agronomy

MDPI

Article

Effects of Planting Practices on Soil Organic Carbon during Old Apple Orchards' Reconstruction on the Loess Plateau

Wenzheng Li [1,2], Jianen Gao [1,2,3,4,*], Yuanyuan Zhang [2,3], Rafiq Ahmad [1,2], Zhe Gao [5] and Fanfan Zhou [2,6]

1 Institute of Soil and Water Conservation, Northwest Agriculture and Forestry University, Yangling, Xianyang 712100, China
2 Water and Soil Conservation Ecological Engineering Technology Research Center, Ministry of Water Resources, Yangling, Xianyang 712100, China
3 Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Xianyang 712100, China
4 The Research Center of Soil and Water Conservation and Ecological Environment, Chinese Academy of Sciences and Ministry of Education, Yangling, Xianyang 712100, China
5 College of Water Resources and Construction Engineering, Northwest Agriculture and Forestry University, Yangling, Xianyang 712100, China
6 Pingluo County Water Affairs Bureau, Pingluo, Shizuishan 753400, China
* Correspondence: gaojianen@ms.iswc.ac.cn; Tel.: +86-133-5924-8788

Abstract: Changes in the soil organic matter are related to the land-use change of sustainable agricultural production. However, few studies have been reported on the effects of changes in planting practices on SOC during the reconstruction period of old apple orchards. In this study, 4 treatments were applied during the reconstruction period of old apple orchards (more than 20 years old) on the Loess Plateau: thinning and replanted apple saplings (TR); all felled and planted corn (CR); all felled and planted millet (MT); all felled and planted potato (PT). It was found that: SOC was ranked as MT > PT > CR > TR, and decreased with soil depth, obeying the power function law; this first decreased and then increased, with the lowest ranking of the year being obtained in August in a year; MT was the most effective in increasing SOC, with an average annual growth rate of 0.54 g/(kg·year). In this study, the complex relationship between rainfall, temperature, solar radiation, soil moisture content, and soil organic carbon was established. The results not only provide a reference for the reconstruction of old apple orchards, but also provide support for sustainable agricultural production in the fragile ecological zone of the Loess Plateau.

Keywords: planting practices; soil organic carbon; old orchard; Loess Plateau

Citation: Li, W.; Gao, J.; Zhang, Y.; Ahmad, R.; Gao, Z.; Zhou, F. Effects of Planting Practices on Soil Organic Carbon during Old Apple Orchards' Reconstruction on the Loess Plateau. *Agronomy* **2023**, *13*, 897. https://doi.org/10.3390/agronomy13030897

Academic Editor: Hailin Zhang

Received: 10 February 2023
Revised: 1 March 2023
Accepted: 15 March 2023
Published: 17 March 2023

1. Introduction

About 1500 Gt (1 Gt = 10^9 t) of global terrestrial carbon is stored in soil (1 m soil depth), which is 3 times the vegetation carbon pool and more than twice the atmospheric carbon pool. This amount of organic carbon is the material basis of soil fertility, and its concentration changes are related to sustainable agricultural production. Land-use change is an important factor affecting soil organic carbon (SOC) [1,2]. As a cash crop, apples have been planted on 4.95 million ha worldwide according to FAOSTAT, and play an extremely important role in the global fruit industry. The reconstruction of old orchards is crucial to the sustainable development of the apple industry, and different planting practices during the reconstruction of old orchards lead to land-use changes, which in turn affect SOC changes. The study of the effect of planting practices on SOC during the rebuilding period of old apple orchards can not only guide the rebuilding of old apple orchards, but also relate to the sustainable agricultural production.

The Loess Plateau is an important apple ecoregion, with 1.22 million ha of planted apples area accounting for 58% of the planted area in China and 25% of the global planted area according to the China Statistical Yearbook. However, about 85% of apple orchards on the Loess Plateau are more than 20 years old, and apple trees show degradation and decline in yield and quality with increasing growth age [3–7], and large-scale old orchards face reconstruction. The study of the effects of planting practices on SOC during the reconstruction period of old orchards in this region can not only provide a reference for the reconstruction of old apple orchards in other regions, but also has important implications for the sustainable agricultural production of fragile ecological zones in the Loess Plateau.

Land-use patterns directly affect SOC [8–17]. There are significant differences in SOC among land-use practices, with grassland SOC being the highest, farmland and cropland SOC being the lowest, and forest SOC being the second highest [10,14,15]. Meanwhile, many scholars have also conducted studies on the changes in SOC after a land-use transformation occurred; the SOC increased significantly after the return of farmland to forest and grassland while it decreased significantly when the grassland and forest were reclaimed as cropland [16,17]. This is also well demonstrated by Laganiere (2010) [18], where the conversion of agricultural land to plantation forest increased SOC by 26%, and the average annual rate of soil carbon accumulation was 0.62 and 1.60 Mg/hm^2 in the process of returning farmland to grassland and secondary forest, respectively [19]. In addition, when agricultural land is converted to a land-use type with perennial vegetation, carbon losses due to decomposition and erosion can be reduced [16–18,20–22]. In contrast, when perennial vegetation is destroyed and converted to cropland, SOC is lost to the atmosphere by erosion and decomposition leads to an increase in atmospheric CO_2 [13,23–28]. The conversion of agricultural land to tree forest has a slower soil carbon sink rate compared to shrubland or grassland, but the soil has a greater capacity to sequester carbon [29–31]. The conversion of agricultural land to scrub or natural grassland is beneficial for SOC [32–36]. In summary, research on land use on SOC has mainly focused on typical land-use types, such as forest land, grassland, and cropland, and no research has reported on the effects of different planting practices on SOC during the reconstruction period of old orchards.

In this study, we selected the major apple production areas on the Loess Plateau as the experiment area and investigated the changes in SOC under four planting practices of old orchards during the reconstruction period, namely thinning and replanted saplings, and all felled and planted corn, millet or potato. The purpose of this study is to: (1) study the SOC distribution law of different planting practices in the reconstruction period of old apple orchards, (2) compare the SOC changes in different planting practices in the reconstruction period of old apple orchards, and (3) study the relationship between SOC and rainfall, temperature, solar radiation, and soil moisture content under different planting practices in the reconstruction period of old apple orchards on the Loess Plateau.

2. Materials and Methods

2.1. Experiment Area

The experiment area is located in Ansai County, Yan'an City, in the middle of the Loess Plateau (108°50′–109°26′ E, 36°30′–37°19′ N) (Figure 1). The landscape belongs to the Loess Hills and gullies area, with an elevation of 1012.1~1731.7 m, an average temperature of 8.8 °C, an average annual rainfall of about 480 mm, and a medium temperate zone. The area has a continental semi-arid monsoon climate which is characterized by the varying length of the four seasons, dry and wet, concentrated rainfall, more rain from July to September, quick temperature changes in spring and autumn, and dry winters with less rainfall. The soil is mainly yellow loam, a typical silt loam soil. The soil capacity is about 1.28 g/cm^3 with a pH of 8.26. The soil constitutes 63.04% powder particles, 16.82% clay particles, and 20.14% sand particles.

