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Soil Water Balance Computation - The Instrumental Part

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Abstract

This paper presents a methodological/instrumental/calculative assignment used to delineate soil water balance components. From the last decade, a number of publications appeared in reputed journals on the soil water balance computation under different cropping patterns with divergent establishment methods/Resource Conservation Technologies (RCTs) without discussing much on the calculative/instrumental part. This creates confusion between budding students/scientists as they hesitate to work onto the problems of soil water balance computation during their masters or even at doctoral level because of lacked basic (instrumental/methodological) knowledge. Present compilation focused in detail on the instrumental/calculation of the soil water balance components *viz*. rainfall, irrigation, evaporation, transpiration, drainage, seepage and change in the soil moisture profile. Each component is of importance in calculating soil water balance. In spite of being familiar with the instrumental part, methodological and calculative parts are equally important. Currently, scientists focused on identification of opportunities for water savings and increasing water productivity; developing a better understanding of present patterns of water use and impacts of interventions. Further one could delineate the impact of a particular RCT in a particular region under diverse agro-climatic conditions for improving land and water productivity only being fully conversant with instrumental/methodological/calculative part required for calculating the soil water balance components.

Keywords: Evaporation; Transpiration; Seepage; Drainage; Water balance; Unsaturated hydraulic conductivity

Abbreviations

RCT: Resource Conservation Technologies; SMP: Soil Matric Potential; Es: Soil Evaporation; D: Drainage; S: Seepage; T: Transpiration; q: Flux; K = Unsaturated hydraulic conductivity; $\Delta H/L$: Hydraulic gradient; Ψm: Matric Potential; Ψg: Gravitational Potential; W: Moisture on mass basis; D_b: Bulk Density; Øi: Moisture content on volumetric basis

Introduction

Soil water balance computation is a must for improving the water use efficiency by reducing the unproductive loss of water *viz.* evaporation which further improved the sustainable use of irrigation water [1-5]. Therefore, scientists across the globe working to reduce the soil evaporation [4-9]. Aquifer management must be given high priority for establishing a better balance between discharge and recharge components as is widely practiced in Germany, Switzerland, the USA, the Netherlands and Sweden where share of artificial recharge to total groundwater use ranged between 15-25% [3,10]. The sustainable use of water is a critical issue against the backdrop of rising water demand for agricultural use [3,11-13] as the world needs about 60% more food [14] to feed the 9.5 billion people in 2050 [15]. However, the situations becoming more complicated with shrinking natural resources [3,16,17] and climate change impacts on agriculture [16,18,19]. Furthermore, improved living standards [2] and changing dietary habits [12], requiring more water-intakes, make this issue more complicated. About 90% of the global consumptive water use is for irrigation [20,5], and about 40% of the irrigation water is derived from groundwater [21] which ultimately resulted in declining underground water levels and land-water productivity.

Effective strategies for realizing higher productivity along-with mitigating global warming consequences must be verbalized by dissecting wastes and non-productive water uses to where it urgently required [3]. Water budgeting is a procedure for analysing the addition-depletion relationship of water which further helped us to increase water use efficiency [1,11,22]. Computation of water budgets provides underpinning for effective water management strategies, which further helps us to switch onto the effective RCTs. Water budgets helped us to quantify the adverse effect of anthropogenic activities on water resources *viz.* puddling. From percentage of water resources oceans has highest percentage of the total worldwide water [8].

Scientists across the globe coined different terms to quantify water use *viz.* Hoekstra and Hung defined local water use efficiency, water allocation efficiency and global water use efficiency [23] and [24] for improving the water use efficiency. Further the term “virtual water” coined by Allan in relation to water, food and their trades. Generally, in literature, terms green, blue, gray and black water is water often used [23]. Blue water is the rainwater directly enters to the lakes and recharges the underground water table, and that is directly consumed by the human being green water is the water in soil pores, which is available to the plants for transpiring to produce biomass [25] while gray water is the wastewater generated from domestic activities such as bathing, dish washing and laundry whereas black water consists of toilet water. Gray water is a large potential source of water and could

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be reused for toilet flushing, irrigation in parks, school yards, golf areas, car washing, and fire protection, which may reduce freshwater demand up to 30% in cities [26].

