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WATER REQUIREMENTS OF MAJOR CROPS IN THE CENTRAL PUNJAB: A LYSIMETRIC STUDY

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By

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Abstract

Pakistan has one of the largest contiguous irrigation systems in the world and among the top ten countries with largest water withdrawal for agriculture. Despite huge canal network, Pakistan is water scare county mainly due to poor water management, lack of storage and governance problems. However, in Pakistan, there is potential for improvement in water management by applying appropriate irrigation depths in view of the crop water requirements (CWR). However, over irrigation is a common practice in the country which is one of the reasons for low water productivity in agriculture. Efficient application of irrigation water to crops depends on the actual water demand of crops which can be determined through lysimeters. Pakistan Council of Research in Water Resources (PCRWR) determined crop water requirements of staple crops of Punjab like rice, hybrid-maize and wheat using a series of 18 drainage-type lysimeters. All the components of the water balance were studied using the standard equipment to determine actual crop evapotranspiration (ET_a) and the crop coefficients (K_c). The actual crop water requirement (CWR) of rice, hybrid maize and wheat were 513 mm, 405 mm and 356 mm respectively. While seasonal crop coefficient (K_c) for rice, hybrid maize and wheat were 0.9, 0.7 and 0.9 respectively.

Key words: Crop water Requirement (CWR) Reference Evapotranspiration (ET_0), Actual Evapotranspiration (ET_a), Crop Coefficient (K_c)

Introduction:

The demand for fresh water resources has increased in recent times and has been exacerbated by escalating global population and increasing drought indices in the world's agricultural zones (Bwambale et al., 2022). Agriculture sector is also the biggest user (more than 90%) of water in Pakistan. The country is already water scare and heading towards the absolutely water scarcity. With the escalation of this water crisis, water management and governance have become more essential concerns across the country (Saddiqa et al., 2022). About 90% food production in Pakistan comes from irrigated agriculture, whereas dry-land (rain-fed) agriculture contributes only 10% due to scanty and low rainfall (World Bank, 2006). With the rapid growth of the economy and population, water shortage is becoming more and more serious, especially in arid and semi-arid areas (Li et al., 2020a).

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Pakistan has one of the largest contiguous irrigation systems in the world so, when irrigation water is abundant and available for free or low price, farmers are more inclined to irrigate liberally to save manpower, material resources and management input cost (Pandey et. al., 2020). Young et. al., 2019 reported that considering population growth projections, increasing demand from industrial, domestic, and environmental sectors, and assuming no or little change in the renewable freshwater resources. It is highlighted that Pakistan is the fifth populous country in the world with an annual increase rate of 1.75% (Ishaque et. al., 2023).

It has been revealed through a literature review that in 1951, Pakistan had a per capita water availability of 5,000 m^3, which fell to 1,100 m^3 in 2005, and by 2025, it is expected to fall to 800 m^3 (Qureshi and Ashraf, 2019). In the Central and South Asia regions, Pakistan would be the third most water-scarce country after Afghanistan and Tajikistan (Baggio et. al., 2021). Furthermore, Pakistan is ranked among countries facing shortage of good quality of ground water (Ishaque and Shaikh, 2017). The ground water has played a major role in increasing the overall cropping intensity in Pakistan from about 63% in 1947 to over 120% in 2018 (Khan et al., 2016). It is the only reliable resource that provides resilience against droughts and climate change impacts.

On the other hand, water productivity of crops in Pakistan is remarkably low than the other countries. The gap in the water productivity for various crops shows that there is a tremendous scope for the improvement in water productivity that can help increase both horizontal and vertical expansion of agriculture (Ashraf et al., 2010; Qureshi, 2011). The average yield of crops (and animals) per unit water is also much lower than the international levels, and the yields obtained at the research farms and by the progressive farmers within the country (Wyn Jones et al., 2006). The yield can be improved by using high yielding varieties, appropriate seed rate, time of sowing and use of fertilizers (Mahmood et al., 2015). The amount of water applied can be reduced through (i) precision land leveling, (ii) proper layout of the field, (iii) applying water according to crop water requirement and (iv) appropriate irrigation methods (Ashraf, 2016). Crop water requirement i.e. crop evapotranspiration refers to the water consumption, which reach or approach the maximum yield under suitable growing conditions and it plays an important role in determining the agricultural irrigation water consumption. Application of irrigation water to crops depends on the actual water requirement of each specific crop.

A lysimeter is a container of soil intended to represent the field environment that is used to monitor soil-water-plant interactions for the purpose of studying the fate and movement of water, evapotranspiration, crop water requirements etc. (Prueger et al., 1997). Lysimeters have been used for over 300 years to study the relations between soil, water and plant (Kahlown et al, 2003). PCRWR initiated lysimetric setup in Lahore (in 1974) having the drainage type lysimeters to determine on actual CWR, ET_c and K_c values. Current study was carried out on 3 staple crops (i.e., rice, maize and wheat) and three repetition were conducted for each crop. The crop water requirement (CWR) and crop coefficient (K_c) of rice, maize and wheat were determined which is the essential foundation for efficient use of precious water in agriculture in Punjab, Pakistan.

Methodology:

PCRWR has lysimetric setup in Lahore since 1974 which contains drainage type lysimeters to determine ET_c and K_c values at Water Resource Zone (WRZ) Mughalpura, Lahore (31° 34" N, 74° 20" E), with the collaboration of Punjab Irrigation Department. PCRWR has eighteen square shaped concrete lysimeters with the dimensions of 3.05 m x 3.05 m and 6.1-m deep. All (18) lysimeters are places in two parallel rows, in between the rows, there is an observation chamber. In surroundings of lysimeters setup, a strip of 3-5 m was maintained for growing same crops as in the lysimeters to avoid the oasis effect.

