Deficiency of water in the rhizospheric area of soil results in reduced crop growth adversely affecting crop yield. Thus, the objective of irrigation is to maintain the adequate moisture content in the root zone, such that the crop yield is not adversely affected (Kumar et al. 2012; Kumar et al. 2020). However, in the current scenario of climate change, rapid industrialization and population increase, there is tremendous pressure on water resources both quantitatively and qualitatively (Rao and Poonia 2011). Hence, precise allocation of water resources considering the crop water requirement and proper knowledge of soil composition is essential to attain optimum yield, and maximum water use efficiency (Mehta and Pandey 2016). The crop water requirement is generally crop evapotranspiration (ETc) considering atmospheric water loss through plant transpiration and soil evaporation simultaneously (Kumar 2017; Poddar et al. 2021). There are several methods for direct estimation of ETc which includes energy balance, microclimatological methods, field water balance and lysimeters. However, the indirect methods includes measurement of reference evapotranspiration and crop coefficients (Chaudhari et al. 1999). Estimating water balance in the Lysimeter is the most reliable and useful approach for determining actual ETc under field conditions (Kashyap and Panda, 2001). Hence, the present study was undertaken for rabi (Wheat, Indian mustard, Potato) and kharif (Maize, Sorghum, Guar) crops grown in a humid subtropical agro-climate of western Himalayas with a specific objective to estimate the ETc using the lysimeter water balance approach.

Description of the field experiments

An experiment was conducted in the campus of National Institute of Technology Hamirpur, Himachal Pradesh, India situated at 31°68’68”’ N latitude and 7613.3‘52’’ E longitude, and 895 m amsl altitude. The field trials were conducted during the 2017 – 2019 crop growing seasons. The crops considered in the experimental study were wheat (Triticum aestivum), Indian mustard (Brassica Juncea), potato (Solanum tuberosum L.), maize (Zea mays), sorghum (Sorghum bicolor L. Moench) and guar (Cyamopsis tetragonoloba L.). The details of the crop type, crop duration, growth stages, and irrigation events for the present study are illustrated in Table 1. Local agronomic practices (i.e., land preparation, manuring, fertilization) were followed while conducting experiments on different crops.

Water balance method

Two drainage type lysimeters (1.5×1.5×2 m) were installed separately and rim of the lysimeter was kept 0.1 m above ground level to prevent surface runoff. A land gravel filter (0.3m) was provided at the bottom of the lysimeter to facilitate drainage to a calibrated collector. A soil moisture capacitance probe was used to measure soil moisture content at 0.1 m interval till 1.6 m in the soil profile on daily basis. The applied irrigation was measured using a discharge meter installed at the outlet of the water tank. The daily rainfall was recorded using a tipping bucket rainfall.

The water balance method assesses the incoming and outgoing water flux into the crop root zone. Since drainage type lysimeters were used, ETc was obtained for long periods. The ETc was determined using the water balance equation (Bandyopadhyay and Mallick, 2003) as:

\[ P + I = D + ETc + RO + ΔS \]  

where, \( P = \) precipitation (mm), \( I = \) irrigation (mm), \( D = \) Drainage from lysimeter (mm), \( RO = \) runoff (mm), and \( ΔS = \) change in soil moisture storage (mm). \( ΔS \) for a specific depth \( d_z \) for a specific time period is computed as:
\[(\Delta S_z) = (\theta_{z,\text{final}} - \theta_{z,\text{initial}}) \times dz \]  

(2)

where \( \theta_{z,\text{final}} \) and \( \theta_{z,\text{initial}} \) is the final and initial moisture content, respectively in the soil profile in a discrete-time interval.

**ETc variation in rabi crops**

The seasonal ETc of *rabi* crops, i.e., Indian mustard, wheat, and potato, was 165.8 mm, 242.7 mm, and 308.7 mm, respectively (Table 2). The precipitation received during the crop period of wheat, Indian mustard, and potato was 112.4 mm, 114.5 mm, and 108.5 mm, respectively. The amount of irrigation required for wheat, Indian mustard, and potato, was 195.0, 140.0, and 240.0 mm, respectively. This indicated that the irrigation requirements of *rabi* crops are higher than the precipitation received during the crop period. In the case of wheat and potato, the irrigation supplied was almost twice the precipitation, indicating that nearly two-thirds of the crop water requirements were fulfilled by irrigation. The contribution to the groundwater during the *rabi* crop season was quite low as compared to the amount of water received. The variation of stage-wise ETc for *rabi* crops considered has been shown in Table 2. It is evident from the table that the ETc during the initial and mid-season stage for *rabi* crops was quite similar. However, during the crop development stage, the ETc for potato was significantly higher than wheat and Indian mustard. During the late season, the ETc for wheat was higher as compared to the other two crops.

