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# Delineation of Soil Moisture Potentials and Moisture Balance Components

*Rajan Bhatt and Ram Swaroop Meena*

## Abstract

Root architecture in soils is directly affecting crop yield potential, through influencing the moisture potential of soil and its balance components, as only transpiration share is useful for them. Soil moisture potential responsible for the soil moisture curves on the basis of differential energy states is quite important. Generally, a soil moisture flow rate is considered for its kinetic energy. Consequently, soil moisture energy state is defined by its equivalent potential energy, which is by virtue of its place in a force field which could assist to improve the water-use efficiency. Irrigation water losses significantly occur under the flood irrigation through evaporation, seepage, and drainage. While the soil moisture potential declines with help of the tensiometer, and significantly save the irrigation water. For evaluating the performance of any resource conservation technologies (RCT) in the region, estimation of the evapotranspiration (ET) is very important to analyze the effect of the RCT. It is also helpful in balancing the nutrient inflows in the plants through roots, which results to the improvement of land and water productivity. Hence, delineation of the soil moisture potentials and moisture balance components is important to improve the land as well as water productivity; it makes the livelihood security better in the water-stressed regions on the globe. This chapter deals with the methodological part of soil moisture potentials and moisture balance components, which is useful for the policymakers, modelers, scientists, students, and teachers engaged in the irrigation experiments under texturally divergent soils.

**Keywords:** moisture potential, tensiometer, seepage, drainage, unsaturated hydraulic conductivity, irrigation

## 1. Introduction

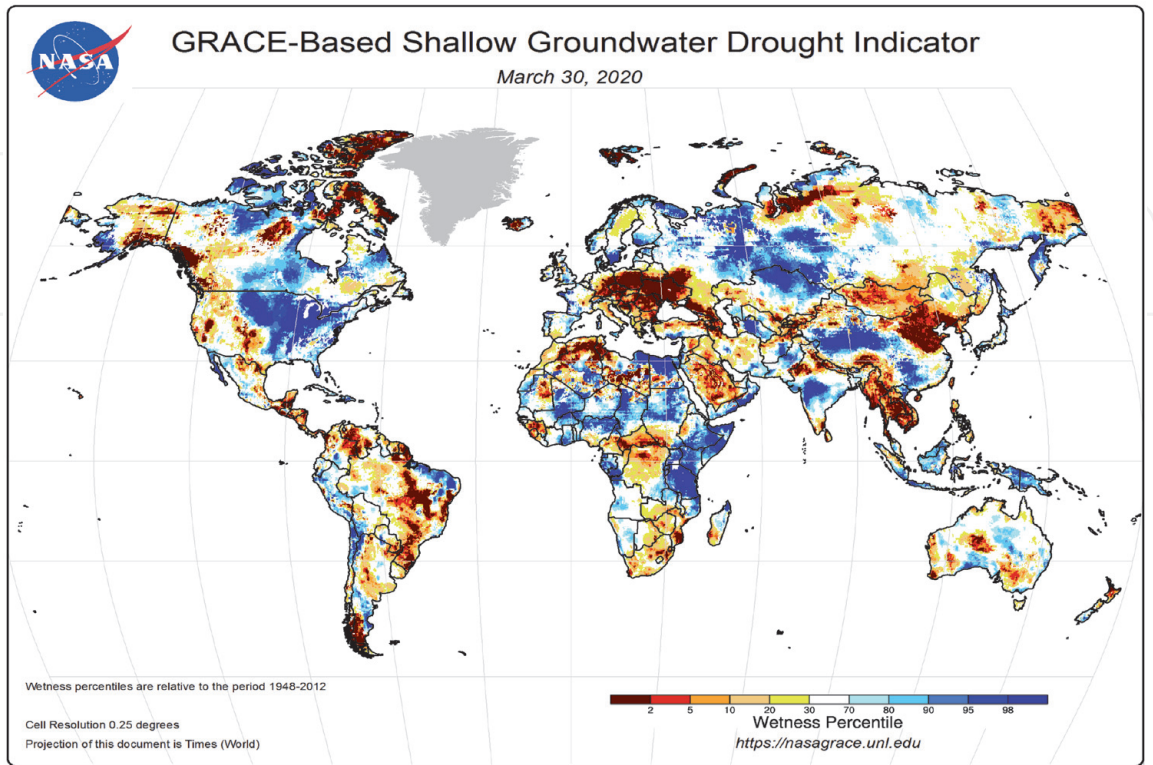
The complex nature of the soil pore space and the water held therein makes it difficult to delineate the soil-water interface and moisture advancements in the soil, which is further influenced by soil matrix geometry. Soil moisture is the amount of moisture present in soil pores, which is a must for all important ecological processes and plays a critical and significant role in all the physiological processes. Throughout the globe, water scarcity is an emerging problem that must be worked out for sustaining agricultural growth [1–3]. Different RCTs are recommended for having improved water productivities across the globe [4–6]. The scientists at NASA's Goddard Space Flight Center generate groundwater and soil moisture drought

indicators each week. They are based on terrestrial water storage observations derived from GRACE-FO satellite data and integrated with other observations, using a sophisticated numerical model of land surface water and energy processes. The drought indicators describe current wet or dry conditions, expressed as a percentile showing the probability of occurrence for that particular location and time of year, with lower values (warm colors) meaning dryer than normal, and higher values (blues) meaning wetter than normal (**Figure 1**).

