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Estimation of Irrigation Return Flow in Sandy-Loam Soil using Water-balance Approach

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ABSTRACT

In this study, irrigation return flow (deep percolation) has been estimated by using water balance approach. The experimental setup consisted of two lysimeters installed at the College of Agricultural Engineering & Technology field lab, SKUAST-Kashmir, Shalimar in which pea crop was grown, simulating the natural conditions available in the vicinity of lysimeter. Regular measurements of soil moisture were made at the depths 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm using gravimetric method. The evapotranspiration estimates were determined using FAO-Penman-Monteith equation. The deep percolation was calculated using the water-balance approach. The deep percolation losses calculated by water-balance approach are comparable to the observed values of deep percolation obtained by the lysimeters. The observed and the calculated values of deep percolation have 7.65% (using water balance method) difference. Results obtained showed that locally constructed lysimeters could effectively be utilized in water balance studies of a cropped area when used in combination with root zone soil moisture monitoring devices.

Keywords: Deep Percolation, Lysimeter, Penman-Monteith equation, Pea.

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INTRODUCTION

The scarcity of water for agricultural sector has been a common phenomenon in the recent times. This in turn, demands the proper management of the water resources in each and every sphere. Agriculture being a major shareholder in the consumption of the water resources, water resource management in this sector needs more attention. Growing more crop per drop of water use is the key to mitigating the water crisis and this is a big challenge to many countries. It is now well known that the water policies need to facilitate market-based approaches to water allocation and commercialization of agriculture. Only a fraction of irrigation water applied to the fields is utilised by the plants for meeting its water requirement. Some portion of the applied water that is not consumed in agricultural fields, flows to streams/drainage canals or is percolated downwards.

Salinity problems in irrigated areas are often associated with excess deep percolation, defined as the net amount of water percolating below the plant root-zone. Deep percolation under irrigation occurs when infiltrated water exceeds the storage capacity of the soil. Surface irrigation is the most widespread form of irrigation in the world (Kulkarni *et al.,* 2006). Soil infiltration characteristics and the duration of ponding govern the amount of infiltration during surface irrigation (Kruse *et al.,* 1990). The amount of infiltration that results in deep percolation will depend on soil properties, root water extraction patterns and the water table depth (Bethune, 2004). Understanding the response of Deep Percolation to biophysical properties and management factors is critical to developing options for reducing the salinity risk under surface irrigation. Direct measurement of Deep Percolation is difficult under field conditions (Bond, 1998). Deep percolation is often calculated as a residual of the water balance. The uncertainty in measuring the various water balance terms typically introduces errors that are of a similar magnitude to the estimated Deep Percolation (Ward et al., 1998).

So far, various devices fabricated to monitor root zone soil water dynamics including tensiometers of different types, gypsum blocks, frequency domain reflectometry (FDR) probes, time domain reflectometry (TDR) instruments, wetting front detector, neutron moisture meter and heat dissipation devices (Momin et al., 2011, Charlesworth, 2005). However, these types of devices are accompanied by their own demerits and are usually costly to acquire and implement. Lysimeters have been developed for use in soil science and used for over 300 years to study the relations between soil, water and plants (Grebet and Cuenca, 1991). Lysimeters represent the actual field conditions by enabling direct measurement of deep percolation water or change of soil moisture due to evapotranspiration or percolation.

Hatiye *et al.,* (2017) studied deep percolation in paddy fields using drainage type lysimeters under varying regimes of water application in IIT Roorkee and found that more than 80% of the input water was lost through deep percolation during continuous irrigation season, while approximately 75–80% of the input water was lost due to deep percolation during the intermittent application of irrigation season. Upreti *et al.,* (2015) estimated deep percolation by using water-balance approach in IIT, Roorkee and concluded that deep percolation can be estimated very accurately in a field using the moisture content data and the Penman-Moneith estimates

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of the evapotranspiration. The various variables of water-balance in Gicheon watershed in the Republic of Korea was determined by using water-balance model (Kim *et al.,* 2009). Deep percolation through the paddy fields due to irrigation was coined as delayed return flow and was computed by the difference between discharge from the paddy fields to the groundwater when irrigation is applied and discharge from paddy fields to the ground water when no irrigation is provided. Other methods developed to quantify deep percolation in the field conditions were using weighing lysimeters, sap flow methods (Lopez-Urrea *et al.,* 2009; Jara *et al.,* 1998 and Trambouze *et al.,* 1998). GIS and remote sensing methods are suitable for estimation of deep percolation and other water-balance components on a large scale but it is difficult to apply them on field scale (Arif *et al.,* 2012). In this study, deep percolation has been quantified using the water-balance approach using the FAO-Penman-Monteith estimates of evapotranspiration.

