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Importance of Temporal Scale in Assessing Changes in Soil-Water Storage in Apple Orchards on the Chinese Loess Plateau

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Abstract: Knowledge of changes in soil-water storage (SWS) at multiple scales in apple orchards is important for formulating policies for the scientific management and sound planning of apple plantations on the Loess Plateau in China. In this study, we measured precipitation, partitioned evapotranspiration (*ET*) into canopy interception, transpiration, and soil evaporation, and calculated the changes in SWS using the water-balance method at multiple scales in two neighbouring apple orchards (8 and 18 years old) on the Loess Plateau from May to September in 2013, 2014, 2015, and 2016. The results showed that *ET* was consistently lower for the 8- than the 18-year-old orchard in each year at the same scale ($p < 0.05$). The changes in SWS differed between the two orchards at the same scale, but the trends of change were similar in each year. The trend of the change in SWS at the same scale differed amongst the years for both orchards. The maximum supply of water from soil reservoirs for the two orchards also differed at different scales in each year and was higher at a daily cumulative scale than a monthly and annual scale in 2013, 2014, and 2016. The daily cumulative scale was thus a more suitable scale for representing the maximum contribution of the soil reservoir to supply water for the growth of the orchards during the study periods. Changes in SWS at a daily cumulative scale should be considered when assessing the effect of apple orchards on regional soil reservoirs on the Loess Plateau or in other water-limited regions.

Keywords: apple orchard; tree age; evapotranspiration; change in soil-water storage; maximum water supply

1. Introduction

The Loess Plateau in China has a dry climate but is one of the best areas for the cultivation of apples due to its sufficient sunlight, low levels of environmental pollution and good ventilation [1]. Following the introduction of several policies to convert agricultural land to forests by the Chinese Central Government, apple orchards covering large areas were established on the plateau [2]. Apples grown in this region are crisp and have clean surfaces, thick wax, bright colour, high storage resistance, and long shelf life, and have been accepted by native and foreign markets [3]. Apple acreage and yield in Shaanxi Province in 2017 were 7.3×10^5 ha and 1.1×10^7 t, respectively, and the apple industry has become important for the national economy [3].

Precipitation (*P*) is the only source of water on the Loess Plateau for agricultural production [4,5], and most crops, including apples, are cultivated under rainfed conditions. Evapotranspiration (*ET*) refers to the amount of water vapor evaporated from the unit area of the land surface during a unit of time [6] and consists of transpiration from plants (*T*), evaporation from soil (*E*) and canopy interception

(I) [7]. Methods based on micro-lysimeters and measurements of sap flow have been widely used to measure E and T [8–11]. More than 90% of all P input to the system in semiarid regions returns to the atmosphere via ET [12,13]. ET in this region is higher in apple orchards than for traditional crops [14]. The area devoted to apple orchards is still expanding, so the effect of these orchards on regional water balance cannot be ignored, and many studies have been conducted to quantify ET or its components [15–18].

Global climate change is expected to increase atmospheric water demand and terrestrial ET [19–21], which may offset modest increases in P [22]. The soil-plant-atmosphere environment is a mutually interacting system [23], and soil-water cycles are strongly affected by land use in these environments [24]. Jia et al. [25] found that afforestation decreased soil-water content across the Loess Plateau and that any decrease in soil-water content could negatively affect soil-water storage (SWS) in both the upper and deeper soil layers. Apple orchards would decrease local and regional SWS and available SWS if long-term water shortages ($ET > P$) occurred in the orchards on the plateau [26,27]. Several studies found that soil desiccation had formed in deep soil in apple orchards on the plateau due to a negative water balance [28–30]. Such layers negatively affect ecosystems, altering the processes of water cycles in soil-plant-atmosphere systems [31] and thus limiting the sustainability of large-scale apple plantations. Knowledge of changes in SWS (ΔSWS) in apple orchards on the plateau are therefore essential for understanding the formation of soil desiccation and formulating reasonable management planning of apple orchards.

Previous studies have calculated SWS in apple orchards on the Loess Plateau based on in situ point measurements of soil-water content at monthly or annual scales [32–35], so this information can only be used to quantify ΔSWS in apple orchards at a monthly or annual scale. Daily cumulative ΔSWS for apple orchards based on measurements of soil-water content in deep soil profiles involve large and expensive expenditures of time and labour [36], and there is little information about ΔSWS in apple orchards at a daily cumulative scale. Given the increasing conflict between soil desiccation and the sustainable development of vegetation on the Loess Plateau [37], accurate quantification of dynamic ΔSWS in apple orchards is thus clearly needed for exploring the maximum supply of water from soil reservoirs at a suitable temporal scale.

In this study, we measured daily P, T, and E and calculated daily I and ΔSWS at multiple scales during the growing seasons (May–September) in 2013, 2014, 2015, and 2016 in the 8- and 18-year-old apple orchards in Changwu County on the Loess Plateau. The objectives of this study were to: (1) quantify and compare ET at different scales in the 8- and 18-year-old apple orchards during the four successive study periods, (2) characterise and compare ΔSWS at different scales in the two orchards, and (3) explore the maximum supply of water from soil reservoirs at different scales in the two orchards and analyse the differences between the supplies and the reservoirs amongst the scales (if any).

