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Evaluation of the Effects of Returning Apple Shoots In Situ on Soil Quality in an Apple Orchard

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Abstract: Fruit tree shoots are potential useful resources that are rich in carbohydrates and inorganic nutrients but that are not typically utilized in sustainable agriculture. Our objective was to evaluate the soil properties and soil quality of an orchard after returning apple shoots in situ and to investigate the contribution rate of apple shoots as an exogenous source of organic carbon for fertility amendment of the apple root domain. One-year-old apple shoots were pruned in spring before budding, chopped into 10 cm sections and placed on the soil surface. Soil samples were collected in the first year and third year after returning the shoots. Principal component analysis, Pearson correlation analysis and soil quality index (SQI) comprehensive analysis methods, combined with fuzzy mathematics, were adopted to evaluate the effects of returning apple shoots on comprehensive soil quality, including the soil fertility indicators, soil exchangeable cations, soil neutral sugar and amino acids. Increases in soil organic carbon (SOC), available potassium (K), and available phosphorus (P) were observed in different layers of the orchard soil with returned shoots over time. The total nitrogen (N) content decreased by 18.75% and 13.79% in the 0–20 cm and 20–40 cm soil layers, respectively, in the first year, but increased significantly in the third year. Significant increases in exchangeable cations (Na^+, Ca^{2+}, Mg^{2+}) in the 0–20 cm soil layer were also observed in the third year after returning shoots, compared to the control. In addition, obvious accumulation of glucose and xylose was observed in the 0–20 cm soil layer compared to the controls in the third year after returning shoots. The total water-soluble free amino acid contents in the third year after returning shoots were 1.08- and 1.16-times higher, respectively, than those of the controls in the 0–20 cm and 20–40 cm soil layers. The SQI in the third year was higher than that of the other treatments in the 0–20 cm soil layer. This study suggests that abandoned apple shoots used as a supplementary carbon source for orchards enhanced the soil fertility of different soil layers, regulated the soil micro environment, and improved the overall soil quality.

Keywords: apple shoots; exogenous organic carbon; fuzzy mathematics; soil chemical properties; soil quality

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1. Introduction

Soil quality is the integrated effect of management of the main soil properties that determine crop productivity [1,2]. Land use and management practices greatly impact the direction and degree of soil quality changes in time and space [3,4]. In recent years, high-density cultivation and the excessive use of chemical fertilizers have increased the harvest index per unit area, increased the loss of soil carbon, and led to the deterioration of soil quality in orchards [5]. These negative effects disrupt the circulation of matter and energy in the orchard ecosystem, inhibiting the development of fruit trees. Effective measures to ensure adequate soil carbon content, maintain soil fertility levels in orchards, and improve the comprehensive quality of orchard soil are urgently needed in modern orchard management.

Plant residue is one of the most important organic carbon resources and plays an important role in improving soil quality in agricultural production by remediating soil carbon loss. Plant residue has a notable effect on soil active organic carbon components by optimizing the structure of soil, promoting nutrient cycling, increasing the effectiveness of nutrients for plants and improving the level of soil fertility [6–8]. Using 14 different species of litter as the research objects, Reich et al. [9] determined that changes in species can affect soil structure and nutrient availability due to differences in the diversity of plant tissue and the quantity and quality of debris. Uselman et al. [10] also reported that plant material diversity affects the cycling of soil carbon and nutrients and that degradation products of roots and leaves are an important source of soil-soluble inorganic phosphorus. In addition, plant carbon eventually forms stable components of carbon stored in the soil. The increases in cotton yields under hairy vetch (*Vicia villosa* Roth.) as groundcover were equal to those produced by regular fertilizing, and the higher residue inputs improved soil quality by 5% compared to no cover [11]. Returning plant residues improve the soil environment and increase the soil health level, thus ensuring the continuity and effectiveness of the soil nutrient supply [12,13].

Assessing the influence of plant residue on soil quality is difficult because soil quality depends on a large number of physical, chemical, and biological properties [14]. Among these properties, soil chemical properties are considered the most important [15,16]. Soil organic C is the most widely acknowledged indicator of soil quality [17]. Neilsen et al. [18] used soil organic C, N, P and K as key indicators of changes in the soil environment. The content and proportions of soil neutral sugars reflect biological residues in plant residues in soil [19]. In pure Chinese fir systems, a lack of amino acids is a crucial indicator of the degeneration of soil fertility [20]. Furthermore, each of these properties is reproducibly measurable.

Fruit tree branches are rich in organic matter and inorganic nutrients, such as cellulose, lignin, protein, carbohydrate and fat [21]. The estimated area of apple cultivation in China is 2.5 million hectares. Most of the pruned shoots in orchards each year are discarded as waste or burned, resulting in wasted resources. Returning pruned shoots would add carbon content to orchard soil and might improve the level of soil fertility, similar to coarse woody debris in forest ecosystems [22,23]. However, changes in soil nutrients in time and space and the effects of returning abandoned apple shoots on orchard soil quality are yet to be investigated.

The aims of this study were to conduct a comprehensive evaluation of soil quality after returning abandoned shoots by investigating changes in soil nutrients, soil neutral sugars, amino acids and chemical indicators as short-term indicators of soil quality. In addition, this research will provide farmers and researchers with a theoretical basis for the comprehensive utilization of organic carbon.

