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Soil water dynamics and deep soil recharge in a record wet year in the southern Loess Plateau of China

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ABSTRACT

Terrestrial water cycles are influenced by hydrologic and textural properties of the deep loess layer in the Loess Plateau. Analyses of soil water profile distributions are needed to understand the regional water cycle processes and to guide agricultural production and sustainability. The objective of this study was to quantify the extent of deep soil water recharge and soil water profile dynamics during 1987–2003, especially in a record wet year of 2003, in common cropping systems in a semiarid-subhumid region of the southern Loess Plateau. The Chinese Ecological Research Network (CERN) site and a long-term rotation experiment site in a flat tableland were selected for this study. Soil moisture profiles were measured by a neutron probe to a depth of 6 m in 2003. The precipitation of 954 mm at the Changwu County Meteorological Station in 2003 was 63.4% higher than the long-term average (584 mm), and was a record high since 1957. Although cropping systems affected deep soil water recharge, the persistent dry soil layer formed between 2- and 3-m depths in croplands, resulting from many years of intensive cropping, was fully replenished in all cropping systems in 2003. Further frequency analysis indicated that the desiccated layer between 2- and 3-m depths would be fully recharged at least once in about 10 years for all existing cropping systems excluding continuous alfalfa. This finding should alleviate concerns about the formation of a permanent deep-soil desiccation layer as well as its potential impact on the long-term sustainability of the existing intensive cropping systems in the region.

1. Introduction

Soil water dynamics are strongly affected by land use/cover in the Loess Plateau (Chen et al., 2007). Precipitation is the key factor limiting agricultural production in the region. Precipitation is the main water source for agriculture, and therefore efficient use of limited rainwater to improve crop yield has long been the primary research focus. Years of intensive farming by increasing fertilization and implementing yield-enhancing management practices have led to the gradual depletion of soil water or soil desiccation between 2- and 3-m soil depths due to high plant water use (Li, 2001b). The dry soil layer was defined as the soil layer that has soil moisture ranging between the wilting point and a steady soil moisture level, normally less than 75% of field capacity (Li, 2001a). Such multi-year soil water deficit has raised the concerns of many soil scientists and agronomists on whether the desiccated soil layer can be fully recharged under the existing continuous cropping systems as well as the potential impacts of the dry soil layer on crop yields and the sustainability of the current production systems in the region.

Selection of a soil profile depth (or control volume) is crucial for calculating field water balance, which is useful to estimate total plant available water, crop yield, and extent of soil water depletion by a crop or recharge under a certain climate condition. Maximum rooting depth and maximum wetting depth of rainwater are the two primary depth parameters for selecting a soil profile depth. The former is determined by the vegetation type (Hodnett et al., 1995; Williamson et al., 2004), and the latter by the amount of precipitation and antecedent soil water deficit in a soil profile (Wright and Black, 1978). Li et al. (1985) reported that for evapotranspiration (ET) estimation of annual field crops including winter wheat, maize, sorghum and cotton in the Loess Plateau area, a soil depth of no less than 2 m should be used because more than 90% of ET normally comes from this zone. Considering that field

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soil water profile measurement is labor-intensive and time-consuming, a soil thickness between 2 and 3 m should be sufficient for estimating field water balance in the region in years having average or below-average precipitation. This recommendation implies that significant soil water recharge generally would not occur beyond 2–3 m depth. In wet years, however, the wetting depth of infiltrated rainwater may exceed 2 or even 3 m, and amounts infiltrated below this depth may become significant. Thus, the 2–3 m soil depth recommended for water balance calculation needs to be reexamined for wet years in the study region.

To characterize water recharge into deep soil layers or maximum wetting depth of rainwater, it is necessary to know the initial water deficit in a soil profile, precipitation, and total ET (or plant water use) under common cropping systems in years with above-average precipitation, especially in extremely wet years. The objective of this study is to quantify the extent of deep soil water recharge and soil water profile dynamics in common cropping systems in a semiarid-subhumid region of southern Loess Plateau using field measured data during 1985–2003, especially in the record wet year of 2003.

2. Materials and methods

2.1. Study region

The Changwu tableland region is situated in the tableland-gully region of southern Loess Plateau, in the middle reaches of the Yellow River in northern China (Fig. 1). The tableland-gully landscape is one of the main topographic-ecological units in the Loess Plateau, which consists of two geomorphic subunits: tableland and dissected tableland. The Changwu Agro-ecological Experiment Station, 2.5 km west of the Changwu County Meteorological Station, is located in the Wangdonggou experimental watershed in the Changwu tableland region. The Wangdonggou watershed is comprised of 35% tableland and 65% dissected land. The farmlands are mainly distributed in the flat areas of the tableland and dissected lands. The wheat–wheat–maize rotation and continuous wheat are the most common cropping systems in the region.