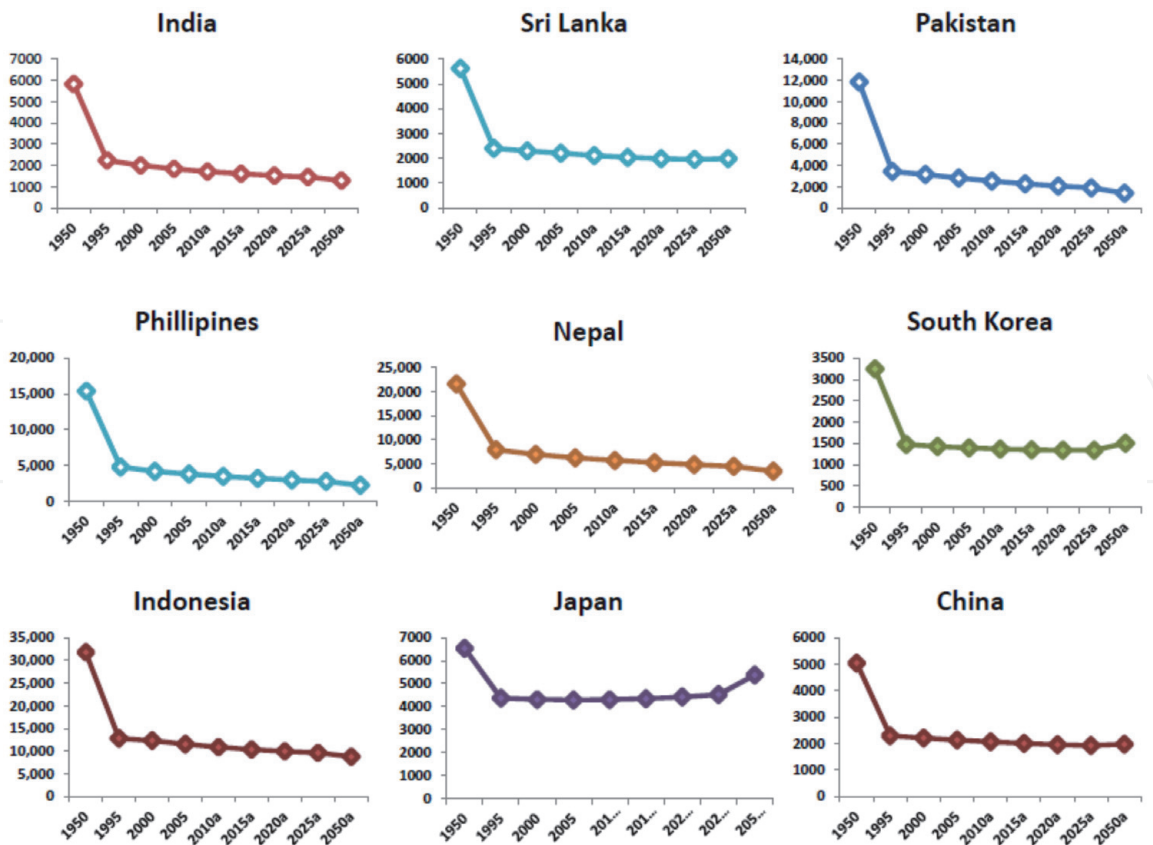
Global analysis based on intermediate population growth rate revealed that water scarcity is a global issue and therefore needs to be addressed for mitigating its adverse effects onto the overall land and water productivities of agricultural crops (**Figure 2**).

Further, in India, the net irrigated area increased from the 1960s and is further projected to increase by 2030 (**Figure 3**), which further increased the installed tube wells and further declined the underground water table of the country, which might be beyond the reach of the poor farmers.

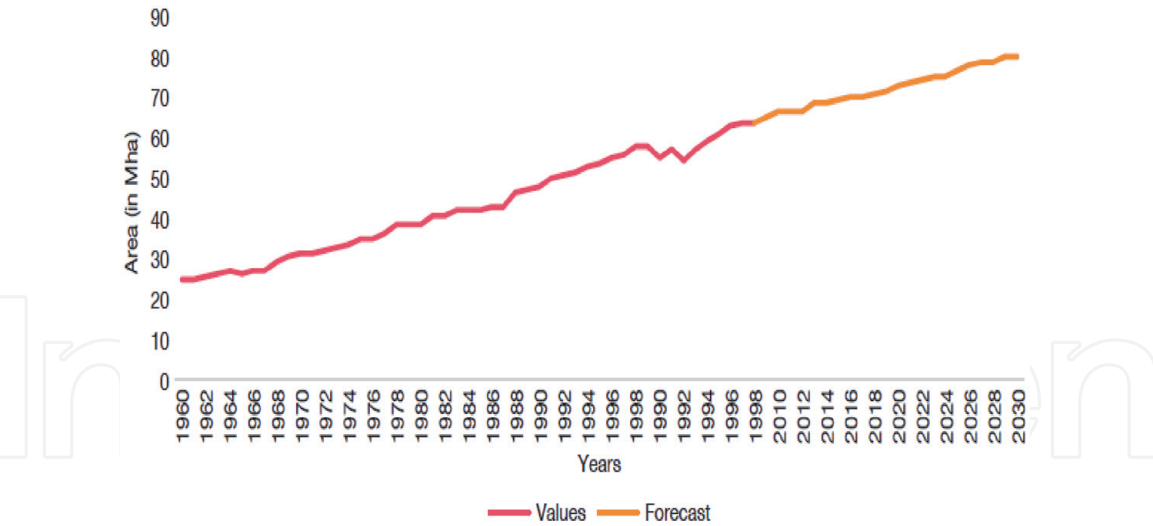
Soil water potential must be understood, and its applications must be applied in field conditions. For measuring the soil water potential, the instrument highlighted as tensiometer is used for irrigating the crops, namely, rice, without affecting the overall land as well as water productivity [7]. Tensiometer measured the soil suction, and when soil dries, then the inner water in the tensiometer via porous cup moves out in the soil. Hence, as a result, the potential reading in tensiometer increased, and at predefined levels of potential, irrigation is applied to crops [1, 7]. After irrigation, water moved back into the tensiometer from the irrigated soil, and water level of inner tube moved back to normal, namely, green level. Soil water potential (as controls moisture movements) is the ultimate technique, under unsaturated conditions when only micropores are water filled, while macropores are air filled for improving the declined water-use efficiency without affecting the grain yields more particularly in global water-stressed regions [7, 8]. However, both macro- and micropores are water filled, and conducting it under saturated soil condition seldom



**Figure 1.**  
GRACE based global shallow groundwater drought indicators (<https://nasagrace.unl.edu/>).



**Figure 2.**  
Water availability Per capita ( $m^3$ ) in chief paddy-growing Asian countries viz-a-viz upcoming years (1950–2050) a Estimate based on the population growth trends Source: Modified from [1]).



