnitude (Figure 11).

The variation in surface irrigation requirements under each treatment and water-table depth, can mainly be attributed to higher upward-flow of water under drier treatment from shallow water-table and comparatively lower transpiration rate under restricted surface irrigation supplies.

4.2 Effect of Different Water-table Depths on Groundwater Contribution

Groundwater contribution, in terms of percent of total ET of the corps under different water-table conditions has been presented in Figures 14 to 19. The figures reveal that groundwater contribution was the highest under the shallowest water-table conditions, which gradually reduced with increasing water-table depth.

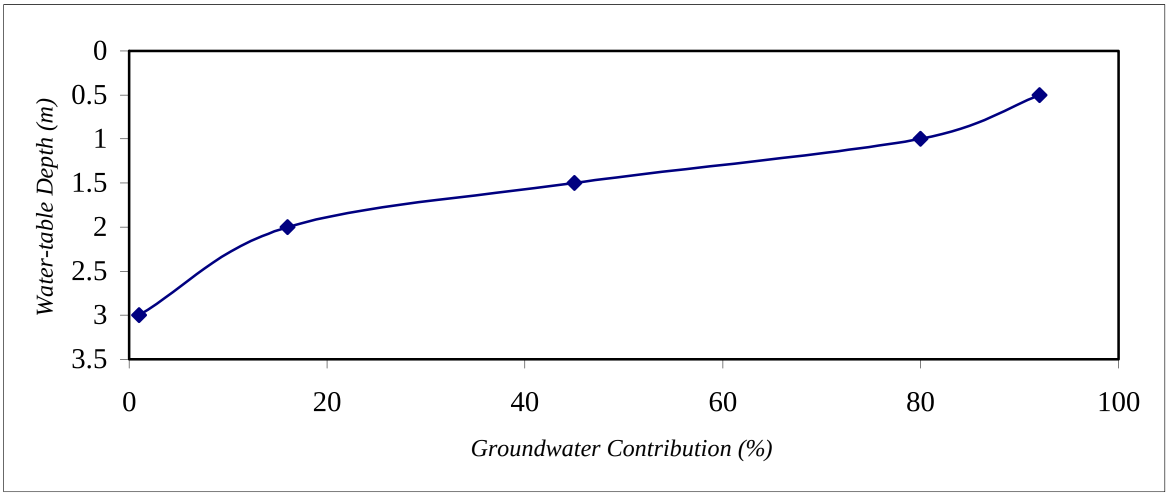

Figure 14: *Groundwater Contribution as a Function of Water-table Depth for Wheat*

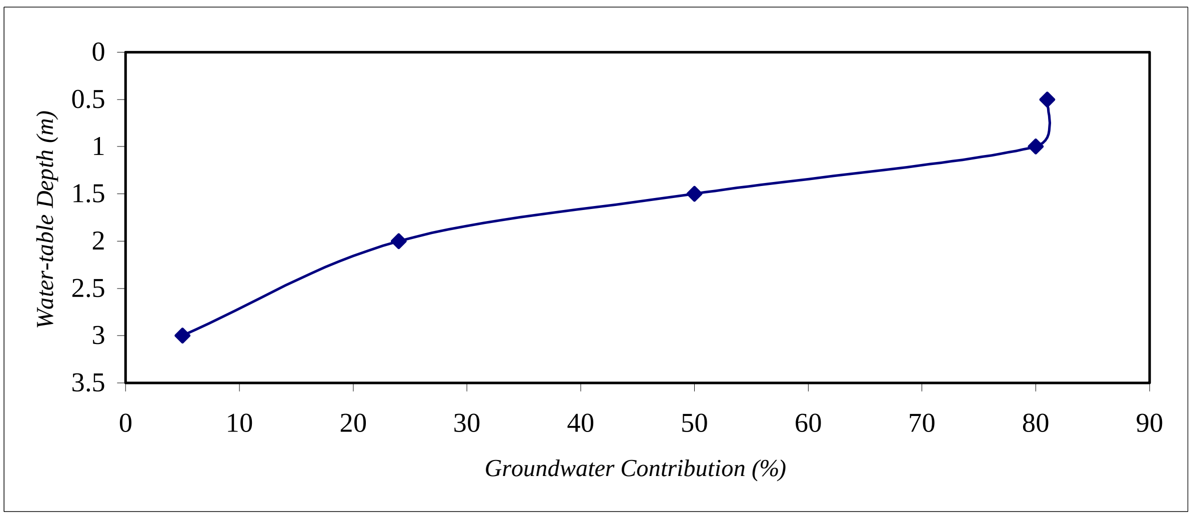

Figure 15: *Groundwater Contribution as a Function of Water-table Depth for Sunflower*

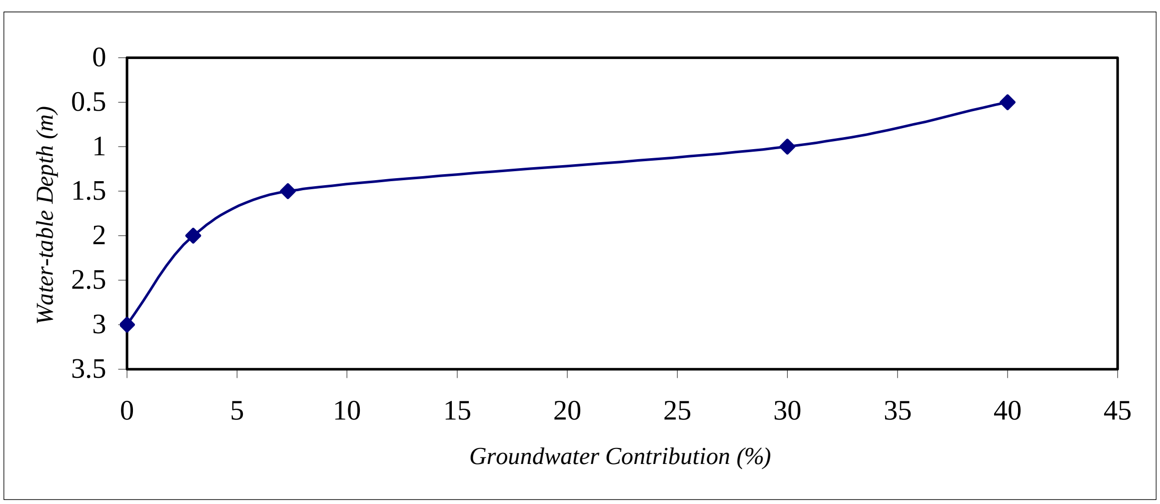

Figure 16: *Groundwater Contribution as a Function of Water-table Depth for Maize*

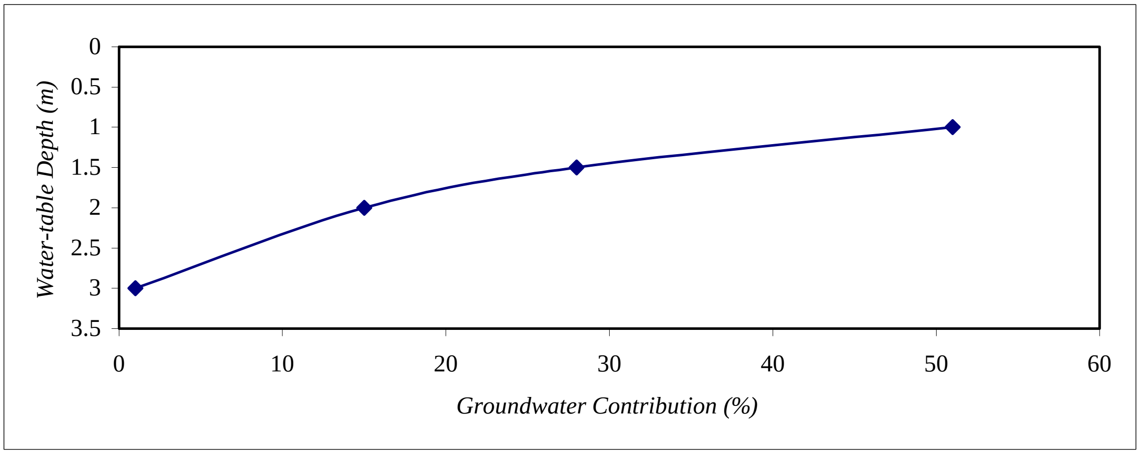

Figure 17: *Groundwater Contribution as a Function of Water-table Depth for Sugarcane*

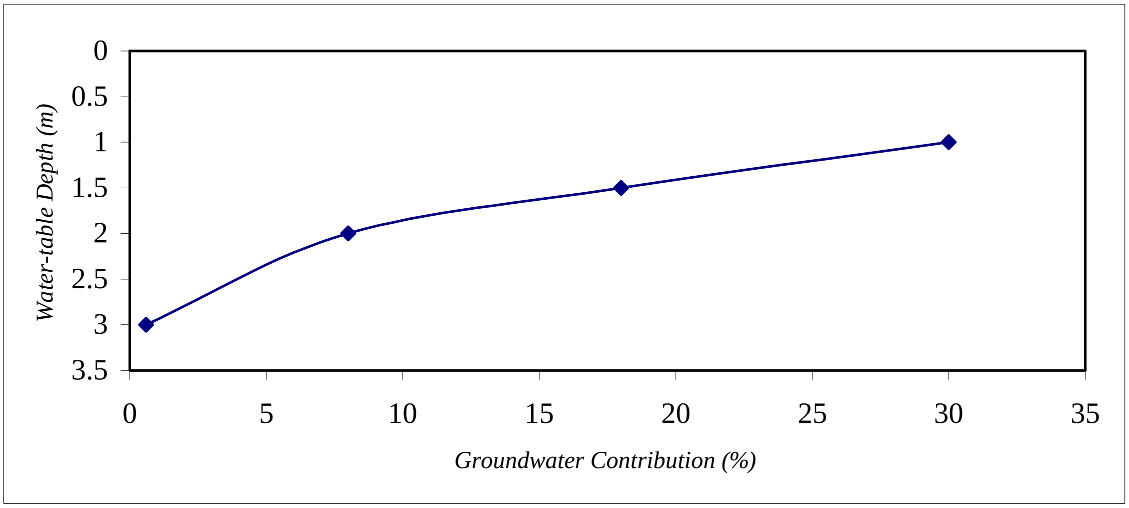

Figure 18: *Groundwater Contribution as a Function of Water-table Depth for Berseem*