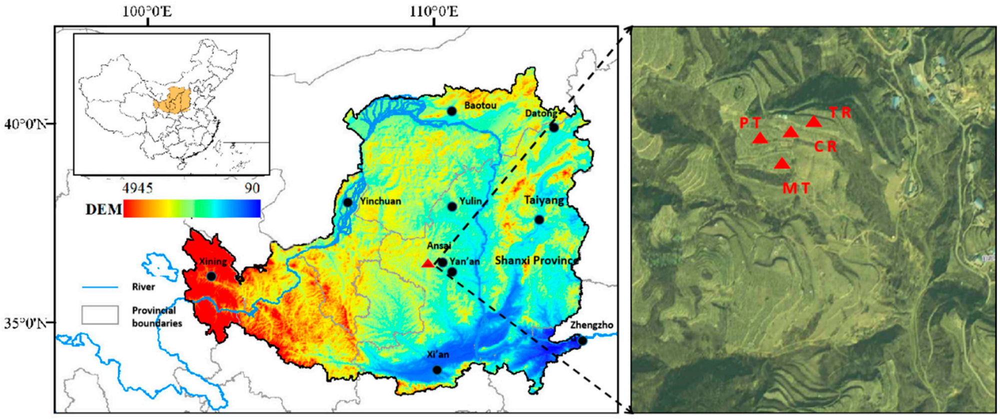

Figure 1. Location of the experimental area. The red triangle symbols with red labels represent sample plots. (Note: thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

2.2. Experiment Design

Apple cultivation in the experimental area is more than 25 years old, and orchard aging is common. In 2019, the reconstruction of old apple orchards was carried out. Four different treatments were established according to planting practices during the reconstruction period of old orchards. The four different treatments were: thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT). A brief diagram of the experimental design is presented in Figure 2. In the TR treatment, apple tree seedlings were planted in April at a spacing of 3 m between plants and 4.5 m between rows, with a planting density of 750 plants per ha. In treatment 1, corn was sown in April at a planting density of 67,500 plants per ha using machine seeding at a depth of 5–7 cm. In the MT treatment, millet was planted in April with a millet seeding rate of 15 kg/ha, sown by hand to a depth of 3–5 cm again. In the PT treatment, potatoes were planted in April at a planting density of 60,000 plants per ha, with a plant spacing of 30 cm and a row spacing of 55 cm. Commonly used fertilizers by farmers in the area were selected: urea (46% N), calcium superphosphate (15% P_2O_5), and potassium sulfate (51% K_2O). Each treatment was fertilized with 600 kg/ha per year ($N:P_2O_5:K_2O$ = 3:2:3) and tilled once a year in spring. Fertilizer and seeding was applied during tilling, which is commonly adopted in the study area. All other farm operations were according to traditional farming methods.

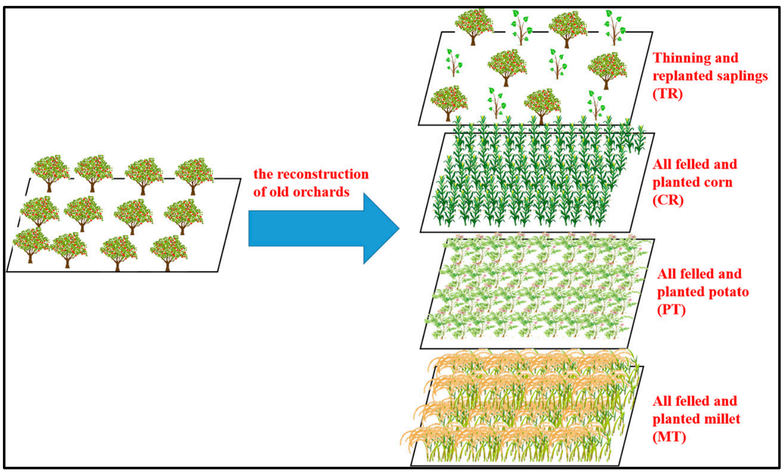

Figure 2. Schematic diagram of the experimental design. (Note: thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

2.3. Soil Sampling

The plot areas of the TR, CR, PT, and MT treatment plots were 0.21, 0.23, 0.25, and 0.16 ha, respectively. According to the characteristics of the sample plots and considering the representativeness of the sample point distribution, three 1 m × 1 m sampling areas were set up in each sample plot, and each soil sample was taken within the sampling area. The soil organic carbon of the Loess Plateau tends to stabilize below 100 cm. In agricultural land, soil organic carbon changes are mainly expressed in the depth of the tillage layer [19,37]. Soil samples were collected in April, June, August, October, and December of 2019, 2020, and 2021, respectively, according to the crop growth cycle. The soil samples of the same soil layer in the same place are mixed and bagged, and numbered and bagged with a 4 cm diameter soil auger to take 6 soil layers: 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm.

The distribution of SOC at different sample plots of the April 2019 soil samples is shown in Figure 3; the SOC and vertical distribution of different treatments are basically the same.

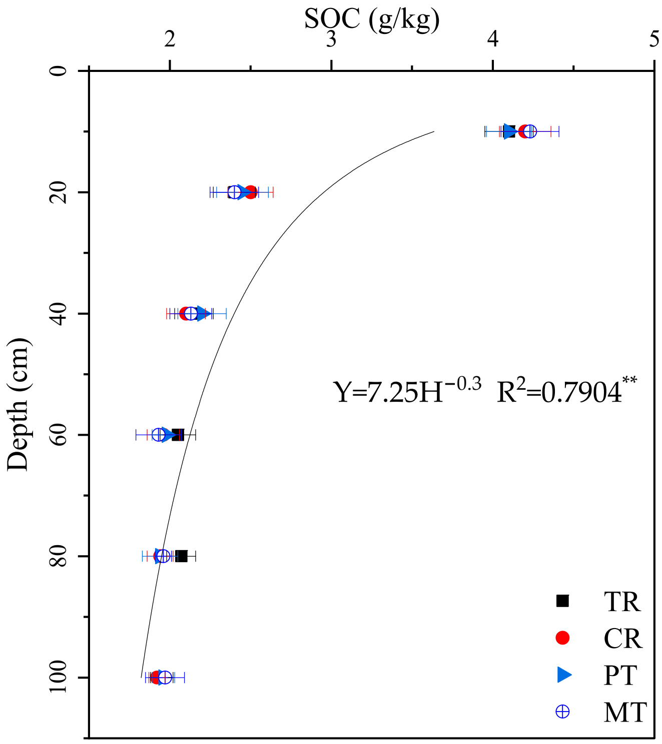

Figure 3. Vertical distribution of soil organic carbon (SOC) at different sample plots in April 2019. (Note: Y represents the soil organic carbon content; H represents the depth of soil layer. Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT), ** means significance $p < 0.01$).

2.4. Laboratory Analyses and Calculation

Soil samples were sieved at 0.5 mm, and soil bulk weight was determined by the ring-knife method. SOC was determined using the potassium dichromate volumetric method. Finally, the SOC (g/kg) for each sampling site was calculated using the following formulae:

$$\text{SOM} = \frac{(\text{V}_0 - \text{V})\text{N} \times 0.003 \times 1.724 \times 1.1}{\text{M}_\text{S}}$$

$$\text{SOC} = \frac{\text{SOM}}{1.724}$$

where SOM is soil organic matter (g/kg), SOC is soil organic carbon (g/kg), M_S is dried soil weight (g), V_0 is the amount of $FeSO_4$ consumed in the titration blank, V is the amount of $FeSO_4$ consumed in the titration sample, N is the equivalent concentration of $FeSO_4$, 0.003 is the gram of 1 mg equivalent carbon, and 1.1 is the correction coefficient.

