Changes in Deep Soil Water Content in the Process of Large-Scale Apple Tree Planting on the Loess Tableland of China

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Abstract: Soil water has become a major limiting factor in agriculture and forestry development on the Loess Plateau of China. In the past 20–30 years, large areas of apple orchards have been built in this region, which have resulted in excessive consumption of deep soil water and soil desiccation. To evaluate the effects of orchard development on deep soil water content (SWC), a meta-analysis of 162 sampling sites on the loess tableland from 44 peer-reviewed publications was conducted in this study. The results showed that the deep SWC in orchards depended on stand age, planting density and annual precipitation. In regions with 550–600 mm precipitation, the orchard with lower planting density showed no soil desiccation in young and early fruiting stages, while deep soil (>2 m) desiccation occurred in full fruiting and old orchards. The effect of planting density on deep SWC varied with stand age. There were significant differences in SWC among different planting densities in early fruiting orchards (p < 0.05), in which soil desiccation occurred in orchards with higher planting density. However, with the continuous consumption of soil water by apple trees, deep soil desiccation occurred in old orchards regardless of planting density. Further, affected by the spatial variation of annual precipitation, deep SWC in orchards significantly decreased with annual precipitation from 650 to 500 mm among the 44 study sites (p < 0.05). Our results suggest that the planting density should be reasonably regulated on the level of annual precipitation, and apple trees need to be pruned appropriately with a goal of moderate productivity, so as to achieve the sustainable use of regional water resources, food security and economic development.

Keywords: deep soil; soil water content; apple orchard; soil desiccation; Loess Plateau

1. Introduction

Soil water plays an important role in agricultural production and vegetation growth in dryland farming areas [1–4]. The Chinese Loess Plateau is a typical dryland farming region with abundant sunshine and large diurnal temperature variation, which makes it one of the main apple planting areas in the world [5]. In 2017, the area and yield of apple orchard accounted for 25% and 27% of the world, respectively [6]. However, the limited precipitation usually cannot meet the water demand of apple trees in this region, and plant growth is heavily dependent on the deep soil water storage [7]. Therefore, large areas of orchard planting in this area have resulted in an imbalance in water supply and demand, increasing soil desiccation and hindering the sustainable development of apple orchards [8,9]. Understanding the depletion of deep soil water and its influencing factors in apple orchards can provide a theoretical basis for sustainable water resource management and fruit production.
Studies worldwide have shown that vegetation type is one of the important factors affecting soil water content (SWC) [10–12]. For example, a large area of revegetation in the Loess Plateau severely depleted regional soil water [10], decreased the ratio of runoff to annual precipitation [13] and even resulted in soil desiccation [14,15], which has also been found in the eastern Amazon and southern Australia [16,17]. Since the 1990s, driven by the policy of “Grain for Green” and the need for economic benefits, large areas of cropland have been converted to apple orchards in the Loess Plateau [18]. However, most regions in the Loess Plateau are considered typical rain-fed areas; agricultural production entirely depends on natural precipitation without irrigation [3,19]. Soil water is the primary factor that restricts the sustainable development of apple production in this region [20]. Compared with cropland under similar conditions, apple trees have high water consumption [21], which results in decreasing SWC as trees grow [22]. Therefore, a rapid development of apple orchards may cause a higher consumption of deep soil water [7], which further enhances soil desiccation [8,18]. Soil desiccation has a negative impact on regional ecological and hydrological processes, such as soil quality degradation, poor vegetation growth and even a decrease in groundwater level [23–25].