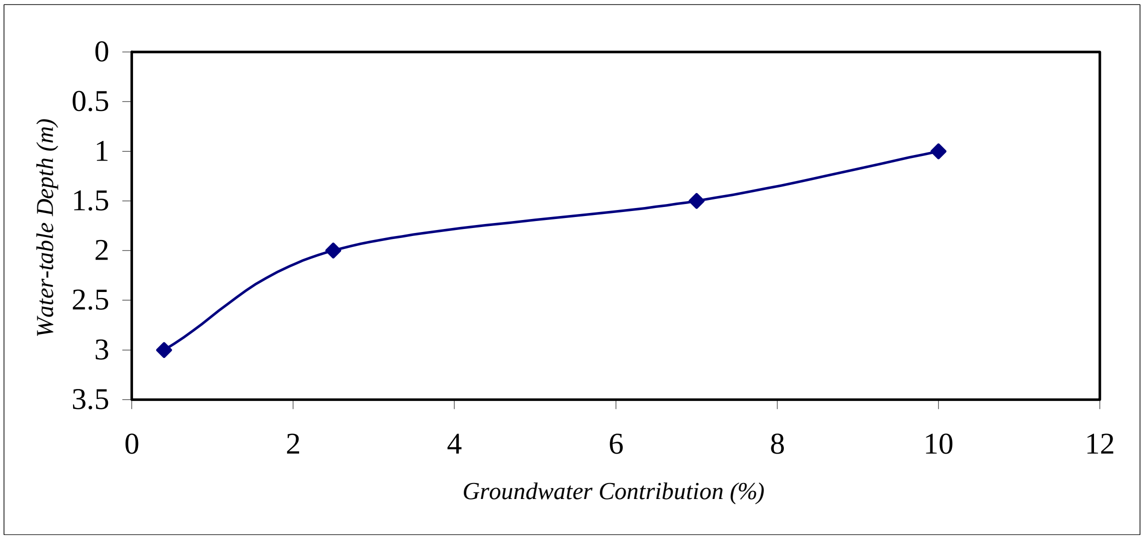

Figure 19: *Groundwater Contribution as a Function of Water-table Depth for Sorghum*

Maximum groundwater has been taken up by wheat *i.e.* more than 90% at a water-table depth of 0.5 m followed by sunflower that fulfilled more than 80% of its requirement for the groundwater. Asad (2001) also concluded that high wheat yield could be obtained with 1-2 irrigations of 75 cm each with water-table of 1-2 m depth. Maize showed maximum groundwater contribution of about 40% at the same depth. Sugarcane and berseem extracted maximum water from 1.0 m depth and the groundwater contribution was 50 and 30%, respectively. However, for Sugarcane groundwater contribution could not be determined at 0.5 m depth. Sorghum showed little interest in extracting groundwater *i.e.* only 10% at 1.0 m depth. With increase in water-table depth, the groundwater contribution decreased in all crops with different magnitudes.

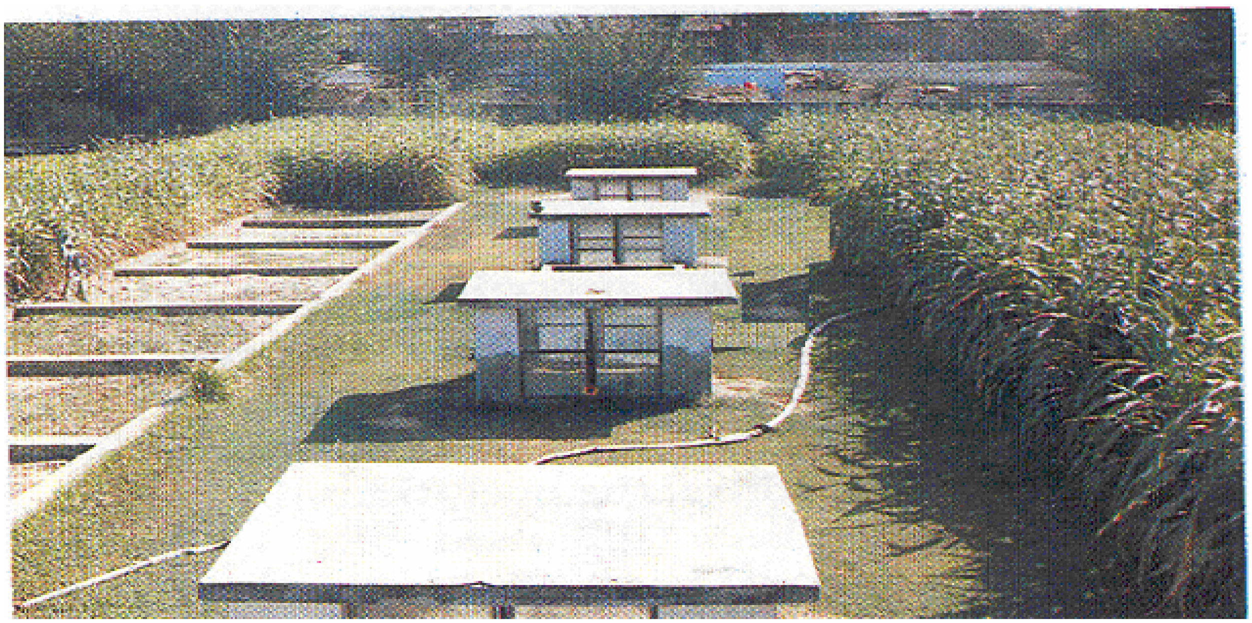

Figure 20: *A View of the Lysimeters at Lahore*

4.3 Effect of Different Water-table Depths on Evapotranspiration by Crops

Figures 21 to 26 show evapotranspiration as a function of water-table depth for various crops. It can be seen that evapotranspiration was the highest at 0.5 m water-table depth for wheat, sunflower, berseem and sorghum. It slightly decreased with increase in water-table depth and attained a minimum value at about 1.50 m depth. With further lowering of water-table there was slightly increasing trend. This observation can be explained on the basis of the fact that with increase in water-table, the water contents in the top layers remain high due to capillary flux causing high evaporative flux from the soil surface and lavish transpiration by the plants. In case of comparatively deep water-table conditions, the capillary action does not extend up to the soil surface. Therefore, due to the drying of the soil surface, the evaporation from the soil surface and plant transpiration decreased. However, in case of very deep water-tables, where surface irrigation requirements are significantly high, evaporation and transpiration losses are also high in the period when the soil surface is very wet after irrigation. Being an annual crop, the ET of sugarcane was maximum (more than 150 cm) whereas, the ET of sorghum was minimum (less than 35 cm). Maize showed almost reversed trend. With an increased water-table depth, its ET also increased.