**Figure 3.**  
Net irrigated area in India (Source: Food and Agriculture Organization, 2008).

exists in nature. Gravity and soil water potential are the main driving forces under saturated and unsaturated conditions, responsible for soil moisture movement. Micropores of fine-textured clayey soils are capable of holding water for a longer period of time even at higher value of suction, while macropores of sandy soil drain out the water quickly at a smaller suction. Therefore, generally frequent irrigations resulting in lower water productivity are reported in the sandy soils as compared to the clayey fine-textured soil. In nature, soil moisture has different quantities and forms of energy by virtue of which it moves from one to another point in soil. The potential concept to the soil water in relation to its movement was first given by



Buckingham [9] in his classical paper on the capillary potential, while Gardner [10] showed the dependency of water potential on the water content, and Richards [11] prepared a tensiometer for measuring it. Hence, the concept of soil moisture movement is not new but is still difficult to understand by the new budding students and agricultural scientists dealing with agricultural water management. Moreover, quite often research papers published in reputed journals discussed the water balance components without discussing much on their estimation/calculative part, which further confuses the students. Therefore, estimation of the different soil moisture components is a must so as to perform new water management experiments with clear objectives of having higher water productivity under texturally divergent soils. These RCTs are site and situation specific, and a single RCT is not effective equally in all places for improving the water-use efficiency [12]. Therefore, considering above discussions, this chapter focused on the estimation of components of soil moisture potentials and balance components for the proper understanding of the concept by the end users, namely, agricultural students and even budding scientists, for conduction of more region-specific water management experiments under texturally divergent soils for ultimately improving water productivity without affecting the grain yields in water-stressed regions of the globe.

## 2. Soil moisture potential ( $\psi_w$ )

Soil moisture potential in the common language is the potential of moisture to do work by its position in soil.  $\psi_w$  is the difference between the activity of the water molecule in pure distilled water and soil solution at normal atmospheric temperature and pressure which might be greater or lesser. In the definition of International Soil Science Society [13],  $\psi_w$  may be defined as “the amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the soil water (at the point under consideration).” Hence, a reference state is a must.

$\psi_w$  could also be delineated by knowing in a solution of nonelectrolytes, the chemical potential of water which further depends upon mean free energy per molecule and water molecule concentration. The chemical potential of pure water reduces with the addition of salts, which could be expressed as

$$\psi_w = \mu_w - \mu_w^* = RT \ln N_w \quad (1)$$

where  $R$  is the universal gas constant,  $T$  is the absolute temperature, and  $N_w$  is the mole fraction of water, respectively.

For the simple ionic solution,

$$\psi_w = \mu_w - \mu_w^* = RT \ln a_w \quad (2)$$

where  $a_w$  is the activity of the water molecules, which measured how easy the water content may be utilized. Further, the water vapor pressure of the solution expressed as a fraction of the vapor pressure of pure water at the same temperature (or the equilibrium humidity expressed as a fraction) is numerically equal to the activity of the water ( $a_w$ ) in the solution. Eq. (2) is more useful as water always has ions.

When water contains a number of ions, then

$$\psi_w = \mu_w - \mu_w^* = RT \ln e/e_o \quad (3)$$

where  $\psi W$  is the water potential,  $\mu W$  is the solution's water chemical potential,  $\mu W^*$  is the pure state's water chemical potential,  $R$  is the universal gas constant ( $82 \text{ bars cm}^{-2}$ ),  $T$  is the absolute temperature, and  $e/e_o$  is the relative vapor pressure, respectively.

$\psi W$  could be expressed depending upon the units used for the expression of quantity of water.

Expressed units	Units of $\psi W$
Mass	$\text{erg g}^{-1}$
Volume	$\text{Dynes cm}^2$
Weight	cm, m, mm

Among all the units, weight units are more convenient to use.

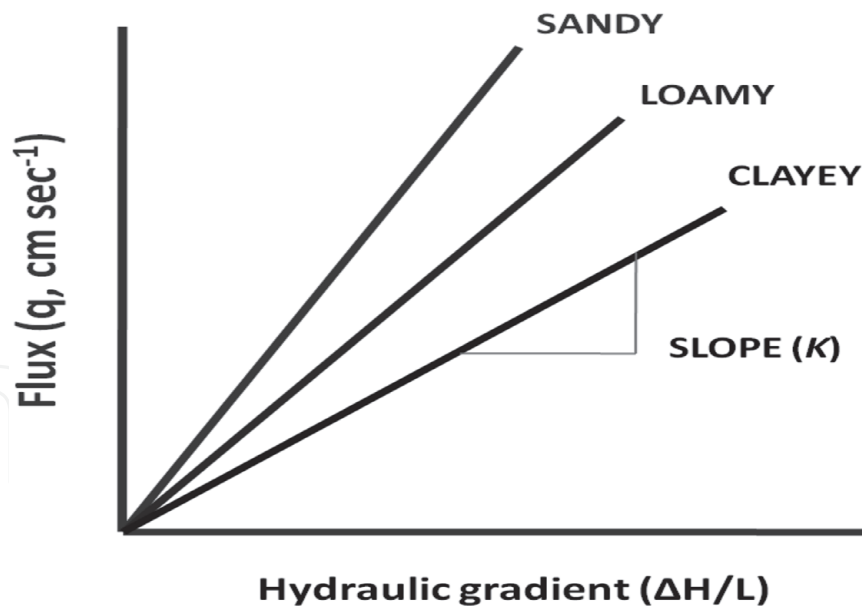
However, when all pores are water filled, conducting it under saturated conditions, then the actual and potential vapor pressure is the same, and thus  $e/e_o$  comes out to be 1 ( $\log 1 = 0$ ). Thus, under saturated soil conditions,  $\psi W$  comes out to be zero, which is the highest potential of the water, and under unsaturated conditions, it is always expressed as -ve value. Under natural soil environment, soil moisture movement is mainly controlled by the hydraulic potential ( $\psi h$ ), which is the total moisture potential. There is a brief explanation regarding all the components of the soil moisture potential one by one.

2.1 Hydraulic potential

$\psi h$  is the total moisture potential, that is,  $\psi t$ , which is the sum of other potentials by virtue of its pressure ( $\psi p$ ), attractive forces ( $\psi m$ ), and gravity ( $\psi g$ ) [14]. The  $\psi h/\psi t$  provides direction of the movement of soil moisture; however, if  $\psi h$  is the same throughout the soil profile (under pounded conditions or under prolonged rainfall), then the water will not move at all in the soils as energy state is the same throughout and moisture only moves under the deviation in the moisture levels/energy levels. Normally under the unsaturated soils, the water moves from the lesser to higher negative potential. Moisture potential of soil delineation is quite important, as it directs us irrigation timings [9, 14]. Further, hydraulic conductivity of a particular soil having a particular textural class is very important, which is further important for nutrient movements within the plants. The slope of the curve between flux (discharge  $\text{area}^{-1} \text{ time}^{-1}$ ) and hydraulic gradient decides the hydraulic conductivity itself varied with texturally divergent soils (Figure 4). This figure explains why movement of water differs in texturally divergent soils and we could manage our cultivation and management practices so as to increase the water-use efficiency.