Automatic soil moisture monitors and a weather station were deployed in the test area to record soil moisture content and meteorological changes. Soil moisture was measured using the dry method for calibration of the automatic soil moisture data that are monitored.

2.5. Data Analysis and Statistics

Basic statistical processing of the data was performed using Excel, and one-way ANOVA was performed using SPSS on soil indicators from different sites and profiles, and Origin 2023 was used for mapping.

3. Results

3.1. Characteristics of Monthly Rainfall, Solar Radiation, and Temperature

The monthly variation in rainfall, temperature, and solar radiation in the study area during the pilot study period 2019–2021 is shown in Figure 4. The rainfall distribution is uneven, with rainfall concentrated in July–September; the average monthly rainfall varies from 0 to 180 mm. The average monthly temperature varies from −6.5 to 26.5 °C, and the average monthly solar radiation varies from 185 to 687 MJ/m^2. Rainfall, temperature, and solar radiation show obvious correlations and a cyclical variation pattern.

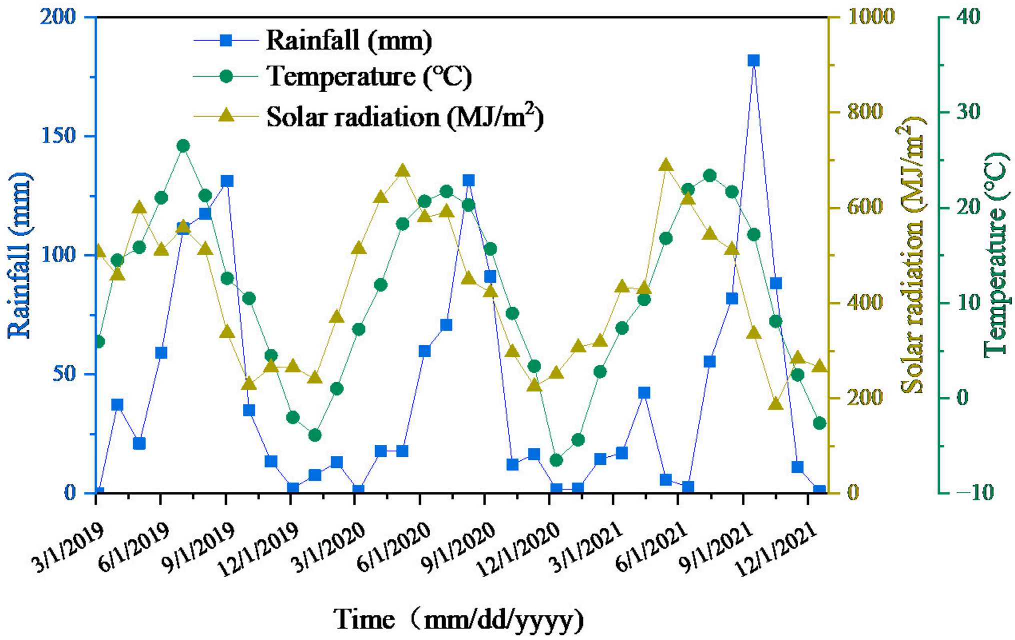

Figure 4. Monthly variation in rainfall, temperature, and solar radiation. (Note: data from automatic weather stations during the experimental period 2019–2021).

3.2. SOC and Soil Moisture Content under Different Planting Practices

Monthly changes in soil moisture content for different planting practices in 2019–2021 are shown in Figure 5. The integration of water content over time reflects the average magnitude of the soil moisture content for each cropping method. In the 0–100 cm soil profile, the soil moisture content magnitudes from April to October were ranked as MT > TR > CR > PT. From October to April, soil moisture content was the highest for TR and decreased rapidly after harvesting grain, corn, and potatoes. Soil moisture content ranged from 8.7 to 20.4% for TR, 7.7 to 21.4% for CR, 4.7 to 18.1% for PT, and 6.6 to 24.5% for MT.

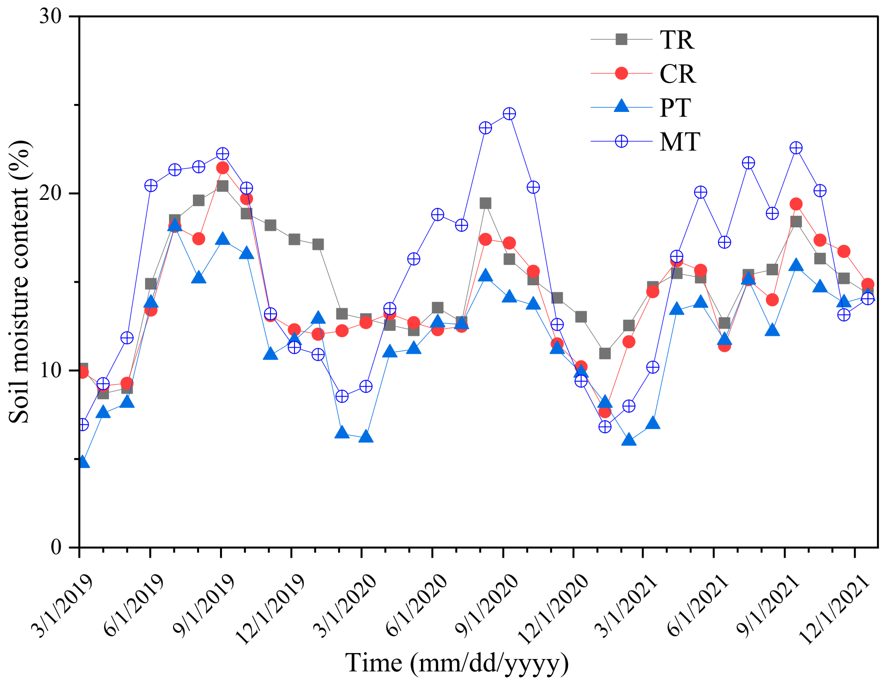

Figure 5. Variation in soil moisture content with time for different planting practices. (Note: data from automatic moisture monitors during the experimental period 2019–2021. Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

The SOC was recorded by regular sampling and measurement, and the change in SOC from 2019–2021 for different planting practices is shown in Figure 6. During the rebuilding period of old orchards, SOC was improved with different planting practices, and the improvement effect was significantly different. The improvement of 0–100 cm SOC was ranked as MT > PT > CR > TR: TR soil organic carbon increased from 2.53 g/kg to 2.66 g/kg; CR increased from 2.56 g/kg to 3.31 g/kg; PT increased from 2.72 g/kg to 3.67 g/kg; and MT had the best hair-lifting effect, increasing from 2.75 g/kg to 4.36 g/kg.