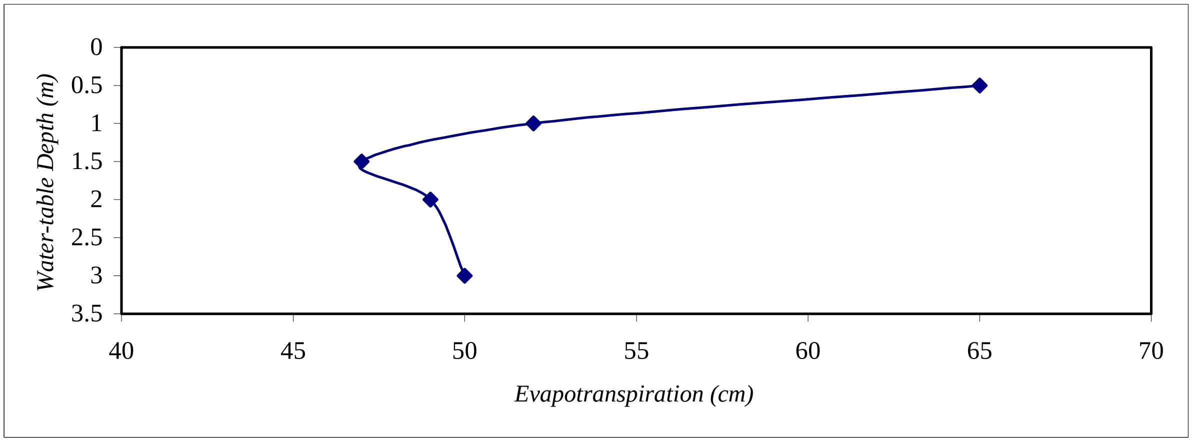

Figure 21: *Effect of Water-table Depth on Evapotranspiration for Wheat*

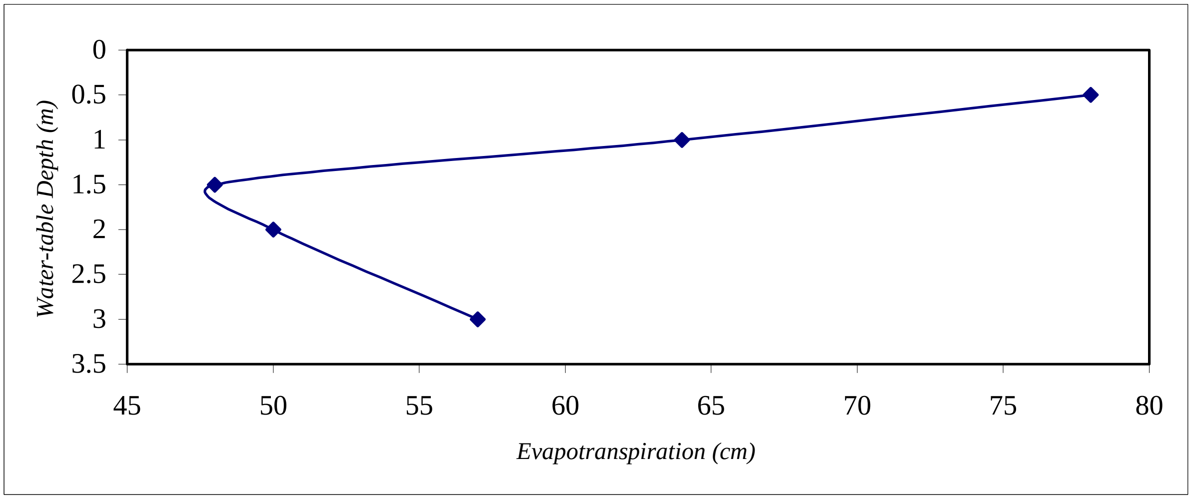

Figure 22: *Effect of Water-table Depth on Evapotranspiration for Sunflower*

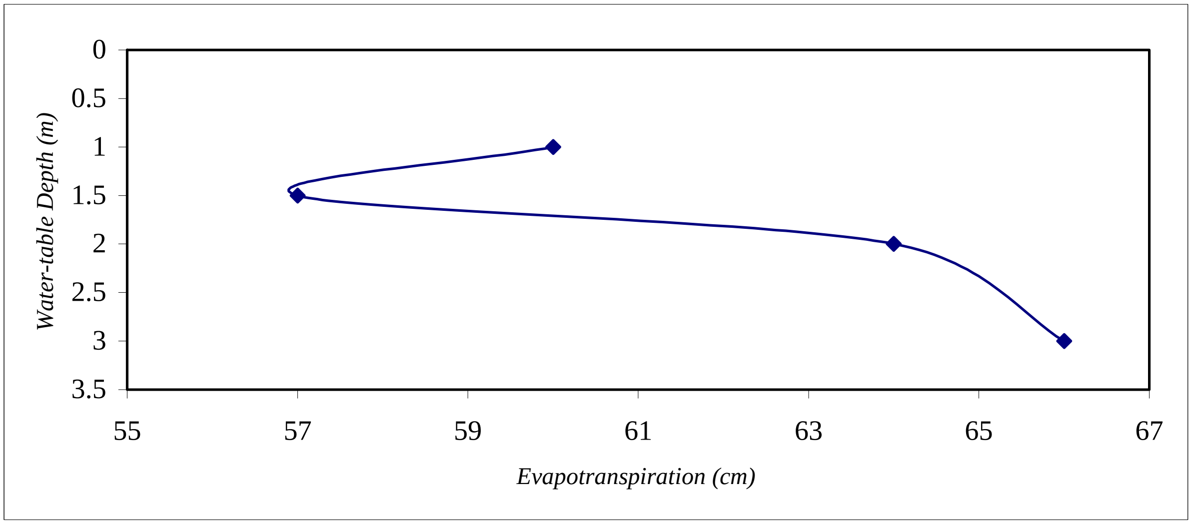

Figure 23: *Effect of Water-table Depth on Evapotranspiration for Berseem*

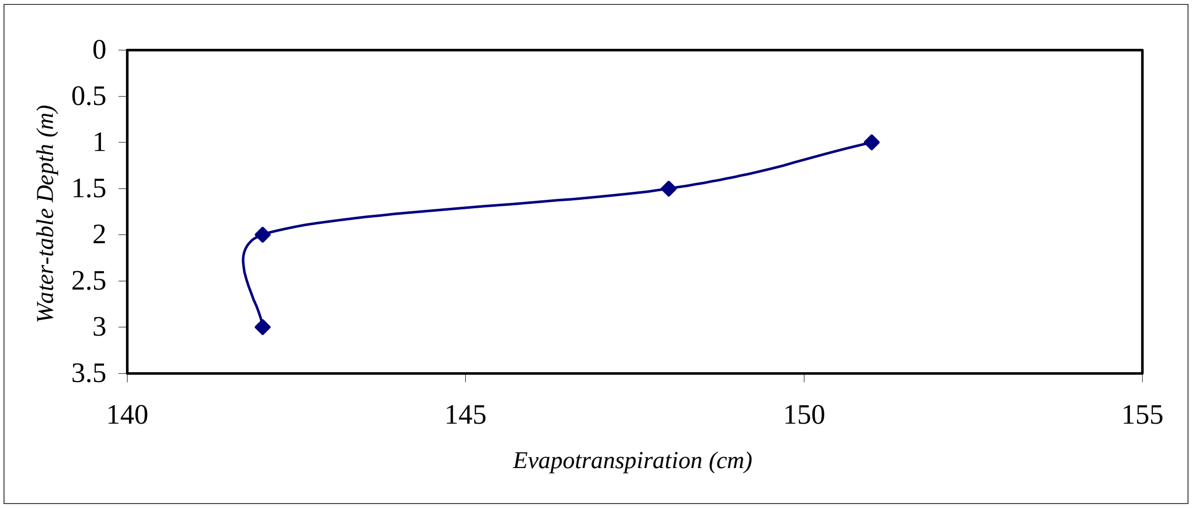

Figure 24: *Effect of Water-table Depth on Evapotranspiration for Sugarcane*

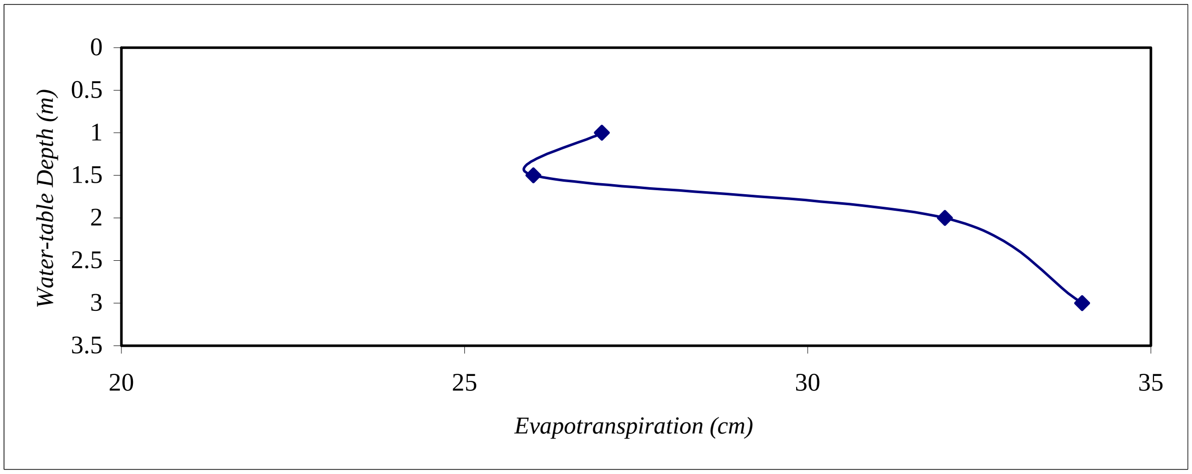

Figure 25: *Effect of Water-table Depth on Evapotranspiration for Sorghum*

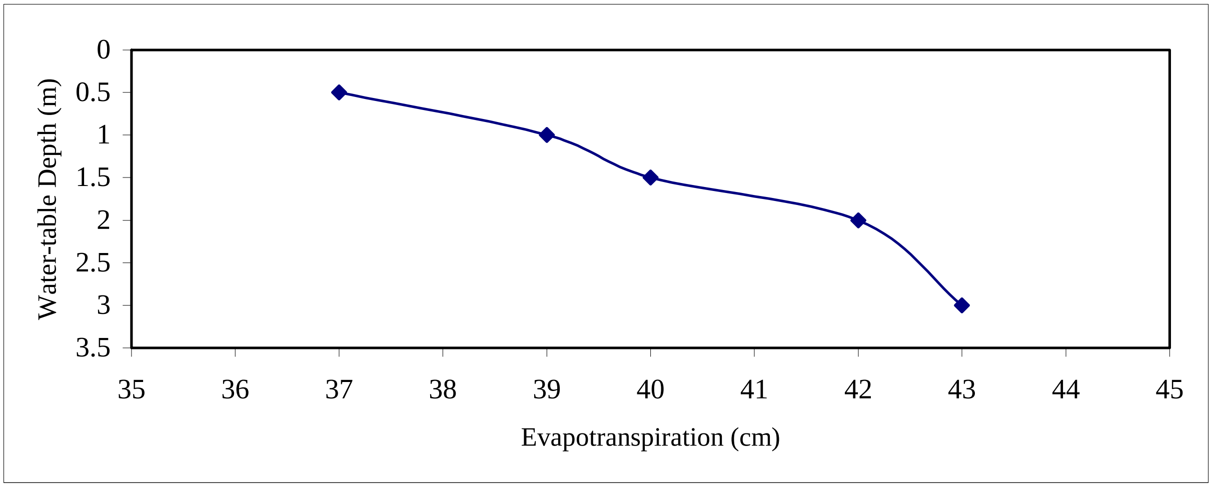

Figure 26: *Effect of Water-table Depth on Evapotranspiration for Maize*

4.4 Monthly Crop Coefficient and Evapotranspiration-Pan Evaporation (ET/EP) Ratio

The effect of crop characteristics on crop water requirements is accounted for by the crop co-efficient (Kc), which is used to relate the reference ETO to the actual crop evapotranspiration of a crop under optimum soil moisture. Monthly crop coefficients of crops with respect to different water-table conditions have been presented in Figures 27 and 28. It is obvious from these figures that, in general Kc value was the lowest in the first month, which gradually increased and attained a peak value at grain formation stage. The Kc values dropped down by about 50 to 60% at the time of crop maturity. Sugarcane had maximum Kc values during May-June and the lowest during September-October. For berseem (Figure 32) however, the Kc value increased gradually. It maintained peak value until the harvesting of crop.