Irrigation and rainfall constitutes the major input side of soil water balance equation. Coming over to the right side of the equation, Evapo Transpiration (ET) constitutes a major part of water loss. It is documented that total ET losses almost remain same [9,27]. Evaporation is the unproductive loss of water which has to be partitioned to transpiration (whereby inflow of nutrients along with nutrients increased) for finally improving the grain yields [12,6]. Drainage and seepage losses are the situation when the irrigation water is beyond the reach of the rhizosphere. During the wheat season/winter season, drainage losses assumed to be negligibly small because of significantly lower irrigation requirements than the rice season/summer season. Generally, deep drainage during the wheat season was very small (negligible to less than 100 mm) in comparison with that from rice (up to ~2,000 mm) [11].

Change in profile moisture storage through the profile could be measured before sowing and after harvesting the crop as it provides us an idea regarding the total moisture used during the cropping period which might be differs a lot depending upon the adoption of a particular establishment method/resource conservation technique. Soil water balance variables provide a wayout to identifying technologies which helped to improve the water use efficiency. Intervening period is the least attended area of research as scientists are generally busy in analysing the effect of already applied treatments onto the main crops [24,28-30] and delineating soil moisture dynamics during this period also helped us to study the treatment effect during the fallow period which further having a significant effect onto the fodder crops and next crop right from the germination [28,29,31]. Thus, soil water balance studies strengthen the scope of effective, judicious, climate smart, farmer friendly and environmental friendly irrigation water use. Now we are going to discuss different soil water balance components and their computation/instrumental part in detail.

Methodological/Instrumental Part

Among the different soil water balance components *viz.* rainfall, Irrigation, evaporation, transpiration, drainage, seepage and change in the soil moisture profile:

$$R + I = E + T + D + S + \Delta G \quad (1)$$

Following we are discussing it one by one in the detail way their methodological/instrumental part for easy understanding.

Irrigation water amount (I)

It is one of the most main input parameter of the soil water balance equation but mostly its measurement is not so accurate. Scientists earlier used area-velocity flow method but provide us a rough estimate and depend upon several factors. But presently, we have different meters which accurately quantify the irrigation water applied to a particular plot *viz.* digital area velocity flow meter (AVFM 5). The AVFM installed at the mouth of each plot to a depth of 5 cm in wheat and 7.5 cm in rice during each irrigation [1]. Digital flow meter (Figure 1) manufactured by GREYLINE is irrigation water measuring device on quantitative basis. From parts, it comprised of sensor which has to be fit in plastic pipe. Further, it required a battery for its power at the field as electricity supply is not available at remote points. We need to calibrate it by measuring water in a drum of known dimension. In case of any mismeasurement necessary steps *viz.* a correction factor could also be applied.

Figure 1: Complete set of flow meter with sensor in the pipe and battery for functioning of meter.

Figure 2: Rain gauge used for measuring the rainfall (mm) received during the experimental season.

Before applying irrigation water to a particular plot, pipe with the sensor needs to be installed at the plot. Now when irrigation water entered the plot through this pipe from the sensor, then automatically flow meter start showing the reading and one could easily now the liters of irrigation water supplied to a particular plot which is very important to measure the irrigation water productivity.

Rainfall (R)

Rain fall amount (cm) can be determine on the rainy day using rain gauge (Figure 2) installed at the experimental site, itself, which is very important for measuring the rainfall water productivity (WP_I) [1]. Some precautions need to kept in mind:

- It should be away from trees, buildings etc. so that readings are not.
- In case of heavy rainfall, the cylinder of the rain gauge if overflowed then necessary correction factor must be applied.

Figure 3: Installation and measurement procedure for mini lysimeters.

Figure 4: Installation and measurement procedure of Tensiometer.

- Its base must be fixed with ground with some cementing agent so that in case pf heavy wind, it is not misplaced from its site.

Evaporation (E)