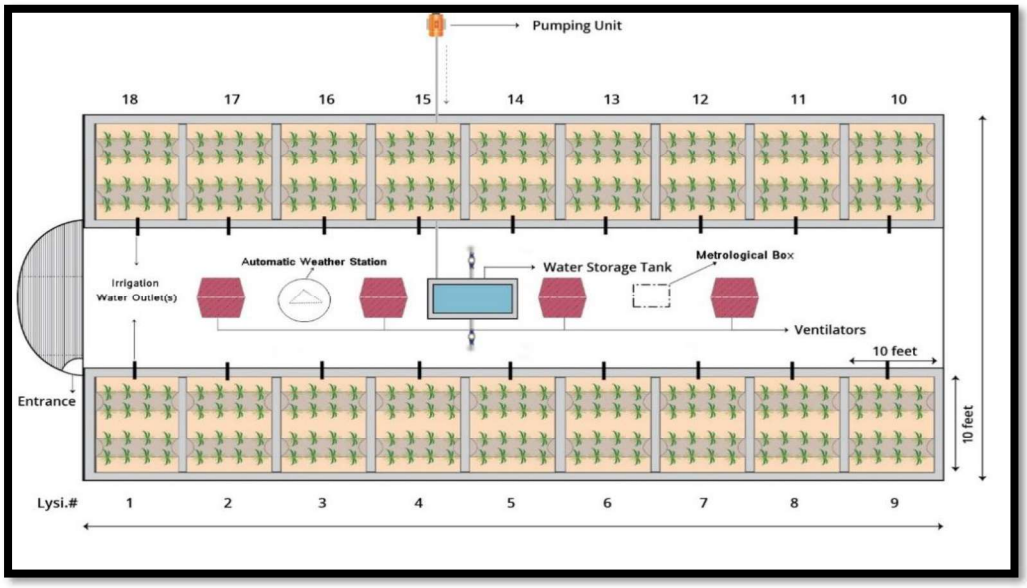


Figure-1: Schematic diagram of PCRWR lysimetric setup at Lahore

Three types of soil (silt loam, loamy sand and silty clay) were used to make 4 soil profile A, B, C, D, as shown in Figure-2 to fill the lysimeters up to 5.2 m in different horizons. A 0.9 m thick calcareous graded gravel filter was provided at the bottom of each lysimeter to lysimeter to facilitate the flow of excess water towards drainage pipe and ultimately collected in drainage bottles where it is measure in liters as well as in mm through conversion *(Drainage in Liters * 0.1076 = Drainage in mm)*.

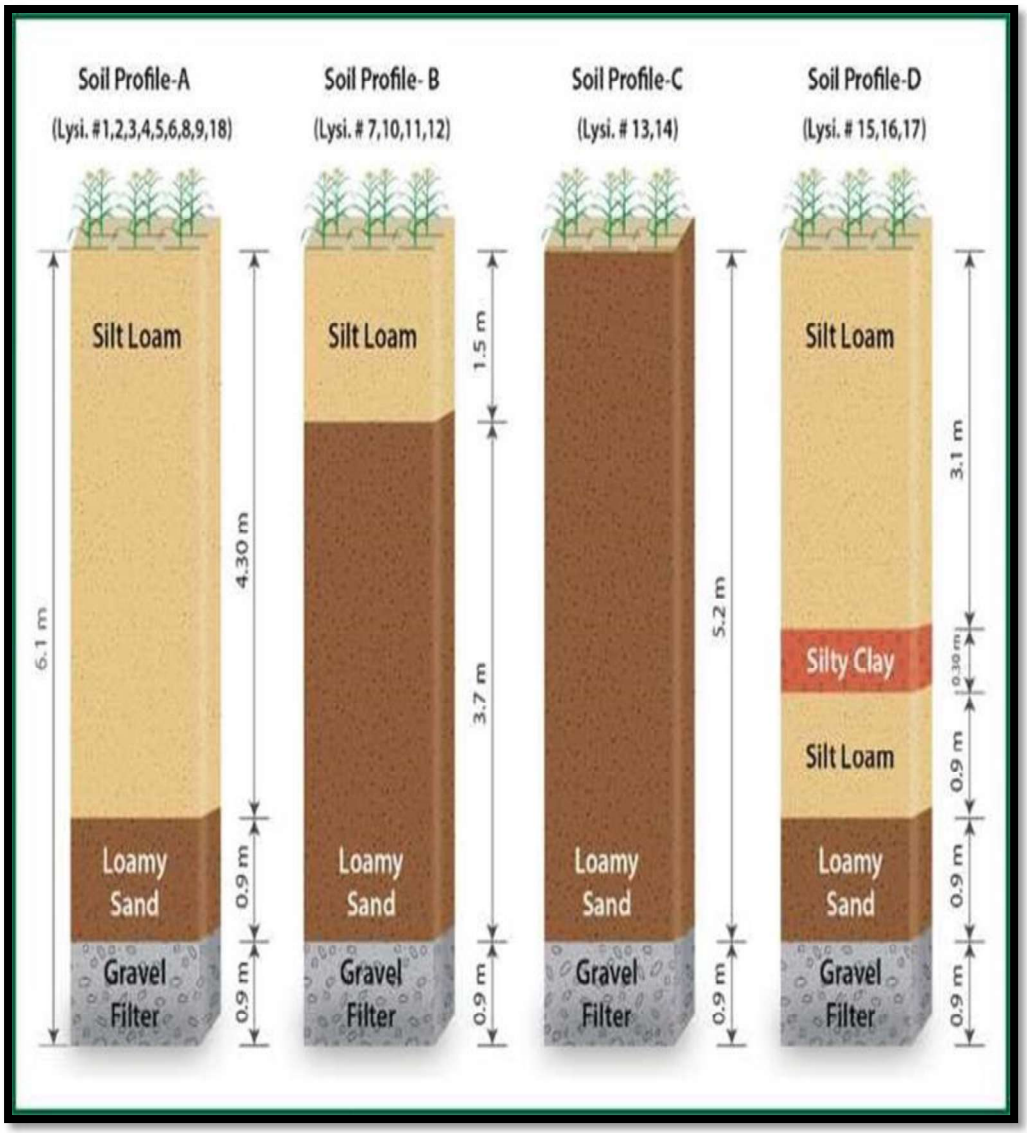


Figure-2: Soil profiles of PCRWR lysimeters at Lahore

Crop water requirement (CRW) or Actual evapotranspiration (ETc) at lysimeter station is determined through the following equation