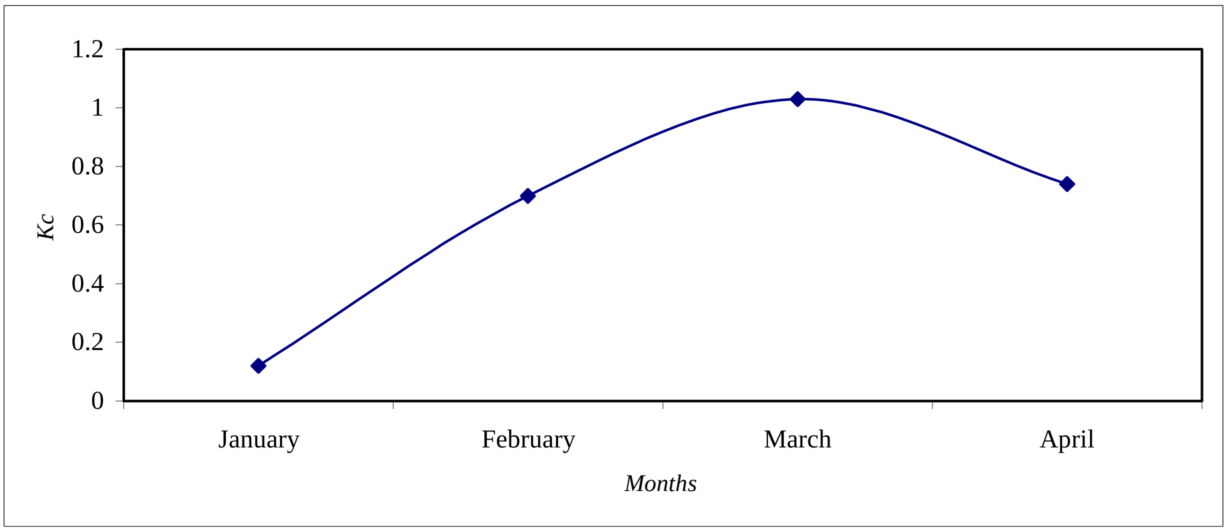

Figure 27: *Monthly Crop Co-efficient for Wheat*

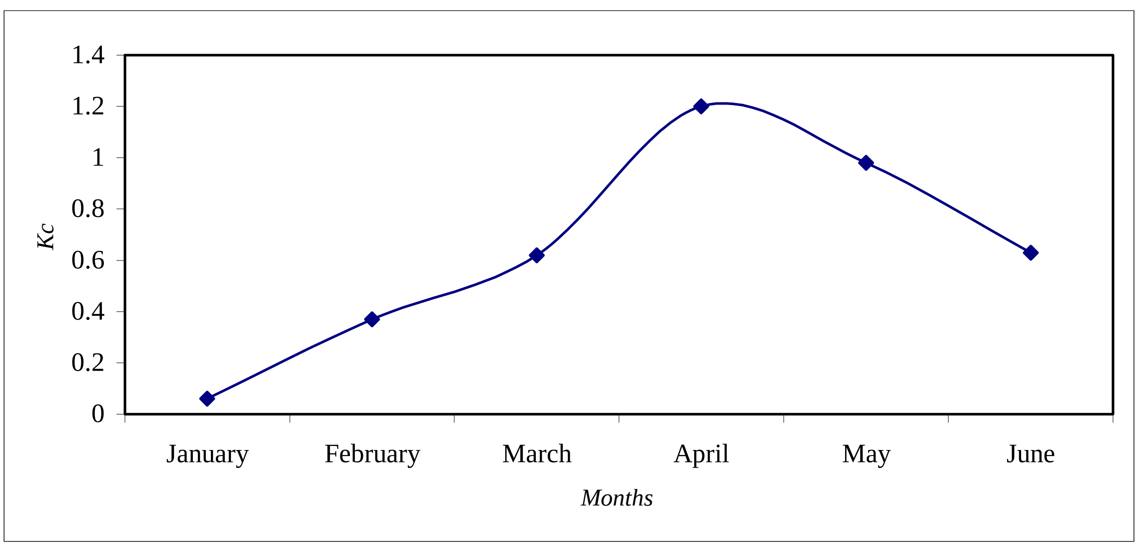

Figure 28: *Monthly Crop Co-efficient for Maize*

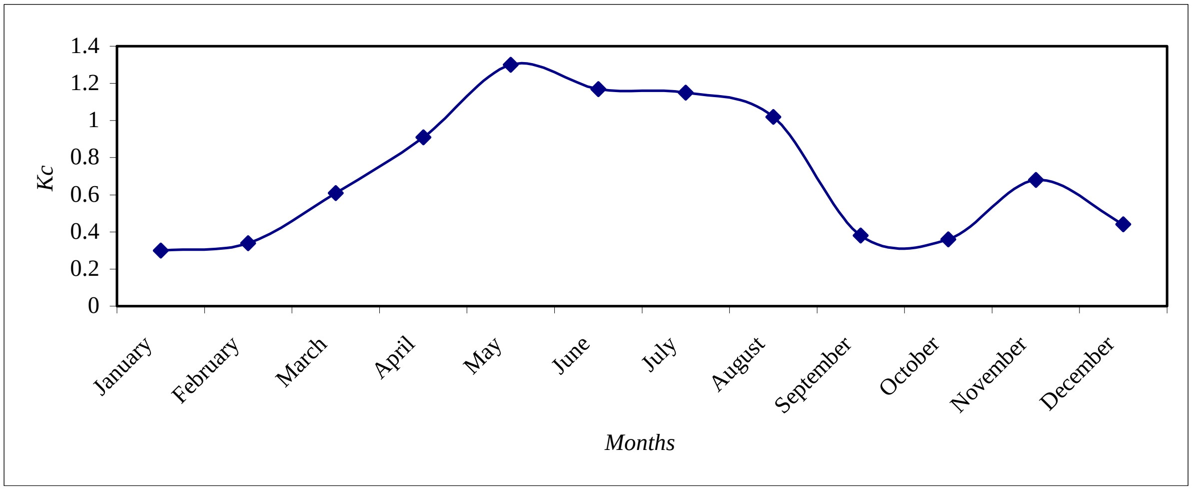

Figure 29: *Monthly Crop Co-efficient for Sugarcane*

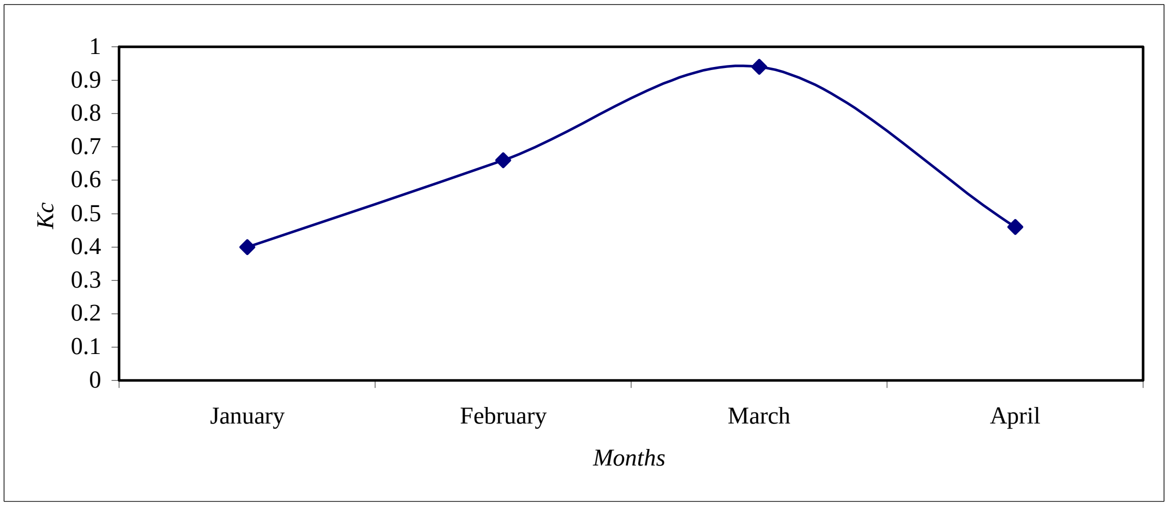

Figure 30: *Monthly Crop Co-efficient for Sunflower*

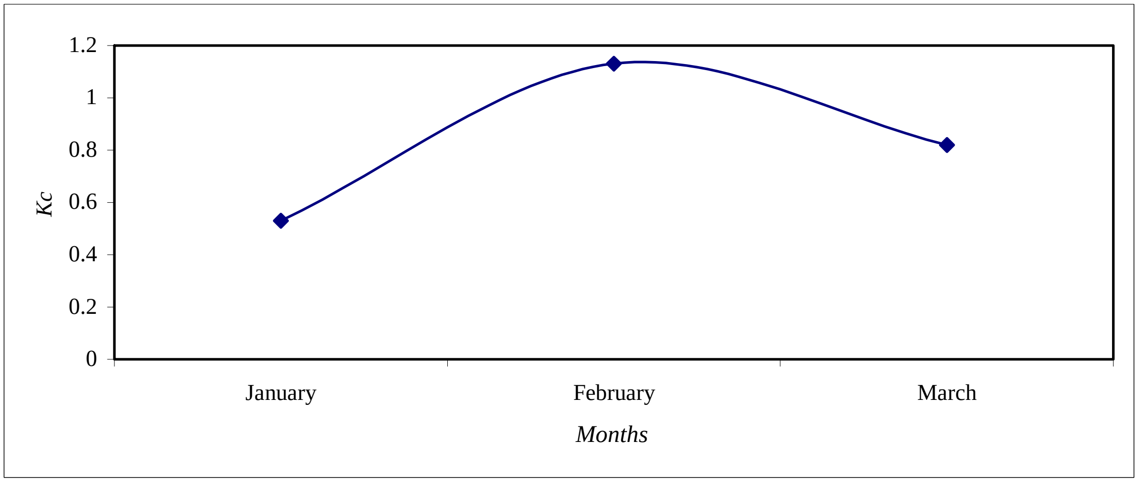

Figure 31: *Monthly Crop Co-efficient for Sorghum*

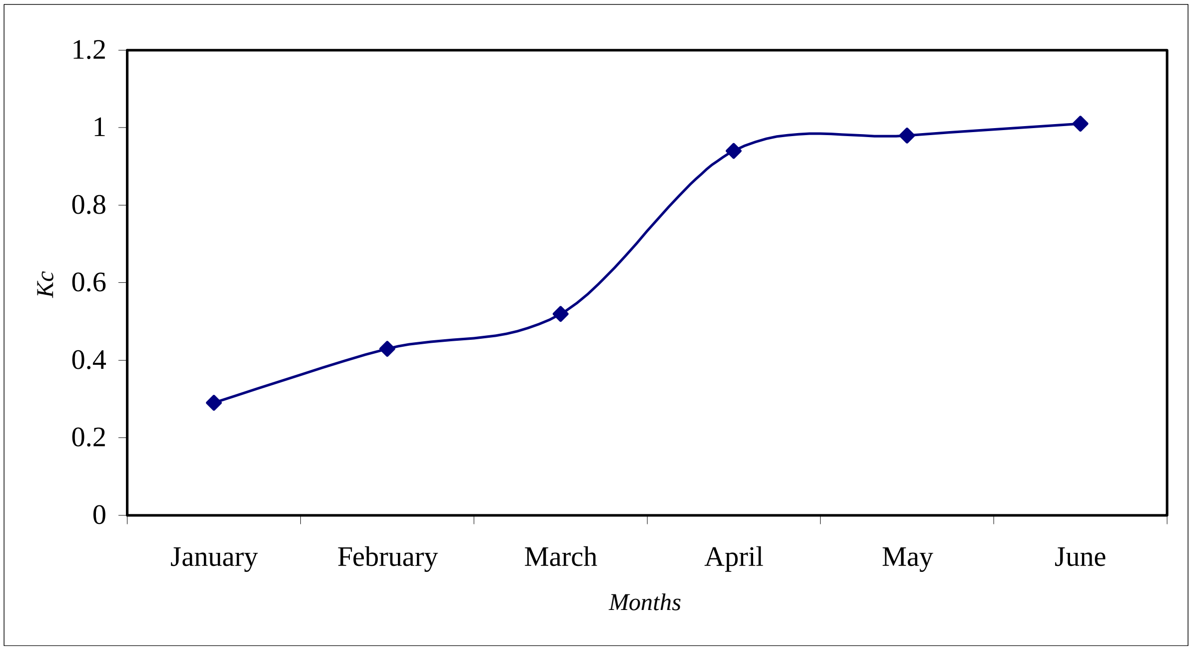

Figure 32: *Monthly Crop Co-efficient for Berseem*

Monthly ET/EP of the crops have been shown in Figures 33-38. These figures show that ET/EP values were the lowest in the 1st month after sowing. It gradually increased in the subsequent months and attained peak value at grain formation stage. Then it again dropped down gradually until crop maturity. The ET/EP values behaved almost in similar fashion as that of crop coefficients however with lesser magnitude. ET/EP for berseem (Figure 38) however, increased linearly with crop stage.

