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A Comparative Study of Rotation Patterns on Soil Organic Carbon in China's Arid and Semi-Arid Regions

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Received: 3 November 2019; Accepted: 16 January 2020; Published: 22 January 2020

Abstract: The practice of crop rotation can significantly impact carbon sequestration potential. In exploring whether crop rotation has the potential to improve soil carbon sequestration in China's Loess Plateau, soil organic carbon (SOC), soil water content (SWC), soil bulk density (SBD), and soil pH were compared across the 0–1.0 m soil profile, under four crop rotation patterns: lentil–wheat–maize, wheat–potato–lentil, wheat–maize–potato, and wheat–flax–pea. The lentil–wheat–maize and wheat–maize–potato rotations have been practiced over the past 20 years, while the wheat–potato–lentil and wheat–flax–pea rotations were established in 1978 (~40 year rotations). The results showed that under the 20-year lentil–wheat–maize rotation, SOC was not significantly different to that of the wheat–maize–potato rotation, at 6.81 g kg^{-1} and 6.91 g kg^{-1}, respectively. However, under the lentil–wheat–maize rotation, SWC (9.81%) and SBD (1.19 Mg m^{-3}) were significantly higher, but soil pH (8.42) was significantly lower than the same metrics under wheat–maize–potato rotation (8.43% and 1.16 Mg m^{-3}, and 8.50, respectively). For the 40-year rotations, SWC (9.19%) and soil pH (8.41) under the wheat–potato–lentil were not significantly different to that of the wheat–flax–pea (8.87%, and 8.40, respectively). SOC (6.06 g kg^{-1}) was significantly lower, but SBD (1.18 Mg m^{-3}) was significantly higher under the wheat–potato–lentil than the wheat–flax–pea (7.29 g kg^{-1}, and 1.15 Mg m^{-3}, respectively) rotations. Soil carbon sequestration for the lentil–wheat–maize and wheat–potato–lentil rotations was co-influenced by SWC, SBD, and soil pH, while for wheat–maize–potato and wheat–flax–pea rotations, it was co-influenced by SWC and soil pH. The economic value of the four studied crops is, in order: potato > maize > wheat > flax. The results of the present study suggest that the lentil–wheat–maize and maize–flax–pea rotations are the most suitable patterns to optimize simultaneous economic and ecological development of the study area.

Keywords: crop rotation; maize; wheat; soil organic carbon; soil water content; arid and semi-arid region

1. Introduction

Soil is an important carbon pool in terrestrial ecosystems and is estimated to contain from 1200 to 2200 Gt of soil organic carbon (SOC) [1,2]. Improving SOC sequestration in farmland soil through the adoption of conservation agricultural practices such as no-tillage and residue management has received considerable attention in the literature [3–5]. Many field experiments show that SOC can be influenced by the type of cropping system employed, and is impacted by factors such as crop rotation characteristics and environmental conditions [6–8]. Crop rotation is currently regarded by many to be an important method to improve SOC sequestration, as rotation patterns have significant effects on soil structural stability due to the action of crop root systems. For example, upon the death of a cover crop, the biopores left by cover crop roots support root growth in subsequent crops, even in soils with high penetration resistance [9,10]. Compared to monocultures, crop rotations favor a more efficient use of soil nutrients by plants, which can prevent SOC loss, enhance soil fertility, and raise crop yields—results that promote food security and help to mitigate climate change by maintaining the CO_2 balance of the atmosphere [11]. In addition, compared to conventional monoculture systems, plant disease diffusion has been shown to be reduced when crop rotation is employed [10,12–16].

Water scarcity is the most common issue in semi-arid regions, for example in parts of China, India and the US [17]. Generally, water scarcity contributes to reduced SOC sequestration because soil water content (SWC) directly impacts microbial activity and the diffusion rate of soil gas into the atmosphere [14,18]. In China, especially in the semi-arid and rain-fed crops of the Loess Plateau [19,20], uneven precipitation contributes significantly to water stress and nutrient deficiencies, the limiting factors of crop production in the region [21].