MATERIALS AND METHODS

Pea crop was grown in a lysimeter set-up in the College of Agricultural Engineering & Technology field lab, SKUAST-Kashmir, Shalimar, Srinagar Jammu & Kashmir. The crop period was from November 20, 2020 to May 18, 2021 (180 days). Moisture content readings at certain depths are taken at regular interval of time in the lysimeter setup. Apart from the lysimeter, crop is also grown in the field surrounding the lysimter, in which the field conditions are maintained same as that of the lysimeter. Records of crop parameters such as root depth, plant height are also taken regularly from the surrounding field. Regular measurements of soil moisture were made at the depths 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm using gravimetric method. Soil parameters such as soil texture, bulk density, etc. were determined few days before the sowing of the crop.

Experimental Site

SKUAST-Kashmir is located 1586.0 m altitude above mean sea level at 74°9' E longitude, 34°1' N latitude. The climate of Kashmir falls in temperate class according to Thornthwaite climate classification (Allen *et al.,* 1998). Summers are moderately hot while winters are bitterly cold. It was evident from the meteorological data that the mean maximum temperature was 24.5°C and mean minimum temperature was -5.87°C during the cropping season of 2020-2021. The mean daily maximum and daily minimum temperature

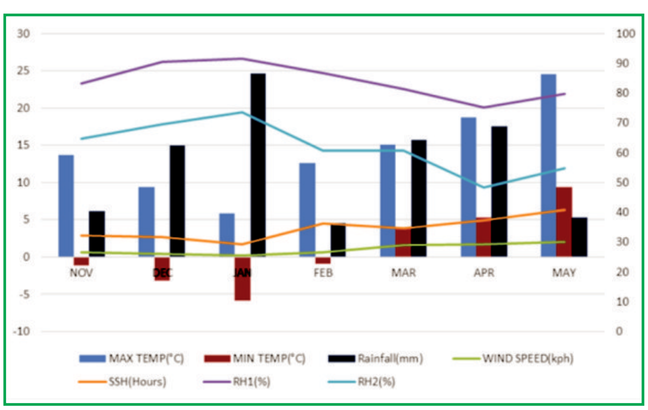

Fig. 1: Monthly meteorological data during the crop growth period

during the growing season of pea fluctuated between 14.2°C and 1.05°C respectively. The average rainfall recorded as 12.7 mm during the entire crop growing season. The average sunshine hour during crop growing period was 4 hours. The average wind speed was 1.02 km h^{-1} during crop growing season. Soil in the experimental field is in sandy loam classification according to the USDA soil classification system (58%, 18% and 24% of sand, slit and clay respectively for 0-1 m depth). Monthly meteorological data during the crop growth period is shown in fig. 1.

Lysimeter setup

A lysimeter setup surrounded by the field has been installed in the field lab to conduct the field experiments. The inflows and outflows of the lysimeter are timely monitored. It has been installed in the open field to simulate close to actual field conditions with the boundary effects avoided due to the metallic boundaries of the lysimeter. There is no horizontal seepage and the water-table does not affect the waterbalance due to the metallic boundaries. The dimensions of the lysimeter used are 1.2 m depth and 1 m×1 m cross-section. A drainage port is provided at the bottom side of each lysimeter to allow the percolated water to drain in the buckets placed below the drainage ports. Fig. 2 shows the schematic representation of the lysimeter setup.

