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FIELD EVAPOTRANSPIRATION AND WATER CONSUMPTION OF DRYLAND SPRING CORN

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Abstract

Soil reservoirs are the foundation for stable grain production and sustainable development in dryland agricultural areas. This study combines long-term field positioning experiments to study the changes in soil moisture of spring maize in the Changwu Arid Plateau in the southern Loess Plateau from 2021 to 2024, and analyzes the interannual and intra annual variation characteristics and dynamic laws of soil reservoirs. The results showed that there was a significant deficit in soil reservoirs during dry years, with a deficit of 94.3 mm in the second season and 123.7 mm in the fourth season, and negative compensation in water balance was observed. In the year of abundant water, the soil reservoir had a significant surplus (208.6 mm), and the water balance showed positive compensation. The water source for evapotranspiration and water consumption during the growth period of spring corn indicated that, in wet years, it came solely from precipitation during the growth period, whereas in dry years, it was derived partly from precipitation and partly from soil water storage from the previous season. The water status of soil reservoirs had a significant impact on the growth of spring maize, and the water storage function of soil reservoirs was of great importance in alleviating the adverse effects of drought on crop growth.

Introduction

The soil moisture cycle in the Loess Plateau is a relatively single process of precipitation infiltration and evapotranspiration. Due to the deep burial of groundwater and the deep loess layer, almost all precipitation is stored in the soil. Ultimately, the deep soil water storage is used to cope with climate drought, known as the soil reservoir effect.

Changwu Dryland is a typical dryland agricultural area in the southern Loess Plateau. Regarding the reason for the continuous water supply of soil reservoirs, Li (1983a and 1983b) found in his early research that the water stored in soil reservoirs is deeply hidden in the soil and must be transmitted to the surface of evaporation before it can evaporate and dissipate. The water conductivity decreases exponentially with the decrease of soil moisture content. Even under long-term physical evaporation conditions, when the water storage in soil reservoirs drops to a certain level, a relatively stable state will occur. Shao (1987) comprehensively considered various influencing factors in SPAC and for the first time quantitatively established a dynamic model of plant root water uptake-soil water availability. They provided a reasonable explanation for the fact that even in years of drought and low rainfall in the Loess Plateau region, soil reservoirs can continue to supply water and crops can maintain high yields. Specifically, soil water remained nearly equally available to crops when the soil moisture was within 40-80% of the field water-holding capacity, enabling the soil to provide its stored effective water to crops and largely meet their water requirements.

Soil water storage function, as the core assessment element of zonal hydrological balance, its water storage efficiency directly restricts the agricultural development. In drought-prone areas, it

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has become a key natural carrier for maintaining the sustainable use of water (Zhao *et al.* 2017), an in-depth analysis of the characteristics and dynamic evolution mechanism of soil reservoirs constitutes the scientific basis for constructing a precise agronomic management paradigm, especially having significant guiding value in the practice of water regulation in seasonal arid areas (Zhang and Feng 2023). The research on the evolution of soil reservoirs based on the analysis of hydrological flux balance provides a multi-dimensional mechanism explanation and quantitative evaluation framework for the optimization of water use thresholds in rain-fed agricultural systems and the systematic exploration of the ecological-hydrological coupling process in the semi-arid zone of the Loess Plateau (Li *et al.* 2013).

The traditional ecological hydrological processes on the Loess Plateau are undergoing profound changes. The regulating function of soil reservoirs is becoming unstable, resulting in negative compensation for soil moisture balance and increased soil drying. Dryland agriculture is facing enormous challenges, and negative compensation for soil moisture balance can slow down or even block water exchange between the upper and lower layers of soil, weaken the ability of precipitation to vertically infiltrate and recharge groundwater, lead to weakened soil reservoir function, deterioration of soil moisture ecological environment, and reduced land productivity, affecting the sustainable development of dryland agriculture on the Loess Plateau (Jing *et al.* 2018, Cai *et al.* 2020).

Materials and Methods

The study area is located in Qinling field monitoring center station in Mei County, Shaanxi Province. The area belongs to Weibei Dry tableland, with flat terrain and deep soil layer. A one-year-old corn field was selected as the experimental site, with continuous cropping practiced under rain-fed conditions. Field management followed traditional tillage methods, including tillage and fertilization before sowing and topdressing after sowing, with no irrigation applied.

In this experiment, the growth period of the first spring maize was from April 16, 2021 to September 15, 2021. The growth period of the second spring maize was from April 15, 2022 to September 17, 2022. The growth period of Spring Maize in the third season was from April 17, 2023 to September 18, 2023. The growth period of Spring Maize in the fourth season was from May 4, 2024 to September 16, 2024.