A large number of studies have shown that the soil desiccation in the Loess Plateau has been widely distributed in artificial vegetation [15,23,26]. Because of the negative effects of soil desiccation on regional environment, numerous studies have explored the characteristics of SWC in apple orchards based on some in-situ SWC measurements across the Loess Plateau [3,8,20,27]. For example, previous studies have shown that SWC in the 0–2 m soil layer varied greatly due to the effect of precipitation and root absorption for water, while SWC in deep soil (depth > 2 m) was relatively stable during a year [7,12]. The evapotranspiration in a full fruiting orchard during the growing season (May to October) in 2014 was reportedly 610 mm, which was about 1.3 times higher than the precipitation in the same period [21,28]. Further, it was demonstrated that the roots of apple trees in the Loess Plateau could reach to 22.8 m, which extracted soil water from soils as deep as 25 m [7]. Due to the difference in water consumption in different growth stages, the stand age of apple orchards is one of the main factors affecting SWC [8,20,21,25]. A recent study on the Loess Plateau showed that it needs more than 26 years to recover the depleted soil water storage after the deforestation of apple trees [22]. Specifically, the deep SWC in apple orchards was similar to that in annual cropping fields during the early stage of planting, then gradually decreased with an increase in stand age [7,21,29]. Previous studies reported that mean SWC within the 0–18 m soil layer in a fruitful orchard accounted for about 75% of the farmland in the same depth [8]. It has been found that the SWC in orchards with lower planting density was larger than that in orchards with higher planting density [20,30]. Thus, the consumption of deep soil water in apple orchards is affected by many factors such as stand age, productivity level (which is related to the planting density) and climate conditions.

Although many studies have explored the SWC in apple orchards, these studies were usually carried out based on individual measurements or scattered sites [7,8,18,20]. Consider the limitation of the small scale of SWC sampling sites, changes in the deep SWC during apple orchard development at the regional scale have not been systematically studied. Further, few studies took into account the stand age, the planting density and the spatial heterogeneity of precipitation in the changes in SWC. Accordingly, we conducted a meta-analysis to quantify the effects of the large-scale expansion of apple orchards on deep soil water across the loess tableland in this study. The objectives of this study were to (1) quantify the depletion of deep soil water in apple orchards in the loess tableland and (2) explore the potential factors that affect the dynamics of SWC in apple orchards. The results could provide some basis for the sustainable utilization of soil water resources and management of rain-fed apple orchards in this region.
2. Materials and Methods

2.1. Description of the Study Area

The Loess Plateau of China covers an area of $6.4 \times 10^5$ km$^2$, which is located in the upper and middle reaches of the Yellow River (Figure 1). The main geomorphic types are ridge, hill, tableland and gully, with an elevation of 800–2000 m above sea level [31]. The tableland is flat with insignificant runoff and was cut deeply by the surrounding gullies [32]. Soils are typically developed from the loess deposits. The area is characterized by a continental monsoon climate, and 60%–70% of the precipitation falls in June to September [33]. The depth to the groundwater table ranges from 30 to 80 m [34], and agricultural production mainly depends on precipitation without irrigation.

Figure 1. Distribution of sampling sites in the study area.

2.2. Data Collection

All of the available peer-reviewed publications were used to gather the data of SWC in apple orchards on the Loess Plateau up to June 2019. Literature searches were performed using the online databases of Web of Science (http://apps.webofknowledge.com/) and the China National Knowledge Infrastructure databases (http://www.cnki.net/) with the search terms “soil water” or “soil moisture”, “apple orchard” and “Loess Plateau”. To focus on the research objectives of the meta-analysis listed in Section 1, the following criteria were used to select publications: (a) the study sites were located on a flat tableland, and the orchards were rain-fed without any irrigation; (b) the characteristics of orchards including location, planting density, stand age, mean annual precipitation (MAP) and soil field capacity were clearly given; (c) SWC was determined from various depths, and the measured depths should be more than 5 m; (d) SWC data could be either obtained from tables or extracted from graphs using the GetData Graph Digitizer (version 2.24, Russian Federation, http://getdata-graph-digitizer.com).