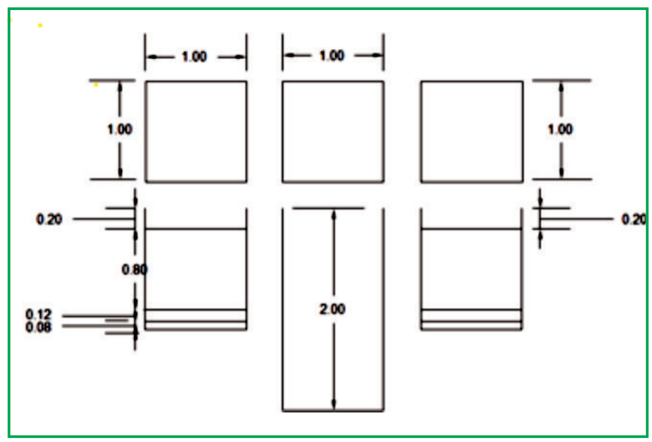

Fig. 2: Plan and elevation of lysimeter setup

An observation trench is provided besides the lysimeter (in which measuring containers are placed) to monitor the drainage water. The bottom-most 8cm of the lysimeter is filled by very coarse gravel of gravel size more than 2.5 cm. 12 cm depth of coarse gravel of size 2 cm is filled above it. Sandy-loam soil of 0.8 m depth which is similar to the soil in the surrounding field is filled over the coarse gravel layer. Soil in the lysimeter has been disturbed and so to attain the field conditions. Soil in the lysimeter continuously irrigated and allowed to drain through a draining arrangement at the bottom of each lysimeter repeatedly, to bring it near to actual field condition. Before starting the sowing of crop, in situ tests for determination of soil characteristics have been carried out. Top 20 cm of the lysimeter is kept empty to ensure that surface runoff does not occur when rainfall occurs or irrigation is applied. The idea behind placing coarse gravel in the bottom portion of the lysimeter is to prevent the clogging of the percolated water in the lysimeter and to provide a perforated barrier to drain it off to the measuring buckets. Drainage from the drainage port of the lysimeter is taken as actual or observed value of deep percolation. Table 1 summarizes the measurement of the inflow-outflow variables of the lysimeter setup.

Table 1: Determination of inflow and outflow variables

Measured variable	Methods
Rainfall	Data obtained from AMFU, SKUAST-K
Irrigation	Flood irrigation
Percolation	Measuring buckets below the drainage ports
Evapotranspiration	Penman-Monteith equation
Change in soil moisture torage	Gravimetric method

Crop and Soil Parameters

Crops were suitably fertilized with fertilizers at suitable growth stages. The irrigations were scheduled at 50% depletion in available soil moisture in the root zone. The irrigation water to the lysimeters has been provided by a hosepipe after calibrating its discharge. The cropping period for pea in this study is 180 days and the entire crop growth period is divided in four stages: initial, development, mid-season and late-season (FAO-Water Development and Management Unit - Crop Water Information: Pea). In the initial stage, ground cover of the crop is less than 10%. It corresponds to the seed germination and very starting of the crop growth. Development stage commences with the end of the initial stage to the stage when the crop ground cover is 70-80%. Crop requirements are substantially increased during this period. The period from the attainment of full crop growth to the full bloomand pod maturity is midseason period. After that to the pick-up is late-season. The division of the crop the crop period into the four stages is shown in Table 2.

Table 2: Summary of the crop period of the pea crop

Crop	Date of sowing	Date of harvesting	Duration	Growth stages (Days)			
				Initial	Development	Mid-season	Late-season
Pea	November 20, 2020	May 18, 2021	180 days	35	45	70	30

Soil parameters such as soil texture, field, porosity, soil moisture etc. are measured or estimated using standard methods which are mentioned in Table 3.

Table 3: Methods used to measure various soil parameters

Measured parameter	Method/equipment used
Soil Texture	Sieve analysis, hydrometer
Soil moisture	Gravimetric method
Bulk density	Core samples
Field capacity	Gravimetric method

Deep percolation is estimated using the water balance equation. The inflow and outflow variables required in the water balance equation are measured in the lysimeter set-up. The inflow to the field can consist of precipitation and applied irrigation water and water can leave the field through evapotranspiration, surface runoff, seepage and vertical percolation. The water balance equation for a field can be expressed as:

$$\Delta S = P + I - ET - DP - HS - R \qquad (1)$$

Where, ΔS is the change is storage in the root zone (mm), P is precipitation amount (mm), I is irrigation water (mm), ET is actual evapotranspiration (mm), DP is vertical deep percolation (mm), HS is horizontal seepage through bunds (mm) and R is surface runoff (mm).

As the experiments are conducted in a lysimeter, horizontal seepage (HS) is zero and as the soil is not fully filled in the lysimeter, surface runoff (R) is negligible. So, the water balance equation for the lysimeter set-up becomes:

$$\Delta S = P + I - ET - DP \qquad (2)$$

Rearranging equation (2) and knowing all other variables, deep percolation is estimated using:

$$DP = P + I - ET - \Delta S \qquad (3)$$

Change is storage (ΔS) is calculated using the initial and final moisture content readings over required time duration. Precipitation (R) data is taken from the meteorological observatory of Agromet Field Unit, SKUAST-K, Shalimar. Evapotranspiration (ET) is estimated using FAO-Penman-Monteith equation (Allen *et al.,* 1998). Irrigation (I) to the crop is measured by calibrated hosepipe.