2. Materials and Methods

2.1. Study Area

This study was carried out at the Changwu Agro-ecological Experimental Station of Northwest A&F University in the Wangdonggou watershed (107°40′–107°42′ E, 35°12′–35°16′ N; 1219 m a.s.l.), Shaanxi Province, northwestern China. The watershed is in the gully region of the plateau in the middle reaches of the Yellow River and has a continental monsoon climate with cold winters, hot summers, a mean annual temperature of 9.1 °C (1957–2014), an annual accumulated temperature >10 °C of >3029 °C, mean annual hours of sunshine >2230 h, and about 171 days without frost. Mean annual P is 584 mm (1957–2006), with rain or snow falling mainly from July to September (>58% of the annual total) [38]. Mean annual reference evapotranspiration is 1016 mm, which can cause water deficits. The soil texture in this region is uniform, and the main soil is classified as a light silty loam (Heilutu series) with a mean soil bulk density of 1.3 g cm^{-3}. Water content at field capacity of this soil is

29% by volume ($m^3\ m^{-3}$) with a wilting point of 9.8% by volume ($m^3\ m^{-3}$). The depth of groundwater table in this area is lower than 50–80 m, which precludes upward capillary flow into the root zone [4].

Most of the apple trees in the area were planted in 1996 and 2006, encouraged by local governmental policy. The dominant orchards were thus 8 (young) and 18 years (old) in 2013. In this study, we conducted experiments in two neighbouring orchards 8 and 18 years of age (Figure 1). The apple tree species used in the two orchards was *Malus domestica*, cv. Fuji Apple. As the orchards were very close to one another, their environmental conditions were assumed to be the same. Each orchard was 70 m long, 16 m wide, and oriented east-west. Tree and row spacings were 3.5 m and 4.0 m, respectively, so the density was 720 trees ha^{-1}. The orchards were managed by local farmers and received similar annual treatments for pest and weed control, the trees were similarly pruned, and the management practices were typical for the region.

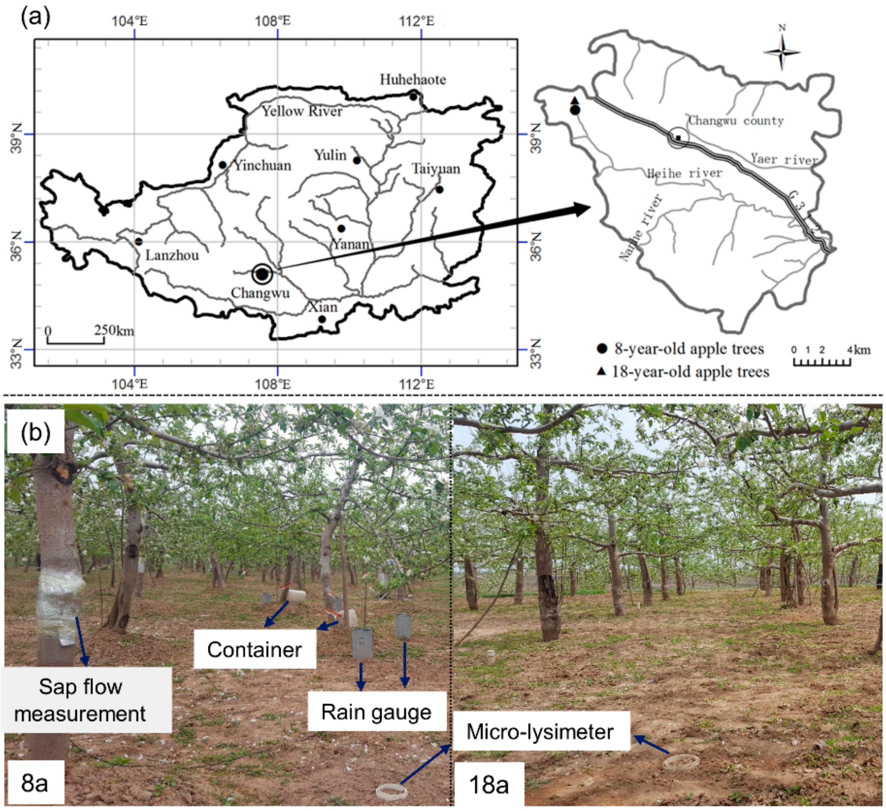

Figure 1. Locations of the 8- and 18-year-old orchards (8a and 18a, respectively) in the Wangdonggou watershed (**a**) and facilities for measuring the components of evapotranspiration in the orchards (**b**).

2.2. Precipitation

P (mm) was determined regularly during the four growing seasons (May–September 2013, 2014, 2015, and 2016) by a tipping-bucket gauge at a meteorological station that is close to the two experimental orchards.

2.3. Measurement of Evapotranspiration

ET can be expressed as:

$$ET = T + E + I \quad (1)$$

All three components of *ET* were measured in both orchards.

2.3.1. Transpiration

Sap-flux velocities were measured for eight apple trees in each orchard and growing season using Granier thermal-dissipation sensors [39]. One to three trees were selected for these measurements to represent trees in four diameter classes at a height of 0.8 m. The percentage distributions in the two orchards are shown in Table 1.

Table 1. Diameters, numbers, and percentages of trees and numbers of sample trees for the sap-flow measurements in the 8- and 18-year-old orchards (8a and 18a, respectively).

Diameter Class	8a				18a			
	Diameter (mm)	Number of Trees	Percentage (%)	Sample Trees	Diameter (mm)	Number of Trees	Percentage (%)	Sample Trees
1	<90	11	13.8	1	<130	24	30	2
2	90–100	17	21.3	2	130–140	17	21.3	2
3	100–110	17	21.3	2	140–150	16	20	2
4	>110	35	43.8	3	>150	23	28.7	2
Total		80	100	8		80	100	8

None of the selected trees were at the ends of rows to avoid edge effects. Only one thermal-dissipation probe (Dynamax, Houston, TX, USA) was installed on the trunks of the selected trees, 0.8 m above the ground, to minimise injury and preserve the trees for future studies [40]. The theoretical method for Granier thermal-dissipation sensors has been described previously by Granier [39,41,42]. The installation of probes and extrapolation of sapwood area at a height of 0.8 m in the two orchards are described in more detail by Wang and Wang [18].