$$ETc = I + S + R - D \pm \Delta SM \quad \text{..... eq. 1}$$

Where,

ETc	Crop evapotranspiration (mm)
I	Surface irrigation (mm)
S (mm)	Sub surface irrigation/ground water contribution
R	Rainfall (mm)
D	Drainage effluent (mm)
ΔSM	Change in Soil moisture (mm).

Surface Irrigation (I)

The irrigations were applied regularly through surface irrigation methods (border/furrow) to the crops to keep the enough moisture available for potential evapotranspiration. Ground water (EC = 0.95 dS/m) was used for irrigation throughout the experiments whose chemical properties are given below

Table-1: Water quality of irrigation water at PCRWR lysimeter station, Lahore

Source of Irrigation Water	Color	pH	Turbidity (NTU)	Electric Conductivity (µS/cm)	Sodium Absorption Ratio	Residual Sodium Carbonate. (meq/L)
Ground water	Colorless	7.10	1.10	1380	2.76	5.92*

(RCS should be < 2.5 meq/L for irrigation, grater values shows water is sodic),*

Irrigation water was channelized to the lysimeters through a pipeline network constructed around the lysimeter station. The amount of water applied (mm) was measured through a calibrated concrete water storage tank and water flow meter.

Change in Soil moisture (▲SM)

Soil moisture in the root zone was monitored through tensiometers. Two tensiometers were installed in each lysimeter at 20 cm and 50 cm depths. It measures the matric potential (tension) applied on it by soil due to dryness. As the moisture content in the soil decreases the tension on it due to soil also increases due to which it shows higher values in terms of suction pressure in centibar. Soil moisture retention curve was used to convert metric potential (tension) into soil moisture content. Change in soil moisture recorded on daily basis which is used to determine monthly and seasonal variations in soil moisture.

Drainage Surplus (D)

Drainage surplus is the amount of water percolated below the root zone; if any, escaped from the bottom of the each lysimeter and collected in Percolation storage bottles placed inside the chamber.

Reference Evapotranspiration (ET_0)

ET_0 represents the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. It was determined by two different methods

1) FAO, CROPWAT 8.0 which based on Penman-Montieth equation

2) Blaney Criddle Equation

In which it was used monthly climatic data i.e., minimum and maximum air temperature, relative humidity, rainfall, sunshine duration and wind speed etc., and all these climatic data values were obtained from weather station installed adjacent to lysimeter station, Lahore.

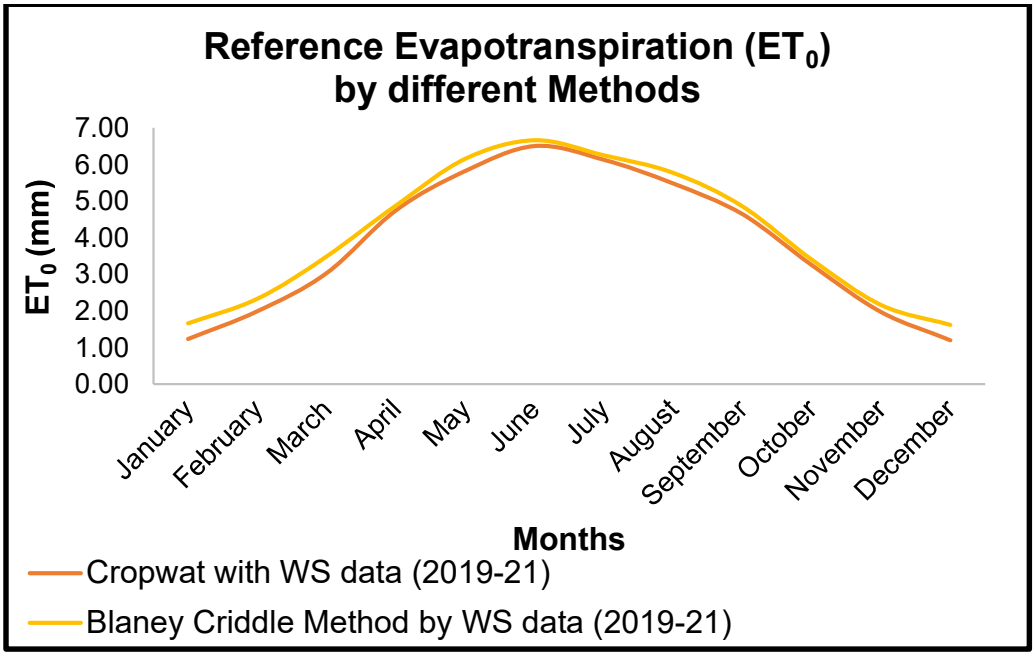


Figure-3: Comparison of ET_0

The CROPWAT model is preferred for use in this study in the determination of the reference evapotranspiration (ET_0) as it is reported to deliver very reliable values on actual crop water use data worldwide (Khan et. al., 2019).

Crop Coefficients (K_c)

Crop coefficient is the ratio of actual evapotranspiration (ET_a) to reference evapotranspiration (ET_0). In current study ET_a was obtained from equation1 and ET_0 was obtained from CROPWAT model and K_c was calculated for each month of crop from sowing till harvest.