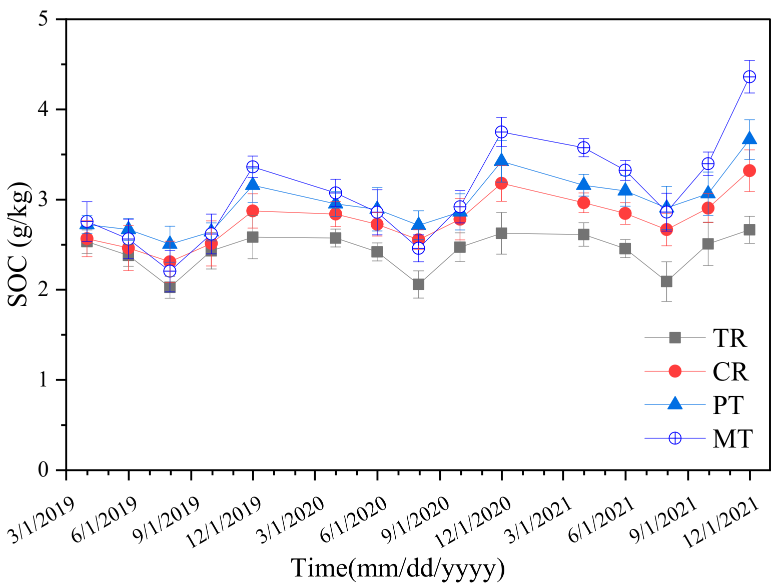

Figure 6. Variation in SOC with time for different planting practices. (Note: thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

3.3. Variation in Depth of SOC under Different Planting Practices

The variation in the depth of SOC in April 2021 is shown in Figure 7, which was similar for all 4 treatments obeying the power function law. Compared with April 2019, the vertical distribution pattern of SOC was different for various treatments with differences in the rate of decreasing depths. The decreasing velocity was ranked as MT > CR > PT > TR.

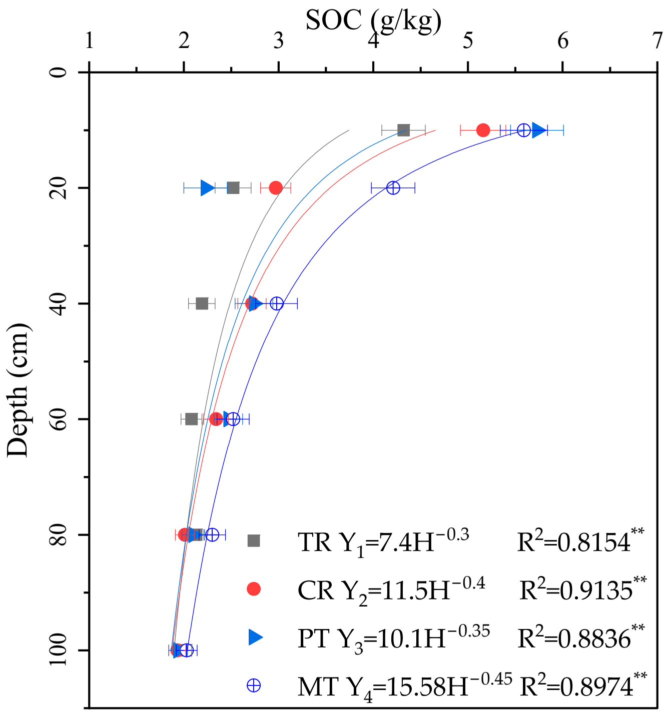

Figure 7. Content of soil organic carbon (SOC) at different depths for different planting practices. (Note: Y represents the soil organic carbon content; H represents the depth of soil layer; sampling data for April 2021. Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT), ** means significance $p < 0.01$).

The amount of SOC change in different soil layers in April 2021 is shown in Figure 8. The SOC in 4 treatments in different soil layers increased, except for PT in the 10–20 cm and 80–100 cm soil layers, where SOC decreased, and the closer to the surface layer, the greater the change. SOC changes gradually decreased with the increase in depth. Planting practices have a limited effect on organic carbon in deep soil. In the same soil layer, the difference in SOC change between different treatments was obvious. In the surface soil layer of 0–40 cm, the difference in SOC change between different treatments was the most obvious. the treatment with the largest change was MT, with a change of 1.5 g/kg, 7 times the change in TR; the deeper the soil layer, the smaller the differences in change. The smallest difference in organic carbon content was at 80–100 cm; the difference in change was around 0.05 g/kg. The greatest difference in SOC variation between different planting practices was mainly found in the soil surface layer.

3.4. Change with Time of SOC under Different Planting Practices

Soil surface vegetation growth and production directly influenced SOC. SOC variation curves in the 0–100 cm soil layer over time are shown in Figure 6. Different treatments showed similar patterns of SOC variation over time in the 0–100 cm soil layer, decreasing first and then increasing, with the lowest variation found in August. Compared with April, SOC in TR and MT decreased the most in August by 19.8%, followed by SOC in CR with a decrease of 10.1% in August, and SOC of PT with a decrease of 8.0% in August. SOC under different planting practices showed an increasing trend throughout the reproductive cycle.

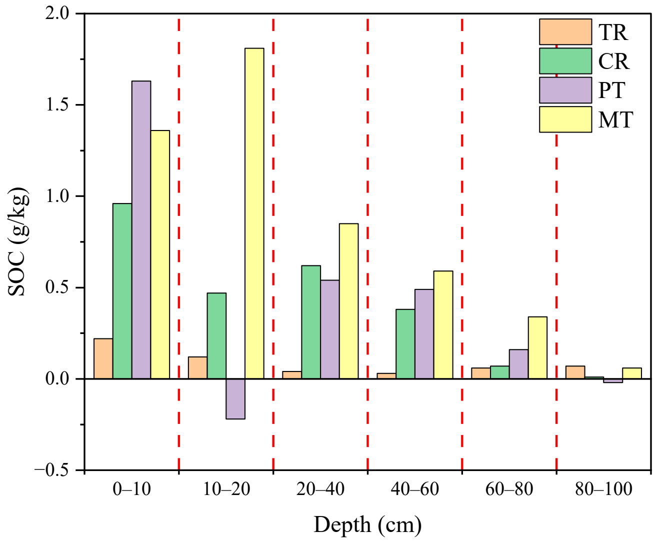

Figure 8. Amount of change in soil organic carbon (SOC) content in different soil layers for different planting practices. (Note: positive values represent increases; negative values represent decreases; sampling data for April 2021. Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

Before the orchard reconstruction in April 2019, there was no significant difference in SOC in the 0–100 cm soil layer, as shown in Figure 2, which was 2.53, 2.56, 2.72, and 2.75 g/kg, respectively. Figure 6 shows that all different planting practices helped to improve SOC, but the ability to improve was significantly different. The MT treatment was the most effective in improving SOC, which increased by 1.6 g/kg with an average annual growth rate of 0.54 g/(kg·year). This is followed by 0.31 g/(kg·year) for the PT treatment, 0.25 g/(kg·year) for the CR treatment, and the slowest increase was the TR treatment with a growth rate of 0.04 g/(kg·year) with the rapid accumulation of soil organic carbon in dense planting.

The difference between MT and TR in SOC values with time was established as Figure 9 shows. The difference between MT and TR in SOC values changes seasonally with a maximum in December and a minimum in August each year. Both maximum and minimum values increase with the number of years. Similarly, any two planting practices can be compared.