2.2 Matric potential ( $\psi m$ )

Different adsorption forces prevailing in the soil matrix are responsible for the  $\psi m$ —the force of attraction of free water with soil particles [14]. The greater the adsorption forces, the more is the matric potential, and thus the water is less free. In other words, water is tightly attached to the soil particles. However,  $\psi m$  is dependent on many factors, out of which soil texture is important, for example, sandy coarse-textured soils drained out moisture quickly at a smaller suction than clayey fine-textured soils because clayey soils have greater matric adsorption forces which



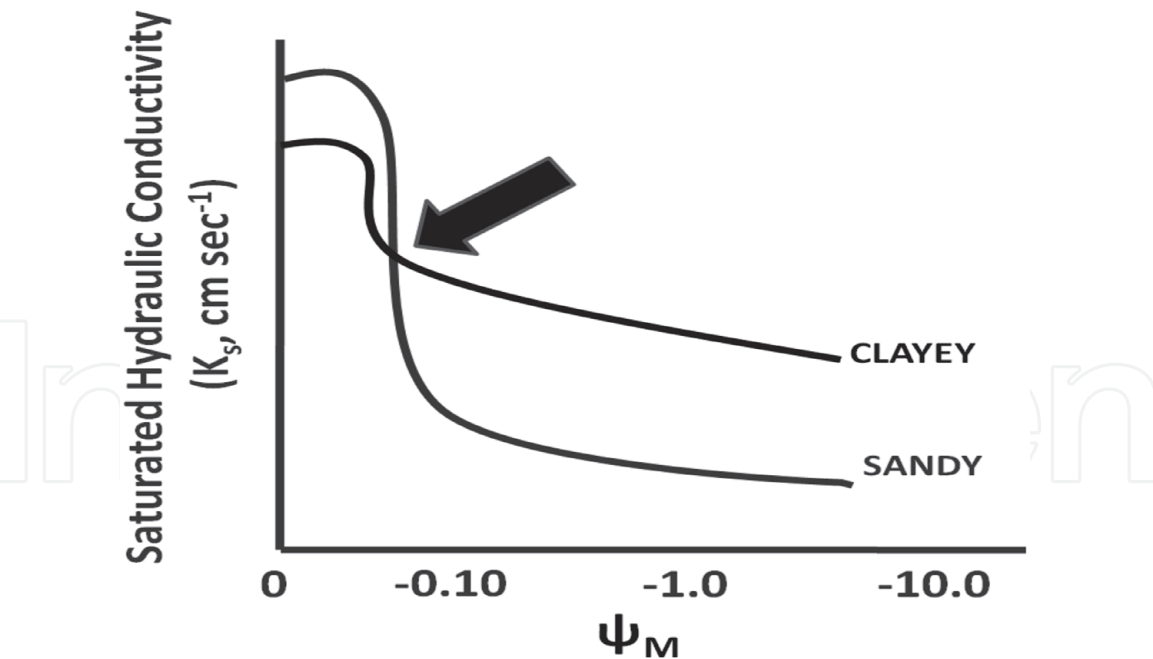
**Figure 4.**  
Relationship between flux and hydraulic gradient in three texturally divergent soils.

hold the water tightly and not allowed the water to drain out quickly. In other words, clayey soil has more –ve values of  $\psi_m$  than that of sandy soils, depicting the higher capacity of former soil water holding capacity of clayey soils. Similarly, the soils with higher organic matter (OM) content have higher water content and thus greater –ve value. *It is very important to understand that the greater is –ve  $\psi_m$  value, the higher is the water content as water always moves from the higher potential to lower potential or from lesser –ve to more –ve as more negative values of  $\psi_m$  depict the lower water content.*  $\psi_m$  has been considered as capillary potential. If we consider weight as the unit for expressing the unit quantity of water, then  $\psi_m$  with respect to a particular height in the soil is the distance in the vertical direction between that selected height and level of water in a manometer. Generally, the  $\psi_m$  resulted from the two processes, namely, capillary “wedges” and “films,” which cannot be changed without upsetting the others.  $K$  under saturated conditions varied in texturally divergent soils, due to attractive forces in soil separates and soil moisture (**Figure 5**). As shown in the picture, saturated hydraulic conductivity of sandy soil is more than of the clayey soil; however, the unsaturated conductivity of sandy soil decreases more steeply with increased suction and decreased from the clayey soils.

$\Psi_m$  reported to be zero under saturated conditions; hence a –ve sign is always there under the unsaturated conditions which is the most prevalent situation in natural field conditions. Matric potential is always zero at the water level, positive below the water table, and negative above the water table. For measuring the suction or  $\psi_m$  in soils, we used tensiometer in soils (**Figure 6**) and set a particular reading for irrigating the fields.

However, tensiometer could measure the suction  $< 0.85$  bar (most prevalent in natural conditions), and pressure plate apparatus and tension plate assembly are used for measuring suctions  $> 0.85$  [7]. The graphical behavior of tension of soil moisture with absolute water content is developed through a soil moisture characteristic curve, which delineates the moisture levels that the soils could hold and thus helps in scheduling the irrigation to crops accordingly.

Under this scenario, the available soil moisture of Indo-Gangetic Plains is described by  $\psi_m$  [15]. Locally fabricated, low-cost tensiometers [16] that could delineate soil matric potential are generally preferred by the farmers for scheduling irrigation more particularly to rice [17, 18]. According to Kukal et al. [19],



**Figure 5.**  
*Association between saturated hydraulic conductivity and  $\psi_m$  in two soils.*



**Figure 6.**  
*Soil spec in action measuring soil matric potential [20].*

increasing suction values to 2000 and  $2400 \pm 200$  mm reduced the land productivity of the rice than earlier recommendation (2-day interval), which mean drying of soils to certain extent saves significant irrigation water without significantly affecting grain yields. Further, an average of 5-year study delineated (**Table 1**) a saving of up to 30% of irrigation water without adversely affecting the land productivity [21].