Evapotranspiration

Reference evapotranspiration is estimated using FAO-Penman-Monteith equation (Thornwait, 1948). The meteorological data (e.g., air temperature, relative humidity, sunshine hours, solar radiation, wind velocity, etc.) have been taken from the meteorological observatory of Agromet Field Unit, SKUAST-K, Shalimar which is within 500 m aerial distance from the experimental site. Actual evapotranspiration is determined by multiplying reference evapotranspiration with a suitable crop coefficient (Kc). FAO-irrigation and drainage paper-56 on guidelines for computing crop water requirements provides comprehensive listing of crop coefficients for different growth stages of various crops (Thornwaite, 1948) (Fig. 3).

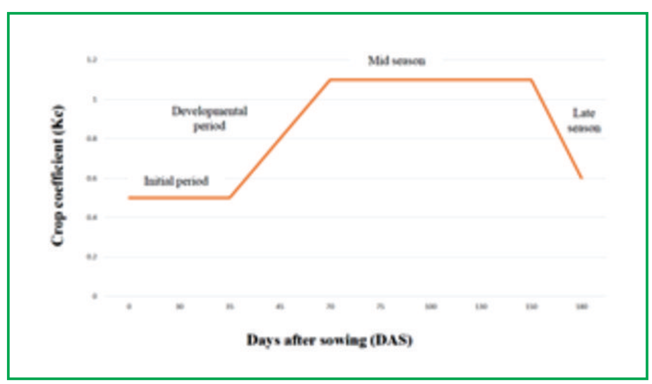

Fig. 3: FAO recommended crop coefficient values for pea crop

FAO provided crop coefficients for various stages correspond to standard crop and climatic conditions. The values of crop coefficient for the pea crop have been shown in Figure 3. FAO proposed Kc_{ini}, Kc_{mid} and Kc_{late} values for pea crop grown in Indian conditions are 0.3, 1.15 and 0.6 respectively. Kc_{ini}, Kc_{mid} and Kc_{late} are the values of crop coefficients during the initial

Table 4: Observed values of deep percolation (in the Lysimeter)

Growth Stages	Rainfall (mm) P	Water applied (mm) I	Change in soil moisture (mm) ΔS	Crop evapotranspiration (mm) ET	Water drained (mm) DP_{obs}
Initial	88.8	30.0	85.56	15.94	16.5
Development	206.0	0	161.64 376.08	24.36	20.0
Mid-season	399.4	80.0	-1.68	74.82	28.5
Late-season	99.6	30.0	622.4	119.28	12.0
Total	793.8	140.0		234.40	77.0

period, during the mid-season period and at the end of late-season stage respectively.

RESULTS AND DISCUSSION

Daily estimates of actual crop evapotranspiration (ET) determined by using FAO-Penman-Moneith equation for the cropping period of Pea (Fig. 4). The values of daily crop evapotranspiration are less during the initial stage of the crop period due to the absence of leaves. It is very less during next two months due to snow fall in the study area. It gradually increases with the increase in the crop canopy due the increase in transpiration from the leaves and attain maximum values during the mid-season stage. Towards the late-season stage, the ET values gradually decrease (Fig. 4).

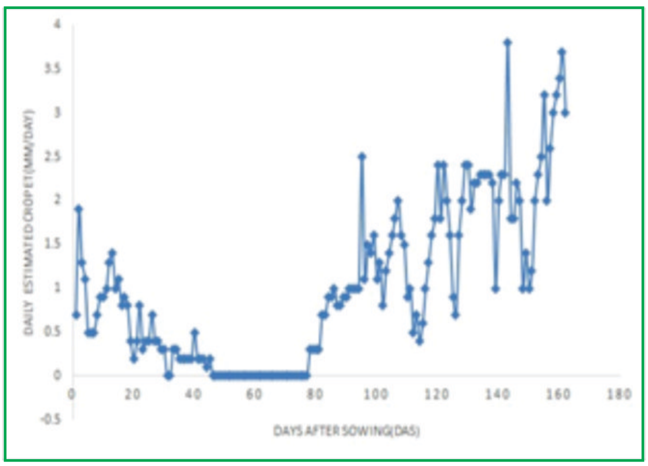

Fig. 4: Daily estimated crop evapotranspiration for the pea crop throughout the crop period.