According to the selected criteria, a total of 162 sampling sites from 44 published studies were retrieved, including 805 observations (Figure 1, Table S1). The SWCs were measured by oven-drying, neutron probe, or time domain reflectometry (TDR) sensors in the collected publications. Apple trees usually start to bear fruit at about 6 years old, reach their highest yield levels around 15 years old and show a gradual decline in yield after 20 years old. Therefore, the orchards were divided into four subgroups based on their stand...
ages as follows: young (<8 years), early fruiting (8–12 years), full fruiting (13–20 years) and old (>20 years) orchards. Based on the collected data in this study, the planting density of apple orchards ranged from 416 to 1666 trees/ha, with a mean value of 870 trees/ha. The orchards were also divided into four subgroups based on the planting density as follows: <500 trees/ha, 500–1000 trees/ha, 1001–1500 trees/ha and >1500 trees/ha. Over the past several decades, although the annual precipitation and annual mean air temperature fluctuated year by year, changes in average precipitation over four or five consecutive years were small [7]. As previous studies demonstrated, the mean annual precipitation (ranging from 503 to 622 mm) can represent the level of precipitation over a long period of time [33], which was roughly divided into three precipitation regions: 500–550 mm, 550–600 mm and 600–650 mm. Detailed information about the collected sampling sites is shown in Table 1.

Table 1. Basic information about the collected sampling sites in this study.

| Basic Information                      | Values           |
|----------------------------------------|------------------|
| Number of publications                 | 44               |
| Number of sampling sites               | 162              |
| Longitude (°E)                         | 101.63–109.75    |
| Latitude (°N)                          | 34.02–36.20      |
| Mean annual precipitation (mm)         | 503–622          |
| Air temperature (°C)                   | 8.3–13.5         |
| Stand age (years)                      | 3–37             |
| Planting density (trees/ha)            | 416–1666         |
| Field capacity (%)                     | 20.2–23.0        |
| Measured depth (m)                     | 5.0–23.2         |

2.3. Data Analysis

A dried soil layer is a hydrological phenomenon occurring in the soil profile below the rainfall infiltration layer, which results from the excessive depletion of deep soil water by plants, and shortage of rainwater in the long term [35]. The widely accepted range of SWC in the dried soil layer is from the permanent wilting point to stable field capacity (upper limit) [23,36]. Generally, 60% of field capacity is considered to be equivalent to stable capacity in the Loess Plateau, i.e., soil desiccation occurred as the SWC was lower than 60% of the field capacity [15,26]. Taking into consideration the differences in field capacity due to soil texture variations in different regions [14], to make the SWC from different regions comparable, the response ratio ($R$) was used in current study, as shown in Equation (1):

$$ R = \frac{X_e}{X_c} - 1 $$(1)

where $X_e$ and $X_c$ are the observed SWC and 60% of the field capacity, respectively. A negative $R$ value stands for soil desiccation.

To maximize the number of observations included in the present analysis, an unweighted meta-analysis was used in this study [10,37]. The mean response ratio for each categorical subdivision was quantified and the standard error of the response ratio ($SE_R$) was calculated as follows:

$$ SE_R = \sqrt{\frac{V_R}{N}} $$

where $V_R$ and $N$ are the variance in the response ratio and the number of observations, respectively. Next, according to a method described in [38], the 95% confidence interval (95% CI) of the mean response ratio was calculated for each category, i.e., $95\% \text{ CI} = 1.96 \times SE_R$. The observed response ratios were considered significantly different from zero if the 95% CI did not overlap with zero ($p < 0.05$).
2.4. Statistical Analysis

A one-way analysis of variance (ANOVA) was used to determine the effects of stand age, planting density and MAP on deep SWC. Post-hoc tests were performed using Tukey’s LSD method with a significance level of 0.05. A regression analysis was used to investigate the relationships among response ratio, mean annual precipitation and stand age. All statistical analyses were conducted using SPSS 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Vertical Distribution of SWC in Apple Orchards

Based on the data collected in this study, we first analyzed the vertical distribution of SWC in orchards with different stand ages (Figure 2). All the orchards were in the same region, with a MAP of 584 mm and planting density of 833 trees/ha. As can be seen from Figure 2, the SWC in orchards with different ages showed significant differences along the profile. The SWC in the four stand ages was similar in the 0–2 m soil depth. The SWC in full fruiting and old orchards decreased with increasing depth and reached a stable value of around 13% in the 2–13 m soil layer, and the SWC was lower than that in the young and early fruiting orchards. Specifically, in the layer of 2–5 m depth, the SWC in the old orchards was higher than that of full fruiting orchards. For the 13–20 m soil layer, the differences in SWC among the four orchard ages were smaller than that in the 2–13 m soil layer. Overall, the SWC in orchards with different ages varied along the soil profile, among which old orchards had the lowest SWC, with a mean value of 15.8%.