Crop rotation practices in the Loess Plateau are common [22]. Mixed results in the literature suggest a need for further study of the effects of crop rotation practices. For example, some studies show that continuous crops have greater SOC fixation potential [7,23,24], though these practices consume more water [25] than rotation crops. Other studies suggest that continuous cropping reduces SOC sequestration [15]. Although there are various types of crop rotation patterns employed in the Loess Plateau comprising various combinations of lentil (*Lens culinaris*), wheat (*Triticum æstivum* L.), potato (*Solanum tuberosum* L.), pea (*Pisum sativum*), flax (*Linum usitatissimum* L.) and maize (*Zea mays* L.) crops, their impacts on SOC sequestration and on other soil properties are not well documented. The environmental sustainability of the current rotation patterns is unknown and warrants further exploration.

The objectives of the present study are: (1) to investigate the effects of crop rotations on SWC, SOC, soil bulk density (SBD) and soil pH, and (2) to identify the most sustainable rotation pattern for the study region. The researchers hypothesize that different crop rotation patterns may have different effects on SOC sequestration, as previous studies found that SWC, SBD, and soil pH are often influenced by the crop rotation patterns, and that variations in these soil properties can result in differences in SOC [26–29].

2. Materials and Methods

2.1. Study Area

Huining County (104°29′–105°31′ E, 35°24′–36°26′ N) is located on the south-to-north slopes of the Loess Plateau, with an average altitude of 2025 m and an area of approximately 6439 km^2. The region is situated in a temperate continental climate zone with a mean annual temperature of 6–9 °C and a mean rainfall of 180 to 450 mm y^{-1}, of which 58% falls between July and September. The mean evaporation rate is over 1800 mm y^{-1} [30]. Soils in this area mainly are of a loessial type, with field capacity being between 13–25%, and permanent wilting point being between 3–8%. In terms of soil composition, silt, clay and sand account for above 60%, 5% and 30% of the soil particles, respectively [31]. As a typical rain-fed agricultural region, crop lands are the traditional source of income for Huining County locals. For many years, wheat, flax, potato, pea, and lentil have been the major regional crops. Each of these crops are planted and harvested once a year due to the region's scarcity of water resources. Approximately 20 years ago, the dry farming industry began to use mulching techniques, allowing for the introduction of maize to the area. This promoted the co-occurrence of four primary inter-annual crop rotations, including lentil–wheat–maize and wheat–maize–potato—introduced approximately 20 years ago with the establishment of maize production in the area—and wheat–potato–lentil and wheat–flax–pea—rotations that have existed since the rural lands were contracted to households in 1978 as each household can manage its lands.

The primary cultivation method for all crops in this area was similar. Fifteen years ago, animals were a key source of draft power, but were eventually substituted for farm machineries, which are now universally used in agriculture production. Wheat is planted in February and harvested in July, while maize and potato are planted in May, and harvested in October. Flax and legumes such as peas and lentils are often planted in March and harvested in August. In the study area, irrigation is not used for all crops, and crop straw is fed to domestic livestock or used as fuel. The majority of livestock manure is returned to the field as a primary fertilizer, and a small amount of chemical fertilizer is used. Herbicides are seldom applied; weeds are mainly removed manually.

2.2. Experimental Design

In order to investigate the response of SOC to crop rotations over time, a space-for-time substitution approach was employed in the present study, as it has been adopted and successfully used in similarly targeted field studies [32–34]. Overall, three sites (Figure 1) were selected to explore the effects of crop rotations on SOC, SWC, SBD and soil pH at the later growth or harvest state of crops, during the period from late of July to September, 2017, in Huining County. Notably, there was an unprecedented 3-month drought before the sampling period, in which virtually all precipitation was fully depleted by plants and soils in all of the investigated sites [35]. Each of the four crop rotations, lentil–wheat–maize, wheat–potato–lentil, wheat–maize–potato, and wheat–flax–pea, was collected, respectively, at each site. Due to the limited size of the study areas, soil was sampled from three to five 10 m × 10 m plots, spaced 10 m apart along the horizontal contour. There were 12 plots for each crop rotation. In each plot, the soil profile was excavated to a depth of 1.0 m at three 1 m × 1 m quadrats, spaced along the diagonal (one at each end and one at the mid-point), and thus a total of 216 soil samples were collected for each crop rotation. Soil samples were taken at profile depth ranges of 0–0.1 m, 0.1–0.2 m, 0.2–0.4 m, 0.4–0.6 m, 0.6–0.8 m and 0.8–1.0 m, using a cutting ring with diameter of 5 cm. Compared to other methods, this approach allows for a better comparison of soil properties at multiple depths [36].