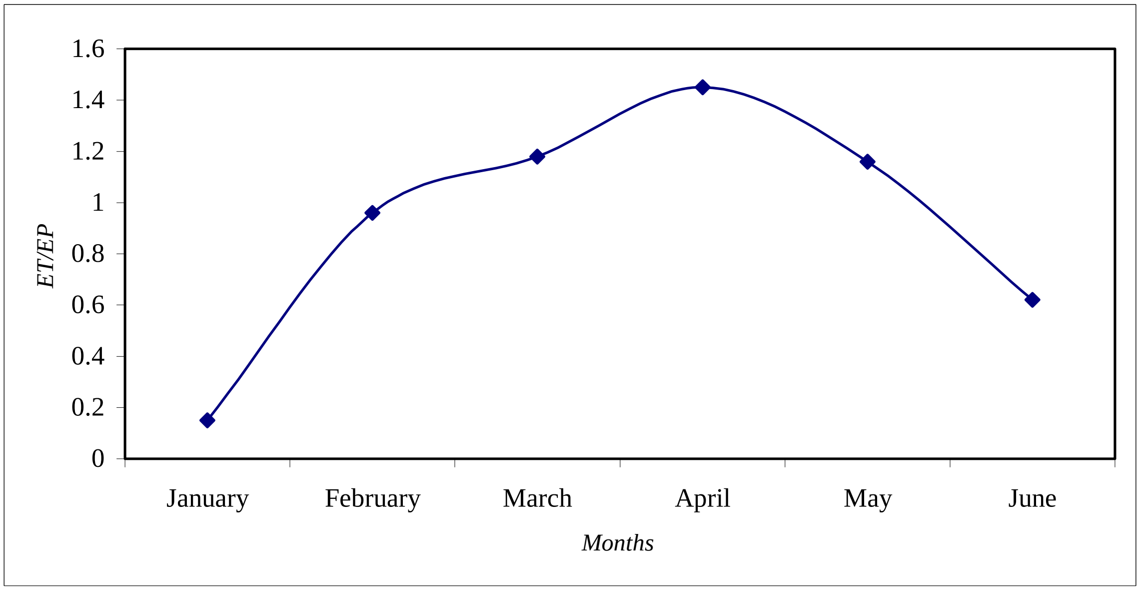

Figure 33: *Monthly ET/Pan Evaporation Ratio for Wheat*

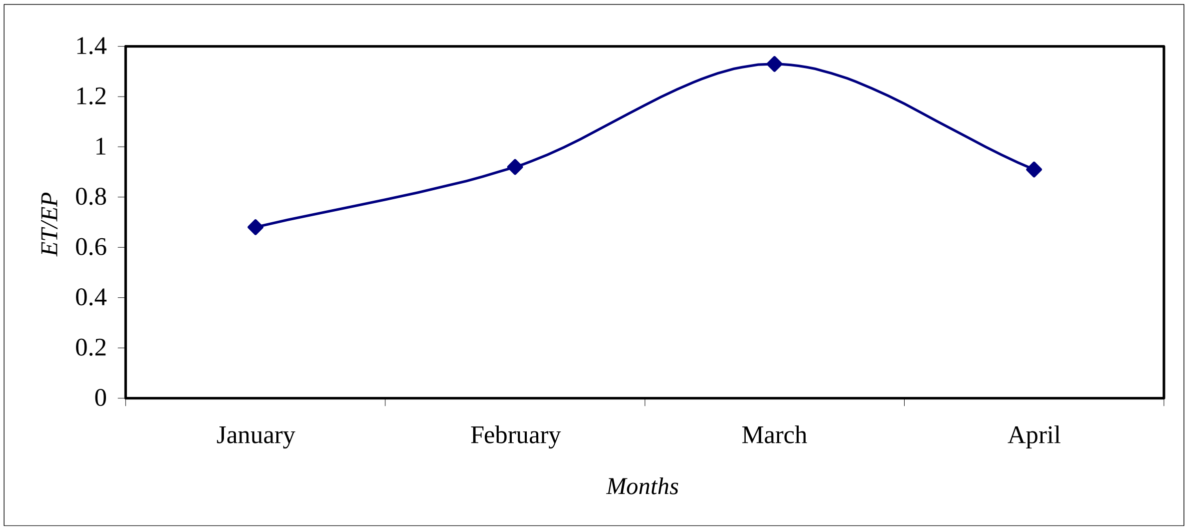

Figure 34: *Monthly ET/Pan Evaporation Ratio for Maize*

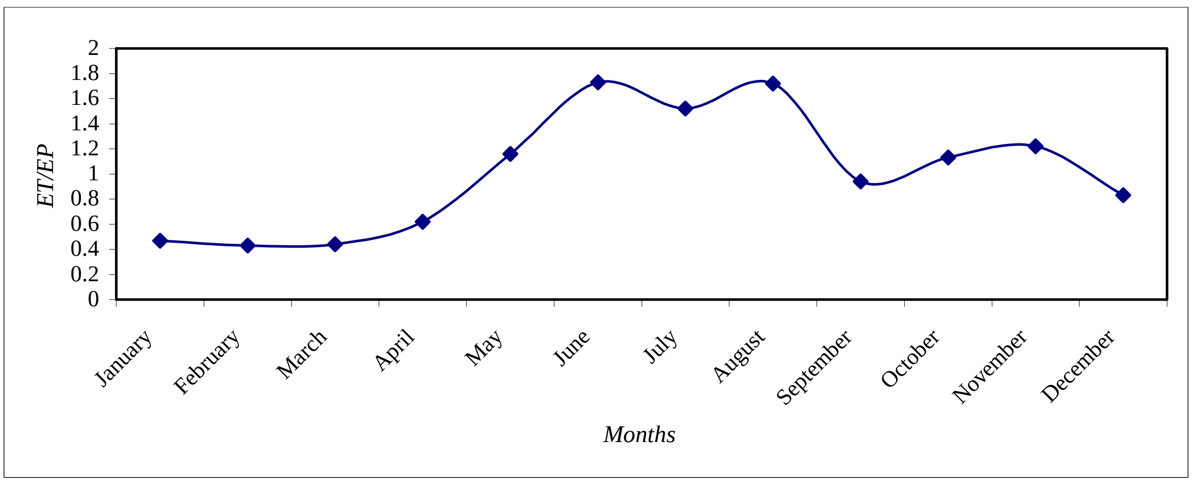

Figure 35: *Monthly ET/Pan Evaporation Ratio for Sugarcane*

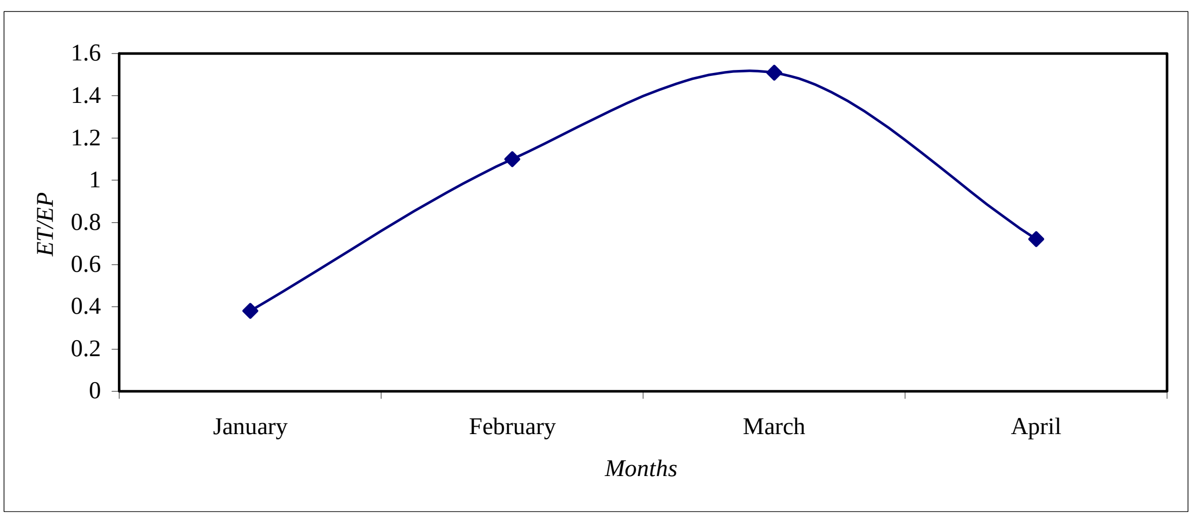

Figure 36: Monthly ET/Pan Evaporation Ratio for Sunflower

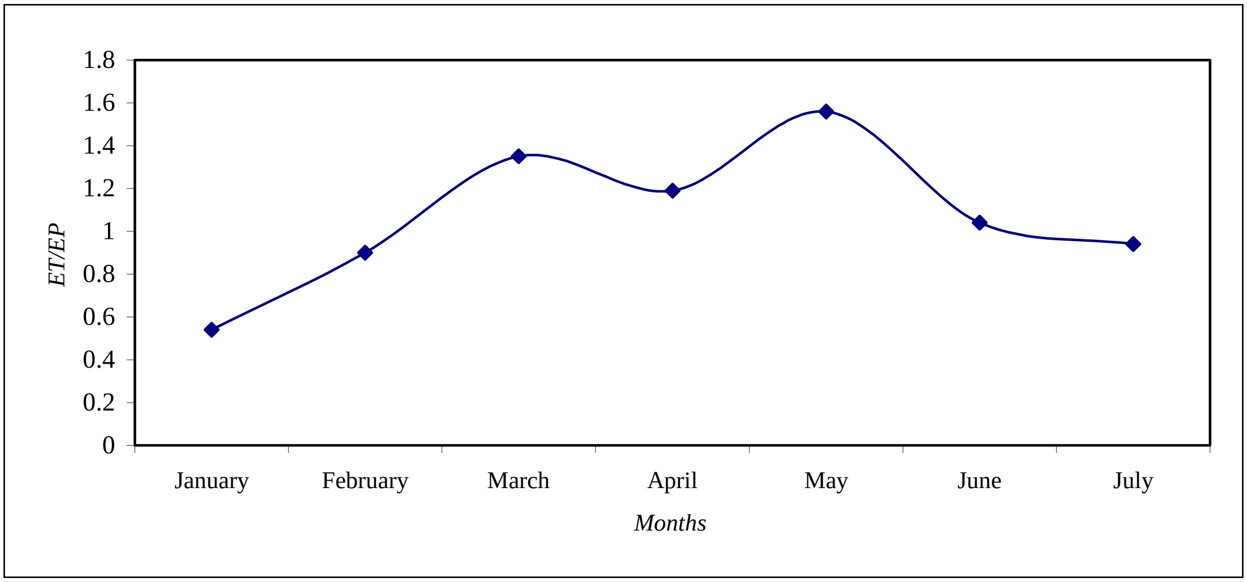

Figure 37: *Monthly ET/Pan Evaporation Ratio for Sorghum*

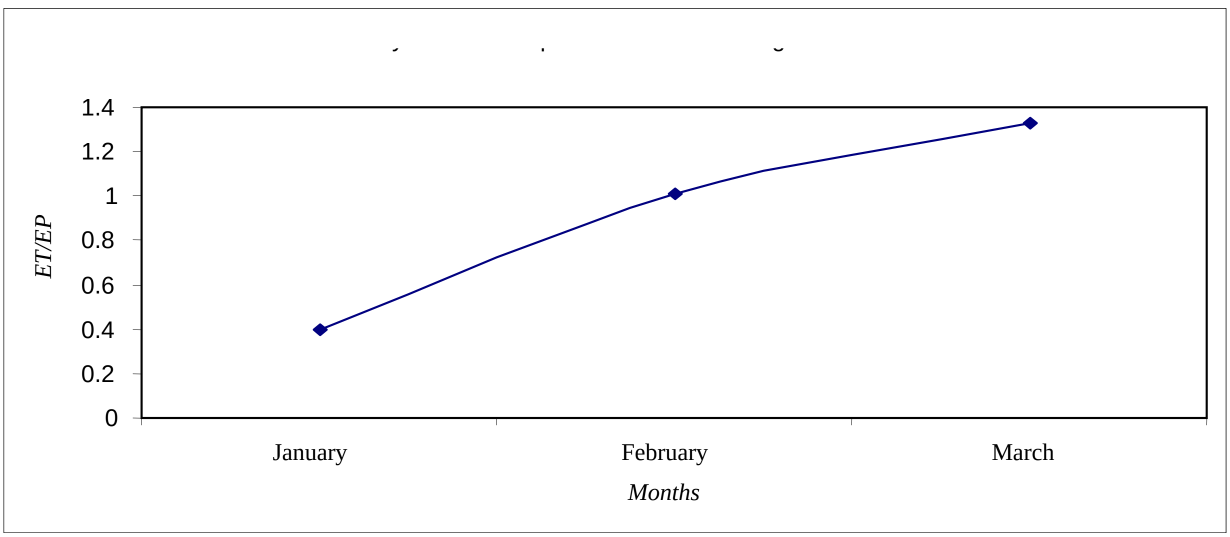

Figure 38: *Monthly ET/Pan Evaporation Ratio for Berseem*

4.5 Effect of Different Water-table Depths on Re-Distribution of Salts

It has been observed that the salts are accumulated in the root zone under high water-table conditions (Figure 39). The shallow water-table contributes significantly to evaporation and soil surface salinization. The total salt affected area in the Indus plain is about 5.8 Mha, out of which about 2.93 Mha is under cultivation. Figures 40-43 show the effect of different water-table depths on re-distribution of salts for wheat crop. Under high water-table conditions, there was more salt accumulation in the top layers. This was mainly due to upward movement of salts with comparatively higher upward water flux under shallower water-table conditions. Particularly, for wheat crop after harvesting, the EC_e increased mainly due to high groundwater contribution. At shallow depth *i.e.* at 3.8 cm from the soil surface, soil EC_e increased after harvesting of wheat crop. The upward movement from the groundwater pumped the salts from the soil profile and brought it to the soil surface. However, at deeper depths, the soil salinity remained almost unchanged. The threshold EC_e for wheat is 6.0 dS m^{-1} (Rhoades, *et al*., 1992). Therefore, for all treatments the soil salinity remained within the threshold limit. Nevertheless, these salts may increase and affect the crop growth. Periodic flushing of such salts therefore is necessary for sustained crop production.