Whole-tree sap flow was calculated, assuming a constant sap-flux velocity across the sapwood profile, as Granier [39], Oren and Pataki [43] and Santiago et al. [44]:

$$SF = A_s \times 0.0119 \left(\frac{T_{max} - \Delta T}{\Delta T}\right)^{1.231} \times 3600 \quad (2)$$

where SF is sap flow (L h^{-1}), A_s is the area of the sapwood (cm^2), ΔT is the difference in temperature between the heated and unheated thermocouples, and ΔT_{max} is the difference in temperature at zero sap flow.

Stand T (mm d^{-1}) was extrapolated from the measurements of sap flow for individual trees [45]:

$$T = \frac{\sum_{i=1}^{n} J_{si} \times A_{si}}{A_G} \times K \quad (3)$$

where J_{si} is the average sap-flux velocity of the trees in diameter class i (mm s^{-1}), A_{si} is the total cross-sectional area of the sapwood of the trees in diameter class i (cm^2), n is the number of trees in each diameter class in the orchard, A_G is the ground area of the orchard (m^2), and K is a conversion coefficient equal to $3600 \times 24/10000 \approx 8.64$ (m^2 s cm^{-2} d^{-1}).

2.3.2. Soil Evaporation

E was measured by micro-lysimeters [46] made from PVC tubes (diameter 10.5 cm, height 20 cm). Eight pairs of micro-lysimeters were installed in each orchard, one below the canopy of each selected tree, and the other midway between the tree and one of its neighbours [47]. The micro-lysimeters were reinstalled every 3–5 days, or one day after a heavy rain. The micro-lysimeters were weighed at 08:00 standard local time every morning. E (mm d^{-1}) was calculated using the following equation:

$$E = 10 \times \frac{\Delta W/\rho}{\pi (D/2)^2} \quad (4)$$

where ΔW (g) is the difference in weight between two adjacent days, ρ is the density of water (g cm^{-3}), D is the diameter of the micro-lysimeter (cm), and 10 is a factor for converting centimetres to millimetres.

2.3.3. Canopy Interception

P was partitioned into three fractions during and after a rain: I, stemflow, and throughfall [48]. I (mm d^{-1}) cannot be measured directly but can be calculated as:

$$I = P - TF - StF \tag{5}$$

where TF is throughfall (mm), and StF is the estimated stemflow (mm).

Throughfall and stemflow in each orchard were recorded using rain gauges and containers, respectively (Figure 1). The measurements of throughfall and stemflow in the two orchards are described in detail by Wang and Wang [49].

2.4. Water-Balance Method

Soil-water balance is based on the principle of conservation of mass, and ΔSWS is controlled by six processes: (1) P (mm), (2) irrigation (mm), (3) upward movement of water from the water table (mm), (4) ET (mm), (5) surface runoff (mm), and (6) drainage (mm) [50]. P is the only source of water in this unirrigated area. The upward movement of water from the water table was considered to be negligible, because the water table is lower than 50–80 m [4]. Both orchards were on a flat terrace and were separated and surrounded by segregation belts, so runoff and drainage can be negligible based on in situ observations [51].

The soil-water balance can be simplified as Wang et al. [35]:

$$\Delta \mathrm{SWS} = P - ET \tag{6}$$

ΔSWS for the orchards at different scales can therefore be calculated using the simplified soil-water balance equation because of the limited amount of deep percolation and runoff on the plateau [23,52].

2.5. Data Analysis

There were no P and ET data for the two orchards from 11 to 30 September 2014 due to equipment failure. During the study periods, daily ET of each orchard was the sum of daily T, E and I. Daily cumulative ΔSWS for the orchards was the sum of daily ΔSWS during each growing season. Summary statistics, such as means and standard deviation of daily ET, monthly ET, and annual ET for each orchard, and coefficients of variation (CVs) of annual ET, monthly P, and annual P, were calculated with Microsoft Excel (2013). A one-way analysis of variance was performed to evaluate the statistical differences of daily ET, monthly ET and annual ET between the two orchards, and the statistical differences of maximum supplies of water from soil reservoirs amongst different scales for each orchard. The level of significance was set at 95% confidence interval ($p = 0.05$). Graphs were constructed using Sigmaplot 10.0 (Systat Softeware, 2006) and Origin 8.0 (Origin Lab Corporation, 2007) for windows.

3. Results

3.1. Precipitation and Evapotranspiration at Different Scales

In total, 57, 42, 54, and 50 rainfalls were measured, and daily P ranged from 0.2–28, 0.2–43.6, 0.2–34.4, and 0.2–38.1 mm, in 2013, 2014, 2015, and 2016, respectively (Figure 2). Daily ET in each year differed between the orchards and was consistently lower in the 8- than the 18-year-old orchard ($p < 0.05$). The trends of daily ET for the two orchards in each year were similar. Daily ET ranged from 0.8 to 4.4, 0.5 to 4.0, 0.8 to 3.4, and 0.5 to 4.1 mm d^{-1} for the young orchard and from 0.9 to 4.5, 0.6 to 4.2, 0.9 to 3.7, and 0.7 to 4.2 mm d^{-1} for the old orchard in 2013, 2014, 2015, and 2016, respectively. Mean daily ET was 2.2 ± 0.9, 2.3 ± 0.7, 1.8 ± 0.6, and 1.9 ± 0.7 mm d^{-1} for the young orchard and 2.4 ± 0.8, 2.5 ± 0.8, 2.1 ± 0.7, and 2.1 ± 0.8 mm d^{-1} for the old orchard in 2013, 2014, 2015, and 2016, respectively.