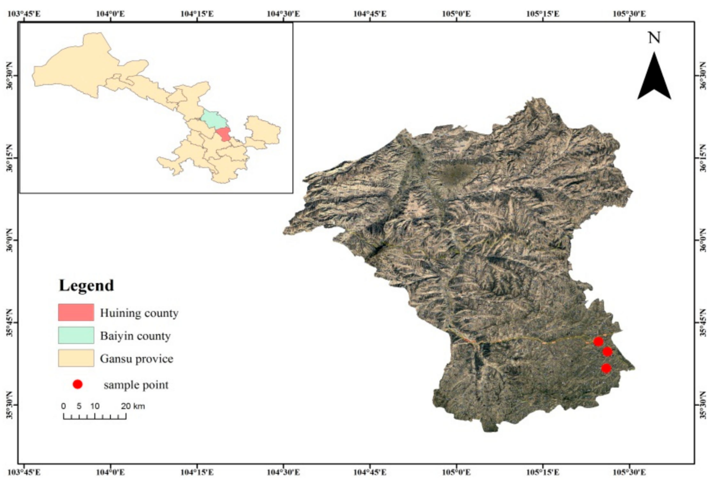

Figure 1. Location of the three experimental blocks in Huining County, Gansu Province, China.

2.3. Soil Analysis

Each soil sample was placed in a plastic Ziplock bag with its cutting ring and weighed (g) on site. In the laboratory, each sample was removed from the plastic bag and placed in an individual pre-weighed aluminum box, then dried in an oven at 105 °C for 24 h. Each soil sample was again weighed, and its net dry weight calculated as the total weight minus that of the aluminum box. The SWC was then calculated as [35]

$$SWC = 100 \cdot \frac{W_1 - W_2}{W_2}$$

where W_1 = fresh weight, and W_2 = dry weight.

SBD was then calculated as SBD (Mg m^{-3}) [37] = $\frac{\text{dry weight}}{\text{volume}}$.

The pH of a 2:5 soil: water suspension was measured using a Sartorius PB-10 pH meter [37], and the SOC (g kg^{-1}) was determined with wet dichromate oxidation using an air-dried homogenized subsample of 0.2 g soil and titration with $FeSO_4$ [38].

2.4. Data Analysis

Data were analyzed using SPSS 22.0 statistical software (SPSS Inc., Chicago, IL, USA), and expressed as mean ± standard deviation. One-way analysis of variance (ANOVA) was applied to determine the statistically significant differences in the soil pH, SWC, SOC and SBD between the different crop rotations at the equivalence of a $p < 0.05$ significance level. The Pearson's product moment correlation (r) was used to identify the statistically significant relationships among soil pH, SWC, SOC and SBD. The Origin Pro 9.0 software was applied to visualize data and analysis results through appropriate visual and statistical diagnostic plots. Linear regression was used to identify the dominating soil factors that influence SOC sequestration for each crop rotation pattern.

3. Results

3.1. The Distribution of SWC and SBD of Different Rotation Patterns

At the 1.0 m soil depth profile, for the 20-year rotations, SWC of the lentil–wheat–maize (9.81%) was significantly higher than that of the wheat–maize–potato (8.43%) rotation, while for the more established 40-year rotations, no difference in SWC was found between wheat–potato–lentil (9.19%) and wheat–flax–pea (8.87%) (Table 1). In a vertical direction, with an increase in soil depth, the SWC of the lentil–wheat–maize, wheat–maize–potato and wheat–flax–pea rotations first increased, and then decreased and increased again, while the SWC of the wheat–potato–lentil first increased and then decreased. Specifically, SWC values peaked at the 0.1–0.2 m soil layer both for the lentil–wheat–maize and wheat–potato–lentil rotations (10.92%, and 9.83%, respectively), while the SWC of the wheat–maize–potato rotation showed no clear change from one layer to another. For the wheat–flax–pea rotation, SWC was significantly lower at the 0.2–0.4 m soil layer. The SWC for all crop rotation patterns showed major fluctuations at the 0.1–0.4 m soil layer (Figure 2).