Results & Discussion:

Weather Data for Kharif Season

Weather data obtained from automatic weather station installed at Lysimeter Station, PCRWR, Lahore was plotted by taking average of same months in 3 year's data. Average max temperature during the kharif season was observed 34.9 ºC to 31.9 ºC, while the min temperature drops from 27.8 ºC to 19.4 ºC as the weather changes from summer to autumn and so the relative humidity decreases to 73% to 68% as show in Figure-4.

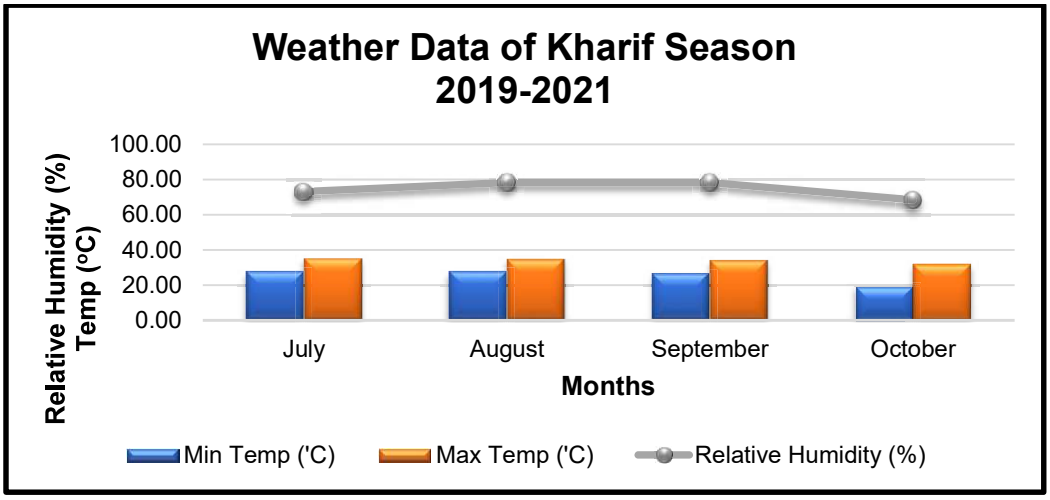


Figure-4: Average weather data for kharif season

Average max temperature during the rabi season was observed in April 33.5 ºC and which lowers to 16.7 ºC in January and so the minimum temp ranges from 19.8 ºC to 7.8 ºC. Similarly, the relative humidity was observed maximum in December as 83% which tend to decrease up to 52% in April.

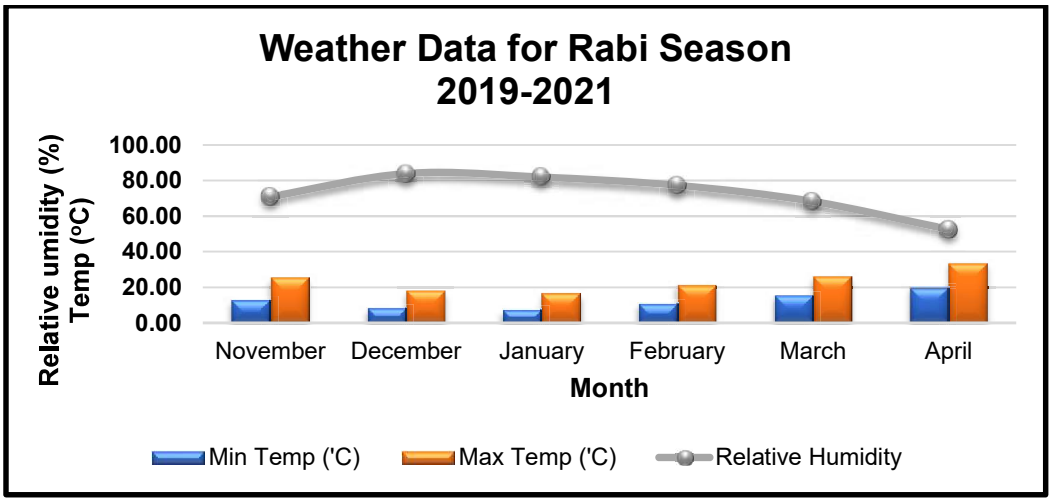


Figure-5: Average weather data for rabi season

Rice

Rice feeding over 50% of the global population (Cao et al., 2021). Rice yield, however, has stagnated in recent years. Ensuring that rice is available to the projected population increase will require an increase in rice production (PARC, 2020). Therefore, timely, reliable and large-scale rice production are valuable for policy-makers to develop government development plans for food security (Saddiqa et al, 2022). Generally, rice is known as a plant of water and is mostly grown in standing water. Due to this misconception, the farmers keep on applying water and the actual water applied to rice crop may exceed 3000 mm i.e. more than 6 times the actual water requirement of rice (Ashraf et al, 2010). It therefore, consumes more that 60% of the irrigation water withdrawals. However, Soomro et al, (2015), through a series of experiments, have been able to break this myth that rice needs standing water.

Average values of evapotranspiration and rainfall along with the irrigation water applied to crop was plotted in Figure-6 where, irrigation was applied according to soil moisture requirements to maintain it as field capacity and it was applied more than ET_0, so that plant can utilize moisture to its full potential without any stress. Which ultimately assist to measure monthly/seasonal crop water requirement of corresponding plant. These values represent the amount of water applied to crop to meet irrigation needs under different crop development stages. Efficient irrigation practices are essential for optimizing wheat yields and ensuring sustainable water use in agriculture. By understanding the specific water requirements of wheat crops and implementing appropriate irrigation strategies based on soil moisture levels, farmers can enhance crop productivity while conserving sufficient water resources. From given trend it can be observed that rainfall in July and October crossed the evapotranspiration value but surplus irrigation was applied it was because of the variability of rainfall as most probably it showers more or less than the actual requirement of crop in a certain day over the corresponding month. The excess of the water in lysimetric setup is collected below the crop root zone and measured which is called surplus water/ drainage.