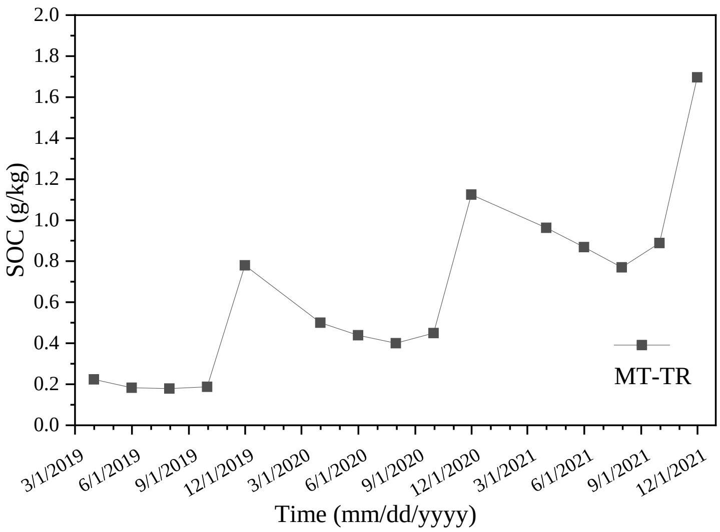

Figure 9. Difference between MT and TR in SOC values with time. (Note: Thinning and replanted saplings (TR), and all felled and planted millet (MT)).

3.5. Relationships between Rainfall, Soil Moisture, Solar Radiation, Temperature, and SOC

The analysis of the effects of soil moisture content, rainfall, average temperature, and solar radiation separately on SOC is shown in Figure 10. SOC decreases with increasing soil moisture content, rainfall, average temperature, and solar radiation (mean value in 0–100 cm). Soil moisture content, rainfall, average temperature, solar radiation, and SOC have a different relationship when using different treatments; the relationship between soil moisture content and SOC was significantly negative for the TR and MT treatments and insignificant for the CR and PT treatments. Additionally, the rate of decrease in SOC with increasing soil moisture content was significantly greater for both the TR and MT treatments than for the CR and PT treatments. Rainfall and average temperature showed a significant negative correlation with SOC under different planting practices, and the rate of decrease of SOC with increasing rainfall and average temperature was significantly greater for the MT treatment than for the TR, CR, and PT treatments. Solar radiation showed a negative correlation with SOC, and the rate of decrease in SOC with increasing solar radiation was significantly greater in MT than in TR, CR, and PT.

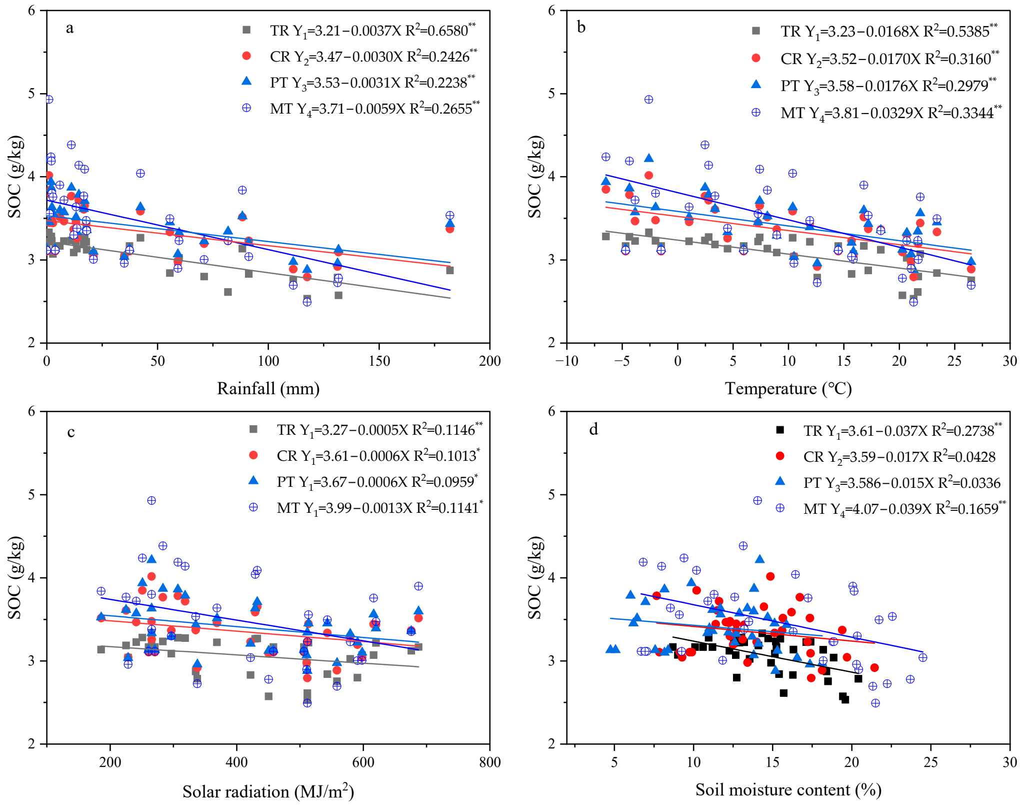

Figure 10. Relationship between rainfall, temperature, solar radiation, soil moisture content, and SOC under different planting practices. (Note: thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT), ** means significance $p < 0.01$, * means significance $p < 0.05$).

The multiple linear regression equations for different planting practices are shown in Table 1. The soil organic carbon content of TR has a regression effect with rainfall, average temperature, and soil moisture content, but not with solar radiation. In contrast, the soil organic carbon content of CR, PT and MT only has a regression effect with rainfall and average temperature, but not with soil moisture content and solar radiation.

Table 1. Multiple linear regression of SOC, rainfall, temperature, solar radiation, and soil moisture content for different planting practices.

Planting Practices	Multiple Linear Regression	Adj. R-Square
TR	$Y_1 = 3.14 - 0.00215\ X_1 - 0.0099\ X_2 - 0.00878\ X_4$	0.73238 **
CR	$Y_2 = 3.08 - 0.00193\ X_1 - 0.02046\ X_2$	0.31909 **
PT	$Y_3 = 3.08 - 0.00157\ X_1 - 0.02683\ X_2$	0.31753 **
MT	$Y_4 = 3.14 - 0.00371\ X_1 - 0.05032\ X_2$	0.34534 **

Note: Y represents the soil organic carbon content; X_1 represents rainfall, X_2 represents temperature, and X_4 represents soil moisture content. Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT), ** means significance $p < 0.01$.

4. Discussion

4.1. Changes in SOC under Different Planting Practices

The growth of vegetation directly affects SOC, which decreases with soil depth and obeys the power function rule, and the rate of decreasing SOC with depth varies with different planting practices. This is consistent with the crop growth pattern; plant growth is processed mainly through the root system to absorb organic matter in the soil, and the root system can directly replenish the soil organic matter after death. Consequently, the soil surface organic matter changes the most. However, as the distribution of the root system varies from crop to crop, the organic carbon content of the soil does not change in exactly the same way [38–40].