Table 1. The soil water content (SWC), soil organic carbon (SOC), soil water content (SWC), soil bulk density (SBD) and soil pH of different crop rotation patterns (mean ± standard deviation).

Duration	Crop Rotations	SWC (%)	SOC (g kg^{-1})	SBD (Mg m^{-3})	Soil pH
20 years	wheat–maize–potato	9.81 ± 2.64 a	6.81 ± 4.84 a	1.19 ± 0.08 a	8.42 ± 0.12 a
	lentil–wheat–maize	8.43 ± 2.11 b	6.92 ± 3.86 a	1.16 ± 0.10 bc	8.50 ± 0.15 b
40 years	wheat–flax–pea	8.87 ± 2.88 bc	7.29 ± 3.12 a	1.15 ± 0.10 b	8.40 ± 0.16 a
	wheat–potato–lentil	9.19 ± 1.43 c	6.06 ± 2.27 b	1.18 ± 0.08 ac	8.41 ± 0.17 a

Note: The lowercase letters indicate differences between the two crop rotations with 20 years, and 40 years, respectively ($p < 0.05$), SWC represents soil water content, SOC represents soil organic carbon, and SBD represents soil bulk density.

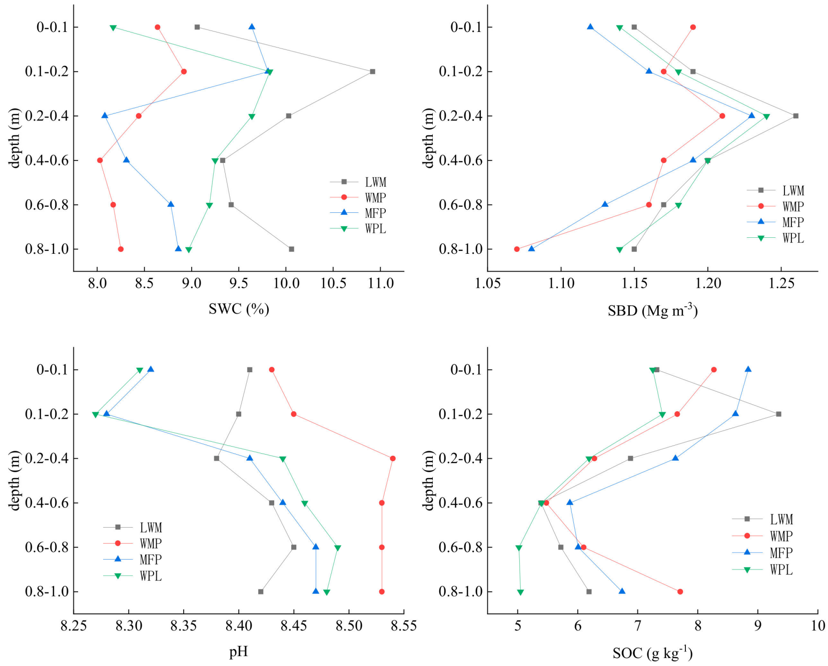

Figure 2. SWC, SOC, SBD, and soil pH at 1 m depth for different crop rotation patterns. Note: LWM represents lentil–wheat–maize, WMP represents wheat–maize–potato, WFP represents wheat–flax–pea, WPL represents wheat–potato–lentil; SWC represents soil water content, SOC represents soil organic carbon, SBD represents soil bulk density.

At the 1.0 m soil depth profile, for the 20-year rotations, the SBD of lentil–wheat–maize (1.19 Mg m^{-3}) was significantly higher than that of wheat–maize–potato (1.16 Mg m^{-3}). In terms of the 40-year rotations, the SBD of wheat–potato–lentil (1.18 Mg m^{-3}) was significantly higher than that of wheat–flax–pea (1.15 Mg m^{-3}) (Table 1). With an increase in soil depth, SBD of all rotations showed a similar trend, specifically an initial increase followed by a decrease, with their values peaking within the 0.2–0.4 m soil layer (1.26 Mg m^{-3}, 1.21 Mg m^{-3}, 1.23 Mg m^{-3}, and 1.24 Mg m^{-3}, respectively) (Figure 2).