**ETc variation in kharif crops**

The seasonal ETc of *kharif* crops, i.e., maize, sorghum, and guar, was 502.9 mm, 518.9 mm, and 494.7 mm, respectively (Table 2). The amount of precipitation obtained during the crop period of maize, sorghum, and guar, was 1052.5, 1059.3, and 1124.3 mm, respectively, which is comparatively much higher than the *rabi* crops. The total amount of irrigation required for maize, sorghum, and guar, were 10.0, 31.4, and 20.0 mm, respectively, which is substantially less than the irrigation required for *rabi* crops. This also indicates that the irrigation requirements of *kharif* crops were very low as compared to the received precipitation. More than 95 per cent of the crop water requirements were fulfilled by the precipitation alone. The groundwater contribution during the *kharif* crop season was substantially high. The variation of stage-wise ETc for *kharif* crops considered has been shown in Table 2. The ETc for *kharif* crops during the initial and late-season stages was nearly the same. The ETc for sorghum was significantly low during the crop

**Table 1:** Details of the crop duration, growth stages, and irrigation days pertaining to *Rabi* and *Kharif* crops grown in the field

| Crop Variety | Date of sowing | Date of harvesting | Duration | Growth stages (Days) | Irrigation provided (DAS) | Spacing (cm) |
|--------------|----------------|--------------------|----------|---------------------|--------------------------|-------------|
| *Rabi* Crops |               |                    |          |                     |                          |             |
| Wheat (*Triticum aestivum*) | Super (6776/PB) | 3rd Jan, 2017 | 15th May, 2017 | 133 | 25, 36, 45, 28 | 26th, 44th, 56th, 80th, 96th, 116th | 20x5 |
| Indian mustard (*Brassica juncea*) | VL-804 | 22nd Jan, 2018 | 14th May, 2018 | 113 | 19, 32, 38, 25 | 11th, 25th, 37th, 59th, 91st | 40x15 |
| Potato (*Solanum tuberosum L.*) | Kufri Himsona | 7th Jan, 2019 | 6th May, 2019 | 120 | 22, 32, 38, 29 | 21st, 40th, 52nd, 64th, 87th, 104th | 45x15 |
| *Kharif* Crops |               |                    |          |                     |                          |             |
| Maize (*Zea mays*) | Maize 7074 (HYBRID) | 20th May, 2017 | 10th Sept, 2017 | 114 | 20, 34, 36, 24 | 22nd, 36th, 48th, 64th | 50x20 |
| Sorghum (*Sorghum bicolor L. Moench*) | TX 610 | 16th May, 2018 | 22nd Sept, 2018 | 130 | 21, 35, 39, 35 | 22nd, 48th, 75th, 93rd | 30x15 |
| Guar (*Cyamopsis tetragonoloba L.*) | Agaita Guara - 112 | 28th May, 2019 | 1st Sept, 2019 | 97 | 20, 26, 28, 23 | 26th, 53rd, 81st | 25x15 |
development and significantly high during the mid-season stage when compared to maize and guar crops. The ET\textsubscript{c} variation of maize and guar crops was similar during all stages of crop growth.

The seasonal ET\textsubscript{c} in the case of rabi crops was highly variable, but for kharif crops, it was nearly similar. The stage-wise ET\textsubscript{c} variation was different for each rabi crop considered. For kharif crops, maize and guar followed similar stage-wise ET\textsubscript{c}, whereas sorghum followed a different pattern. The estimated ET\textsubscript{c} of different crops may further help in planning of optimal irrigation schedules in the humid sub-tropical agro-climate of the western Himalayas.

**ACKNOWLEDGMENTS**

The authors gratefully acknowledge the financial support received from the Ministry of Earth Sciences, Govt. of India.

**Conflict of Interest Statement**: The author(s) declare(s) that there is no conflict of interest.

**Disclaimer**: The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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