Evaporation is the change of phase of water from the liquid to the gaseous and is effected by establishment methods [9,32,12,30]. Further, if this loss occurs from the open water body or soil surface or from the plant surface then we referred as "Evaporation (E)" while if this phase change occurs through the stomata of the leaf then terminology used for this process is "Transpiration (T)". In both cases water lost to the atmosphere. Transpiration is the necessary evil, thereof, total ET water must be partitioned from the E to T by using different technologies [1,11]. E measurement is the challenging job while transpiration is estimated through by determining other variables of the equation. The evaporation from the soil surface (Es) of growing crop was measured using mini-lysimeter [1,29,32]. The minilysimeter consisted of two cylindrical PVC tubes. The outer tube was 0.16 m in diameter and 0.20 m long, whereas the inner tube was 0.102 m in diameter and 0.20 m long. The inner tube was covered by porous end cap at the bottom end, whereas the outer was open at both the ends. The cylindrical auger was used to make a hole of diameter equivalent to that of the outer PVC tube which was inserted in the holeof 0.20 m long. The undisturbed soil cores were obtained in the inner PVC tube at weekly interval during wheat season and after every irrigation/rainfall during rice season. The end caps were put on the bottom end of the inner tube and placed in the outer tube. The weight of the inner tube was recorded daily at 0.900 hours (Figure 3d). Mini-lysimeters were used (Figure 3a-d) in the selected treatments to work out daily mm of water evaporated below the wheat and rice canopy which was capped and placed in outer pipes of bigger diameter [1,32]. The purpose of the outer cap was to provide a location within the crop where evaporation could be regularly measured. At each sampling, the lysimeter were inserted into the plots with hammer (Figure 3a) and then removed using the chain-pulley arrangement (Figure 3b). The above ground portion of any small weeds that may have been growing in the mini-lysimeters was cut at the soil surface and removed. The mini-lysimeters were carefully removed without dicturbing the soil inside lysimeter, the bottom was levelled off, the outsides of the cylinders were cleaned and dried, and a clean cap was fitted to the bottom. Each lysimeter was weighed (Figure 3d) and then placed in outer cap in the experimental plot. During weighing care was taken to ensure that no damage occurred to the soil surface.

Calculations for Evaporation Delineation

Generally, this part is lacking and thus reproduction of the carried-out work is quite difficult for the others especially budding scientists which are working on the same track under texturally divergent soils under different agro-climatic regions.

As far as calculations are concerned, different lysimeters were installed under differently established methods.

Weight of the Lysimeter + Soil (Day 1) = A gm

Weight of the Lysimeter + Soil (Day 2) = B gm

Weight of the water evaporated after 24 hours= A-B = X gm (suppose it is 13 gm)

1 g = 1cm^3 (13 g = 13 cm^3)

Now for calculating cm of water evaporated after 24 hours under different establishment methods, we have to divide cm 3 with the area of the lysimeter (π r^2) cm^2 where r is the radius which is supposed to be 7.5 cm.

Hence, cm of the water evaporated = 13 cm^3= 0.073 cm

3.14 × 7.5 cm× 7.5 cm

For converting cm of water evaporated into mm, the figures with cm units need to be multiplied with 10. Thus, mm of water evaporated from a particular plot under a particular treatment during the last 24 hours= 0.073 × 10 = 0.73 mm. By employing the above calculation part, one could calculate the mm of water evaporated during last 24 hours from the plots established using different resource conservation technologies.

Figure 5: Disk permeameter used to measure the unsaturated hydraulic conductivity (cm s^{-1}).

Drainage (D)

The daily drainage was recorded during rice (for wheat drainage assumed to be zero) by installing electronic tensiometers at (Figure 4) at 45 and 60 cm (assuming rhizosphere of 50 cm) as in wheat deep drainage is very small upto 100 mm while during rice season it accounts to more than 2000 mm [1]. For calculating of the unsaturated hydraulic conductivity, disk permeameter is used in the start of the experiment throughout the soil profile (Figure 5).

As per Darcy's law

$$q=K.\frac{\text{ÄH}}{L} \quad (1)$$

q= Flux; K=Unsaturated hydraulic conductivity

$$\frac{\text{ÄH}}{L} = \text{Hydraulic gradient}$$

When we used the tensiometers to measure the drainage loss then Hydraulic gradient changed to suction gradient ($\Delta\Psi t$ /L) and the above equation changed to,

$$q=K.\frac{\text{Ä}\psi t}{L} \quad (2)$$

where Ψt is the total potential and is calculated as,

$$\Psi t = \Psi m + \Psi g \quad (3)$$

Here Ψm and Ψg is the matric potential and the gravitational potential. The values of the Ψg is in cm whereas the values of Ψm is in kPa as originally recorded with the soil spec from the tensiometers. Now to convert the kPa values in cm, the figures in kPa will be multiplied with 10.K is the unsaturated hydraulic conductivity values and is measured by using the Disk permeameter (Figure 5) from each and every depth of soil profile (0-150 cm). Now finally for calculating the amount of water deep drained following formula used.