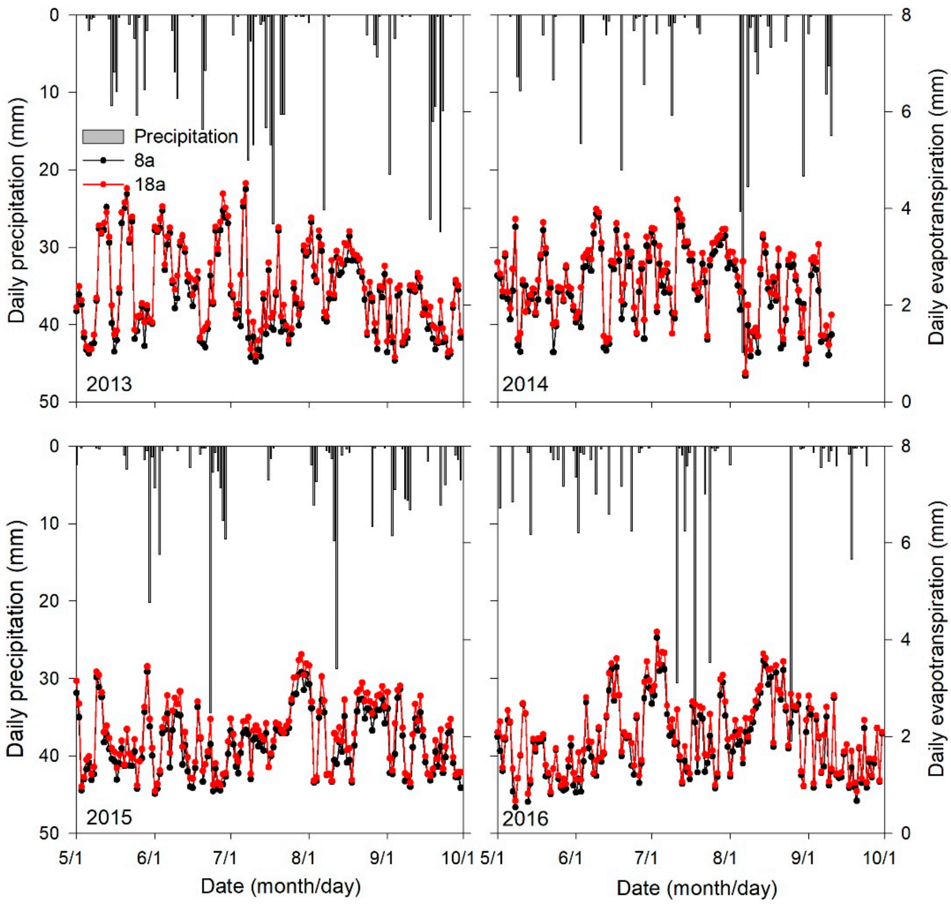

Figure 2. Dynamics of daily precipitation and evapotranspiration for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

Monthly P ranged from 38.4 to 129, 22.1 to 135.6, 6.2 to 93.6, and 27.8 to 115.9 mm in 2013, 2014, 2015, and 2016, respectively (Figure 3). Monthly P was highest in different months in different years: July in 2013, August in 2014, June in 2015, and July in 2016. Monthly P was highly variable, with CVs of 54.6, 83.7, 65.0, and 64.2% in 2013, 2014, 2015, and 2016, respectively.

Monthly ET was consistently higher for the old than the young orchard in each year ($p < 0.05$) (Figure 3). Monthly ET ranged from 49.4 to 83.3 and 54.6 to 88.5 mm for the young and old orchards, respectively, in 2013 and from 17.8 to 86.6 and 20.5 to 91.6 mm, 46.6 to 65.7 and 52.7 to 71.8 mm, and 46.1 to 72.8 and 49.8 to 78.1 mm for the young and old orchards in 2014, 2015, and 2016, respectively. The trends of monthly ET were similar in the two orchards in each year. Monthly ET was highest in June in 2013, July in 2014, July in 2015, and August in 2016 for both orchards. Mean monthly ET was 68.2 ± 13.5, 62.5 ± 26.3, 56.5 ± 8.4, and 58.3 ± 11.8 mm for the young orchard and 73.4 ± 13.3, 67.3 ± 27.4, 62.6 ± 8.9, and 63.1 ± 12.9 mm for the old orchard in 2013, 2014, 2015, and 2016, respectively.

During the past four years, annual P was 388.7, 277.8, 264.6, and 274.0 mm, respectively (Figure 4). Annual ET was consistently lower for the young than the old orchard ($p > 0.05$). Annual ET was 341.4, 312.4, 282.4, and 291.5 mm for the young orchard and 367.2, 336.3, 312.8, and 315.5 mm for the old orchard in 2013, 2014, 2015, and 2016, respectively. Annual mean ET for the young orchard was 306.9 ± 26.2 mm, with CVs of 8.5%. While for the old orchard, corresponding values were 332.9 ± 25.4 mm and 7.5%, respectively.