Figure 39: *Effect of Shallow Water-table on Soil Salinity*

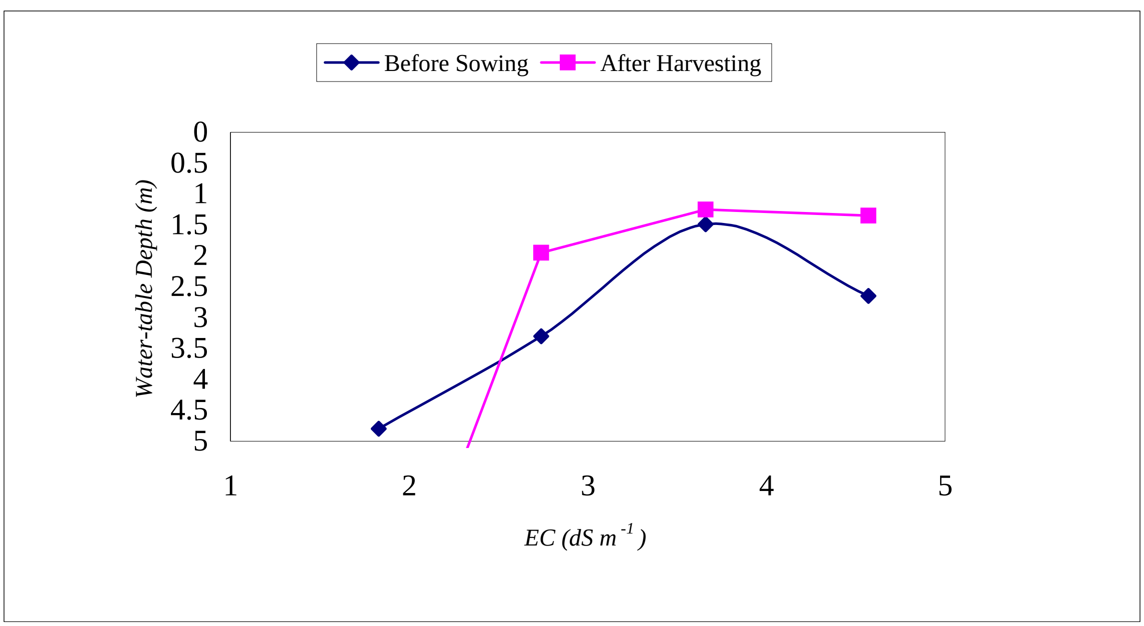

Figure 40: *Electrical Conductivity as a Function of Water-table Depth for Wheat at 3.8 cm Depth*

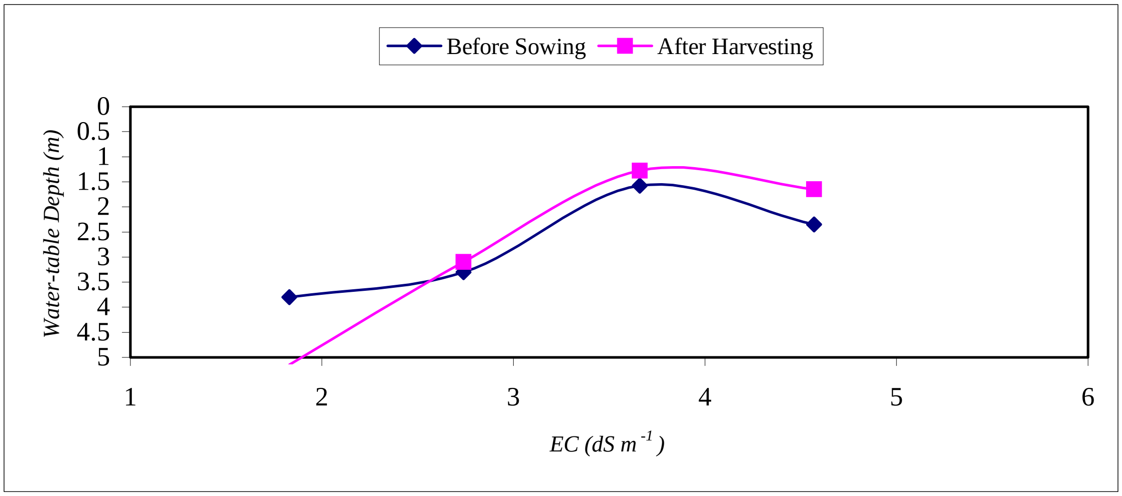

Figure 41: *Electrical Conductivity as a Function of Water-table Depth for Wheat at 15.3 cm Depth*

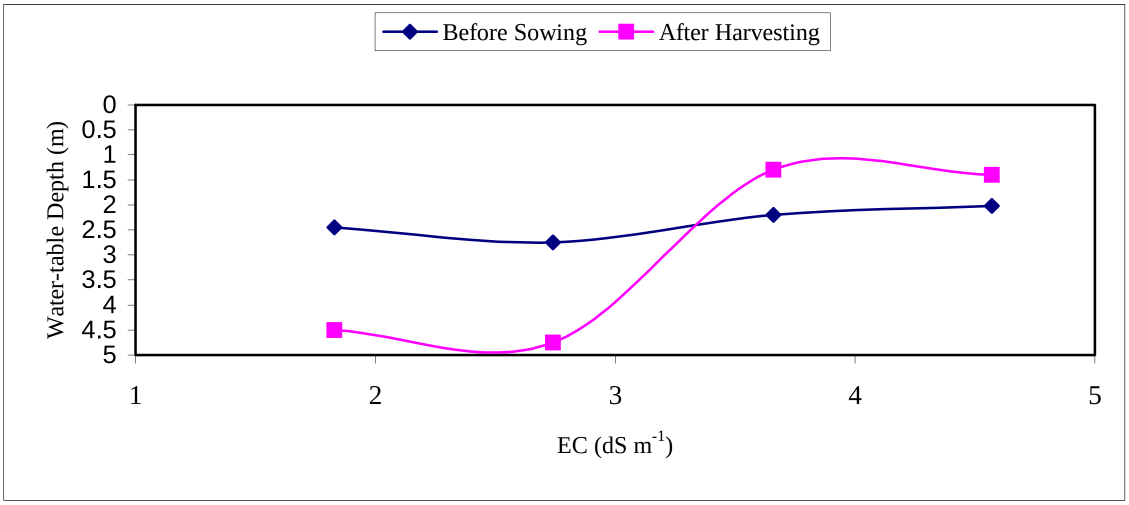

Figure 42: *Electrical Conductivity as a Function of Water-table Depth for Wheat at 30.5 cm Depth*

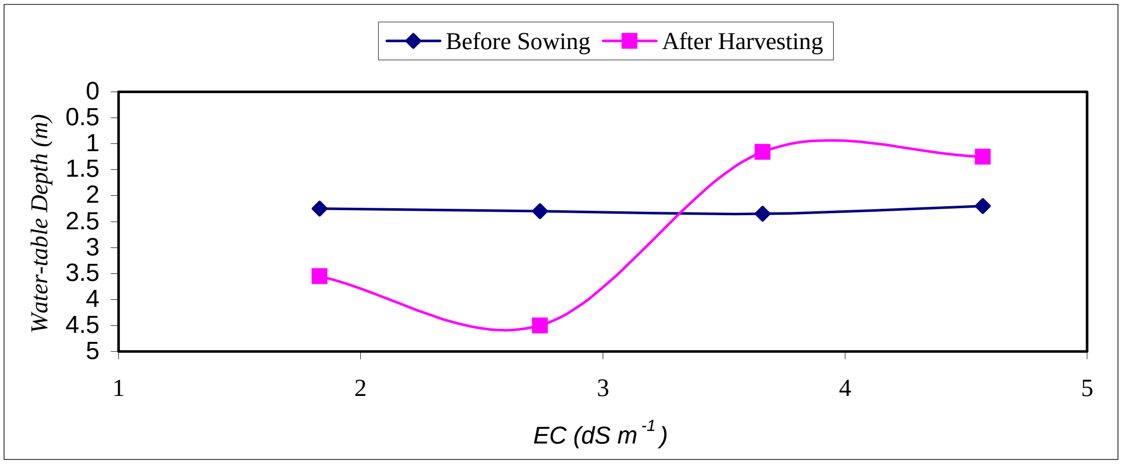

Figure 43: *Electrical Conductivity as a Function of Water-table Depth for Wheat at 45.7 cm Depth*

4.6 Effect of Different Water-table Depths on Crop Yield

The effect of different water-table conditions on crop yield has been shown in Figures 44 to 49. Wheat yield was maximum (5.5 ton/ha) at 1.5 m depth. Below and above this level, wheat yield was reduced. This reduction however, was more pronounced at 0.5 m depth most probably due to reduced aeration in the root zone. Therefore, water-table depth less than 1.5 m may be detrimental to the growth of long rooted crops. The reduction in wheat yield below 1.5 m may be attributed to less availability of water for crop use. Almost similar trend can be seen for sunflower. Maize and sorghum were seemed to be water sensitive crops. With decrease in water-table depth, their yield were decreased. The response of berseem for water was very much hydrophilic since its yield decreased linearly with decrease in water-table depth.