Values of deep percolation estimated using water balance method are comparable to the observed value. The observed and the calculated values of deep percolation have 7.65% (using water balance method) difference. The values of deep percolation estimated by the water balance method and observed deep percolation values for the four crop growth stages are shown in Tables 4 and 5 respectively. The error in the estimation of percolation using water-balance method can be explained by error in actual evapotranspiration estimation. The estimated values of daily evapotranspiration (using FAO-Penman-Monteith equation) can differ slightly from the actual ones (Fig. 5).

The average value of percolation/day (both observed and estimated) is highest for the initial stage of the crop (Fig. 6). This can be explained because of the absence of the less density of the roots in the initial period. Less root density will result in less uptake of water from the root zone and hence, more percolation. In other terms, percolation is more during the initial period because of the less evapotranspiration during the same period. During the initial period, due to the absence of leaves or their feeble growth, only evaporation contributes to evapotranspiration and value of the actual evapotranspiration is very low which gradually increases with crop growth (growth of leaves) in the initial period. As, the outflow in the lysimeter only include percolation and evapotranspiration. So, lower values of evapotranspiration mean that percolation is higher along with some moisture storage in the soil root zone.

CONCLUSION

Crop evapotranspiration is estimated using Penman-Monteith equation to approximate deep percolation using water balance method. Two 1.21 m deep and 1.21 m×1 m cross-

Table 1: Deep percolation values estimated by water balance method

Growth Stages	Rainfall (mm)	Water applied (mm)	Change in soil moisture (mm)	ET_c by Penman method (mm)	Deep percolation (mm)DP_{cal}
Initial	88.8	30	85.56	17.16	15.28
Development	206	0	161.64	25.95	18.41
Mid-season	399.4	80	376.08	75.62	27.7
Late-season	99.6	30	-1.68	121.17	10.11
Total	793.8	140.0	622.4	239.9	71.5

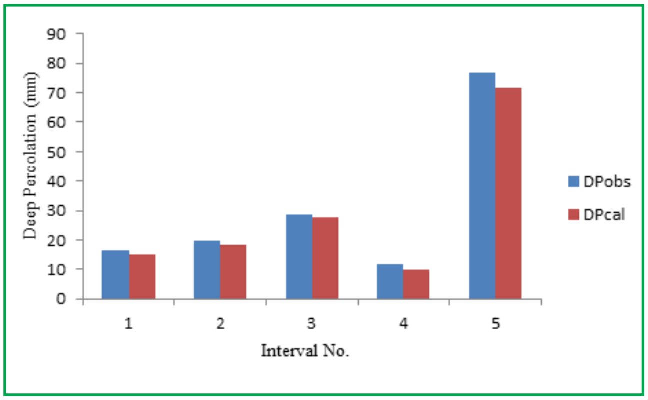

Fig.5: Comparison between observed (DP_{obs}/day) and calculated (DP_{cal}/day) crop stage wise percolation values

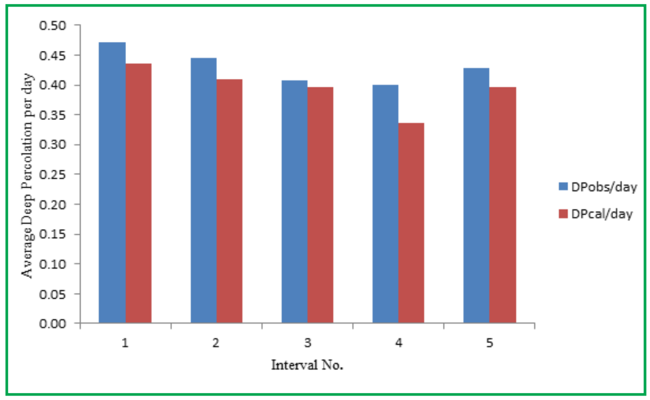

Fig.6: Comparison between averaged observed (DPobs/day) and calculated (DPcal/day) crop stage wise percolation/day values

section lysimeters are used for monitoring the variables of water-balance for the pea crop (inflows and outflows) and the drainage from their outlets is taken as the observed value of deep percolation. Deep percolation estimated using the water balance approach is found comparable to the observed value of deep percolation (drainage from the lysimeter).

This study shows that deep percolation can be estimated very accurately in a field using the moisture content data and the Penman- Moneith estimates of the evapotranspiration. But in practical situations, depth of water table, surface runoff and horizontal seepage are needed to be taken into consideration.

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