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Review Paper

A review of the methods available for estimating soil moisture and its implications for water resource management

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SUMMARY

The maintenance of elevated soil moisture is an important ecosystem service of the natural ecosystems. Understanding the patterns of soil moisture distribution is useful to a wide range of agencies concerned with the weather and climate, soil conservation, agricultural production and landscape management. However, the great heterogeneity in the spatial and temporal distribution of soil moisture and the lack of standard methods to estimate this property limit its quantification and use in research. This literature based review aims to (i) compile the available knowledge on the methods used to estimate soil moisture at the landscape level, (ii) compare and evaluate the available methods on the basis of common parameters such as resource efficiency, accuracy of results and spatial coverage and (iii) identify the method that will be most useful for forested landscapes in developing countries. On the basis of the strengths and weaknesses of each of the methods reviewed we conclude that the direct method (gravimetric method) is accurate and inexpensive but is destructive, slow and time consuming and does not allow replications thereby having limited spatial coverage. The suitability of indirect methods depends on the cost, accuracy, response time, effort involved in installation, management and durability of the equipment. Our review concludes that measurements of soil moisture using the Time Domain Reflectometry (TDR) and Ground Penetrating Radar (GPR) methods are instantaneously obtained and accurate. GPR may be used over larger areas (up to 500 × 500 m a day) but is not cost-effective and difficult to use in forested landscapes in comparison to TDR. This review will be helpful to researchers, foresters, natural resource managers and agricultural scientists in selecting the appropriate method for estimation of soil moisture keeping in view the time and resources available to them and to generate information for efficient allocation of water resources and maintenance of soil moisture regime.

Contents

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1. Introduction

Soil moisture is the content of water in the soil, held in the spaces between soil particles (Ali, 2010). It represents a small fraction (0.15%) of the globally available freshwater (Dingman, 1994) but is an influential store of water in the hydrologic cycle and is of fundamental importance to many hydrological, biological and biogeochemical processes. Soil moisture modulates interactions between the land surface and atmosphere, thereby influencing the climate and weather (Delworth and Manabe, 1993; Jung et al., 2010; Mittelbach et al., 2012) and is important in determining the rainfall-runoff response of catchments, especially where saturation excess runoff processes are important (Wei, 1995). The maintenance of elevated soil moisture is an important ecosystem service of the natural ecosystems; a failure in its management may lead to desertification (MEA, 2005a). The availability of moisture in soil is essential for nutrient cycling, a pre-requisite for primary production. Soil moisture affects the land evapotranspiration which is a central process in the climate system and a nexus of the water, energy and carbon cycles (Wan et al., 2007; Garten et al., 2009; Holsten et al., 2009; Jung et al., 2010; Falloon et al., 2011). Maintenance of such related ecosystem services enhances the productivity of natural ecosystems (Betts, 1999) and helps to sustain biodiversity (Pielke et al., 2002; Rhymer et al., 2010). Soil moisture retention is also an important determinant of water availability in agroecosystems (Power, 2010).

The chemical and physical properties of a soil, such as alkalinity, acidity, field capacity, wilting point, soil water potential and soil matric potential (Table 1) determine the quality and productivity of the soil (Burk and Dalgliesh, 2008; SAI, 2010). Soil moisture is the main source of natural water for agriculture and natural vegetation and influences a variety of processes related to plant growth and (Rodriguez-Iturbe, 2000) agricultural production, as well as a range of soil processes (White, 1997). Changes in the hydrological regime resulting from climate alterations, especially with regard to water availability and quality, are affecting society more than any other change (Schroter et al., 2005; Fraiture et al., 2008; Madani, 2010) with 1.2 billion people worldwide already living in areas of acute water shortage (Mayers et al., 2009). Human migrations due to desertification, land degradation and climate change may affect between 50 million and 1 billion people by 2050 and displace more than half the expected human population of the world by 2030 (IPCC, 2007; UNWWDR, 2009). Therefore, the conditions and accessibility of the soil moisture will decide the fate of water allocation for various human needs, including domestic, agricultural and industrial uses (MEA, 2005b).

According to the United Nation Convention to Combat Desertification (UNCCD), understanding long term negative effects of improper management on soil ecosystems causing reduced structural stability of the ecosystems, availability of important nutrients and the water holding capacity of the soil is needed to prevent desertification (Prince et al., 2007; Sivakumar, 2007). Soil moisture information is valuable to a wide range of agencies concerned with the weather and climate, runoff potential and flood control, soil erosion and slope failure, reservoir management, geotechnical engineering and water quality (NASA, 1999). Knowledge of the spatio-temporal variability and the patterns of soil moisture distribution at watershed level is helpful in estimating the rates of soil erosion and release of sediments in rivers, which are important for sharing limited resources during crises (Gleick, 1998; Borga et al., 2007). Information gaps exist with regard to determining those situations in which agriculture, plantations and natural forests enhance the water yielding capacities of ecosystems (FAO, 2007; Thompson et al., 2009). The need for accurate measurement of soil moisture at spatio-temporal scales for hydrologic, climatic, agricultural and domestic applications over time has led to the development of different methods of determination of soil moisture content (Minet et al., 2011, 2012). However, the large heterogeneity in the spatial and temporal distribution of soil moisture at the landscape level and the lack of standard methods to estimate this property limit its quantification and use in research (Engman and Chauhan, 1995; Western et al., 2002; Mittelbach et al.,

Table 1
The properties of soil that are influenced by soil moisture content and vice versa.

Soil property	Definition	References
Field capacity	Field capacity is the amount of water a soil can hold against gravity, i.e. volume of water retained after drainage due to gravity from a thoroughly saturated soil	Burk and Dalgliesh, 2008; Kabat and Beekma, 1994; Duryea and Dougherty, 1991
Permanent wilting point	The permanent wilting point is the soil moisture content at which plants that have wilted during the day will not regain turgor at night in a saturated atmosphere	Werner, 2002; Kabat and Beekma, 1994; Duryea and Dougherty, 1991
Available water	The amount of water held by a soil between field capacity and wilting point is defined as the amount of water available for plants	International Atomic Energy Agency, 2008; Kabat and Beekma, 1994
Soil water potential	The soil water potential, also called the soil tension, is the energy status and describes how tightly the water is held in the soil	Ali, 2010; Huang et al., 2010; Werner, 2002
Soil's porosity	A soil's porosity and pore size distribution characterize its pore space, that portion of the soil's volume that is not occupied by or isolated by solid material	Nimmo, 2004; Robock et al., 2000
Soil matric potential	Soil matric potential is the portion of the total water potential due to the attractive forces between water and soil solids as represented through adsorption and capillarity. It is always negative in nature and is also called the soil moisture tension	Ali, 2010; Huang et al., 2010
Soil alkalinity	Soil alkalinity is associated with the presence of sodium carbonate (Na_2CO_3) in the soil, either as a result of natural mineralization of soil particles or brought in by irrigation and/or floodwater	Merry et al., 2002
Soil acidity	Soil becomes acidic due to oxidation of the pyritic minerals in it. Un-drained soils containing pyrites need not be acid, and they are called potential acid sulfate soils	Merry et al., 2002