SOC was improved under different planting practices, and the improvement effect was significantly different. The improvement of 0–100 cm SOC was ranked as MT > PT > CR > TR with the effect of plant residues entering the soil differing per crop. It is the quantity and quality of plant residues that determine the amount of soil organic matter. Thus, potato and corn most probably provide the minor input of biomass (with the traditional farming practice), apple trees can supply some root biomass (root exudates and decaying small roots) and millet can give the highest input of biomass (roots and probably stubbles). Soil surface organic carbon increased in different planting practices; TR increased insignificantly and MT increased most obviously. All abandoned garden fallow vegetation belong to the herbaceous vegetation; this kind of vegetation grows rapidly where the root system is concentrated in the surface layer and the conversion rate of organic matter into soil is high. Additionally, compared with economic tree vegetation, the accumulation effect on soil organic carbon is faster and more obvious, especially the accumulation of soil surface organic carbon [41–43]. For MT, millet has the best effect on improving soil organic carbon accumulation in orchards due to their dense root system.

The MT treatment was the most effective in improving SOC, which increased by 1.6 g/kg with an average annual growth rate of 0.54 g/(kg·year), equivalent to 700 g/(m^2·year). Post and Kwon [37] reviewed the literature for SOC changes in agricultural soils subject to different land-use changes and found that the rate of SOC accumulation ranged from 47 to 310 g/(m^2·year) during forest establishment (average 33.8 g/(m^2·year)) and from 90 to 113 g/(m^2·year). Martens and Reedy [19] found that the SOC accumulation for forest averaged 98.5 g/(m^2·year) and pasture averaged a gain of 61.5 g/(m^2·year) with the secondary forest accounting for 160 g/(m^2·year). In this study, the rate of SOC accumulation in the MT treatment was slightly higher than for the forest, pasture, and secondary forest. Millet is a native crop to the Loess Plateau and would be a suitable choice for improving organic carbon accumulation during the reconstruction period of old apple orchards.

SOC in the 0–100 cm soil layer in different planting practices showed a decrease and then an increase with time, with a low value in August every year. Plant growth shows cyclical changes. Soil organic carbon must be consumed for plant growth. With temperature increase, solar radiation, and rainfall, plants start to grow, soil microbial activity increases, and respiration is enhanced. Soil organic carbon consumption is greater than replenishment [44,45], showing a decreasing point trend; plants and soil microorganisms are active to a certain extent and start to metabolize, followed by replenished soil organic and gradual increases in organic carbon content.

4.2. Relationships between Rainfall, Soil Moisture, Solar Radiation, Temperature, and SOC

Rainfall and temperature are important factors affecting plant and microbial activity. SOC decreased with the increase in soil moisture content, rainfall, average temperature, and solar radiation in different planting practices. Increases in rainfall, temperature, soil moisture content, and solar radiation all favor plant growth and soil microbial activity due to increased plant consumption of soil organic matter, increased rate of decomposition of organic matter by microorganisms, enhanced soil respiration, and greater soil organic carbon consumption [44–46]. Therefore, soil organic carbon content always shows a negative correlation with rainfall, temperature, soil moisture content, and solar radiation. In addition, enhanced plant and microbial activities simultaneously produce more organic matter, which is converted into soil organic carbon after a certain period of time [47–49]. Therefore, the increase in soil organic carbon content always lags behind the above factors by a certain amount of time (Figure 11).

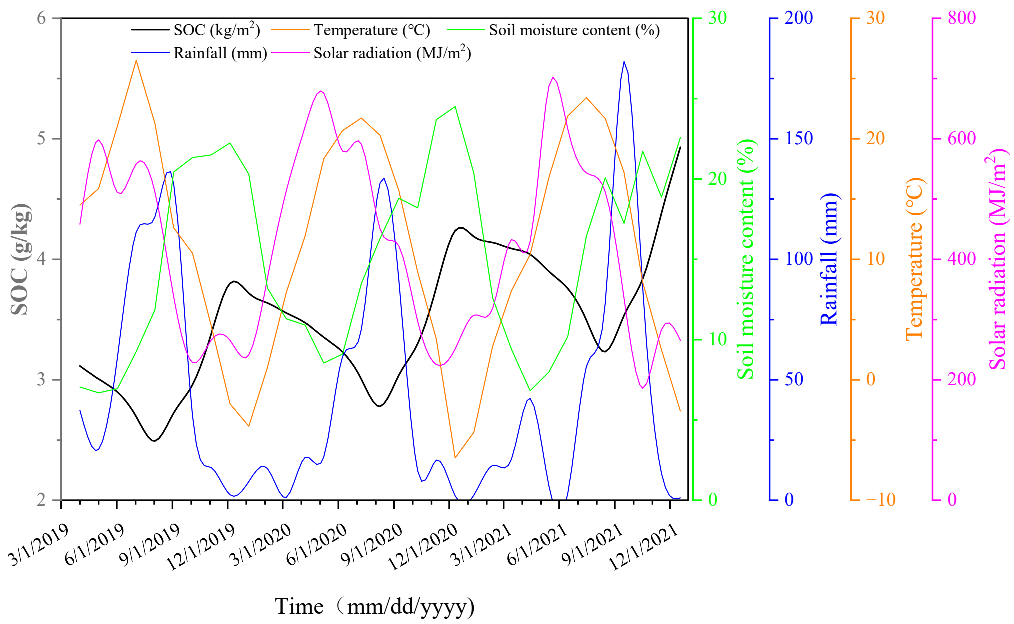

Figure 11. Changes in soil organic carbon (SOC), rainfall, temperature, solar radiation, and soil moisture content over time. (Note: plotting SOC and soil moisture content using MT as an example. All felled and planted millet (MT). Thinning and replanted saplings (TR), all felled and planted corn (CR), all felled and planted millet (MT), and all felled and planted potato (PT)).

The amount of rainfall directly affects the change in soil moisture content; the amount of rainfall that increases the soil moisture content also becomes larger. The amount of solar radiation is closely related to the average temperature; the amount of solar radiation is large, while the average surface temperature is high. There is a competitive relationship between rainfall and soil moisture content, solar radiation, and average temperature, respectively, as shown in the multiple regression analysis of four factors on the influence of soil organic carbon content. Therefore, some factors have no regression effect relationship with soil organic carbon and do not appear in the equation. The relationships between rainfall, temperature, solar radiation, soil moisture content, and SOC can be used to estimate the change in SOC under the same conditions. In turn, this helps to estimate the soil carbon pool.

5. Conclusions

SOC decreased with increasing soil depth with the distribution law obeying the power function, and the decreasing rate of SOC with depth was different under different planting practices. The decreasing speed was ranked as MT > CR > PT > TR. This study gave four power functions for different plant practices in the experiment. SOC was improved under different planting practices, and the improvement effect was significantly different. The improvement of 0–100 cm SOC was ranked as MT > PT > CR > TR, and the closer to the surface layer, the greater the change, with the largest change of 1.5 g/kg in MT being 7 times larger than TR; with increasing depths, the change in SOC gradually decreased. The change in SOC in soil layers with time showed a decrease followed by an increase, with the lowest SOC being found in August. SOC showed an increasing trend throughout the reproductive cycle. The MT treatment was the most effective in improving SOC, which increased by 1.6 g/kg with an average annual growth rate of 0.54 g/(kg·year). SOC decreased with the increase in soil moisture content, rainfall, average temperature, and solar radiation. The relationship between soil moisture content, rainfall, average temperature, solar radiation, and SOC were different for different planting practices. Millet would be a suitable choice for improving organic carbon accumulation during the reconstruction period of old apple orchards on the Loess Plateau.

