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Estimation of Deep Percolation in Sandy-Loam Soil using Water-balance Approach

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Abstract

The most reliable method used to estimate deep percolation is using Lysimeter which proves to be expensive and time consuming as well. In this study, deep percolation has been estimated by using water balance method. The experimental setup consisted of two lysimeters in the Hydraulic Engineering field lab, I.I.T., Roorkee in which maize crop was grown. 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 Penman-Moneith equation. The deep percolation is calculated using the water-balance approach. The deep percolation calculated using the water-balance approach is comparable to the observed values of deep percolation which are obtained from the lysimeters.

Keywords: Deep percolation; Water balance method; Penman-Moneith equation; Lysimeter

Introduction

The growing shortage of water has been a common phenomenon in the recent time. This in turn, demands the proper management of the water resources in each and every sphere. Agriculture being a major share-holder in the consumption of the water resources, water resource management in this sector needs more attention. 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. Some portion of the applied water that is not consumed in agricultural fields, flows to streams/drainage canals or is percolated downwards. So, the quantitative measurement of the irrigation return flows (deep percolation, runoff, etc.,) is of prime importance. The ranges of variation in the quality and quantity of sub-surface drainage (deep percolation) are highly site-specific and are affected by the parameters presented here and also, by many other factors. The major factors affecting the quantity of deep percolation are: availability and cost of the supply water, irrigation application methods and efficiencies and special cultural practices.

Kim et al. [1] used water-balance model to determine the various variables of water-balance in Gicheon watershed in the Republic of Korea. 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 [2], sap flow methods [3,4]. 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 [5].

In this study, deep percolation has been quantified using the water-balance approach using the Penman-Moneith estimates of evapotranspiration.

Experimental Programme

Maize crop was grown in a lysimeter set-up in Hydraulic Engineering field lab, Civil Engineering department, Indian Institute of Technology, Roorkee (I.I.T. Roorkee). The crop period was from September 27, 2012 to January 23, 2013 (119 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. Soil parameters such as soil texture, bulk density, etc. were determined few days before the sowing of the crop.

Experimental site

Roorkee is located 274.0 m altitude above mean sea level at 77°53'52" E longitude, 29°52'00" N latitude. The climate of Roorkee falls in semi-arid class according to Thornthwaite climate classification [6]. Summers are hot and humid while winters are cold and dry. Roorkee receives an annual rainfall of 1032 mm, mainly from the south-west monsoons and annual sunshine duration of 2800 hours. 75% of the annual rainfall occurs between July and September. Soil in the experimental field is in sandy loam classification according to the USDA soil classification system (52%, 30% and 18% of sand, slit and clay respectively for 0-1 m depth).

Lysimeter set-up

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 water-balance due to the metallic boundaries. The dimensions of the lysimeter used are 1.5 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

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water to drain in the buckets placed below the drainage ports. Figure 1 shows the schematic representation of the lysimeter setup.

An observation trench is provided besides the lysimeter (in which measuring buckets are placed) to monitor the drainage water. The bottom-most .08 m of the lysimeter is filled by very coarse gravel of gravel size more than 3 cm. 12 cm depth of coarse gravel of size 2 cm is filled above it. Sandy-loam soil of 1.1 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 0.2 m 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.

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.

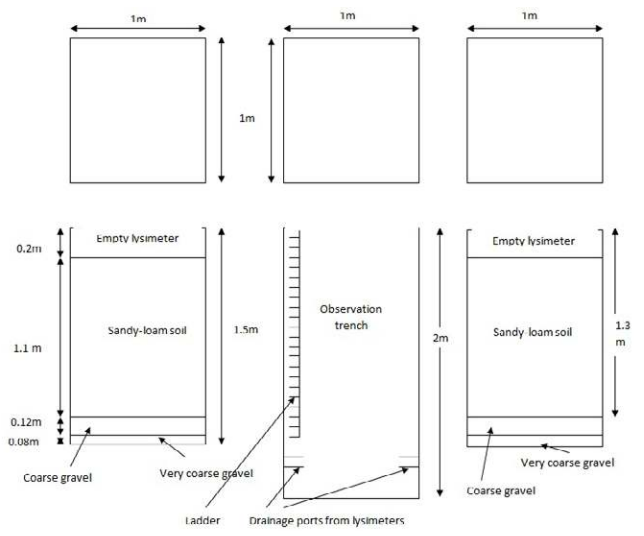

Figure 1: Plan and elevation of lysimeter setup.