3.2. The Distribution of Soil pH, SOC of Different Rotation Patterns

At the 1.0 m soil depth profile, for the 20-year rotations, the soil pH of wheat–maize–potato (8.50) was significantly higher than that of the lentil–wheat–maize (8.42), but for the 40-year rotations, no difference in soil pH was observed between wheat–flax–pea (8.40) and wheat–potato–lentil (8.41) (Table 1). The soil pH levels for the lentil–wheat–maize, wheat–flax–pea, and the wheat–potato–lentil rotations first decreased and then increased with soil depth, while for the wheat–maize–potato rotation, soil pH increased with soil depth. There was no significant difference in pH among soil layers for the lentil–wheat–maize rotation. The soil pH of the wheat–potato–lentil and wheat–flax–pea rotations reached its minimum value at the 0.1–0.2 m layer (8.27 and 8.28, respectively). As a general trend across all four crop rotations, the soil pH of the shallow soil layers was less than that of the deeper layers (Figure 2).

At the 1.0 m soil depth profile, for the 20-year rotations, SOC between lentil–wheat–maize (6.81 g kg^{-1}) and wheat–maize–potato (6.92 g kg^{-1}) was not significantly different, but for the 40-year rotations, it was significantly lower under wheat–potato–lentil (6.06 g kg^{-1}) than that under wheat–flax–pea (7.29 g kg^{-1}) (Table 1). In terms of soil depth, the SOC of the four crop rotations was mainly distributed at the 0–0.2 m soil layer, ranging from 7.25 g kg^{-1} to 9.35 g kg^{-1}. With an increase in soil depth, the SOC of lentil–wheat–maize, and wheat–potato–lentil rotations first increased and then decreased, while wheat–maize–potato and wheat–flax–peas rotations exhibited the reverse trend.

Overall, SOC of all crop rotations decreased with increased soil depth. The peak SOC values were found at the 0.1–0.2 m soil layer and the 0–0.1 m soil layer for the lentil–wheat–maize rotation (9.35 g kg^{-1}) and the wheat–maize–potato rotation (8.27 g kg^{-1}), respectively. The SOC of the wheat–potato–lentil and wheat–flax–pea rotations reached its minimum value at the 0.4–0.6 m soil layer and the 0.6–0.8 m soil layer, respectively, with minimum values of 5.87 g kg^{-1} for the former, and 5.02 g kg^{-1} for the latter. Compared to the lentil–wheat–maize and wheat–maize–potato rotations, the SOC of the wheat–potato–lentil and wheat–flax–pea rotations showed large fluctuations among the soil layers (Figure 2).

3.3. The Relationship of Soil pH, SOC, SWC, and SBD across All Four Crop Rotations

The SWC was positively correlated with SOC, but negatively correlated with soil pH and SBD. The SOC was negatively correlated with soil pH and SBD. The correlation coefficient of SWC and SOC was the highest (Table 2).

Table 2. The relationship among SWC, SOC, SBD and pH.

	SWC	SOC	SBD	pH
SWC	1	-	-	-
SOC	0.306 **	1	-	-
SBD	−0.135 **	−0.160 **	1	-
pH	−0.221 **	−0.295 **	0.039	1

Note: SWC represents soil water content, SOC represents soil organic carbon, and SBD represents soil bulk density, ** indicates $p < 0.01$.