The evapotranspiration consumption of Spring Maize in the growing season from 2018 to 2021 was calculated by using the water balance method. The current general water balance formula is:

$$P + I + Eg - Ic = Ri + Rs + ET + Ip + \Delta S$$

Where, P is precipitation (mm); I is irrigation volume (mm); Eg is the supplement of phreatic water to soil water caused by capillary lifting force (mm); I_C is canopy interception (mm); Ri is the flow in soil (mm); RS is surface runoff (mm); Et is evapotranspiration (mm); Ip is the deep leakage (mm); ΔS is the net increase of soil water storage during the study period (mm), and a negative value indicates the decrease of soil water storage.

The climate in the study area was arid, and the groundwater depth was less than 50 m, meaning it did not participate in the soil water cycle. The effect of groundwater replenishing soil water through capillary rise was therefore negligible. The area had loose soil, flat terrain, and strong infiltration capacity, allowing runoff components (Ri and Rs) to be ignored. Long-term lysimeter monitoring confirmed the absence of leakage (Ip = 0). The findings also indicated that the water intercepted by the canopy eventually entered the atmosphere as vapor, contributing significantly to precipitation loss; hence, canopy interception was included in the evapotranspiration component. Accordingly, the simplified water balance equation for estimating evapotranspiration was developed based on the research results from this region (Zhang and He 2023).

The precipitation (mm) during the study period was continuously monitored to the automatic weather station near the test sample site, and recorded once every 1 hr. The sum of the data recorded in the day is the daily precipitation. At the same time, in order to ensure the continuity of precipitation data, rain measuring cylinders were arranged in the test sample plot, and the precipitation and the start and end time of precipitation were recorded within 30 min after the end of a single precipitation event. In the present study, the middle-type precipitation less than 540 mm was taken at a dry year, and more than 628 mm was takend at a wet year, between which is a normal year (Zhang and He 2023).

The depth for soil moisture determination was 600cm. Six PVC neutron tubes were buried in the community. They were measured every 10cm from 0 to 100cm and every 20cm below 100cm. The average value of the six measurements at the same depth was taken. The monitoring period was from March 18, 2021 to March 15, 2024. The volumetric water content of soil in different soil layers was calculated by using the neutron meter to determine the values, and the soil water storage was calculated by using formulas. The calculation formula for the variation of soil water storage capacity is (Zhang and He 2023):

$$D_w = \sum \theta_i \cdot h_i \cdot 10^{-1}$$

$$\Delta s = D_{w2} - D_{w1}$$

where, D_w is the depth of water layer (mm); D_{w1} is the depth of water layer in the previousperiod (mm); D_{w2} is the depth of water layer in the later period (mm); h_i is the thickness of a soillayer (cm); θ_i is the volume water content of a soil layer (%) (Zhang and He 2023).

Results and Discussion

It can be seen from Table 1 that the precipitation of spring corn in the second and fourth seasons can determine that the year is a dry year. The precipitation of spring corn in the first and third seasons is considered a water-abundant year. Combined with Fig. 1, it is found that the precipitation in the test area is unevenly distributed throughout the year, the rainfall period is concentrated, and the difference in precipitation gradient and seasonal distribution is particularly obvious. By comparing the seasonal distribution of precipitation across the study years, the annual precipitation dynamics were divided into four stages. The first stage, from July to September, showed a rapid increase in precipitation, with a multi-year average of 349.0 mm, representing the wet season. The second stage, from October to December, was characterized by a sharp decline in precipitation, with a multi-year average of 28.9 mm, marking the dry season. The third stage, from January to March, had the lowest precipitation levels of the year, with a multi-year average of 27.1 mm, also corresponding to the dry season. The fourth stage, from April to June, showed a gradual increase in precipitation, with a multi-year average of 166.7 mm, representing the transition period.

Table 1. Classification of precipitation annual patterns in different growing seasons.

Growing season	Precipitation (mm)	Precipitation year type
The first season	653.7	Wet year
The second season	477.4	Dry year
The third season	638.2	Wet year
The fourth season	516.2	Dry year

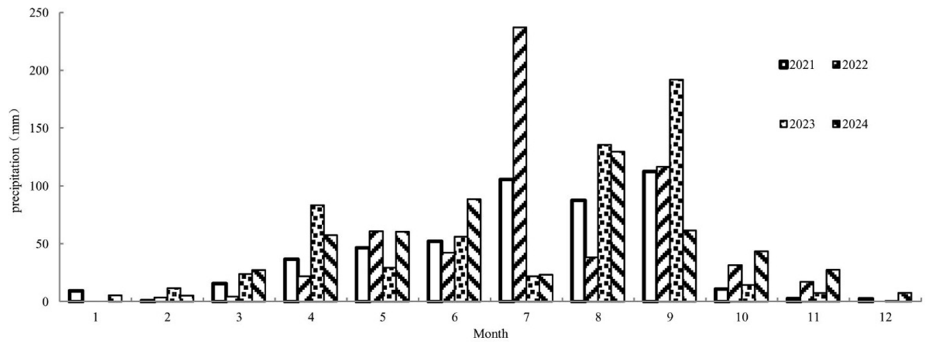

Fig. 1 Monthly precipitation in different growing seasons.