Measured variable	Determined by
Rainfall	Data obtained from AWS (N.I.H., Roorkee)
Irrigation	Calibrated hosepipe
Percolation	Measuring buckets below the drainage ports
Evapotranspiration	Penman-Monteith equation
Change in storage	Gravimetric moisture content values

Table 1: Determination of inflow and outflow variables.

The cropping period for maize in this study is 119 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: Maize). 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 ground cover to the discolouring and falling of leaves is mid-season period. After that to the harvest is late-season. The division of the crop the crop period into the four stages is shown in Table 2.

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

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:

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

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:

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

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

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

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 automatic weather station, N.I.H., Roorkee. Evapotransipration (ET) is estimated using Penman-Monteith equation [6]. Irrigation (I) to the crop is measured by calibrated hosepipe.

Evapotranspiration

Reference evapotranspiration is estimated using Penman-Monteith equation [7]. The meteorological data (e.g., air temperature, relative humidity, sunshine hours, solar radiation, wind velocity, etc.) have been taken from automatic weather station, N.I.H., Roorkee which is within 750 m aerial distance from the experimental site. Actual evapotranspiration is determined by multiplying reference evapotranspiration a suitable crop coefficient (K_c). FAO-irrigation and drainage paper-56 on guidelines for computing crop water

Crop	Date of sowing	Date of harvesting	Duration	Growth stages (Days)			
				Initial	Development	Mid-season	Late-season
Maize	September 27, 2012	January 23, 2013	119 days	28	30	44	27

Table 2: Summary of the crop period for the maize crop.

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Measured parameter	Method/equipment used
Soil texture	Sieve analysis, hydrometer
Soil moisture	Gravimetric method
Bulk density	Core samplers

Table 3: Methods used to measure various soil parameters.

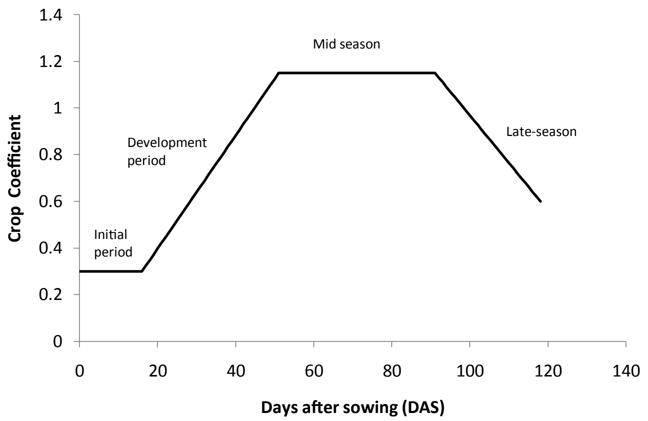

Figure 2: FAO recommended crop coefficient values for maize crop.

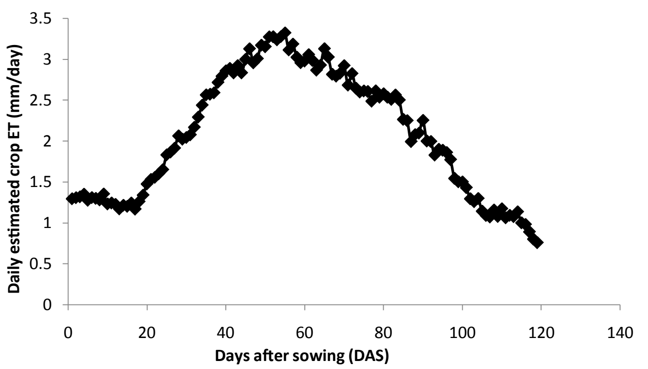

Figure 3: Daily estimated crop evapotransipation for the maize crop throughout the crop period.

requirements provides comprehensive listing of crop coefficients for different growth stages of various crops [7] (Figure 2).