Figure 2. Vertical distribution of soil water content in orchards with different growth stages. The soil water content is the mean value of collected sampling sites, and the number of samples varied with depth due to the differences in measured depth at each sampling site. Error bars represent standard deviations.

3.2. Effects of Stand Age on SWC

The effects of stand age on SWC in apple orchards are shown in Figure 3, and all the orchards were in the same subgroup of planting density (500–1000 trees/ha) and
precipitation (550–600 mm). The SWC in orchards with different ages showed significant differences \((p < 0.05, \text{Figure 3})\). The response ratios of the 0–5 m soil layer in young and early fruiting orchards were 0.32 and 0.25, respectively, indicating that no soil desiccation occurred in these orchards. Additionally, the response ratios of SWC in the 2–5 m soil layer in young and early fruiting orchards were significantly higher than those in full fruiting and old orchards \((p < 0.05)\). For the full fruiting orchard, the response ratio in the 4–5 m soil layer was \(-0.02\). Although the response ratio of SWC in the 3–5 m soil layer in old orchards was less than zero, there was no significant difference between the full fruiting and old orchards.

![Figure 3](image_url)

**Figure 3.** Response ratio of soil water content in orchards with different growth stages. The block with the error bar indicates the mean response ratio with 95% CI, the sample size of each variable is noted in parentheses. Different lowercase letters indicate significant differences in orchards with different ages \((p < 0.05)\). The black symbols represent significant differences \((p < 0.05)\) between the response ratios and zero.

The relationship between the response ratio of SWC and the stand age of apple orchards in different soil layers was analyzed further (Figure 4). There was no significant correlation between the response ratio and stand age in the 1–3 m soil layers \((p > 0.05)\). As depth increased, the response ratio in apple orchards displayed significantly negative correlations with stand age in the 3–5 m soil layers \((p < 0.01)\). Overall, the response ratio of SWC in deep soil layers decreased with increasing tree age in the young, early fruiting, and full fruiting apple orchards (i.e., 0 to 20 years old), especially in the 4–5 m soil layer \((R^2 = 0.45, p < 0.01)\). As trees grew, the decline rate of response ratio was getting smaller in old apple orchards (> 20 years old), even close to zero.
3.3. SWC in Different Planting Density Orchards

The effects of planting density on SWC varied with stand age and soil depth (Figure 5). In the 0–1 m soil layer, response ratios in early fruiting and old orchards were significantly higher than zero, and there was no significant difference between the two planting densities. For the deep 2–5 m soil layer, response ratios in early fruiting orchards showed a significant difference between the two planting densities (\(p < 0.05\)). Specifically, response ratios in the orchards with a low planting density ranged from 0.18 to 0.37, while response ratios in the high planting density orchards were lower than zero, ranging from \(-0.09\) to \(-0.07\) (Figure 5a). However, the response ratios below 3 m depth in old orchards were all negative without significant differences between the two planting densities, indicating that soil desiccation occurred in these old orchards regardless of the difference in the planting density (Figure 5b), while the soil desiccation only occurred in the early fruiting orchards with a high planting density (Figure 5a).

3.4. Changes of SWC in Different Precipitation Regions

For orchards with the same subgroup of planting density and stand age, the response ratio of SWC in different precipitation regions varied with soil depth (Figure 6). In the 0–2 m soil layer, the response ratios of SWC in the different precipitation regions showed no significant difference (Figure 6a,b), while the response ratios in the 2–5 m soil layer showed significant differences among the three precipitation regions (\(p < 0.05\)). Specifically, the response ratio of SWC in the regions with 600–650 mm annual precipitation ranged from 0.07 to 0.17, which was significantly higher than that in the regions with 500–550 mm annual precipitation (\(p < 0.05\)). The response ratio in regions with 500–550 mm annual precipitation ranged from \(-0.23\) to \(-0.13\), indicating that soil desiccation occurred in the 2–5 m soil layer.
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Figure 5. Effects of orchard planting density on SWC in different soil layers. The block with the error bar indicates the mean response ratio with 95% CI; the sample size of each variable is shown to the right of the figure. The black symbols represent significant differences (p < 0.05) between the response ratios and zero, * and ** indicate significant differences at p < 0.05 and p < 0.01, respectively. (a) Low planting density: 500–1000 trees/ha; (b) high planting density: 1000–1500 trees/ha.