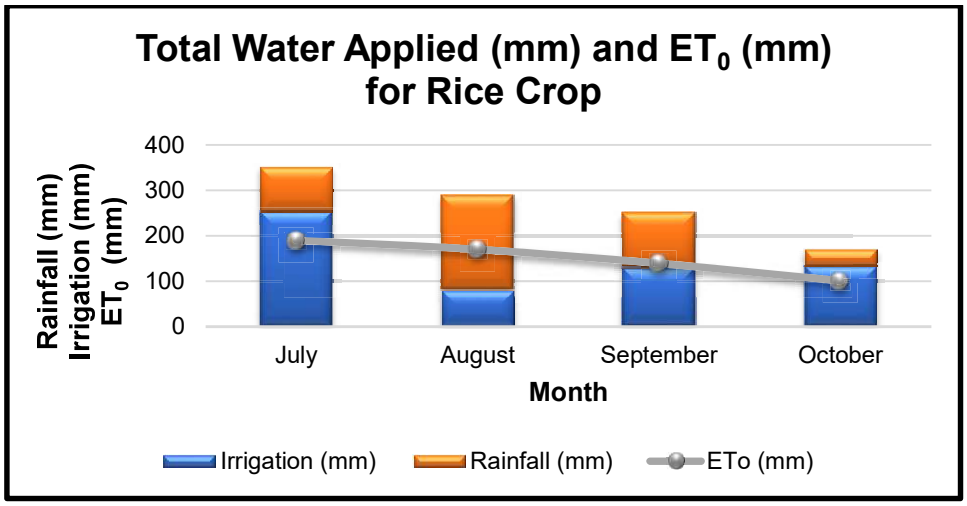


Figure-6: ET_0 and Total water applied to rice at lysimeter station, Lahore

The ET_0 was on its peak in July and tend to fall towards October as the temperature decreases. Actual evapotranspiration (ET_a) of rice in the month of July was observed up to 76 mm as shown in Figure-7, which then, tends to increase in the months of August and September 169 mm and 164 mm respectively, as the crop passes through development stage and then it tends to decrease to 106 mm in its harvesting month October.

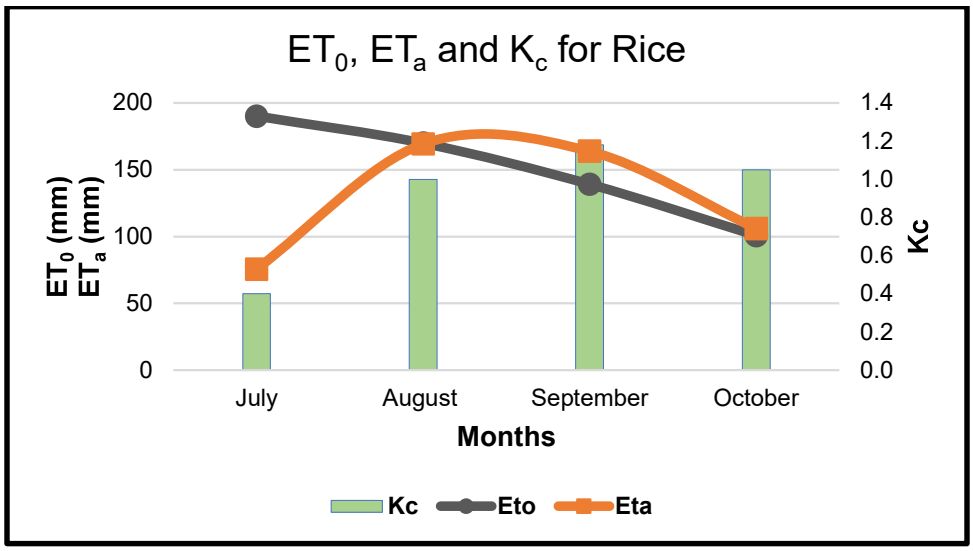


Figure-7: ET_0, ET_a and K_c for rice at lysimeter station, Lahore

Overall average WUE of rice was calculated as 0.37 kg/m^3 and yield was 3.75 tons/ha. The monthly K_c was 0.4, 1.0, 1.1, 1.0 respectively from July to October while total water applied to basmati rice was 514 mm while farmers applies up to 5280 mm of water to rice (Surendran et al, 2021) which is around 10 times more water than its requirement. While, total cultivated area of rice in Pakistan is 3.15 million hectares (Jehangir et al, 2007) thus a huge amount of water is wasted due to over irrigation to rice, which can be saved by applying the appropriate amount of water according to the requirement of rice crop.

Maize

Maize is the third most important cereal crop after wheat and rice, which is cultivated twice in Punjab and once in a year in KPK to produce 97% of total production in Pakistan, while 3% production is obtained from the other two provinces (Tariq and Iqbal, 2010). It is cultivated on 1318 thousand hectares in Pakistan, providing 6.9 thousand tons average yield. Maize contributed about 0.5% in GDP and 2.6% in agriculture. Maize grains contain 72% starch, 10% protein, 5.8% fiber, 3-5% vitamins (A and B), 1.7% ash and 3% sugar (PARC, 2020). Hybrid maize is a dominant Kharif crop of the Central Punjab and is also grown on beds and ridges. Maize is the first major cereal crop to benefit from hybridization. Hybrid maize under optimum conditions of temperature, soil, fertilizer and water can yield up to a maximum of 9,880 kg/ha, which is about three times the local varieties (Ashraf et al., 2010).

Reference evapotranspiration, rainfall and irrigation applied to maize was plotted as shown in Figure-8. The sum of rainfall and irrigation just touch the reference evapotranspiration as in initial and final stages it requires less amount of water but in mid and developing stage it was applied more that the reference evapotranspiration needs to cater the loses during it developing stage when it is mostly vulnerable to get the diseases.