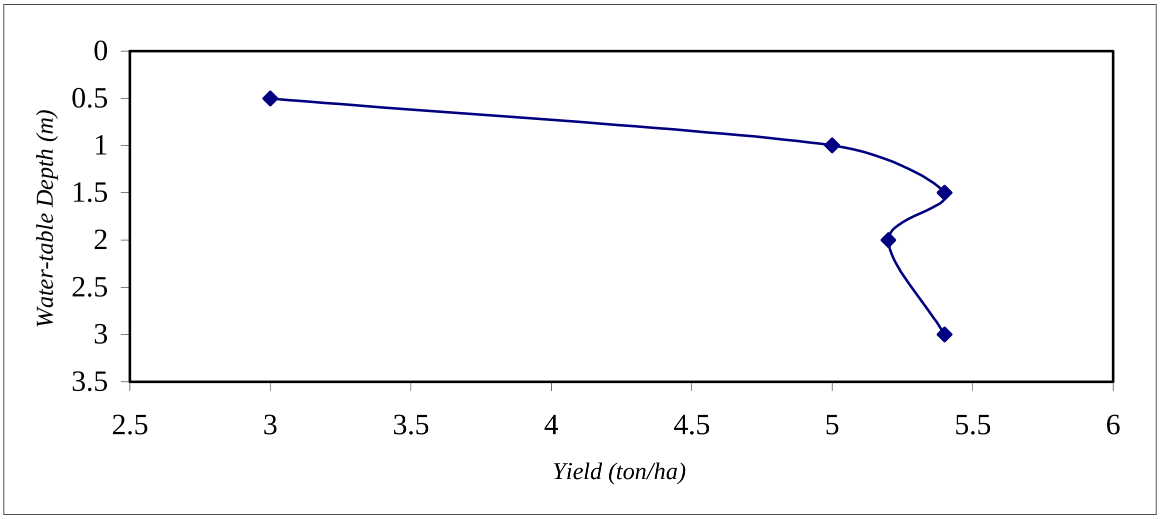

Figure 44: *Effect of Water-table Depth on Wheat Yield*

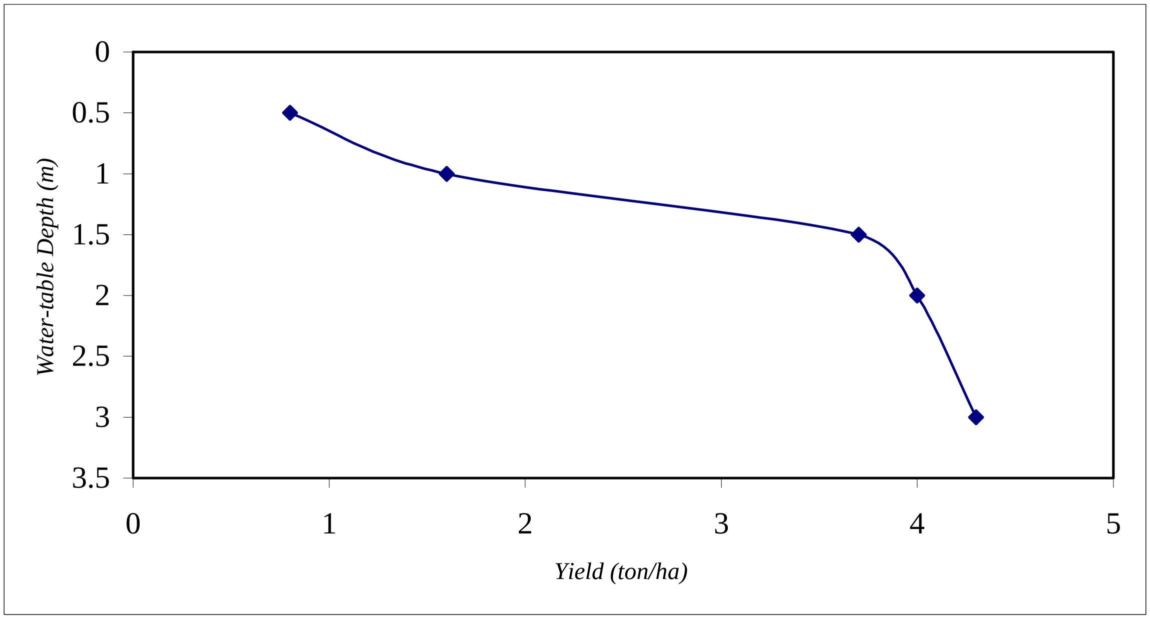

Figure 45: *Effect of Water-table Depth on Maize Yield*

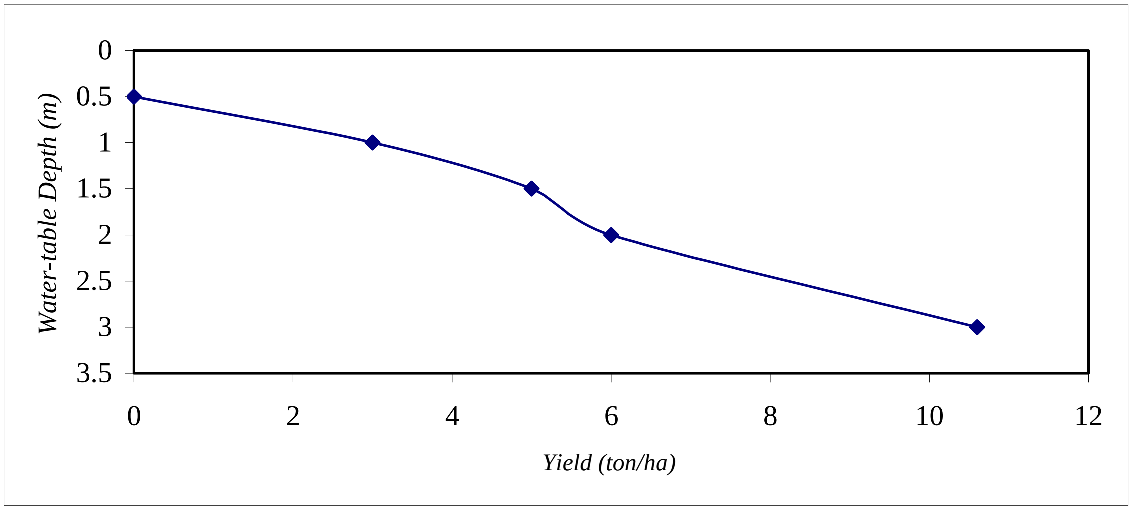

Figure 46: *Effect of Water-table Depth on Sunflower Yield*

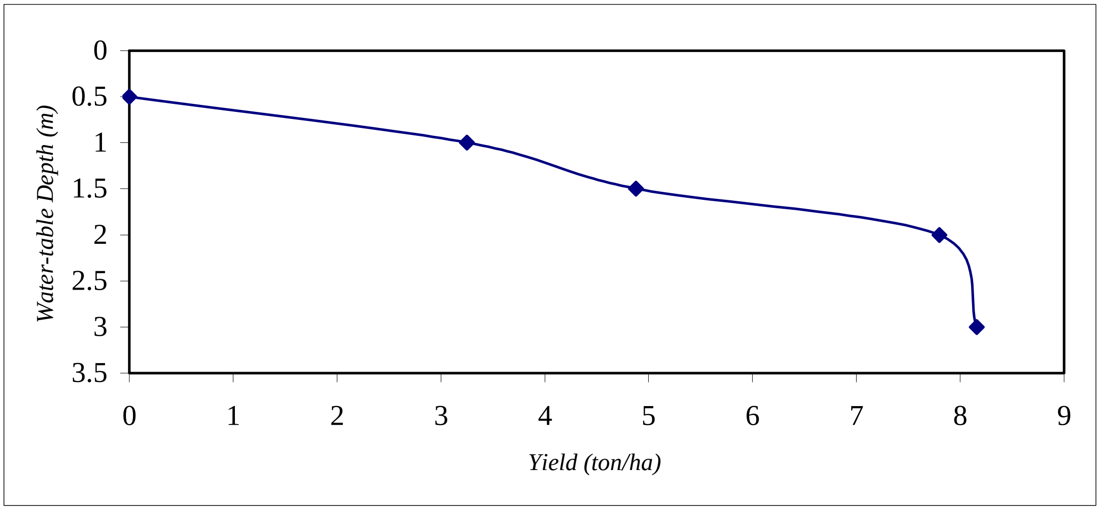

Figure 47: *Effect of Water-table Depth on Berseem Yield*

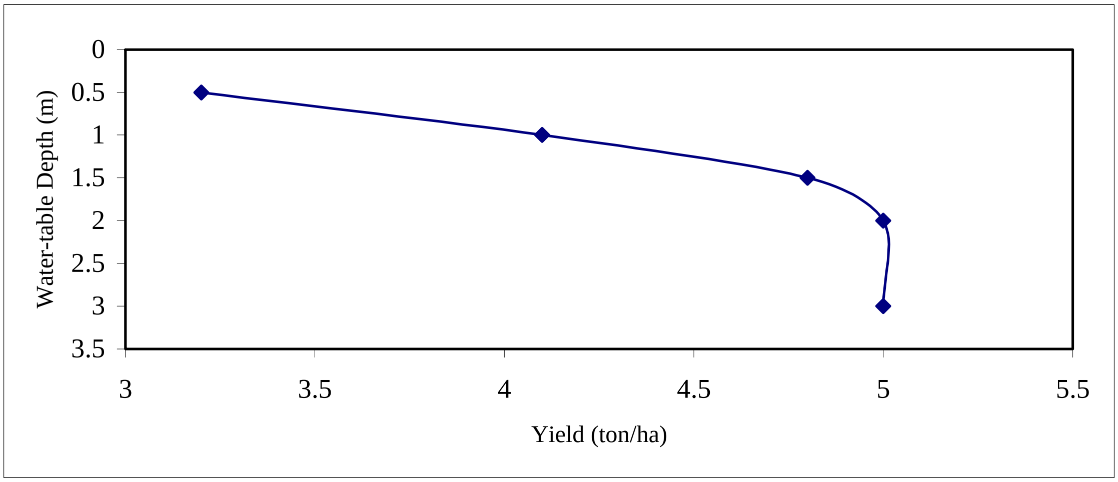

Figure 48: *Effect of Water-table Depth on Sorghum Yield*

Figure 49 shows the yield of sugarcane as a function of water-table depth. Maximum sugarcane yield (over 70 ton/ha) was obtained from 1.0 m water-table depth with drastic reduction in yield when water-table was lowered from 1.0 m. Mejia *et al*. (2000) conducted a two year study with water-table at 0.5 and 0.75 m depth and compared the results with the control (free drainage). On an average, they found 10.2 and 4.8% greater yield for corn and 22.9 and 22.5% for soybean over control.