$$q=K.\frac{\text{Ä}\psi t}{L} \quad (4)$$

$$q=K.\frac{\text{Ä}\text{ø}A-\text{Ä}\text{ø}B}{L} \quad (5)$$

$$q=\frac{k.\{(\text{TR at }45\text{cm}-45)-(\text{TR at }60\text{cm}-60)}{15} \quad (6)$$

where TR is the tensiometer readings. As we are using tensiometers of different lengths at different soil depths, hence a correction factor is applied in the excel sheet of the computer as below:

CF = Tensiometer Reading – (9.8* ($Tensiometer length$ row number/100)

After applying this factor, differently length used tensiometer effect is nullified. The reading of tensiometer is in kPa but in the soil water balance studies cm reading is required. Hence the reading must be multiplied with 10 to change their units from kPa to cm, K is unsaturated hydraulic conductivity (cm s^{-1}), 45 is the Ψg at 45 cm while 60 is the Ψg at 60 cm. By filling all the values, one could easily find out the values of flux or drainage under different experimental plots which further helps us to delineate the drainage pattern in the plot established with different resource conservation technologies.

Seepage (S)

Seepage is the lateral water movement into and through the bunds. The seepage of water during rice season was calculated from the difference in water level in the whole plots and infiltration rings embedded till the hardpan up to a depth of 30 cm during flooding [1,27]. Seepage was calculated after each irrigation in rice season. Suppose an irrigation of 7 cm applied to a particular experimental plot and then at the same time, 7 cm of water is filled in the rings. After 2-3 hours, field water disappears, then water in ring gave us an idea of the seepage which is there in the field.

Change in profile moisture (ΔG)

Soil profile (at depth interval of 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm) moisture distribution was measured thermo-gravimetrically before sowing and after harvesting of each crop with the following formula:

Weight of the soil moisture

$$g\ g^{-1} = \frac{\text{Weight of fresh soil} - \text{Weight of oven dried soil}}{\text{Weight of oven dried soil}}$$

The resulted values come out from the above formula are the values in the weight basis (g g^{-1}). However, to convert it to the volumetric basis (cm^3 cm^{-3} we will have to multiply these values with bulk density.

As

W × Db = Øi

W = Moisture on mass basis; D_b =Bulk Density; Øi = Moisture content on volumetric basis (cm^3cm^{-3}).

Bulk density is being determined using the core method [33] (Bodman 1942) was used for bulk density determination. In situ bulk density was measured after obtaining undisturbed soil cores in cylindrical rings having internal diameter of 5.3 cm and length of 5.0 cm at different soil depths. The fresh weight of soil cores was recorded and these were oven-dried at 105°C for 24 hours, and weighted to record dry weight of the cores. The bulk density was then expressed as the ratio of dry weight of soil cores (Mg) to the internal volume of the metallic rings (m^3) throughout the soil profile [1]. Further cm of moisture in a particular soil depth determined by the following method:

cm of moisture in a particular soil depth = Øi× Depth of soil profile

Add up the cm of moisture for all the soil profile layers (0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm) to get cm of moisture in the soil profile *viz*. 0-150 cm. The moisture content of the soil profile was then expressed in mm of water (by multiplying with 10).

Thus, by using above instruments/methodology, different components of the soil water balance easily delineated which further helps to identify the establishment methods which further utilizes the agricultural water in a more judicious, efficient way which further helps to increase the water use efficiency and land-water productivity which further led to more sustainable/climate smart agriculture [34].

Conclusion

Globally, the underground water declining at an alarming rate. To mitigate its adverse effects on living beings, scientists suggested a number of resource conservation techniques. But for delineating their efficiency, water budgeting is a must. Further intervening period must be attended as it has a certain effect on the next crop seed germination [24,28-30]. Recent years have witness a growing interest on the soil water balance studies throughout the world as quality publications resulted thereof. After fully familiar with the different instrumental/methodological/calculative aspects of soil water balance components *viz*. rainfall by raingauge, irrigation by digital area flow meter, evaporation from mini-lysimeters, seepage from water level difference between whole plots and infiltration rings, change in profile moisture through profile gravimetric method and finally transpiration by simple maths, one could delineate water footprints or effect of a particular resource conservation technology practice on different soil water balance components. After recognizing, most effective one (which decreased the evaporation losses to minimum) which might be site specific, policy makers could frame effective policies for improving land- water productivity. Thus, this compilation gave an insight knowledge to the budding scientists regarding delineation of water balance components during their masters or doctorate or even during their professional service period.

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