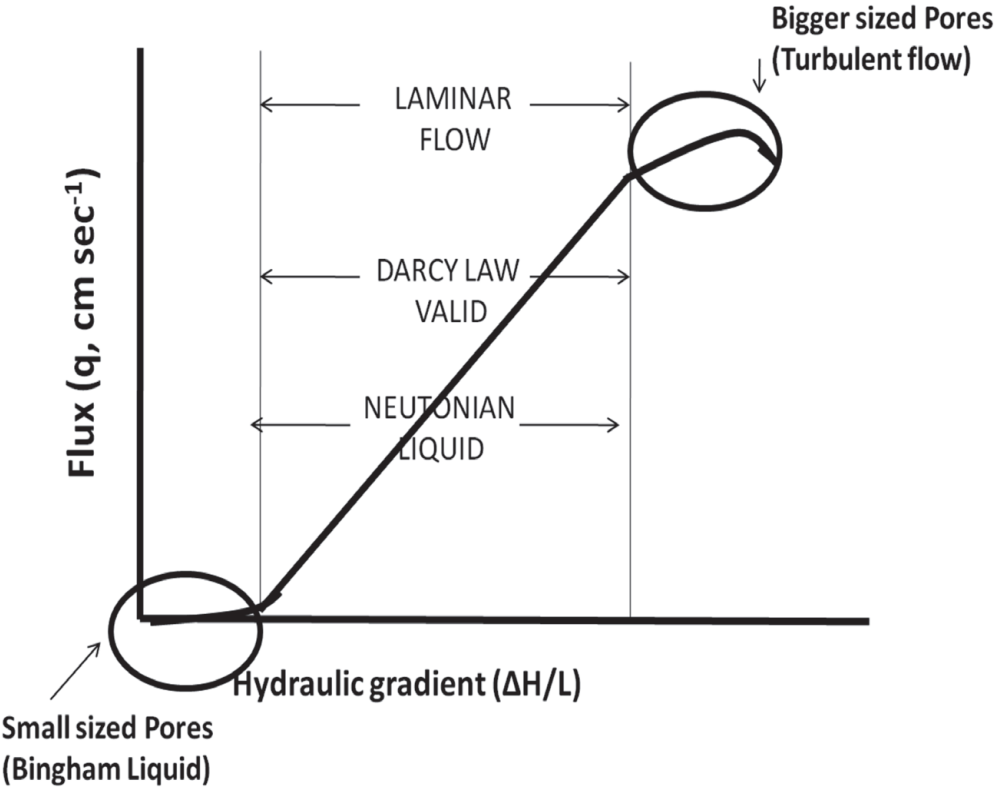
For measuring  $\psi_m$ , tensiometers are installed at 15–20 cm depth, because significant rhizosphere's portion of the rice crops retained to upper 15 cm [15], and therefore, tensiometers are placed at this depth, so that farmers could get the exact idea regarding the exact time to irrigate.



Year	% water saving	Yield differences
2006	29.6–30.7	+0.5–1.5%
2007	25–27.2	At par
2008	18–27.8	At par
2009	16.6–20.8	+0.5–1.0%
2010	11.1–21.4	At par

Source: Ref. [12].

**Table 1.**  
Soil matric potential based irrigation water saving viz.-a-viz. yield differences.



**Figure 7.**  
Deviation in Darcy law.

2.3 Pressure potential

$\psi_p$  is a vital constituent of soil moisture potential but under the saturated conditions which seldom exist in nature [22]. Generally, saturated conditions come only when rains up to a considerable duration or continuous irrigation. When saturated flow becomes high enough to be turbulent and lesser enough for not to generate any flux for a prolonged time is there to meet the constant drainage and evaporation and flow in these conditions is basically governed by the force of gravity but these conditions seldom exist in a field or under natural conditions as here all the soil pores are water filled and conducting it [8, 22]. Under this condition, the discharge is governed by Darcy's law, which further has some limitations as shown in Figure 7.

Negative pressure potential of unsaturated soil becomes positive in the saturated conditions and is delineated as submergence or pressure potential which is generally measured with a piezometer. A piezometer is a hallow tube open from both ends, passing from the reference point. If we consider weight as the unit of expression of

the quantity of water, then certainly  $\psi_p$  is delineated by vertical space from the considered point and piezometer level of water, connected to that point in question. Pressure potential is always positive and zero below the water level and at and above the water level, respectively.  $\psi_p$  and  $\psi_m$  are mutually exclusive to each other as if  $\psi_p$  is positive, then  $\psi_m$  is zero, while if  $\psi_m$  is negative, then  $\psi_p$  is zero.

## 2.4 Gravitational potential

$\psi_g$  constitutes an important soil moisture potential component which is not affected by the soil properties [14]. On considering weight as the unit of quantity of water,  $\psi_g$  comes out to be the vertical distance of elevation from a point under consideration to the point in question and is thus considered as the elevation distance from a point under consideration to the level of reference [14]. To raise an object against the gravitational force of attraction, some work must be done which is stored in the form of energy with respect to its gravity. Gravitational potential is zero at, positive above, and negative below the reference level. It does not depend upon soil properties; this is the reason why  $\psi_g$  is not considered while calculating the water potential. However,  $\psi_g$  played an important role and is considered while calculating the total water potential as

$$\psi_t = \psi_w + \psi_g \quad (4)$$

Further,  $\psi_g$  is independent on the conditions of soil, water, weather, chemical, and pressure, while elevation levels are affecting it. Hence, height is the only criteria affecting the gravitational water in one and all [14].

## 2.5 Osmotic potential ( $\psi_s$ )

$\psi_s$  is an important potential which is there in soil because of the salts in soil water and also due to the presence of the semipermeable layer, which only allowed water entry but not of the salts through it [14]. In soil-water interface, there are mainly two important semipermeable membranes, namely, air-water interface and cell wall in the roots. Air-water interface behaves near to the perfect semipermeable membrane, while cell wall of roots is not a perfect semipermeable membrane as it allows passage of salts as well as water through it. However, while studying liquid water flow in soils,  $\psi_s$  is an unimportant potential due to lack of semipermeable membrane in it, while in plants it is of much importance as plant ease to absorb water is greatly affected by  $\psi_s$  as the more the value of  $\psi_s$ , the higher the energy exerted by plant to pull deep underground water. Consider sodic/saline soil, through which the plants have to exert the water, and then it can exert a  $\psi_s$  equal to the permanent wilting point of soils. Thus determining the value of  $\psi_s = -RTC_s$ , where R, T, and  $C_s$  represent universal gas constant ( $82 \text{ bars cm}^{-2}$ ), absolute temperature, and solute/salt concentration in soils, respectively, is the most difficult as it also includes those species which dissociate into the ions [9].