Furthermore, linear fitting results showed that response ratio in the 0–2 m soil layer had no significant correlation with MAP, while a significant positive correlation between response ratio and MAP was exhibited in the deep 2–5 m soil layer (Figure 7). Affected by the spatial variation of annual precipitation, the deep SWC in apple orchards significantly increased with annual precipitation from 500 to 650 mm (p < 0.05, Figure 7).

Figure 6. Response ratio of SWC in different precipitation regions (a–f). The block with the error bar indicates the mean response ratio with 95% CI; the sample size of each variable is noted in the parenthesis. Different lowercase letters indicate significant differences in different precipitation regions (p < 0.05). The black symbols represent significant differences (p < 0.05) between the response ratios and zero.
Figure 7. Relationship between response ratio and mean annual precipitation (MAP) for different soil layers (a–f).

4. Discussion

4.1. Deep Soil Water Depletion in Apple Orchards

Soil water plays an important role in agricultural production and vegetation restoration, especially in dryland farming regions. The occurrence of soil desiccation is a result of excessive depletion of deep soil water and insufficient recharge by precipitation over the long term [23, 26, 35, 39], which is influenced by many factors, such as vegetation type, stand age and precipitation amount [2, 11, 26, 40]. In the current study, all sampling sites were located on flat terrain, which was covered by thick loess–paleosol layers (30–80 m), and the tableland was cut deeply by the surrounding gullies, even to a depth of 200 m [32]. Thus, the rivers made no contribution to the changes in SWC on the loess tableland, and the effect of groundwater on SWC was also negligible because of the deep groundwater table (>30 m below the surface). As the soil water consumption of plants generally depends on the vegetation type, revegetation could greatly affect the distribution of SWC [10, 41, 42]. Compared with crops, apple trees usually consume more soil water [25]. A rapid development of apple orchards would decrease SWC in deep soils and further exacerbate the regional soil water deficit [8, 22, 43], and subsequently affect regional water cycle and groundwater recharge [18, 25]. Therefore, understanding the soil desiccation in apple orchards is crucial for management of regional water resources and sustainable development of apple orchards.

Although numerous studies have been conducted on the SWC in apple orchards on the Loess Plateau [7, 8, 20, 29, 44], few investigations reached the lower limit of soil desiccation depth [43, 44], which may underestimate the severity of deep soil desiccation. Actually, apple trees could extract deep soil water at a depth of 20 m for their growth (Figure 2), and the depletion of soil water was far greater than the replenishment due to the limited precipitation, which caused a continuous decrease of SWC, especially in the deep soils where infiltrated precipitation could not reach [7, 45]. Previous studies have shown that the roots of 22- and 26-year-old apple trees in this area reached 18.0 and 23.2 m, respectively [7, 25]. In the literature, it has been demonstrated that the SWC was strongly correlated with root systems as plant roots regulate their water absorption function to accommodate soil water environments [7, 46]. According to 162 sampling sites at different spatial scales on the loess tableland, this study revealed that the rapid development of
apple orchards caused deep soil desiccation in the Loess Plateau, and such impact varied with stand age, planting density and annual precipitation.