FAO provided crop coefficients for various stages correspond to standard crop and climatic conditions. The values of crop coefficient for the maize crop have been shown in Figure 2. FAO proposed K_{cini}, K_{cmid} and K_{cend} values for maize crop grown in Indian conditions are 0.3, 1.15 and 0.6 respectively. K_{cini}, K_{cmid} and K_{cend} are the values of crop coefficients during the initial 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 Penman-Moneith equation for the cropping period of maize are shown in Figure 3. The values of daily crop evapotranspiration are very less during the initial stage of the crop period due to the absence of leaves. 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 (Figure 3).

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 14.5% (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 Penman-Monteith equation) can differ slightly from the actual ones (Figure 4).

The average value of percolation/day (both observed and estimated) is highest for the initial stage of the crop (Figure 5). This can be explained because of the absence or less density of 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.

Summary and Conclusions

Crop evapotranspiration is estimated using Penman-Moneith

Interval No.	Crop stage	P	I	ΔS	ET	DP1
1	Initial	0	40	11.8	21.5	6.7
2	Development	0	90	-9.5	84.3	15.2
3	Mid-season	0	110	-12.5	108.2	14.3
4	Late-season	28.3	10	-11.5	38.9	10.9
5	Total	28.3	250	-21.7	252.9	47.1

Table 4: Deep percolation values by water balance method.

Interval No.	Crop stage	P	I	ΔS	DPa	ET
1	Initial	0	40	11.8	10.1	18.1
2	Development	0	90	-9.5	20.1	79.4
3	Mid-season	0	110	-12.5	15.4	107.1
4	Late-season	28.3	10	-11.5	9.5	40.3
5	Total	28.3	250	-21.7	55.1	244.9

Table 5: Observed values of deep percolation (water-balance in the lysimeter).

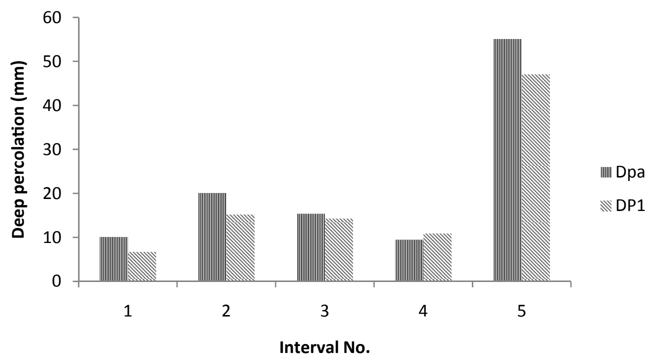

Figure 4: Comparison between observed (DPa) and calculated (DP1) crop stage wise percolation values.

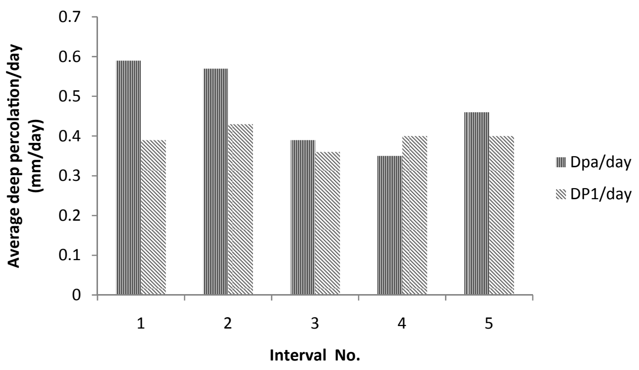

Figure 5: Comparison between averaged observed (DPa/day) and calculated (DP1/day) crop stage wise percolation/day values.

equation to approximate deep percolation using water balance method. Two 1.5 m deep and 1 m×1 m cross-section lysimeters are used for monitoring the variables of water-balance for the maize 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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