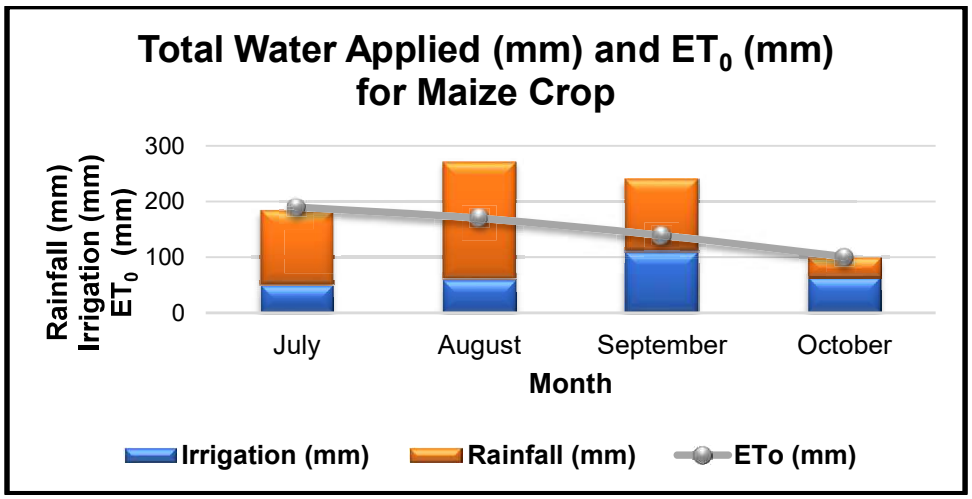


Figure-8: ET_0 and Total water applied to hybrid-maize at lysimeter station, Lahore

ET_a of hybrid maize behaved in the same manner i.e. low during the initial growth stage and harvesting times with the ET_a values ranges from 55 mm, 139 mm, 153 mm and 61 mm. ET_a gradually increased till maturity. The total ET recorded was 408 mm which is close to the already reported ET (320-460 mm) for autumn maize (Saeed, 1994). Similarly, K_c values changed throughout the growth period but with different magnitudes as show in the Figure-9. At the initial stage, the canopy cover was small, therefore K_c values were low, with further development, as the canopy cover increased, more water was transpired by the plants. Consequently, the K_c and ET_a values are highest in the month of September.

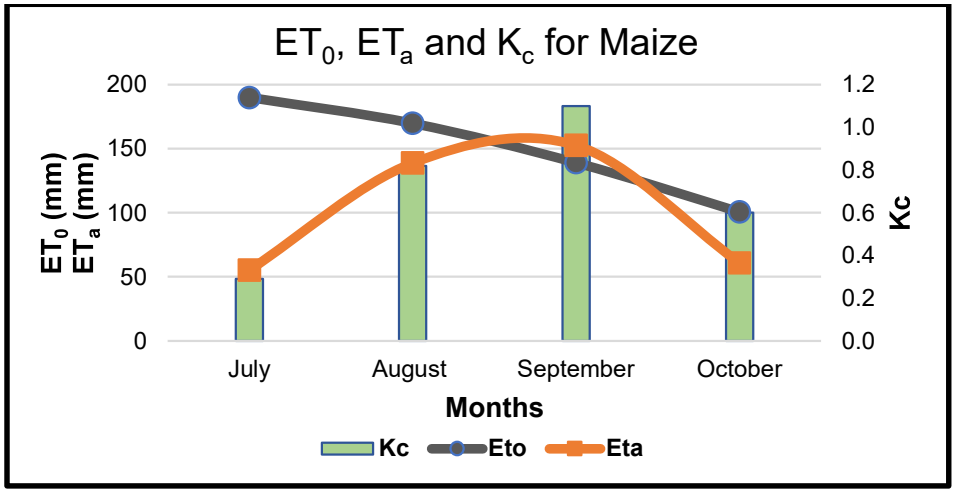


Figure-9: ET_0, ET_a and K_c for hybrid-maize at lysimeter station, Lahore

The average yield concluded from the trails was 7.3 tons/ha while seasonal K_c for maize was 0.3, 0.8, 1.1, 0.6 respectively from July to October. Total water applied to maize was 408 mm. On the other hand, farmers apply almost double of water around 680 to 790 mm for maize (Ray et al, 2024).

Wheat

Wheat (Triticum aestivum) is one of the most valuable crops and a staple food for the vast majority of the human population. Wheat is cultivated under a wide range of moisture conditions where precipitation ranges from 250 to 1750 mm (Tiryakioglu et al., 2015). The share of wheat in national GDP is 2.2 percent and the crop contributes 10.1 percent to value added agriculture (Hussain, 2014). In brief, the crop has a dominant position in the formulation of agriculture sector policies in the country (GoP, 2020).

Figure-10 was plotted for wheat crop between ET_0 calculated by FAO based CROPWAT model, as it is reported to deliver very reliable values on actual crop water use data worldwide (Khan et. al., 2019). It was observed that rainfall met a portion of the crop ET in December, February and March as rainfall in these months was more than ET or the crop water requirements but irrigation was applied due to uneven intensity of rainfall during the month. As the winter started, temperature decreased from November to February, which then tends to increase up to the harvesting month April due to change to weather from winter to summer as mentioned in Figure-5, due to which ET_0 tends to fall and rise in the same pattern during the corresponding months.