There are many terminological terms, namely, water-use efficiency at global and local levels and allocation efficiency pertaining to water used in the literature [20, 23] for sustainable use of the irrigation water throughout the globe. Further, Allan coined the term “virtual water” for human consumption. Further, published literature also delineate some terms pertaining to crop water, namely, green, blue, gray, and black water [20]. The most important term that pertains to human water use is referred to as “blue water” as it is rain water, which directly enters the lakes and is used by humans. For plants, the most important water term is “green water” as it is there in soil pores and meets the transpiration demands of plants to produce

biomass [24]. Domestic activities such as bathing and dishwashing constitute the “gray water,” while “black water” is the produce of laundry which consists of toilet water. Among all the different categories of water, only gray water has the huge potential of being reused, which further cut off the freshwater demand by 30% in cities [9].

### **3. Soil moisture balance computation**

Computation of the soil water balance is an important aspect which needs to be focused, and their detailed methodological understanding is a must more particularly for the budding scientists. Nowadays, many research papers are published in the journals of repute, publishing effect of RCTs, namely, laser leveler, DSR, zero tillage, etc., on improving the water as well as land productivity without discussing much on the estimation part. Thus, there is confusion in between the scientists especially budding ones as to how to estimate the performance of a particular RCT under different conditions of soil texture and climate. Moreover, there is an interest in the evaluation of these RCTs in improving the production potentials by diverting maximum ET water to the T components, thereby providing higher nutrients to the plants [15, 25, 26] and recommending them as per the soil textural class as these technologies are location specific and not a single technology is capable of performing equally under all the conditions. Hence, there is a need to delineate the estimation/calculative part of the different moisture balance components of the soil.

Nowadays, agricultural scientists are focusing on techniques to reduce the soil evaporation [27–30] for partitioning higher part of the soil moisture from evaporation (unproductive component) to the transpiration (productive component) for improving the grain yields of the farmers of the water-stressed regions throughout the globe. Countries, namely, Switzerland, the USA, Germany, the Netherlands, Sweden, etc., recognized the significance of the aquifer management [29, 31]. Proper water allotment, as per demand and availability, is a decisive issue [29, 32]. Further, to feed 9.5 billion population up to 2050 [33], around 60% more food [34] is required to produce from the shrinking natural resources, namely, land and water [29, 35–37]. One other claimed way is to use waste or industrial water, but it needs efforts to clean it first which sometimes is not an easy step. Climate change further complicated the conditions as it has a significant effect on the agriculture by altering the rainfall patterns, CO<sub>2</sub> concentration, air temperature, etc. [29, 36, 38]. Improved standards of living [39] and altered eating habits [8], which need more consumption of water, make the scenario more complex. Therefore, a challenge in front of the agricultural scientist to come out from this situation seems to be a bit difficult. The only way is to partition greater fraction of evapotranspiration (ET) component share to the transpiration side for improving the land productivity even in the water-stressed region, but without knowing the proper procedure for calculating the evaporation component, the budding scientists will not able to assess the impact of different RCTs for this partition. Therefore, estimation of the different soil moistures/water balance components is a must and of course very important for having an idea to what are the added water amounts (through rainfall or irrigation) and what are the lost amounts (either through evaporation, transpiration, seepage, drainage, change in profile moisture storage, etc.). Among all the water lost components on the left side, evapotranspiration generally denoted by ET is most important whose share remained almost the same [29, 38]. Further among ET, E pertains to unproductive water from open surfaces which must be partitioned to T for having higher yields [8, 20]. However, water loss through D and S is always away from the rhizosphere and thus is not used by the crop plants for meeting their ET requirements.

Before sowing and after harvesting the crop, namely, during the intervening periods, profile moisture storage change could be measured, which further played an important role in the cultivation of fodder crops. A soil water balance component provides a way out to identify technologies which improve water productivity. Up to now, this period is the least attended as results of applied treatments evaluated are analyzed during this period [20, 27, 40, 41]. However, the intervening period delineation of soil moisture dynamics helped to assess the residual effects of these RCTs applied during the main crop [40, 41]. Therefore, for sustainable and judicious use of irrigation water, the analysis of the soil water balance component is very important. The following are the important parameters of the soil water balance which needs to be calculated for evaluating the performance of any RCT in any region of the globe:

$$E + T + D + S + \Delta G = R + I \quad (5)$$

where E is the evaporation, T is the transpiration, D is the drainage, S is the seepage,  $\Delta G$  is the profile moisture change, R is the rainfall, and I is the irrigation. Details along with their calculative/instrumental part are discussed below.

### 3.1 Rainfall (R)

Rainfall is an important soil water balance component which decides the fate of the rainfed crops grown particularly in the submountainous tracts where there is no irrigation facilities, which might be because of the hard subsurface and very deep underground water table [17, 23]. Therefore, its timely quantification is very important for recognizing stressed areas which further helps in rescheduling irrigation plans for improving land and water productivity over here. Received rainfall is estimated using a rain gauge, which is installed permanently at the location/period of experimentation, which is further used in calculating the rainfall water productivity ( $WP_I$ ) [15]. However, one should be very careful that the spot selected for rain gauge installation should be away from huge buildings or any obstacles or any hindrance. Necessary correction factor must be applied, which is the case of the heavy rainfall if rain gauge's cylinder overflowed [39]. Many times, it is observed that rain gauge base is not fixed, which may result in tilting of the gauge while recording the rainfall; thus while installing it, it should be made sure that it should be fixed by using cement and sand mixture, so that no error in calculations will be there [15, 23, 39].