4. Discussion

4.1. Effects of Different Rotation Patterns on SWC and SBD

Water over-use by plants results in a soil desiccation phenomenon that may further hamper plant growth [14,31]. Previous studies found that crop rotations could significantly affect soil water and thermal status that play an important role in crop growth in dry-land farming [39]. Crop rotations have been shown to effectively save water through mechanisms associated with alterations between shallow- and deep-rooted crops [22]. For the 20-year rotations, lentil–wheat–maize was found to save more water than wheat–maize–potato (Table 1). This outcome is due partially to the fact that the critical water demand period passed in early August [40] and partially to the fact that legumes tend to increase SWC [41]. However, the SWC of the wheat–maize–potato rotation was the lowest of the four, due to maize being a deep-rooted crop with more biomass than the others, thus requiring more water to ensure growth and survival [11,42]. However, for the 40-year rotations, SWC between wheat–potato–lentil and wheat–flax–pea was similar, suggesting that lentil and pea have a comparable level of influence on SWC. The variation in SWC with an increase in soil depth for the four crop rotations in the present study (Figure 2) was inconsistent with the findings of Cui et al. [42] who observed a decrease in SWC with soil depth. This suggests that the response of SWC to different crop rotation patterns may vary. The SWC of the four studied crop rotations fluctuated significantly at 0.1–0.4 m, results consistent with Zhang et al. [43], who reported that the combination of vegetation transpiration and soil evaporation could consume up to 90% of the total precipitation input in the upper layers. In the present study, samples were taken from late July to September when temperatures were extremely high [35], resulting in high soil evaporation. The peak SWC values were found at the 0.1–0.2 m layer for the lentil–wheat–maize and wheat–potato–lentil rotations. These results agree with Wang et al. [20], who suggested that crop rotations have a substantial effect on the soil surface layer. The SWC of the wheat–maize–potato rotation was relatively uniform among soil layers. The reason for this may be that the deep maize roots absorbed the water at a deeper soil profile to maintain growth, contributing to uniformity in SWC among the soil layers [39,44,45]. Conversely, for the maize–flax–pea rotation, SWC was significantly lower at the 0.2–0.4 m soil layer, likely because flax is a shallow plant with most of its root system concentrated in the upper 0.4 m of the soil [46]. As a result, more water is consumed in the upper soil layers to maintain flax growth [47].

SBD plays a fundamental role in determining a soil's physicochemical state. A lower SBD generally indicates better soil structure with good porosity and a soil with a greater ability to retain water and organic carbon [48–50], due to the various root systems of the crops in the rotation cycle [51]. Both 20- and 40-year rotations including a lentil crop had a higher SBD, (Table 1), suggesting that, although lentil can increase SWC, as mentioned above, they can also contribute to soil structure deterioration. The mechanisms behind this effect warrant further study. The SBD of the four crop rotations showed a similar trend, decreasing initially up to the 0.2–0.4 m soil layer and then increasing with soil depth (Figure 2). This outcome is inconsistent with that of Blanco-Canqui et al. [52], who reported that SBD of the late-maturing soybean increased as soil depth increased. This disagreement in results suggests that the relationship between SBD and soil depth is inconstant. The increase of SBD in the upper three soil layers was the result of sustained pressure from the upper layers [37]. In addition, SBD was affected by the amount of residue available in the soil; even when these residues were not mechanically mixed into the soil, but rather left on the surface, SBD decreased as organic materials were slowly incorporated into the surface soil by soil fauna [16]. The decreasing trend of SBD below 0.4 m was attributed to the decreasing effects of compaction from machines [53,54]. The peak SBD values were all found at the 0.2–0.4 m soil layer, due to the formation of a plough-pan layer, where the nutrient status was extremely poor [55].

4.2. Effects of Different Rotation Patterns on SOC and Soil pH

Vegetation plays an important role in the accumulation of SOC as it directly influences C inputs [56]. For 40-year rotations, the SOC of wheat–potato–lentil was significantly lower than that of the other one (Table 1). This may be explained by the different paths of photosynthesis between C3 and C4 plants. Potato and wheat are C3 plants, a category that exhibits a lower photosynthesis rate, lower water use efficiency, and lower capacity for SOC sequestration than the C4 category [57]. In addition, it is likely that the inclusion of some legumes such as pea into a crop rotation have positive effects on SOC, through the reduction of respiratory CO_2 flux rates of vegetation and soil [41,58]. Furthermore, Haden et al. [28] have reported that roots are the main contributor to SOC formation. Based on Hou et al. [59] and Liu et al. [60], the roots of wheat and maize are mainly concentrated in the 0–0.2 m soil layer, while for potato, roots are mainly located in the 0–0.1 m soil layer [61]. These differences in the rooting depth patterns among the studied crop types could affect the various vertical placements of SOC within the soil profile [62]. However, for the 20-year rotations, no significant difference in SOC was found between the two types (Table 1), suggesting that the lentil–wheat–maize and wheat–maize–potato rotations had considerable ability to sequester SOC, and that some legumes, such as lentil, may have little effect on SOC. These findings should be given more consideration in future research. In agreement with several other studies [2,56], the SOC across the four crop rotations showed a decreasing trend with soil depth increase (Figure 2), suggesting that the contribution of the litter and humus layer and microbial decomposition of organic matter to SOC is most active on the soil surface [63]. This indicates that SOC in the study area is sensitive to changes in management practice [57].