Author Contributions: Conceptualization, W.L.; Data curation, W.L.; Formal analysis, W.L. and R.A.; Funding acquisition, J.G.; Investigation, W.L. and Y.Z.; Methodology, W.L.; Project administration, W.L. and J.G.; Resources, W.L. and Y.Z.; Software, W.L.; Supervision, J.G.; Validation, W.L. and Z.G.; Visualization, F.Z.; Writing—original draft, W.L.; Writing—review and editing, W.L. and J.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China (2021YFD1900704), the Key Research and Development Project of Shaanxi Province (2020ZDLSF06-03-01), National Natural Science Foundation of China (No.41877078), and Knowledge Innovation Program of the Chinese Academy of Sciences (No. A315021615).

Data Availability Statement: Not applicable.

Acknowledgments: We acknowledge Xiping Wang, Mingjuan Ji, Xinghua Li, and Sixuan Liu for their contributions to the experiment. We also sincerely appreciate State Key Laboratory of Soil Erosion and Dryland farming on Loess Plateau, Chafang Village, and Ansai Soil and Water Conservation Comprehensive Experiment Station for providing the test site and support during the experiments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kopecký, M.; Vojta, J. Land use legacies in post-agricultural forests in the Doupovské Mountains, Czech Republic. *Appl. Veg. Sci.* **2009**, *12*, 251–260. [CrossRef]
2. Praise, S.; Ito, H.; Sakuraba, T.; Pham, D.V.; Watanabe, T. Water extractable organic matter and iron in relation to land use and seasonal changes. *Sci. Total. Environ.* **2019**, *707*, 136070. [CrossRef]
3. Li, Z.H.; Ji, Q.; Zhao, S.X.; Wei, B.M.; Wang, X.D.; Hussain, Q. Changes in C and N fractions with composted manure plus chemical fertilizers applied in apple orchard soil: An in-situ field incubation study on the Loess Plateau, China. *Soil Use Manag.* **2018**, *34*, 276–285. [CrossRef]
4. Qi, Q.; Zhang, D.; Zhang, M.; Tong, S.; Wang, W.; An, Y. Spatial distribution of soil organic carbon and total nitrogen in disturbed Carex tussock wetland. *Ecol. Indic.* **2021**, *120*, 106930. [CrossRef]
5. Zimmerman, R.H.; Steffens, G.L. Long-term evaluation of micropropagated apple trees: Vegetative growth, cropping, and photosynthesis. *Sci. Hortic.* **1996**, *66*, 69–76. [CrossRef]
6. Norelli, J.L.; Miller, S.S. Effect of Prohexadione-Calcium Dose Level on Shoot Growth and Fire Blight in Young Apple Trees. *Plant Dis.* **2004**, *88*, 1099–1106. [CrossRef] [PubMed]
7. Kenis, K.; Keulemans, J. Study of tree architecture of apple (Malus × domestica Borkh.) by QTL analysis of growth traits. *Mol. Breed.* **2007**, *19*, 193–208. [CrossRef]
8. Xu, L.; Yu, G.; He, N. Increased soil organic carbon storage in Chinese terrestrial ecosystems from the 1980s to the 2010s. *J. Geogr. Sci.* **2019**, *29*, 49–66. [CrossRef]
9. Bowden, R.D.; Deem, L.; Plante, A.F.; Peltre, C.; Nadelhoffer, K.; Lajtha, K. Litter Input Controls on Soil Carbon in a Temperate Deciduous Forest. *Soil Sci. Soc. Am. J.* **2014**, *78*, S66–S75. [CrossRef]
10. Stumpf, F.; Keller, A.; Schmidt, K.; Mayr, A.; Gubler, A.; Schaepman, M. Spatio-temporal land use dynamics and soil organic carbon in Swiss agroecosystems. *Agric. Ecosyst. Environ.* **2018**, *258*, 129–142. [CrossRef]
11. Schulp, C.; Verburg, P. Effect of land use history and site factors on spatial variation of soil organic carbon across a physiographic region. *Agric. Ecosyst. Environ.* **2009**, *133*, 86–97. [CrossRef]
12. Li, Y.; Duan, X.; Li, Y.; Li, Y.; Zhang, L. Interactive effects of land use and soil erosion on soil organic carbon in the dry-hot valley region of southern China. *Catena* **2021**, *201*, 105187. [CrossRef]