### 3.2 Irrigation water amount (I)

Irrigation is the most important for having potential agricultural yields in any area. But generally irrigation water-use efficiency is quite low in spite of the fact that water already is a limiting factor. Further, irrigation is an important input component for soil water solution; however, its exact measurement is generally not there, even in water management experiments. Nowadays we are well equipped with the water measuring meters which accurately measured the water amount which is being applied to a particular plot under any treatment, namely, area velocity flow meter (AVFM 5) which provides a digital reading of water supplied in any plot [15]. Generally, irrigation water depth of 50 and 75 mm in wheat and rice plots supplied which could be measured through the sensor (fitted in the pipe through which water enters a particular plot) of AVFM [27]. GREYLINE is the company manufacturing the Digital flow meter (**Figure 8**) the irrigation water measuring irrigation water device on a quantitative basis. Their sensor has to be fit





**Figure 8.**  
*Area Velocity Flow Meter for calculating the irrigation water applied.*

in the plastic pipe. When water applied to a particular plot equipped by a particular treatment, sensor placed in the pipe starts recording and displaying the quantity of water entered in the plot in liters which could be further be used in calculating the irrigation water productivity of differently treated plots. As there is no electric supply in the remote agricultural fields, hence a battery is required for its power. Further, calibrations are required before using it by filling the water in a Known volume of drum and in case of any discrepancy, a correction factor must be applied for further calculations for applied irrigation amounts in the agricultural water management experiments so that correct irrigation water productivities will be delineated under different treatments.

### 3.3 Evaporation (E)

Evaporation generally is known as the unproductive loss of the water from any surface, namely, soil or water or leaf, when liquid water changed to vapor form in the presence of the certain energy, and is affected by establishment methods [8, 12, 20, 29, 42] as mulched plots experienced lesser evaporation losses. However, through the stomata of the leaf, loss of liquid water to atmosphere in gaseous form coined as productive loss, delineated as “transpiration (T)” as under transpiration pull along with water nutrient also enters into the plants through the roots which further results in higher grain yields. Therefore, for having higher production of the plants, higher transpiration is required; thus, every effort is made to divert a greater fraction of the ET share of the soil moisture to the T component [15, 39]. Generally, lysimeters are used for delineating the evaporation, while transpiration is delineated after subtracting other water loss factors from rainfall + irrigation. Lysimeters [41, 42] comprised of two pipes of PVC, the outer (0.16 m) being wider than the inner (0.102 m) in diameter while both of the same length (0.20 m). Porous end cap is used to seal the inner one from downward side, while the outer one was opened from both sides for making soil environment homogeneous in mini-lysimeter and the outer field. Cylindrical auger is used for making space in the field for fitting wider outer pipe (0.20 m long), in which inner soil-filled pipe (duly closed from downside with an end caps) is placed.

The inner PVC tube weight was measured daily at 0.900 hours (**Figure 9d**) using a digital weighing balance. Mini-lysimeters are used (**Figure 9a–d**) in the treatment plots, where daily evaporation needs to be worked in mm below the crop canopy [20, 42, 43]. Providing permanent location in the field plots receiving differential treatments throughout the season is the main objective of providing outer PVC pipe, where evaporation could be regularly measured. Hammer is used for inserting the narrower inner PVC pipe in the field during each sampling (**Figure 9a**), which removed from the plot with the help of chain-pulley arrangement (**Figure 9b**). Weeds growing on the mini-lysimeters must be cut and removed, so that it may not affect evaporation readings. Without any soil disturbance, inner pipes should be placed in the outer pipes, and daily in the morning, about 9:00 am, lysimeters were weighed (**Figure 9d**) and placed back in the outer PVC pipe.

*3.3.1 Delineation of calculations of evaporation*

Mostly, very little discussion is there in different research papers regarding the calculative part of the evaporation. Hence, the repetition of the carried-out work under differentially textured soils/agroclimatic conditions is quite difficult. As far as the calculative part, different lysimeters were installed in different plots receiving differently established methods/techniques.



**Figure 9.** Step-wise technique of evaporation delineation with mini-lysimeters (a) Fitting of lysimeter in experimental plot, (b) use of chain-pulley for removing it from plots, (c) removed lysimeter, (d) weighing of lysimeters within the plots receiving differential treatments [23].



Let us suppose.

Day 1 (Mass of the Lysimeter + Soil) = A g.

Day 2 (Mass of the Lysimeter + Soil) = B g.

Evaporated moisture mass after 1 day = A-B = X g (suppose it is 15 g).

1 g = 1 cm<sup>3</sup> (15 g = 15 cm<sup>3</sup>).

For calculating evaporated water in 24 hours under differential treatments, the differential lysimeter weight in cm<sup>3</sup> needs to be divided by the lysimeter area ( $\pi r^2$ ) cm<sup>2</sup> where r is the radius. Let us suppose radius was 7.5 cm.

Hence, evaporated water = 15 cm<sup>3</sup> /  $3.14 \times 7.5 \text{ cm} \times 7.5 \text{ cm}$  = 0.085 cm.

Delineation of moisture evaporated from a particular treatmental plot during the last 24 hours is quite important. The “cm” units are converted into “mm” by multiplying it by 10. Therefore, in the above case, 0.85 mm (0.085 × 10 = 0.85 mm) of evaporation is there. With this way, the performance of different RCTs in reducing evaporation and thereby promoting the transpiration could be delineated in a particular region (**Figure 10**).

### 3.4 Drainage (D)

Drainage is the loss of irrigation or rain water in the downward direction beyond the rhizosphere. Therefore, drained away water could never be used up by the plants. Hence it needs to be checked for providing more moisture to the rhizosphere. In wheat, generally, drainage losses are assumed to be negligible or near to 100 mm, while in the rice season, drainage losses are of significance (>2000 mm). For calculating the drainage losses in the rice season, electronic tensiometers are installed at 450 and 600 mm assuming rhizosphere up to 500 mm [15]. For a drainage calculation, unsaturated hydraulic conductivity needs to be delineated by using the disk permeameter, which is used throughout the soil profile (**Figure 11**).

Now, for calculating the flux using Darcy's law (Eq. (6)), delineation of the unsaturated K of the transitional layer on a daily basis is very important, which is further expressed as deep drainage.

$$q = K \cdot \Delta H / L \quad (6)$$

where Q is the flux, K is the unsaturated hydraulic conductivity, and  $\Delta H / L$  is the hydraulic gradient.