Soil pH directly affects crop growth and nutrient circulation [64]. In terms of the 20-year rotations, soil pH of wheat–maize–potato was higher than that of lentil–wheat–maize (Table 1). This may be due to the fact that the potato crop in the wheat–maize–potato rotation tends to consume more water, resulting in a generally higher soil salinization and soil pH [12,65]. Higher soil pH tends to reduce nutrient availability and influence soil quality, and thus, the wheat–maize–potato rotation may not be helpful for maintaining soil quality. However, in terms of the 20-year rotations—namely, wheat–flax–pea and wheat–potato–lentil—the soil pH for the two rotations was similar (Table 1). The reason for this may be that lentil and pea have the same effect on soil pH because both crops are leguminous: legumes have roots that release protons (H^+) to the soil during the growth period [41].

The variations of soil pH and SOC with soil depth showed opposite trends (Figure 2). This may be attributed to soil pH being significantly negatively correlated with SOC (Table 2). The soil pH of the lentil–wheat–maize crop rotation first decreased, and then increased with soil depth, but no significant difference in soil pH among the layers was observed, likely because the lower water requirements of lentil and wheat acted to stabilize soil pH. The soil pH of wheat–maize–potato rotation increased with soil depth, which is in agreement with Godsey et al. [66]. However, for wheat–flax–pea and wheat–potato–lentil rotations, soil pH first decreased and then increased with soil depth, both reaching minimum values (8.27 and 8.28, respectively) at the 0.1–0.2 m soil layer. This is attributed to the fact that potato, wheat, flax, pea and lentil are shallow-root plants with roots that release H+, effectively reducing rhizospheric pH [67]. The soil pH at shallow layers was less than the pH at deeper layers across all four crop rotations. This may be related to above-ground crop residues; these contribute organic acids to the topsoil that tend to break down before they can acidify the deeper layers, leading to the relatively higher soil pH at the deeper layers [68].

Compared to the results of a 2018 study by Cao et al. [38] that examined SOC in forty-year-old apricot stands (8.06 g kg^{-1}) and forty-year-old poplar stands (7.31 g kg^{-1}) in the same study region (Figure 1), the crop rotations studied in the present research generated a lower SOC (Table 1). This is likely because crops are planted once a year in the study area with three to four months for fallow, resulting in a lower SOC accumulation as a result of fewer C inputs [2]. This suggests that, in the study region, unsustainable crop rotations would contribute to a significant reduction in SOC sequestration [15]. Although all four examined crop rotations were not equally beneficial for SOC sequestration, the maize–flax–pea rotation was the best option for reducing SOC losses in the study area soil.

4.3. Tradeoff between SOC and SWC under Four Rotation Patterns

It is predicted that temperatures will increase and that precipitation will decrease significantly over the next 40 years across the Loess Plateau, creating optimal conditions for increasingly severe droughts [19,20]. In the present study, SOC was positively correlated with SWC (Table 2) and negatively correlated with SBD and soil pH—results consistent with Suuster et al. [48]. Tranter et al. [69] reported that this negative correlation was the result of soil aggregation. From this perspective, the lentil–wheat–maize rotation was expected to improve SOC sequestration, given its higher SWC. However, the results of the present study do not support this hypothesis (Table 1). This contradiction suggests that SWC is not the only factor that can influence SOC sequestration.

To further study the effects of soil factors on SOC, it was necessary to establish regression equations for SOC, SWC, soil pH, and SBD. In the present study, SOC was set as the dependent variable for each of the four crop rotation patterns (Y_1, Y_2, Y_3 and Y_4, respectively), and SWC (X_1), soil pH (X_2) and SBD (X_3) were set as independent variables. The regression relationship at $p < 0.05$ was interesting (Table 3); SOC was found to be influenced by different factors simultaneously. SOC under lentil–wheat–maize and wheat–potato–lentil rotations was co-influenced by SWC, soil pH, and SBD, while SOC under wheat–maize–potato and wheat–flax–pea rotations was co-influenced by SWC and soil pH (Table 3). In terms of water conservation, the present study found the lentil–wheat–maize rotation to be optimal. However, in terms of potential SOC sequestration, the maize–flax–pea was superior to the other rotations (Table 1).