4.2. Factors Affecting SWC in Apple Orchards

In this study, the SWC in the 0–2 m soil layer showed no significant differences among different stand ages, planting densities and precipitation amounts. This could be explained by the influence of rainfall, plant transpiration and surface evaporation [12,43]. The SWC in the shallow soil layer fluctuated greatly, while SWC below 2 m depth exhibited weak temporal variation during the growing season [7,12,19]. The SWC significantly decreased with an increase of tree age, and the SWC in orchards with different ages showed significant differences, indicating the effect of stand age on deep SWC [7]. In the early stage of orchard planting, precipitation and shallow soil water storage can basically meet the water demand from the normal growth of young orchards [21]. Related studies showed that a 7-year-old tree’s transpiration from May to September was about 340 mm [28], thus no soil desiccation occurred in young orchards and a portion of precipitation actually percolated into deep soils [22]. However, as leaf area index and biomass increased with stand age, limited precipitation and shallow soil water could not meet the water demand of plant growth, and apple trees need to consume more soil water [47]. For example, a study from the Loess Plateau reported that the water consumption of a 15-year-old apple orchard was 675 mm, which was higher than the annual precipitation in this region [48]; this likely stimulated apple trees to extract soil water at greater depths [7,46], which resulted in a decrease in deep SWC and soil desiccation [8,20]. As trees get older, some individual studies showed that the SWCs in the deep 4–5 m soil layer were higher than that of young apple orchards (Figure 4), which is also shown in Figure 2. This can be attributed to the relatively lower water consumption and continuous recharge of precipitation, which promoted the increase in SWC in old orchards [22]. Although both the production capacity and water demand of apple trees decreased with increasing stand age in old orchards, due to the large amount of soil water consumed in the early growth stage, and because the recharge of precipitation to groundwater is relatively limited [29,49], the SWC in old orchards was still low but showed no significant difference from that in the full fruiting orchards (Figure 3).

Additionally, orchard planting density could affect SWC [20,30], because plant water demand depends on many factors, such as vegetation type, leaf area index and biomass [21,50]. For orchards with the same area, an orchard with a high planting density produced higher evapotranspiration and water consumption, thus leading to more serious soil desiccation [20,29]. Furthermore, annual precipitation should also be considered for the understanding of soil drought research in this region [26]. As previous studies reported, the SWC in the shallow 0–2 m soil layer fluctuated greatly due to the influence of infiltration and evapotranspiration [7,12]. In the current study, there was no significant correlation between the response ratio of SWC and precipitation in the shallow soil layers (Figure 7), which further confirmed the previous findings [12]. Thus, the relatively high SWC in the 0–1 m soil layer in several old orchards can be explained by the recharge of precipitation (Table S1). In line with previous studies [15,29], the response ratios in the deep soil layer increased with MAP, and the response ratio in orchards showed significant differences among different precipitation regions (Figure 7), indicating that precipitation is also one of the dominant factors affecting SWC. In the current study, all apple orchards were rain-fed without any irrigation; the SWC in the orchards with higher precipitation was greater than that in the orchards with lower precipitation [26].

4.3. Implications for Orchard Management

Due to the negative effects of soil desiccation in apple orchards on land productivity and the soil water environment over the long term, the planting density should be reasonably regulated according to the precipitation [21,22]. Previous studies have demonstrated that the sub-humid region could not sustain a productive aged orchard [22]. In this region, since the deep soil water deficit cannot be recharged in a wet year as it does in humid
regions [51,52], the deep soil water reservoirs cannot continuously provide water for apple trees (Figure 4). Thus, old apple orchards should be properly thinned. As reported in previous studies, soil desiccation could be alleviated after orchard thinning [20]. Therefore, reducing planting density could be an effective way to increase deep SWC in apple orchards [30]. Additionally, renewal pruning, and flower and fruit thinning can adjust and reduce the water transpiration rate, thus improving the soil water conditions, and also stabilizing and even increasing apple yields. Such orchard management experiences have been confirmed in previous studies [9,30,53,54]. Further, a study from the Loess Plateau reported a replenishment of deep soil water when apple trees have been replaced by annual crops [22], which is also an effective approach to improve soil water conditions in apple orchards. Overall, management practices should be carefully considered when planning revegetation initiatives involving apple trees, which will also promote the sustainable and healthy development of the agricultural ecosystem in the Loess Plateau.