The fallow period extended from the harvest of spring maize under dry farming conditions to the sowing of the next season. During this period, the soil reservoir was primarily replenished in wet years, leading to a rise in its “water level,” whereas in dry years, drainage dominated, causing the “water level” to decline. The growth period spanned from sowing to harvest. Overall, the variation in the soil reservoir’s “water level” across different precipitation years followed a pattern similar to that observed during the fallow period. However, at a finer temporal scale, the “water level” of the soil reservoir under both precipitation conditions showed a pattern of first rising, then falling, and finally rising again (Fig. 2).

Differences in precipitation among hydrological years affected the timing of the first peak in the soil reservoir’s “water level.” In the first stage, the “water level” rose. In the second season, it reached its first peak at the end of May, with precipitation of 76.8 mm, evapotranspiration of 47.2 mm, and a precipitation satisfaction rate (ratio of precipitation to evapotranspiration) of 1.6. In the third quarter, the first peak occurred in mid-May, with precipitation of 78.2 mm, evapotranspiration of 43.5 mm, and a satisfaction rate of 1.8. In the fourth quarter, the first peak appeared at the end of June, with precipitation of 138.4 mm, evapotranspiration of 94.7 mm, and a satisfaction rate of 1.5. During this stage, since the precipitation satisfaction rate exceeded 1.0, precipitation surpassed evapotranspiration, increasing soil water storage and causing the “water level” of the soil reservoir to rise. The satisfaction rate in wet years was higher than in dry years, and the soil reservoir reached its first peak earlier in wet years.

In the second stage, the “water level” declined and reached its lowest point in mid-July during the second quarter, with precipitation of 86.4 mm, evapotranspiration of 182.5 mm, and a satisfaction rate of 0.5. In the third quarter, the lowest point occurred at the end of July, with precipitation of 89.0 mm, evapotranspiration of 250.3 mm, and a satisfaction rate of 0.4. In the fourth quarter, the lowest point also occurred at the end of July, with precipitation of 23.3 mm, evapotranspiration of 204.6 mm, and a satisfaction rate of 0.1. At this stage, since the satisfaction rate was below 1.0, precipitation was insufficient to meet evapotranspiration demand, reducing soil water storage and lowering the “water level.” The satisfaction rate in dry years was slightly higher than in wet years, and the lowest “water level” occurred in mid-to-late July, coinciding with the peak growth period of spring maize when water consumption far exceeded precipitation. Although the exact timing varied slightly among years, the overall time range remained consistent.

In the third stage, the “water level” rose again. In the second season, precipitation was 255.4 mm, evapotranspiration was 229.1 mm, and the satisfaction rate was 1.1. In the third quarter, precipitation reached 270.6 mm, evapotranspiration 141.1 mm, and the satisfaction rate 1.9. In the fourth quarter, precipitation was 169.2 mm, evapotranspiration 132.6 mm, and the satisfaction rate

1.3. During this stage, precipitation exceeded evapotranspiration (satisfaction rate > 1.0), increasing soil water storage and causing the "water level" of the soil reservoir to rise again. The satisfaction rate in wet years was significantly higher than in dry years, leading to noticeable recovery of soil moisture in August and early September.