2.2. Site description and cultural practices

The Changwu Agro-ecological Experiment Station (35.2°N and 107.8°E) is located in the warm temperate zone, and has a

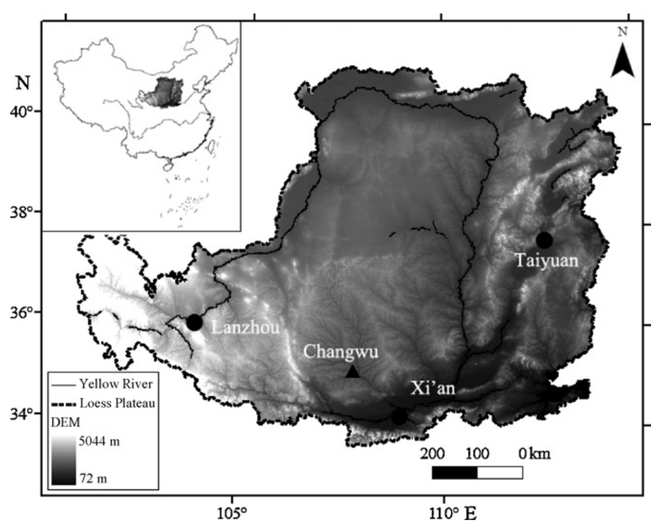

Fig. 1. The location of Changwu Agro-ecological Experiment Station.

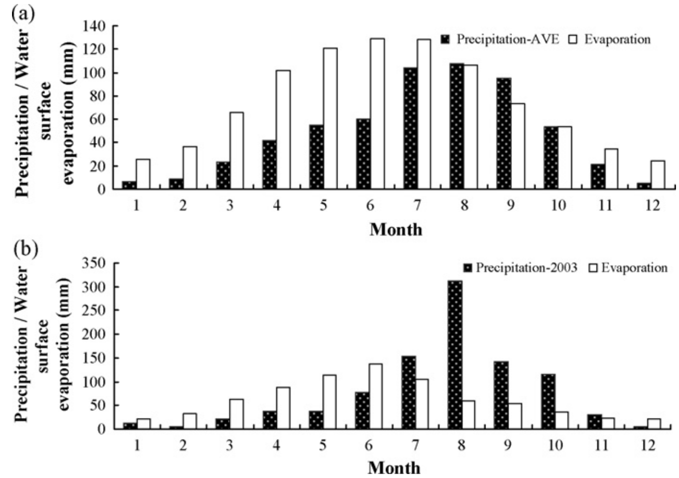

Fig. 2. Monthly precipitation and E601 pan evaporation (Evaporation) at the Changwu County Meteorological Station: (a) average from 1957 to 2003 and (b) year 2003 only.

continental monsoon climate. The experimental sites are in a flat farmland on the Changwu tableland. The elevation is 1200 m above sea level. The average annual precipitation is 584 mm, with 55% falling from July through September (Fig. 2a). The annual average temperature is 9.2 °C. The soil is light silt loam (Heilutu series). The soil properties including soil texture, bulk density, field capacity, and wilting point, are shown by layer in Table 1. The overall depth-averaged bulk density of the soil profile was 1.3 g/cm^3, the field capacity is 22.5% by weight (g/g) or approximately 29% by volume (m^3/m^3), and the wilting point is 7.5% (g/g) or approximately 9.8% by volume (m^3/m^3) (The soil water content in this paper is on a mass basis, unless stated otherwise). The ground water table was 80 m below surface.

Two experimental fields, 5 km apart, were selected for this study. One was on the comprehensive experimental site of the Chinese Ecological Research Network (CERN), which was under a winter wheat–wheat (+broom corn millet)–maize rotation. The winter wheat in the second-year rotation was double cropped with broom corn millet in some years. In 2003, the first-year winter wheat was harvested in June, and the second year wheat was planted in October, with summer bare fallow in between. The field was moldboard plowed to a 20-cm depth in late June after wheat harvest, hoed to a 5-cm depth in mid-August, and rotor tilled to about 20 cm in mid-September before wheat planting. Nitrogen (120 kg N/ha in the form of urea) and phosphorus (60 kg/ha P_2O_5) were applied and incorporated by a rotary tiller before wheat planting. The other field was on the Changwu long-term rotation experiment site. Cropping systems selected for comparisons include continuous winter wheat, alfalfa, and bare-soil fallow, as well as wheat (+broom corn millet)–pea–wheat rotation. In 2003, pea (*Pisum sativum* L.) was planted into bare soil in April and harvested in July, and wheat was planted in October for the rotation of wheat (+broom corn millet)–pea–wheat. Tillage operations varied with cropping systems. Generally, each field was moldboard plowed after harvest and rotor tilled before planting with shallow tillage to remove weeds during fallow or growing season as needed. The fertilizer treatments were check (no fertilization), (N + P)-mixed fertilization at the rates of 120 kg/ha N and 60 kg/ha P_2O_5, and N + P + manure application at the rates of 120 kg/ha N, 60 kg/ha P_2O_5 and 75 ton/ha organic manure.

2.3. Measurement methods

Soil moisture content down to a depth of 6 m was measured with a neutron probe. There were three plots for each treatment,