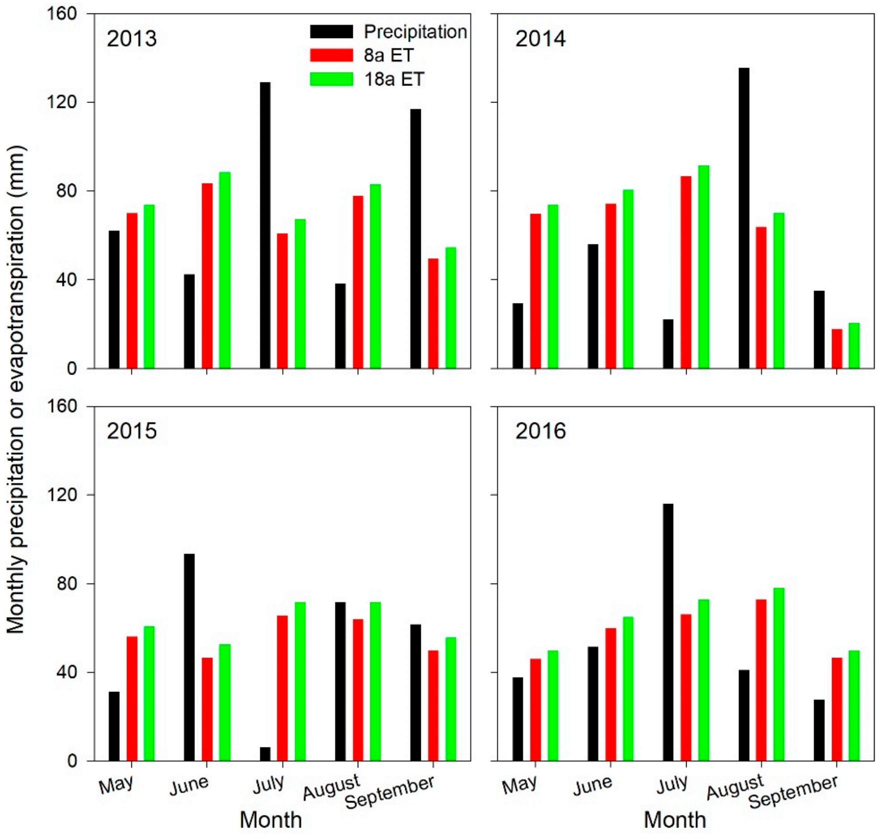

Figure 3. Monthly precipitation and evapotranspiration (*ET*) for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

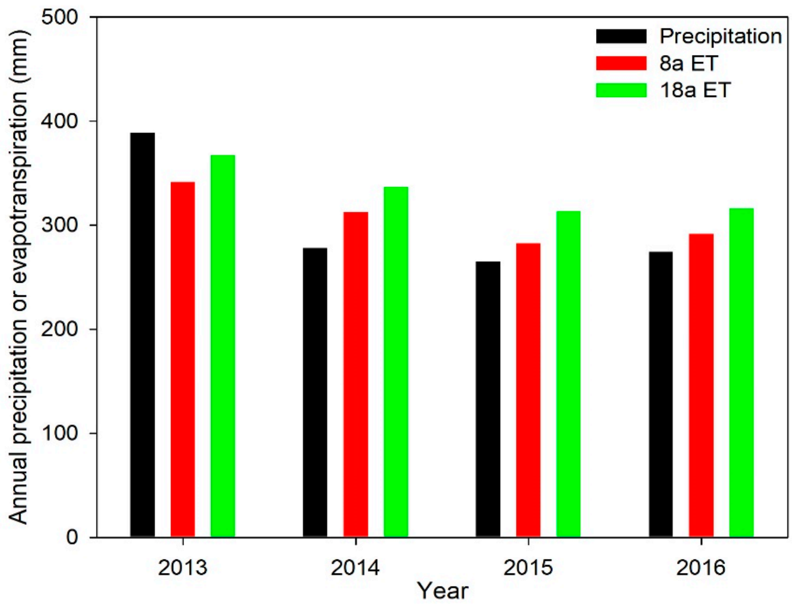

Figure 4. Annual precipitation and evapotranspiration (*ET*) for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

3.2. Changes in Soil-Water Storage at Different Scales

Daily cumulative ΔSWS for the young and old orchards differed in each year (Figure 5), ranging from −64.0 to 58.5, −134.3 to −2.6, −42.5 to 23.9, and −45.0 to 45.8 mm for the young orchard and from −74.8 to 33.1, −150.4 to −2.9, −58.6 to 13.3, and −55.8 to 31.6 mm for the old orchard in 2013, 2014, 2015, and 2016, respectively. The trends in daily cumulative ΔSWS were similar for both orchards, but the trends differed amongst the four years. The supply of water from soil reservoirs for both orchards was highest on the same day: 7 July 2013, 4 August 2014, 2 August 2015, and 10 July 2016.