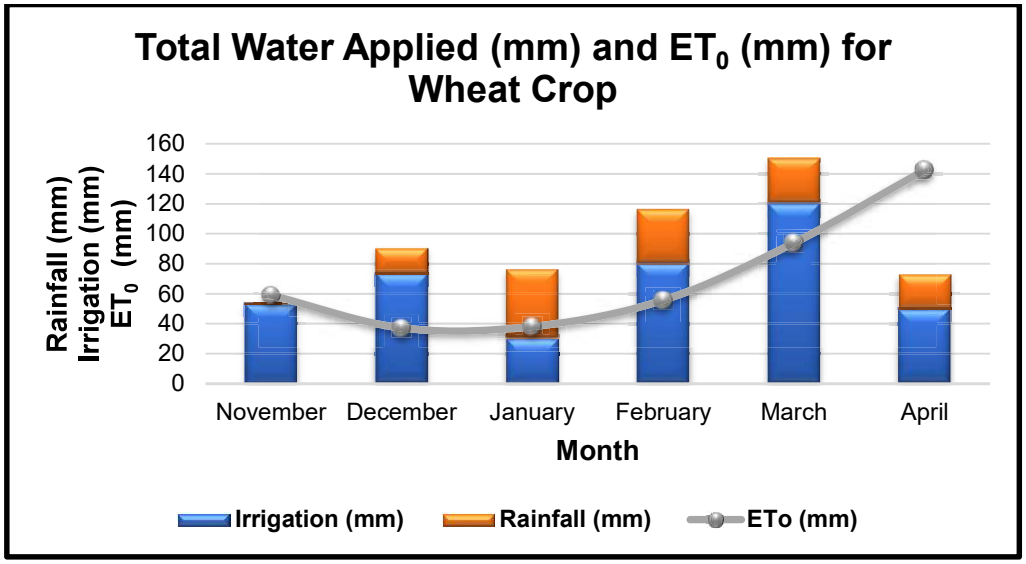


Figure-10: ET_0 and Total water applied to wheat at lysimeter station, Lahore

The higher ET_0 in March and April was due to higher temperature as well as crop maturity stage. However, in November, the crop was at germination stage thus requires more moisture to germinate the seed and in December and January the crop canopy was relatively small thus the water requirement was also less. Wheat is a medium rooted crop having root-zone depth of 0.90 to 1.50 m. Maximum evapotranspiration took place when

temperature was high while the relative humidity was low. It was further reported that the ET in the Upper Indus Basin was 480 mm whereas; in the lower Indus Basin it was 400 mm (Rao et al, 2016). The seasonal variation of the crop coefficient K_c over the growth period was drawn and it shows K_c behaves almost in similar fashion as ET which was initially low i.e. December, January and February which gradually increased and attained a peak value in March as it was grain formation stage. Wheat gained the maximum K_c in the month of March due to grain formation stage and reached to the value of 1.49.

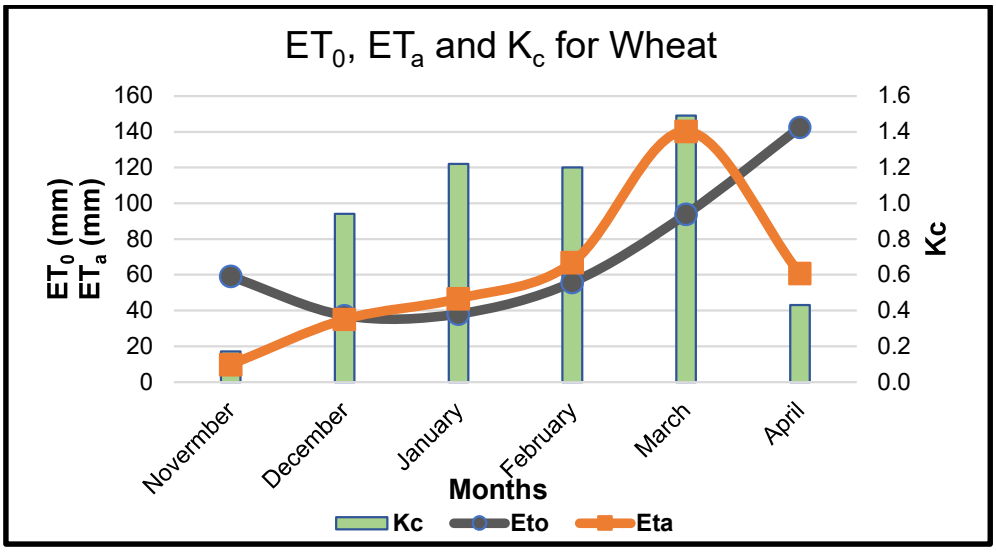


Figure-11: ET_0, ET_a and K_c for wheat at lysimeter station, Lahore

The average yield obtained from the 3 year's trail was 4.35 tons/ha with the monthly K_c of 0.2, 0.9. 1.2, 1.2, 1.5, 0.4 from November to April respectively, and the total consumptive use 360 mm while farmers apply more than double of this water requirement of wheat in 4 to 5 irrigations (Mahmood and Ahmad, 2005) which leads to poor WUE, lower yields, higher cost of production.

Conclusions:

- Actual evapotranspiration for rice, maize and wheat at lysimeter station, Lahore was 515 mm, 408 mm and 360 mm respectively.
- Average seasonal crop coefficient (K_c) for rice, maize and wheat during the study period was 0.9, 0.7 and 0.9 respectively.
- Average grain yield for rice, maize and wheat were 3.75 tons/ha, 7.3 tons/ha and 4.35 tons/ha and water use efficiency (WUE) were 0.37 kg/m^3, 0.95 kg/m^3 and 0.78 kg/m^3 respectively.

References

Ashraf M. (2016). Managing water scarcity in Pakistan: moving beyond rhetoric. Proceedings of AASSA regional workshop, challenges in water security to meet the growing food requirement, p. 2-14.

Ashraf, M., A. Nasir, and M.M. Saeed. 2010. Evaluation of the existing water productivity in the Lower Bari Doab Canal (LBDC) Command–A Case study. Pakistan Journal of Agricultural Sciences. 47(4): 389-396.

Baggio, G.; Qadir, M.; Smakhtin, V. (2021) Population-driven water scarcity trends across countries and national income levels: Challenges and response options. Water 2021.