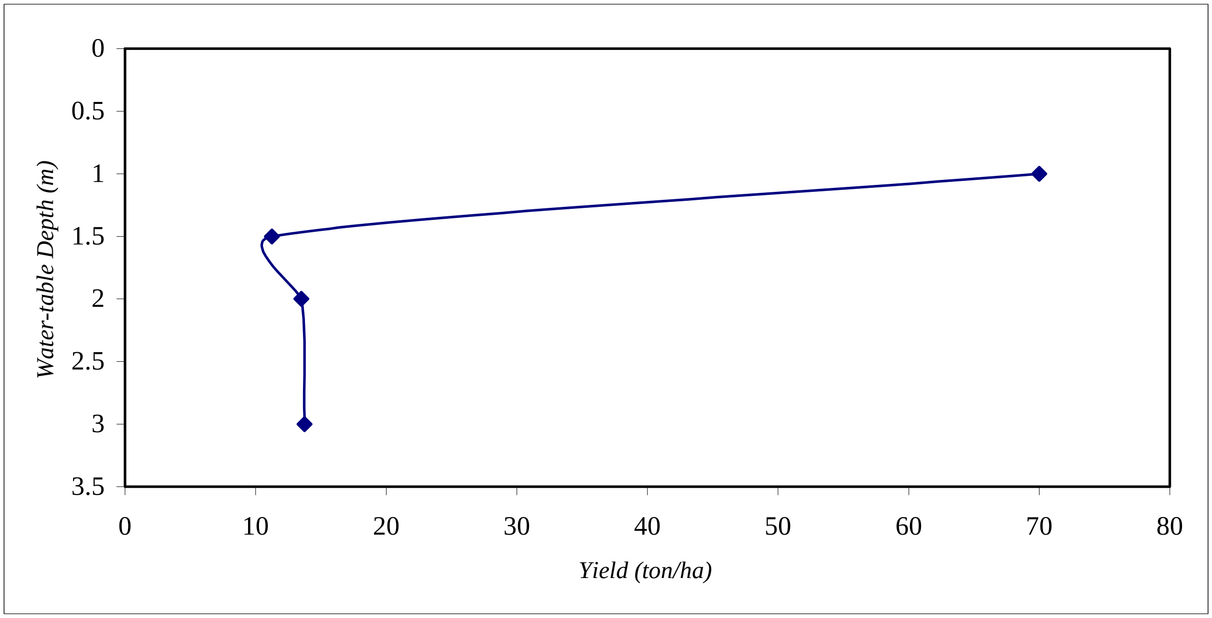

Figure 49: *Effect of Water-table Depth on Sugarcane Yield*

For wheat maize, sunflower, sugarcane, berseem and sunflower, maximum yields were obtained at 1.5 m water-table depth. For sugarcane, however, maximum yield was obtained at 1.0 m depth. It is therefore concluded that water-table depth at 1.5-2.0 m may be the optimum water-table depth for all the crops studied except sugarcane. Asad (2001) however, recommended 1-1.5 m water-table for optimum crop yield.

CHAPTER 5

CONCLUSIONS

The following conclusions can be drawn from the study:

- Scheduling irrigation according to needs of the crops can make most efficient and productive use of available surface and groundwater resources;

- In the areas with shallow water-table (generally less than 3 m), crop yields can be enhanced many fold and the amount of irrigation applied can be reduced significantly;

- The present system of irrigation supplies especially in the areas where water-table is shallow, needs modification to avoid in-efficient use of water;

- Under very shallow water-table conditions (0.5 m depth), wheat extracted almost all its required water from the groundwater whereas sunflower extracted more than 80% of its requirement;

- 1.5-2.0 m may be the optimum water-table depth for all the crops studied except for sugarcane for which the optimum water-table was found to be at 1.0 m depth; and

- Due to reduction in surface irrigation water under shallow water-table conditions, there is always a possibility of salts accumulation in the root zone. Periodic flushing of such salts after harvesting the crops is necessary for sustained crop production.

REFERENCES

Ahmad, S. (1985). Prediction Models for Reference Crop Evapotranspiration in Punjab of Pakistan. *Bull. Water Resources Research.* 15(2):1-8.

Ahmad, C. N and C.A. Rahim (1990). *Crop Management in Pakistan,* In Dr Sardar Riaz (ed). Govt. of Punjab, Agriculture Department. 298p.

Ali, M.S., M.A. Hussain, M. Asghar and G. Hussain (1973). Studies on Consumptive Use of Water by Crops. *Bull. IDFCR Council*. 3(2):49-60.

Asad, S. Q. (2001). Irrigation Requirements of Wheat & Cotton under Different Water-table Conditions, *Sarhad J. Agric*. 17(1).

Asghar, A. G. (1963). *Lysimeter, Objectives and Achievements.* Irrigation, Drainage and Flood Control Research Council.

Asghar, A.G. and N.D. Ahmad (1962). Irrigation Requirement and Consumptive Use of Water by Crops in West Pakistan. *Pak. J. of Sci*. 14(4).

Asghar, A.G., A.R. Khan and H.S. Zaidi (1962). *Studies in Lysimeters: Crop Planning for Salinity Control*. Res. Pub. Govt. Printing Press, West Pak. Lahore. III (7): 9&48.

Assifi, A.T. (1970). *Consumptive Use of Water for Crops in Pakistan*, PARC, 1981. 7p.

Ayars, J. E. and R. A. Schoneman (1986). Use of Saline Water from a Shallow Water-table by Cotton. *Transactions of ASAE.* 29(6): 1674-1678.

Azam, M., A.D. Khan and. R. Aftab (1999). Crop Zoning and Water Requirements in Irrigation Agriculture of Pakistan. Proceedings National Workshop on *Water Resources Achievements and Issues in 20th Century and Challenges for the Next Millennium*, PCRWR. 265-270.

Blaney, H.F. and W.D. Criddle (1957). *Report on Irrigation Water Requirements for West Pakistan.* Tipton and Kalmbach, Denver.

Chaudhry, T.N., V.K. Bhatnagar and S.S. Prihar (1974). Growth Response of Crops to Depths and Salinity of Groundwater and Soil Sub-mergence, *I. Wheat, J. Agron.* 66: 33-35.

Clyma, W. (1973). Evapotranspiration and Irrigation Water Requirements for Pakistan. *Bull. IDFCR Council*. 3(2).

Dastance, N.G. (1966). *Recent Researches in the Field of Irrigation in India*. 7th NESA Irri. Practices Seminar Lahore, Pakistan.

Droogers, P. (2000). Estimating Actual Evapotranspiration Using a Detailed Agro-Hydrological Model. *Journal of Hydrology.* 229: 50-58.

Hameed, A. and A.K. Solangi (1993). *Crop Management in Pakistan*, In Dr Sardar Riaz (ed). Govt. of Punjab, Agriculture Department. 297p.

Hargreaves, G.H. and Z.A. Samani (1985). Reference Crop Evapotranspiration from Temperature. *Applied Engg. in Agric.* 1(2):96-99.

Harza Engineering Co. Ltd. (1968). *Water Requirements for Irrigation Projects in Indus Basin*. Prepared for WAPDA, West Pakistan, Lahore.

Hunting Technical Services, Ltd. (1966). *Lower Indus Project*. Main Report. 322p.

Hussain, M. (1970). *Water Requirements of Crop in West Pakistan.* Directorate of Land Reclamation, W. Pak. Res. Pub., Lahore. II(21).

Hussain, M. and M. Asghar (1969). *The Water Delta Requirements and Cropping Patterns for Salinity Control in Indus* Basin. Res. Pub. Vol. II(19). Govt. Printing Press, Lahore, Pakistan.

Iqbal, M. (1993). *Crop Management in Pakistan*, In Dr Sardar Riaz (ed). Govt. of Punjab, Agriculture Department. 297p.

Iqbal, M. and Bashir A. (1991). *Water Management Strategies under High Water-table Conditions*. Mona Reclamation Experimental Project, WAPDA, Report No.182.

Javaid, M.A and A.K. Solangi (1990). *Crop Management in Pakistan*, In Dr Sardar Riaz (ed). Govt. of Punjab, Agriculture Department. 297p.

Jensen, M.E., R.D. Burman and R.G. Allen (1990). *Evapotranspiration and Irrigation Water Requirements.* ASCE Manuals and Reports on Engineering Practice No. 70, New York, USA.

Kahlown, M. A., M. Iqbal, G. V. Skogerboe and Saeed ur Rehman (1998). *Water Logging, Salinity and Crop Yield Relationships*. Mona Reclamation Experimental Project, WAPDA, Report No. 233.

Khan, R.A., S. Ahmad and M.S. Sharar (1972). *Water Requirements of Wheat and Cotton on a High Water-table Soil under Arid Conditions.* Expl. Agri. 9-41.

Khan, M.I., A.M. Khan, G. Hussain and N. Hussain (1968). *Soil, Water and Plant Relationship*. 7th NESA Irri. Prac. Seminar, Lahore, Pakistan. 277p.

Mejia M.N., C.A. Madramootoo and R.S. Broughton (2000). Influence of Water-table Management on Corn and Soybean Yields. *J. Agri. Water Manag*., 46: 73-89.

Nazir A. (1993). *Water Resources of Pakistan.* Publisher Shahzad Nazir, Gulberg, Lahore, Pakistan.

Hansen J.B., P.E. Holm, E.A. Hansen and O. Hjelmar (2000). *Use of Lysimeters for Characterization of Leaching from Soil and Mainly Inorganic Waste Material*, Nordtest Technical report 473. Institute of Water Management, Denmark.

PARC (1982). *Consumptive Use of Water for Crops in Pakistan*, Pakistan Agriculture Research Council (PARC), Islamabad.

PARC (1993). *Water Use Crop Production Techniques and Consumptive Use of Water for Crops in Pakistan*, PARC, Islamabad.

Pierce, L.T. (1958). Estimating Seasonal and Short-Term Fluctuations in Evapotranspiration from Meadow Crops. *Bull. Amer. Meteorol. Soc*. 39: 73-78.

Pratharpar, S. A. and A. S. Qureshi (1999). Modelling The Effects of Deficit Irrigation on Soil Salinity, Depth to Water-table and Transpiration in Semi-Arid Zones with Monsoonal Rains. *Water Resources Development*, 15: 141-159.

Qureshi, R. H. and E. G. Barrett-Lennard (1998). *Saline Agriculture for Irrigated Land in Pakistan: A Handbook*. Australian Centre for International Agriculture Research, Canberra Australia.

Rafique, M. (1990). Soil Resources and Soil Related Problems in Pakistan. In: *Soil Physics: Applications Under Stress Environments*. Pakistan Agriculture Research Council, Islamabad. 16-23.

Rehman, A., M. Akram and Zia-ul-Haque (1977). Lysimeteric Studies on Irrigation Requirements in Relation to Depth of Water-table. Proc. ESSO Seminar on *Water Manag. for Agri*. Lahore. II : 125-137.

Revelle, R. (1964). *Consumptive Use of Water for Crops in Pakistan* , PARC. 6p.

Rhoades, J.D., A. Kandiah, and A.M. Mashali (1992). *The Use of Saline Waters for Crop Production*. FAO Irrigation & Drainage Paper 48.

Riaz, A. (2001). *Crop Management in Pakistan*. Govt. of Punjab, Agriculture Department. 280p.

Sabir, B.A. *Crop Management in Pakistan*. Govt. of Punjab, Agriculture Department. 296p.

Sadiq Ali, M., M. Altaf Husain, M. Asghar and G. Husain (1973). Studies on Consumptive Use of Water of Crops. *Bull. IDFCR Council,* Rawalpindi. 3(2): 49-60.

Tovey, P. (1963). Consumptive Use and Yield of Alfalfa Grown in the Presence of Static Water-tables. *Nevada Agr. Exp. Sta. Tech. Bull*. 232-65.

Tyagi N.K and D.K. Sharma and S.K. Luthra (1999). *Determination of Evapotranspiration and Crop Coefficients of Rice and Sunflower with Lysimeter*. Agricultural Water management 45, Central Soil Salinity, Research Institute Karala, India.

Veihmeyer, F.J. and .A.H. Hendrickson (1955). Does Transpiration Decrease as the Soil Moisture Decreases? *Amer. Geophys. Union, Trans*. 38: 425-448.

Wallender, W. W., D.W. Grimes, D. W. Henderson and S. K. Stromberg (1979). Estimating the Contribution of a Perched Water-table to the Seasonal Evapotranspiration of Cotton. *Agronomy Journal.* 71(6): 1056-1060.