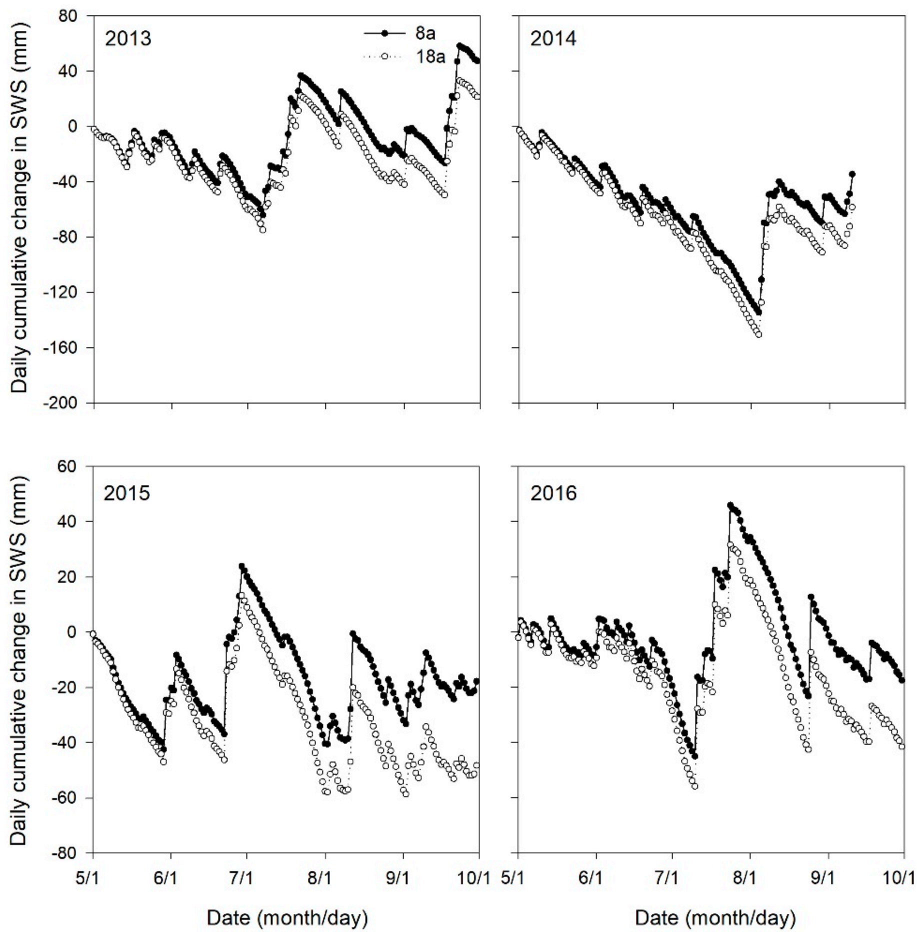

Figure 5. Daily cumulative change in soil-water storage (SWS) for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

Monthly ΔSWS for the young and old orchards had a similar trend in each year and was consistently higher for the young than the old orchard (Figure 6). The trends in monthly ΔSWS for both orchards differed amongst the four years. Monthly ΔSWS ranged from −40.1 to 68.2, −64.6 to 71.7, −59.5 to 47.0, and −31.7 to 49.8 mm for the young orchard and from −46.1 to 62.2, −69.5 to 65.7, −65.6 to 40.9, and −37.0 to 43.2 mm for the old orchard in 2013, 2014, 2015, and 2016, respectively. The supply of water from soil reservoirs for both orchards was highest in the same month: June in 2013, July in 2014, July in 2015, and in August 2016.

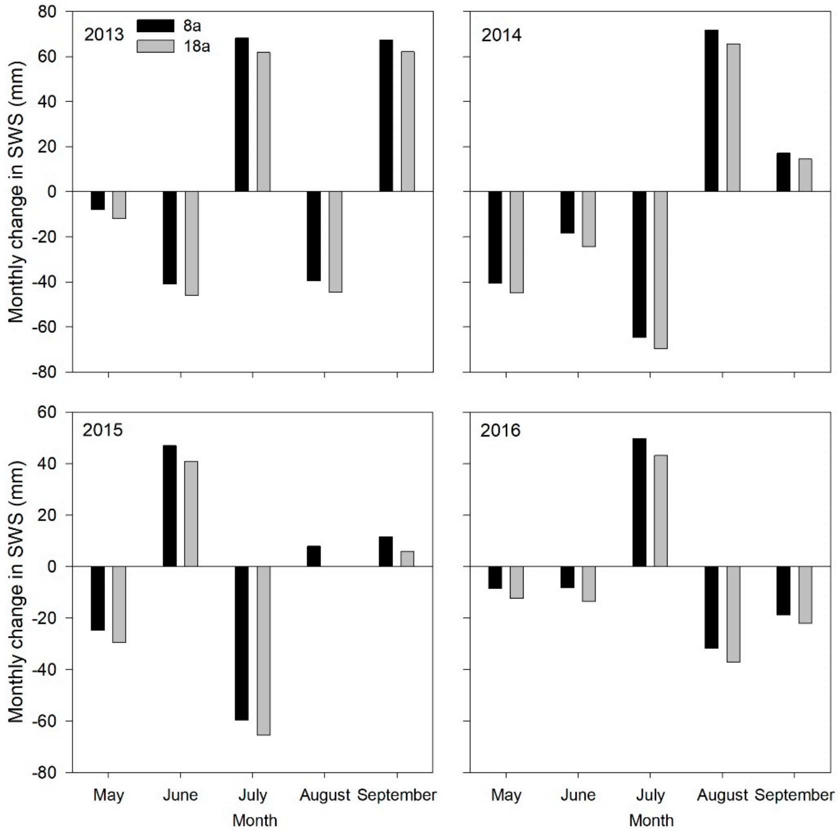

Figure 6. Monthly change in soil-water storage (SWS) for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

Annual ΔSWS was always higher for the young than the old orchard (Figure 7). The trends in annual ΔSWS for both orchards were similar amongst the four years. Annual ΔSWS for the young and old orchards was 47.3 and 21.5 mm in 2013, respectively and −34.5 and −58.5, −17.8 and −48.2, and −17.5 and −41.5 mm in 2014, 2015, and 2016, respectively.