13. Fang, X.; Xue, Z.; Li, B.; An, S. Soil organic carbon distribution in relation to land use and its storage in a small watershed of the Loess Plateau, China. *Catena* **2012**, *88*, 6–13. [CrossRef]
14. Zhou, Y.; Hartemink, A.E.; Shi, Z.; Liang, Z.; Lu, Y. Land use and climate change effects on soil organic carbon in North and Northeast China. *Sci. Total. Environ.* **2019**, *647*, 1230–1238. [CrossRef] [PubMed]
15. Shrestha, B.M.; Sitaula, B.K.; Singh, B.R.; Bajracharya, R.M. Soil organic carbon stocks in soil aggregates under different land use systems in Nepal. *Nutr. Cycl. Agroecosyst.* **2004**, *70*, 201–213. [CrossRef]
16. Guo, L.B.; Gifford, R.M. Soil carbon stocks and land use change: A meta analysis. *Glob. Chang. Biol.* **2002**, *8*, 345–360. [CrossRef]
17. Deng, L.; Zhu, G.-Y.; Tang, Z.-S.; Shangguan, Z.-P. Global patterns of the effects of land-use changes on soil carbon stocks. *Glob. Ecol. Conserv.* **2016**, *5*, 127–138. [CrossRef]
18. Laganiãre, J.; Angers, D.A.; Parã, D. Carbon accumulation in agricultural soils after afforestation: A meta-analysis. *Glob. Chang. Biol.* **2010**, *16*, 439–453. [CrossRef]
19. Martens, D.A.; Reedy, T.E.; Lewis, D.T. Soil organic carbon content and composition of 130-year crop, pasture and forest land-use managements. *Glob. Chang. Biol.* **2004**, *10*, 65–78. [CrossRef]
20. Gregorich, E.; Greer, K.; Anderson, D.; Liang, B. Carbon distribution and losses: Erosion and deposition effects. *Soil Tillage Res.* **1998**, *47*, 291–302. [CrossRef]
21. Evans, M.; Lindsay, J. Impact of gully erosion on carbon sequestration in blanket peatlands. *Clim. Res.* **2010**, *45*, 31–41. [CrossRef]
22. Grünzweig, J.M.; Sparrow, S.D.; Yakir, D.; Chapin, F.S. Impact of Agricultural Land-use Change on Carbon Storage in Boreal Alaska. *Glob. Chang. Biol.* **2004**, *10*, 452–472. [CrossRef]
23. Melillo, J.M.; Houghton, R.A.; Kicklighter, D.W.; McGuire, A.D. Tropical deforestation and the global carbon budget. *Annu. Rev. Energy Environ.* **1996**, *21*, 293–310. [CrossRef]
24. Lin, Z.-B.; Zhang, R.-D. Dynamics of Soil Organic Carbon Under Uncertain Climate Change and Elevated Atmospheric CO_2. *Pedosphere* **2012**, *22*, 489–496. [CrossRef]
25. Lin, Z.; Zhang, R. Effects of climate change and elevated atmospheric CO_2 on soil organic carbon: A response equation. *Clim. Chang.* **2012**, *113*, 107–120. [CrossRef]
26. Kool, D.M.; Chung, H.; Tate, K.R.; Ross, D.J.; Newton, P.C.D.; Six, J. Hierarchical saturation of soil carbon pools near a natural CO_2spring. *Glob. Chang. Biol.* **2007**, *13*, 1282–1293. [CrossRef]
27. Chen, D.; Yu, H.Y.; Zou, L.Y.; Teng, Y.; Zhu, C.W. Effects of elevated atmospheric CO_2 concentration on the stability of soil organic carbon in different layers of a paddy soil. *Ying Yong Sheng Tai Xue Bao J. Appl. Ecol.* **2018**, *29*, 2559–2565.
28. Chappell, A.; Webb, N.P.; Butler, H.J.; Strong, C.L.; McTainsh, G.H.; Leys, J.F.; Rossel, R.A.V. Soil organic carbon dust emission: An omitted global source of atmospheric CO_2. *Glob. Chang. Biol.* **2013**, *19*, 3238–3244. [CrossRef]
29. Deng, L.; Liu, G.-B.; Shangguan, Z.-P. Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: A synthesis. *Glob. Chang. Biol.* **2014**, *20*, 3544–3556. [CrossRef]
30. Plaza-Bonilla, D.; Arrúe, J.L.; Cantero-Martinez, C.; Fanlo, R.; Iglesias, A.; Álvaro-Fuentes, J. Carbon management in dryland agricultural systems. A review. *Agron. Sustain. Dev.* **2015**, *35*, 1319–1334. [CrossRef]
31. McCarty, G.; Ritchie, J. Impact of soil movement on carbon sequestration in agricultural ecosystems. *Environ. Pollut.* **2002**, *116*, 423–430. [CrossRef]
32. Chen, L.; Gong, J.; Fu, B.; Huang, Z.; Huang, Y.; Gui, L. Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, loess plateau of China. *Ecol. Res.* **2007**, *22*, 641–648. [CrossRef]
33. You, M.; Zhu-Barker, X.; Hao, X.-X.; Li, L.-J. Profile distribution of soil organic carbon and its isotopic value following long term land-use changes. *Catena* **2021**, *207*, 105623. [CrossRef]
34. Poeplau, C. Grassland soil organic carbon stocks along management intensity and warming gradients. *Grass Forage Sci.* **2021**, *76*, 186–195. [CrossRef]
35. Heman, L.; Lihua, C.; Changchang, X.; Hong, Y.; Baoguo, L. Distribution characteristics of soil organic carbon and nitrogen in farmland and adjacent natural grassland in Tibet. *Int. J. Agric. Biol. Eng.* **2016**, *9*, 135–145. [CrossRef]
36. Hu, P.-L.; Liu, S.-J.; Ye, Y.-Y.; Zhang, W.; Wang, K.-L.; Su, Y.-R. Effects of environmental factors on soil organic carbon under natural or managed vegetation restoration. *Land Degrad. Dev.* **2018**, *29*, 387–397. [CrossRef]
37. Post, W.M.; Kwon, K.C. Soil carbon sequestration and land-use change: Processes and potential. *Glob. Chang. Biol.* **2000**, *6*, 317–327. [CrossRef]
38. Mays, N.; Brye, K.; Rom, C.R.; Savin, M.; Garcia, M. Groundcover Management and Nutrient Source Effects on Soil Carbon and Nitrogen Sequestration in an Organically Managed Apple Orchard in the Ozark Highlands. *Hortscience* **2014**, *49*, 637–644. [CrossRef]
39. Panzacchi, P.; Tonon, G.; Ceccon, C.; Scandellari, F.; Ventura, M.; Zibordi, M.; Tagliavini, M. Belowground carbon allocation and net primary and ecosystem productivities in apple trees (Malus domestica) as affected by soil water availability. *Plant Soil* **2012**, *360*, 229–241. [CrossRef]
40. Shi, Z.; Li, X.; Zhang, L.; Wang, Y. Impacts of farmland conversion to apple (Malus domestica) orchard on soil organic carbon stocks and enzyme activities in a semiarid loess region. *J. Plant Nutr. Soil Sci.* **2015**, *178*, 440–451. [CrossRef]
41. Zhang, Y.; Wang, L.; Jiang, J.; Zhang, J.; Zhang, Z.; Zhang, M. Application of soil quality index to determine the effects of different vegetation types on soil quality in the Yellow River Delta wetland. *Ecol. Indic.* **2022**, *141*, 109116. [CrossRef]

42. Wu, Y.; Jiang, B.; Zou, Y.; Dong, H.; Wang, H.; Zou, H. Influence of bacterial community diversity, functionality, and soil factors on polycyclic aromatic hydrocarbons under various vegetation types in mangrove wetlands. *Environ. Pollut.* **2022**, *308*, 119622. [CrossRef] [PubMed]
43. Zhang, Y.; Ai, J.; Sun, Q.; Li, Z.; Hou, L.; Song, L.; Tang, G.; Li, L.; Shao, G. Soil organic carbon and total nitrogen stocks as affected by vegetation types and altitude across the mountainous regions in the Yunnan Province, south-western China. *Catena* **2021**, *196*, 104872. [CrossRef]
44. Raza, S.T.; Zhu, Y.; Wu, J.; Rene, E.R.; Ali, Z.; Feyissa, A.; Khan, S.; Anjum, R.; Bazai, N.A.; Chen, Z. Different ratios of Canna indica and maize–vermicompost as biofertilizers to improve soil fertility and plant growth: A case study from southwest China. *Environ. Res.* **2022**, *215*, 65–78. [CrossRef] [PubMed]
45. Ai, W.; Guo, T.; Lay, K.D.; Ou, K.; Cai, K.; Ding, Y.; Liu, J.; Cao, Y. Isolation of soybean-specific plant growth-promoting rhizobacteria using soybean agglutin and evaluation of their effects to improve soybean growth, yield, and soil nutritional status. *Microbiol. Res.* **2022**, *261*, 127076. [CrossRef] [PubMed]
46. Li, Q.; Song, X.; Chang, S.X.; Peng, C.; Xiao, W.; Zhang, J.; Xiang, W.; Li, Y.; Wang, W. Nitrogen depositions increase soil respiration and decrease temperature sensitivity in a Moso bamboo forest. *Agric. For. Meteorol.* **2019**, *268*, 48–54. [CrossRef]
47. Wen, Z.; Chen, Y.; Liu, Z.; Meng, J. Biochar and arbuscular mycorrhizal fungi stimulate rice root growth strategy and soil nutrient availability. *Eur. J. Soil Biol.* **2022**, *113*, 103448. [CrossRef]
48. Liu, Y.; Ma, Z.; Chen, R.; Jiang, W.; Yin, C.; Mao, Z.; Wang, Y. Biochar promotes the growth of apple seedlings by adsorbing phloridzin. *Sci. Hortic.* **2022**, *303*, 111187. [CrossRef]
49. Liu, M.; Ke, X.; Joseph, S.; Siddique, K.H.; Pan, G.; Solaiman, Z.M. Interaction of rhizobia with native AM fungi shaped biochar effect on soybean growth. *Ind. Crop. Prod.* **2022**, *187*, 115508. [CrossRef]