Bwambale, E., Abagale, F.K. and Anornu, G.K., 2022. Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. Agricultural Water Management, 260, p.107324.

Cao, J., Zhang, Z., Tao, F., Zhang, L., Luo, Y., Zhang, J., Han, J. and Xie, J., 2021. Integrating multi-source data for rice yield prediction across china using machine learning and deep learning approaches. *Agricultural and Forest Meteorology*, *297*, p.108275.

GoP, 2020. Pakistan Economic Survey 2019-20. Ministry of Finance, Islamabad.

Hussain, A. 2014. An analysis of technical efficiency of wheat farmers in Punjab. Unpublished Ph.D. Thesis. Department of Economics and Agric. Economics. PMAS Arid Agriculture University, Rawalpindi: Pakistan.

Ishaque, W., Mukhtar, M. and Tanvir, R., 2023. Pakistan's water resource management: Ensuring water security for sustainable development. *Frontiers in Environmental Science*, *11*, p.10.

Ishaque, W., Shaikh, S., 2017. Water and energy security for Pakistan a retrospective analysis. Grassroots 51 (1), 90–100.

Jehangir, W.A., Masih, I., Ahmed, S., Gill, M.A., Ahmad, M., Mann, R.A., Chaudhary, M.R., Qureshi, A.S. and Turral, H., 2007. *Sustaining crop water productivity in rice-wheat systems of South Asia: A case study from the Punjab, Pakistan* (Vol. 115). IWMI.

Kahlown M.A., M. Ashraf, A. Raoof, Zia-ul-Haq (2003). Determination of crop water requirement of major crops under shallow water table conditions. Research Report- 2, 2003. Pakistan Council of Research in Water Resources (PCRWR), Islamabad.

Khan, A.D., N. Iqbal, M. Ashraf, and A.A. Sheikh.2016. Ground water investigation and mapping in the Upper Indus Plain. Pakistan Council of Research in Water Resources (PCRWR). pp. 72.

Khan, M.J., Malik, A., Rahman, M., Afzaal, M. and Mulk, S., 2019. Assessment of Crop Water Requirement for Various Crops in Peshawar, Pakistan Using CROPWAT Model. *Irrig. Drain. Syst*, *10*(9).

Li, M., Fu, Q., Singh, V.P., et al., 2020a. Risk-based agricultural water allocation under multiple uncertainties. Agricultural Water Management. 233 (30), 106105.

Mahmood, A., T. Oweis,M. Ashraf,A. Majid,M. Aftab,N.K. Aadala, and I. Ahmad (2015). Performance of improved practices in farmers' fields under rainfed and supplemental irrigation systems in a semi-arid area of Pakistan. Agricultural Water Management.155, 1-10.

Mahmood, N. and Ahmad, R.N., 2005. Determination of water requirements and response of wheat to irrigation at different soil moisture depletion levels. *Int. J. Agric. Biol*, *7*(5), pp.812-815.

Pandey, V.P., Dhaubanjar, S., Bharati, L. and Thapa, B.R., 2020. Spatio-temporal distribution of water availability in Karnali-Mohana Basin, Western Nepal: Climate change impact assessment (Part-B). Journal of Hydrology: Regional Studies, 29, p.100691.

PARC, 2020. Pakistan Agriculture Research Council, 2020. Maize, Millet. Sorghum Research Program, Islamabad, Pakistan.

Prueger, J.H., Hatfield, J.L., Aase, J.K., Pikul, J.L., 1997. Bowen-ratio comparisons with lysimeter evapotranspiration. Agron. J. 89 (5), 730–736.

Qureshi A.S. (2011). Water management in the Indus Basin in Pakistan: challenges and opportunities. Mountain Research and Development, 31 (3): 252-260.

Qureshi, R., and Ashraf, M. (2019). Water security issues of agriculture in Pakistan. PAS Islamabad Pak 1, 41.

Rao M.I., M. Ashraf, A.Z. Bhatti, H.A. Salam, N. Gul (2016). Water requirements of major crops in Sindh. Pakistan Council of Research in Water Resources (PCRWR), pp. 68.

Ray, L.I.P., Jyothi, K.S., Singh, A.K., Bharti, V. and Pandey, P.K., 2024. Strategies for water productivity enhancement in maize—A comprehensive review. *Irrigation and Drainage*, *73*(1), pp.359-374.

Saddiqa, A., Batool, S., Gill, S.A. and Khan, A.J., 2022. Water Governance and Management in the 21st Century: A Case Study of Pakistan. Pakistan Journal of Humanities and Social Sciences, 10(1), pp.29-42.

Saeed M. (1994). Crop water requirements and irrigation systems. In: E. Bashir and R. Bantel (Eds), Crop Production. National Book Foundation of Pakistan, p. 49-84.

Soomro Z., M.D.Arshad, K. Ejaz, A.Z. Bhatti, M. Ashraf (2015). Rice cultivation on beds - An efficient and viable irrigation practice. Pakistan Council of Research in Water Resources (PCRWR), Islamabad.

Surendran, U., Raja, P., Jayakumar, M. and Subramoniam, S.R., 2021. Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review. *Journal of Cleaner Production*, *309*, p.127272.

Tariq, M., Iqbal, H., 2010. Maize in Pakistan - An overview. Kasetsart J. - Nat. Sci. 44, 757–763.

Tiryakioglu, M., S. Karanlik, and M. Arslan. 2015. Response of bread-wheat seedlings to waterlogging stress. Turkish Journal of Agriculture and Forestry, 39 (5): 807-816.

World Bank. 2006. Reengaging in Agricultural Water Management: Challenges and Options. The World Bank Washington DC. pp. 218.

Wyn Jones, R.G., J. Gorham, and P.A. Hollington. 2006. Proceedings of International Conference on Sustainable Crop Production on Salt-affected Soils. University of Agriculture, Faisalabad. pp 9-16.