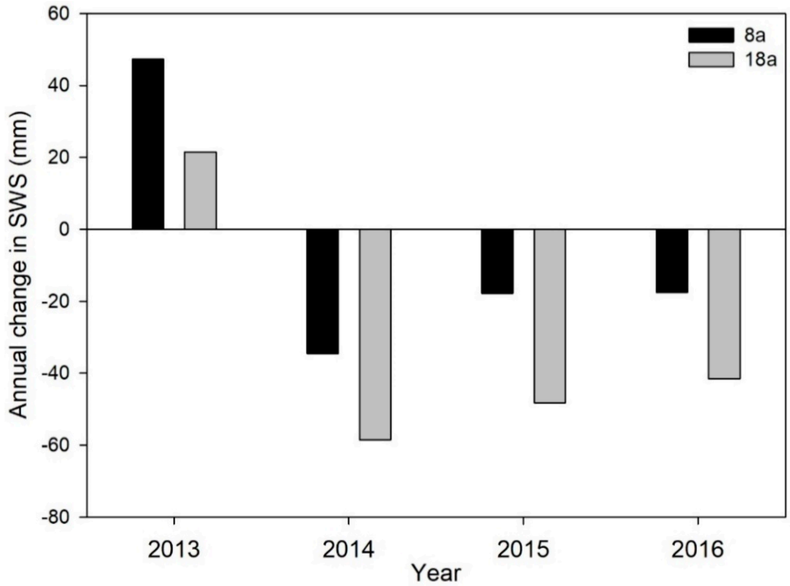

Figure 7. Annual change in soil-water storage (SWS) for the 8- and 18-year-old apple orchards (8a and 18a, respectively) in 2013, 2014, 2015, and 2016.

3.3. Comparison of Maximum Supplies of Water from Soil Reservoirs at Different Scales

The maximum supplies of water from soil reservoirs for both orchards differed at multiple scales in each year and amongst the four years (Table 2). The supplies for both orchards were higher at a daily cumulative scale than a monthly and annual scale in 2013, 2014, and 2016 but were higher at a monthly than a daily cumulative and annual scale in 2015. During the past four years, the maximum supplies of water from soil reservoirs for the young orchard was significantly higher at daily cumulative scale than at annual scale ($p < 0.05$). While for the old orchard, there was no significant differences in maximum supplies of water from soil reservoirs amongst different scales ($p > 0.05$). The maximum supplies of water from soil reservoirs for the young orchard was 64.0, 134.3, 59.5 and 45.0 mm in 2013, 2014, 2015 and 2016, respectively. Corresponding values for the old orchard were 74.8, 150.4, 65.6 and 55.8 mm, respectively. The supplies for both orchards were always lower at an annual than a daily cumulative and monthly scale in each year, except for the old orchard in 2016.

Table 2. Comparison of maximum supplies of water from soil reservoirs in the 8- and 18-year-old apple orchards (8a and 18a, respectively) at different scales in 2013, 2014, 2015, and 2016.

Year	Tree Age	Maximum Water Supply (mm)			Relationship Amongst the Scales
		Daily Cumulative Scale	Monthly Scale	Annual Scale	
2013	8a	64.0	40.9	−47.3	Daily cumulative > Monthly > Annual
	18a	74.8	46.1	−21.5	Daily cumulative > Monthly > Annual
2014	8a	134.3	64.6	34.6	Daily cumulative > Monthly > Annual
	18a	150.4	69.5	58.5	Daily cumulative > Monthly > Annual
2015	8a	42.5	59.5	17.8	Monthly > Daily cumulative > Annual
	18a	58.6	65.6	48.2	Monthly > Daily cumulative > Annual
2016	8a	45.0	31.7	17.5	Daily cumulative > Monthly > Annual
	18a	55.8	37.0	41.5	Daily cumulative > Annual > Monthly

4. Discussion

4.1. Changes in Soil-Water Storage at Different Scales

We may have underestimated T in the two orchards, because calibration of the thermal-dissipation probes at zero sap flow [39,53] and the micro-lysimeters may have prevented the accurate measurement of evaporation during rainy days [54]. The data, however, should at least provide reliable indications of the relative differences in ΔSWS at different scales in the orchards. ET was consistently lower for the young than the old orchard at the same scale in each year ($p < 0.05$). We conducted our experiments in two adjacent orchards, so we assumed that the soil and environmental conditions were the same. The difference in ET between the orchards was thus likely due to morphological differences between the trees. Both orchards had the same tree density, but the 18-year-old orchard had thicker trunks (Table 1), higher heights, and more branches than the 8-year-old orchard. Yang ET al. [55] also found that annual ET was always lower for 7- than 10-year-old trees in 2002 and 2003. Gong et al. [16] found that mean daily ET for an 8-year-old orchard was about 2.3 mm d^{-1}, which was higher than for the 8-year-old orchard in our study (2.0 mm d^{-1} for the four years). These different results may have been due to differences in tree density, P, and local management.

SWS strongly depends on P [56] and land-use type [57]. Huang et al. [58] also found SWS at the interfaces was significantly affected by tree species. In this study, ΔSWS was always higher for the young than the old orchard at the same scale in each year. We assumed that *P* was the same for both orchards, so differences in *P* would not account for the difference in ΔSWS. Zhang et al. [59] found that the water content of soil in forest stages tended to be low due to high root densities. Root densities may have differed between the two orchards in our study, which could have led to large differences in transpirational ability [60]. The trends of ΔSWS for both orchards were similar at the same scale in each year, mainly because ΔSWS was a response to changes in *P* and *ET* on the plateau [23]. The trends of *ET* for both orchards were also similar at the same scale in each year. Peng et al. [61] found that lighter rains usually only affected upper soil layers and that soil water was easily lost by evaporation. Soil water is mainly recharged by heavier rains [62], so heavier rains would be more beneficial for the recovery of SWS in deep soil layers in apple orchards.