5. Conclusions

This study analyzed the depletion of deep soil water in apple orchards and its influencing factors using 162 sampling sites conducted on the loess tableland. Large-scale apple orchard expansion led to deep soil desiccation, which varied with stand age, planting density and annual precipitation. Affected by the spatial variation of annual precipitation, the deep SWC in orchards significantly decreased with annual precipitation from 650 to 500 mm ($p < 0.05$). Stand age has a significant impact on deep SWC, and the effect of planting density on SWC varied with stand age. Our results suggest that the relationship between fruit productivity and soil water should be coordinated and planting density should be regulated according to the local climate conditions. Furthermore, a reasonable management technique such as renewal pruning, and flower, fruit and tree thinning should be applied to apple orchards, so as to achieve the sustainable use of regional water resources, food security and economic development in the Loess Plateau.

Supplementary Materials: The following are available online at https://www.mdpi.com/1999-4907/12/2/123/s1. Table S1: Basic information of the available peer-reviewed publications in this study.

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References
1. Gao, X.D.; Li, H.C.; Zhao, X.N.; Ma, W.; Wu, P.T. Identifying a suitable revegetation technique for soil restoration on water-limited and degraded land: Considering both deep soil moisture deficit and soil organic carbon sequestration. *Geoderma* 2018, 319, 61–69. [CrossRef]
2. Liu, Y.; Zhao, W.; Wang, L.; Zhang, X.; Daryanto, S.; Fang, X. Spatial variations of soil moisture under Caragana korshinskii Kom. from different precipitation zones: Field based analysis in the Loess Plateau, China. *Forests* 2016, 7, 31. [CrossRef]
3. Mu, Y.; Wang, D.; Wang, Y.P. Importance of temporal scale in assessing changes in soil-water storage in apple orchards on the Chinese Loess Plateau. *Forests* 2020, 11, 793. [CrossRef]
4. Zweifel, R.; Zimmermann, L.; Newbery, D.M. Modeling tree water deficit from microclimate: An approach to quantifying drought stress. *Tree Physiol.* 2005, 25, 147–156. [CrossRef] [PubMed]
34. Zhu, X.M.; Li, Y.S.; Peng, X.L.; Zhang, S.G. Soils of the loess region in China. Geoderma 1983, 29, 237–255.
35. Li, Y.S. The properties of water cycle in soil and their effect on water cycle for land in the Loess Plateau. Acta Ecol. Sin. 1983, 3, 91–101.
36. Wang, L.; Wang, Q.J.; Wei, S.P.; Shao, M.A.; Yi, L. Soil desiccation for Loess soils on natural and regrown areas. For. Ecol. Manag. 2008, 255, 2467–2477. [CrossRef]
37. Powers, J.S.; Corre, M.D.; Twine, T.E.; Edzo, V. Geographic bias of field observations of soil carbon stocks with tropical land-use changes precludes spatial extrapolation. Proc. Natl. Acad. Sci. USA 2011, 108, 6318–6322. [CrossRef] [PubMed]
38. Luo, Y.; Hui, D.; Zhang, D. Elevated CO₂ stimulates net accumulations of carbon and nitrogen in land ecosystems: A meta-analysis. Ecology 2006, 87, 53–63. [CrossRef]
39. Jipp, P.H.; Nepstad, D.C.; Cassel, D.K.; Carvalho, C.R.D. Deep Soil Moisture Storage and Transpiration in Forests and Pastures of Seasonally-Dry Amazonia. Clim. Chang. 1998, 39, 395–412. [CrossRef]
40. Esteban Lucas-Borja, M.; Zema, D.A.; Antonio Plaza-Alvarez, P.; Zupanc, V.; Baartman, J.; Sagra, J.; Gonzalez-Romero, J.; Moya, D.; de las Heras, J. Effects of different land uses (abandoned farmland, intensive agriculture and forest) on soil hydrological properties in Southern Spain. Water 2019, 11, 503. [CrossRef]
41. Liu, Z.J.; Ma, P.Y.; Zhai, B.N.; Zhou, J.B. Soil moisture decline and residual nitrate accumulation after converting cropland to apple orchard in a semiarid region: Evidence from the Loess Plateau. Catena 2019, 181, 104080. [CrossRef]