While the ecological benefits of different crop rotation patterns are extremely important to explore, it is also critical to address the economic aspects of the practice, especially as Huining County is a traditional agricultural region in which crop products are the main source of income. According to the crop yield and market price reports from the Bureau of Agriculture in Huining County (Table 4), the economic value of the four primary regional crops can be ordered as: potato > maize > wheat > flax. However, compared to the other crops on the list, maize tends to consume more water, while potato can reduce SOC sequestration potential, suggesting that higher crop yield and economic value may come at the price of diminished SWC and SOC sequestration potential. Policy makers, therefore, should make decisions cautiously; soil water is a valuable resource that can limit future agricultural development in arid and semi-arid regions [42,70]. Considering water conservation, SOC sequestration, and the economic value of crops simultaneously, the results of the present study suggest that the lentil–wheat–maize and maize–flax–pea rotations are optimal for the study area.

Table 3. Regression analysis of soil physical and chemical factors among crop rotations.

Crop Rotations	Regression Equation	Standardization Factor	R^2
Lentil–wheat–maize	$Y_1 = 79.15 + 35.36X_1 - 7.62X_2 - 9.84X_3$	$X_1 = 0.193$; $X_2 = -0.195$; $X_3 = -0.172$	0.14
Wheat–maize–potato	$Y_2 = 68.41 + 59.43X_1 - 7.82X_2$	$X_1 = 0.325$; $X_2 = -0.312$	0.27
Maize–flax–pea	$Y_3 = 69.82 - 7.71X_2 + 24.97X_1$	$X_2 = -0.388$; $X_1 = 0.230$	0.26
Wheat–potato–lentil	$Y_4 = 35 + 41.35X_1 - 3.09X_2 - 5.74X_3$	$X_1 = 0.261$; $X_2 = -0.236$; $X_3 = -0.204$	0.15

Table 4. The price and yield of different crops.

Crops	Price (Yuan RMB)	Yield (kg/hm^2)
wheat	1.1	8400
maize	0.9	15,300
flax	2	3300
potato	0.45	66,000

Note: The source of the yield data is from the Bureau of Agriculture in Huining County.

5. Conclusions

The present study found the lentil–wheat–maize rotation to be better suited for water conservation, while the wheat–flax–pea rotation was superior in terms of SOC. After considering the tradeoffs between ecological and economic benefits among the four studied crop rotations, the researchers suggest that these two types of rotation are most appropriate for concurrent economic and environmental development in the study area.

Sampling time and rainfall may affect the vertical distribution of soil physical and chemical properties across all crop rotations; the samples in the present study were taken at the later stage of crop growth. Further studies are required to accurately compare the differences in SWC, SBD, soil pH, and SOC between different crop rotations across the entire growing season, and other factors that influence SOC, such as roots, microbes, and crop water requirements, which were not considered in the present study, should be taken into consideration in future research.

Author Contributions: Conceptualization, C.W. and J.C.; Methodology, J.C.; Validation, J.C.; Formal Analysis, C.W., X.W. and Y.L.; Investigation, C.W., J.C., X.W. and Y.L.; Data Curation, C.W. and X.Z.; Writing—Original Draft Preparation, C.W.; Writing—Review and Editing, J.F.A., C.L., J.Z., Y.Z. and J.C.; Visualization, C.W.; Funding Acquisition, J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Key Laboratory of Ecohydrology of Inland River Basins, Chinese Academy of Sciences (KLERB-ZS-16-01), Opening Fund of the Key Laboratory of Land Surface Processes and Climate Change in Cold and Arid Regions, CAS (LPCC2018008), the Major Program of the Natural Science Foundation of Gansu province, China (18JR4RA002), and the Innovation Ability Program of Colleges and Universities of Gansu province, China (2019B-033).

Acknowledgments: We thank the reviewers for their valuable comments and suggestions and editors for their constructive work.

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

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