Monthly *ET* for the young and old orchards ranged from 17.8 to 86.6 and 20.5 to 91.6 mm, respectively. Liu et al. [17] reported that water consumption in apple orchards was determined by factors such as leaf area index, reference *ET*, vapour-pressure deficit, and soil-water content. These factors may have differed in different months in our study, which would likely lead to seasonal variation in monthly *ET* for the two orchards. Zhu et al. [63] found no obvious trends in monthly ΔSWS for an 8-year-old orchard in Yanan City in 2001, 2002, and 2003. Monthly ΔSWS for the young and old orchards in our study ranged from −64.6 to 71.7 and −69.5 to 65.7 mm, respectively. Variation in monthly *P* (ranging from 6.2 to 135.6 mm for the four years) and monthly *ET* for both orchards jointly contributed to monthly ΔSWS for the two orchards.

Annual *P* in 2013–2016 ranged from 264.6 to 388.7 mm, which was lower than the 30-year mean total *P* of 424.8 mm reported for the same period [18]. *P* at the annual scale was able to meet the water requirements of the two orchards in 2013, but *ET* exceeded *P* in 2014, 2015, and 2016, so *P* in 2014, 2015, and 2016 was completely consumed by *ET*. This finding was not surprising, because our study area has a continental monsoon climate with low, unevenly distributed annual *P* (the CV of annual *P* was about 19.4% for the four years), and annual *ET* levels are high in the orchards (mean annual *ET* for the four years for the young and old orchards was 306.9 and 332.9 mm, respectively). Yang et al. [55] also found that the relationship between annual *ET* and *P* for a 10-year-old apple orchard differed between 2002 and 2003. Jia et al. [26] found that the mean annual supply of water from soil reservoirs in the 1.0–5.0 m profile on the plateau was about 16.2 mm, and Liu and Song [34] found that the annual supply of water from soil reservoirs for a 5-year-old orchard was about 81.4 mm in 1997 in Chunhua County, which was higher than the annual supplies for our orchards in each year. These different results may have been due to differences in study period, annual *P*, tree age, and orchard management.

4.2. Comparison of Maximum Supply of Water from Soil Reservoirs at Different Scales

Reductions in SWS may aggravate the scarcity of soil water in both upper and deep soil layers on the plateau, thus desiccating the soil [64], if plant and soil *ET* exceed *P* [65]. Previous studies have quantified ΔSWS for apple orchards on the plateau, usually at an annual scale [15,33,63]. Soil water was consumed in the orchards in 2014, 2015, and 2016 but was recharged in 2013 due to a higher annual P. During the study periods, soil desiccation had formed in the old orchard in 2013 [66], but annual ΔSWS (21.5 mm) in this year could not account for the occurrence of a dried soil layer, especially when annual ΔSWS for the orchards was not quantified for successive years.

The supply of water from soil reservoirs for the orchards was highest at the daily cumulative scale in 2013, 2014, and 2016 but at the monthly scale in 2015, mainly because *P* in our study area was unevenly distributed amongst the months and years. Monthly *P* was higher than *ET* in June 2015, and *P* stored in the soil (46.9 and 40.9 mm for the young and old orchards, respectively) was available to maintain the normal growth of the apple trees in July. Soil desiccation in this region is due to the excessive consumption of water in the deep soil layer by artificial vegetation and a long-term insufficient supply of precipitation [28]; accurate quantification of ΔSWS is important for explaining the occurrence of soil desiccation. Our results suggest that the maximum supply of water from soil reservoirs at a daily cumulative rather than a monthly or annual scale would more suitably represent the maximum contribution and ability of the soil to supply water for consumption by the orchards.

The maximum supply of water from soil reservoirs at the daily cumulative scale for the young and old orchards ranged from 42.5 to 134.3 and 55.8 to 150.4 mm, respectively, and these values clearly represented the maximum supply and deficit of water in the soil profile. Water stored in deep soil is extracted and used by roots, so SWS for the orchards would likely decrease. SWS generally increases only in wet years and decreases in drought and normal years [31]. For apple trees, the growth age to sustain a certain yield is usually 30 years, so a dried soil layer begins to develop in the soil profile as the trees age [30]. Wang et al. [23] found that the thickness of dried soil layers increased as the apple orchard aged in the order of: traditional cropland < 5-years old < 12 years old < 18 years old. Long-term desiccation can negatively affect both hydrological conditions and the sustainable development of apple production [5]. Appropriate management practices, such as renewal pruning [67] and the fostering of self-sown grass [68], should be considered in an economic apple forest to reduce undesirable water consumption and improve soil water conditions and thus improve sustainability. Li [69] divided soil desiccation into temporary type and permanent type. The thickness of temporary soil desiccation often varies with the change of rainfall and vegetation [70]. Daily cumulative ΔSWS for the 8- and 18-year-old orchards in our study ranged from −134.3 to 58.5 and −150.4 to 33.1, respectively. Compared with ΔSWS at a monthly and annual scale, the dynamics of daily cumulative ΔSWS in the two orchards would provide more valuable information for understanding changes in dried soil layer thickness.

5. Conclusions

ET was consistently lower for the 8- than the 18-year-old orchard at the same scale. Trends of the changes in daily cumulative, monthly, and annual SWS for both orchards were similar in each year but differed between the orchards at all scales. The maximum supplies of water from soil reservoirs for the two orchards differed at multiple scales in each year. During the past four years, the maximum supplies of water from soil reservoirs for the young and old orchards was from 45.0 to 134.3 and 55.8 to 150.4 mm, respectively. The supply of water from soil reservoirs for both orchards was highest at a daily cumulative scale in 2013, 2014, and 2016, so this scale should be more suitable for representing the actual contribution of soil to supply water for consumption in apple orchards and for identifying water deficits in soil reservoirs. Studying ΔSWS at a daily cumulative scale in apple orchards is thus important for exploring the maximum contribution of the soil reservoir on the Loess Plateau or in areas with similar climatic conditions.

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