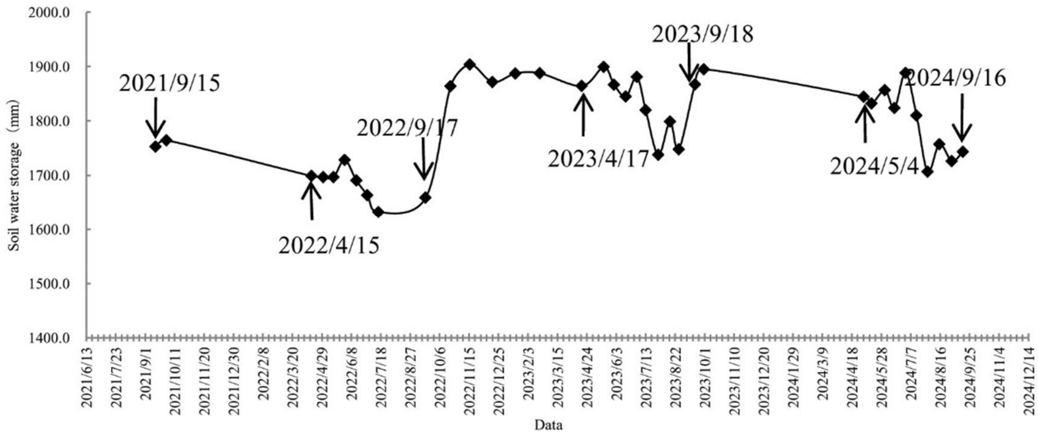

Fig. 2. Dynamics of soil reservoir in spring corn field during the study periods.

During the fallow period before the sowing of spring maize, the net decrease in the 0-600 cm soil water level was 54.1 mm in the second season and 22.6 mm in the fourth season. During the growth period, the net decrease in the 0-600 cm soil water level was 40.2 mm and 101.1 mm, respectively. Precipitation during the growth period was 418.6 mm in the second season and 330.9 mm in the fourth season, while evapotranspiration water consumption was 329.9 mm and 530.3 mm, respectively. In contrast, during the third season, the net increase in the 0–600 cm soil water level during the fallow period before sowing was 205.7 mm, and during the growth period, it increased by 2.8 mm, with precipitation of 437.8 mm and evapotranspiration of 434.9 mm.

The evapotranspiration water consumption of spring maize across the three seasons was strongly influenced by precipitation type, showing considerable interannual variation. In years with relatively low annual precipitation, the soil reservoir experienced a substantial deficit, 94.3 mm in the second season and 123.7 mm in the fourth season, resulting in a negative water balance. Conversely, in wet years, precipitation was relatively sufficient, leading to a large soil reservoir surplus (208.6 mm) and a positively compensated water balance.

During wet years, precipitation during the growth period of spring maize was sufficient to meet the evapotranspiration demand of the field, thereby minimizing the observable effect of the soil reservoir. In contrast, during dry years, precipitation during the growth period was insufficient to meet the evapotranspiration demand of spring maize. In such cases, the soil water storage function established during the early stage (nonfallow period) played an important role in maintaining relatively stable water consumption. However, precipitation during the fallow period in dry years was limited, being 58.8 mm in the second season and 185.3 mm in the fourth season, resulting in a decline rather than an increase in soil water storage. Consequently, the water available to crops was primarily derived from the soil water storage accumulated in the previous season. Overall, in wet years, evapotranspiration during the spring maize growth period relied solely on precipitation, whereas in dry years, it depended partly on current season precipitation and partly on stored soil water from the previous season. In this experiment, the contributions of soil water storage to evapotranspiration were 16.5% in the second season and 19.3% in the fourth season, respectively.

The regulation effect of soil reservoir on the water supply of autumn crops between seasons highlights the regional characteristics of soil reservoir effect in the Loess Plateau (Guo and Shao 2003). Due to the availability of soil moisture and the existence of soil reservoirs in this area, the continuous water supply for crops ensured the healthy and stable yield of crops, so that the dry farming in this area had a good soil moisture ecological environment. However, we should also recognize the limitations of the water cycle in the farmland ecosystem. The negative compensation of soil water balance maked it almost impossible for the vertical infiltration of farmland soil water in this area to supplement groundwater. The main processes of the water cycle in the farmland ecosystem are precipitation infiltration and upward evapotranspiration (Wang *et al.* 2025), which together constitute the small-scale cycle of farmland water. This represented the overall characteristic of the crop–soil water ecological environment in the Loess Plateau and formed the basis for understanding the influence of the regional soil water cycle on the broader land water cycle.

In recent years, soil and water conservation measures including engineering, forestry and grass planting, and farming practices on the Loess Plateau have achieved remarkable results, effectively curbing soil and water loss, with vegetation growth and suitability becoming primary concerns. However, excessive focus on the negative compensation of soil water balance on vegetation growth should not overshadow its impact on the land water cycle. With the increasingly serious problem of land surface water scarcity, it has become urgent to reevaluate the negative compensation of soil water balance and the feedback effects of soil and water conservation measures on the land water cycle. Negative compensation of soil water balance influences the water cycle and hinders groundwater recharge, while soil and water conservation measures intercept surface runoff, reducing regional runoff. The combined effects of these factors can alter regional river runoff, strengthen the small scale water cycle in forests and farmland, and weaken the large scale land water cycle. Therefore, further research is needed to determine the proper development direction for dry farming and to reasonably assess the ecological benefits of soil and water conservation measures.

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