Hydraulic gradient ( $\Delta H / L$ ) changed to the suction gradient ( $\Delta \Psi_t / L$ ), for tensiometers

$$q = K \cdot \Delta \Psi_t / L \quad (7)$$

where  $\Psi_t$  is the total potential which is the sum of matric and gravitational potentials, namely,  $\Psi_m + \Psi_g$ , which are delineated as in cm and kPa, respectively. kPa is easily converted into cm by multiplying it with 10. Disk permeameter (**Figure 11**) is generally used for estimating unsaturated hydraulic conductivity values up to 0–150 cm. For estimating water drained deep through the soil profile, Eq. (4) is used.

$$q = K \cdot \Delta \Psi_t / L \quad (8)$$

$$q = K \cdot \Delta \Psi_A - \Delta \Psi_B / L \quad (9)$$

$$q = K \cdot \{ (\text{Tensiometer readings at 45cm} - 45) - (\text{Tensiometer readings at 60cm} - 60) / 15 \} \quad (10)$$



**Figure 10.**  
*Working of electronic tensiometers (a) Fitting of tensiometers in the field, (b) filling of water in tensiometers, (c–e) installed tensiometers, (f) measuring of matric potential using digital soil spec [24].*

Sometimes under field conditions, different length tensiometers had to be used depending upon their availability; hence, a correction factor is applied to nullify this effect.

$$\text{Correction Factor} = \text{Tensiometer reading} - 9.8 * (\text{Tensiometer length row number} / 100) \quad (11)$$

Generally, the tensiometer reading is in kPa, but for the soil water balance studies, readings in “cm” are necessary, which are converted by multiplying kPa reading with 10. After filling reading in Eq. (5), flux (q)/drainage loss in different plots could be easily delineated.





**Figure 11.**  
*Disk permeameter for delineation of un-saturated hydraulic conductivity [23].*

### 3.5 Seepage (S)

S is the sideways water travels from side to side of the bunds, which could alter the water amounts used. For delineating the seepage loss in the rice season, water level variation in whole plots and infiltration rings is recorded during every irrigation [15, 43]. After each irrigation/heavy rainfall, seepage was calculated. After 2–3 hours depending upon the soil textural class, water from plot disappears, and then, the ring water level provides us with a scheme of the seepage losses from a particular experimental plot.

### 3.6 Change in profile moisture ( $\Delta G$ )

Profile moisture change is also an important part of the soil water balance equation. For measuring soil profile moisture change, the thermogravimetric method is used for measuring moisture before sowing and after harvesting throughout the profile up to a depth of 1.5 m.

$$\text{Moisture of soil (g g}^{-1}\text{)} = \frac{\text{Fresh soil mass (g)} - \text{oven-dried soil mass (g)}}{\text{Oven-dried soil mass (g)}} \quad (12)$$

From the above conversion, above weight basis ( $\text{g g}^{-1}$ ) values of soil moisture to volumetric basis ( $\text{cm}^3 \text{cm}^{-3}$ ), these values must be multiplied with a respective bulk density.

$$\varnothing_i = W \times D_b \quad (13)$$

where  $\theta_i$  is the volumetric soil moisture ( $\text{cm}^3 \text{ cm}^{-3}$ );  $W$  is the mass basis soil moisture; and  $D_b$  is the bulk density.

For  $D_b$  determination, generally, core method [22] was used. Under this method, undisturbed metallic soil cores are used for calculating the  $D_b$ , and fresh core weight was measured. Then, fresh soil + cores weight was recorded, and then, both fresh soil and cores are dried for 1 day in an oven at  $105^\circ\text{C}$ . For  $D_b$ , the dried weight of soil is divided with the internal volume of the metallic cores [15]. Further for a specific depth under consideration, moisture (cm) is determined by

$$\text{In a specific depth of soil, soil moisture (cm)} = \theta_i \times \text{soil profile depth} \quad (14)$$

Further, for delineating soil profile moisture up to 150 cm, each depth value of soil moisture is added up to have soil profile moisture (cm), which is further multiplied by 10 to get soil moisture of the whole profile in mm, the required units for the soil moisture balance.

By adopting above methodology for calculating different soil moisture components, namely, rainfall, irrigation, evaporation, transpiration, seepage, drainage, and change in profile soil moisture, one could easily delineate the soil moisture components or validate the performance of a particular resource conservation technology, namely, happy seeder, laser leveler, tensiometers, direct-seeded rice, etc., in improving the yield potentials by partitioning the maximum share of the evapotranspiration water from evaporation to transpiration.

#### 4. Conclusion

Underground water is globally declining down which in itself is a matter of great concern. Further, population pressure is rising day by day whose requirements whether of food, fiber, etc. should be met out from the ever-diminishing resources, namely, water and land. Climate change further complicated the whole scenario by one or other way. Thus, under this whole current scenario, it is very much important to first have knowledge regarding soil moisture movement under the impacts of different soil moisture potentials, namely, matric potential, solute potential, and gravitational potential, so that irrigation water is applied as required for having higher water-use efficiency for which tensiometers may serve the purpose under the field conditions. Further, many RCTs are being proposed in the water-stressed regions for establishing the wheat-rice cropping sequence with claim to have higher water-use efficiency and, thus, higher land and water productivity. But a careful observation delineates that all of these RCTs are not universally applicable; rather their performance varied as per differential sand, silt, and clay ratios, soil slope, and agroclimatic conditions. Therefore, the first idea regarding different soil water potentials and then, secondly, rechecking of different recommended RCTs in a diversion of maximum share of green water from  $E$  to  $T$  are required. For this, estimating different soil moisture balance components and therefore their instrumental/calculative part needs more attention in the budding scientists more particularly dealing with the agricultural water management experiments in the water-stressed regions of the globe.

#### Conflict of interest

No conflict of interest is expressed by the authors.

Abbreviations

$D_b$	bulk density
RCT	resource conservation technologies
$E_s$	evaporation from soil surface
D	drainage
$\Psi_m$	potential by virtue of attraction due to soil matrix
$\Psi_g$	potential by virtue of gravity
W	mass basis moisture
$\Delta H/L$	hydraulic gradient
$\varnothing_i$	moisture content on volumetric basis
SMP	soil matric potential
q	flux
K	unsaturated hydraulic conductivity
I	irrigation
T	transpiration
AVFM	area velocity flow meter
PVC	polyvinyl chloride
DSR	dry-seeded rice
ET	evapotranspiration
R	rainfall
$WP_i$	irrigation water productivity
E	evaporation
S	seepage

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