2. Materials and Methods

2.1. Study Site

This experiment was conducted at the Shenyang Agriculture University, Shenyang, Liaoning Province, China. The experimental site is located in the apple orchard of Shenyang Agricultural University (4149′ N, 12334′ E, 76.2 m a.s.l.). The area is in the middle east direction of the Liaohe plains, and is characterized by a warm, humid and semi-humid continental monsoon climate with an average yearly sunshine duration of 2372 h, 146–163 d annual frost-free period, and annual mean air temperature and precipitation of 8.1 °C and 721 mm, respectively. The rainy season generally occurs from early August to September. The soil consisted of brown loam.

2.2. Study Materials and Research Design

The experiment was conducted from 2012 to 2015. The investigated species of interest were *Malus domestica* Borkh./*M. baccata* Borkh., which were planted in 2009. The orchard area was 1 ha. The apple trees were planted in the north–south direction, at a density of 1.0 m (in a row) × 1.5 m (between-row). Five fruit trees with no visible signs of pest and disease were randomly selected from the orchard for an in situ shoots cover experiment. The annual shoots, which were pruned in early spring before budding, were used as covering material. This material was then cut into 10-cm-long pieces, placed 1 m^2 around the apple tree trunk (leave a 5 cm gap), and the covering thickness was 10 cm; meanwhile, the soil covered the surface of shoots so as to not expose them to the air. No shoot covering was considered as control. Each fruit tree was a treatment plot, replicated 5 times. Shoots were returned to the orchard in May 2012 and May 2014, respectively. Other forms of soil management were the same for all treatments. Nutrient management was inorganic fertilizer (N 300 $kg \cdot hm^{-2}$, P_2O_5 150 $kg \cdot hm^{-2}$, K_2O 300 $kg \cdot hm^{-2}$) spread in March.

In May 2015, soil samples were randomly selected from the trunk at a distance of 50 cm with soil layers of 0–20 cm and 20–40 cm, repeated 3 times. The soil samples were screened through a 2 mm sieve in the field, then mixed thoroughly and brought back to the laboratory. The samples (approximately 1.5 kg) were air-dried and stored at room temperature for further analysis. The basic properties of annual shoots which were used as experimental material are shown in Table 1.

Table 1. Properties of the 3 years of experimental material (mean ± SD).

	Total C (%)	Total N ($g \cdot kg^{-1}$)	Total P ($g \cdot kg^{-1}$)	Total K ($g \cdot kg^{-1}$)	Lignin (%)	Cellulose (%)	Hemicellulose (%)
Annual shoot	48.00 ± 2.21	4.32 ± 0.35	1.30 ± 0.11	5.92 ± 0.39	30.54 ± 1.22	39.04 ± 2.11	19.28 ± 1.68

2.3. Assay Method

2.3.1. Shoots Nutrient Content, Soil Fertility and the Content of Exchangeable Cations

Soil organic carbon (SOC) content was determined by $K_2Cr_2O_7$ dilution heat method proposed by Bao [24]. Soil total nitrogen (N) content was estimated using the method of Kelvin, assayed with SKD-200 semi-micro Kjeldahl nitrogen determination apparatus (Shanghai Pei'ou Analysis Instrument Co., Ltd., Shanghai, China) after soil sample digestion [24]. Soil available phosphorus (P) content was determined using Olsen et al.'s [25] method, and was extracted by $NaHCO_3$, and measured using a UV-2300 UV-vis spectrophotometer (Shanghai Tianmei Scientific Instrument Co., Ltd., Shanghai, China). Soil available potassium (K) [26], exchangeable calcium (Ca), magnesium (Mg), and sodium (Na) [27] after being extracted by ammonium acetate were determined using an ICE-3500 atomic absorption spectrometer (Thermo Fisher Scientific, Waltham, MA, USA).

Total C, N, P and K contents of shoots were determined by $K_2Cr_2O_7$-H_2SO_4 oxidation method [24], H_2SO_4-H_2O_2 distillation method [24], H_2SO_4-H_2O_2 vanadium molybdate yellow colorimetric method [24] and H_2SO_4-H_2O_2 flame photometry [24], respectively. The lignin, cellulose and hemicellulose contents of shoots were measured using a FIWE3/6 fiber tester (Shanghai Hongji Instrument Equipment Co., Ltd., Shanghai, China).

2.3.2. Soil Neutral Sugar Contents

Neutral sugar analysis followed the procedure of Zhang et al. [28] with a gas chromatography method. The neutral sugar derivatives were separated on an Agilent 7890A gas chromatographer (GC Agilent Tech. Inc., Santa Clara, CA, USA) equipped with a HP-5 fused-silica column (30 m × 0.25 mm × 0.25 µm, Agilent Tech. Inc., Santa Clara, CA, USA) and a flame ionization detector. Helium gas was used as a carrier gas with a constant column flow of 1.2 mL min^{-1}. The injector was set at 250 °C and the injection volume was 1.0 µL.

2.3.3. Soil Water-Soluble Total Free Amino Acid Contents

Total water-soluble free amino acids of orchard soil were estimated using a L-8800 amino acid analyzer (Hitachi Limited, Tokyo, Japan), using the method of Engel et al. [29].

2.4. Data and Statistical Analysis

The total data set for the soil quality evaluation included the SOC, total N, available P, available K, exchangeable Ca, Mg and Na, soil neutral sugars and soil amino acids. Although a more balanced data set has to include soil physical, chemical and biological properties, we focused on chemical soil parameters because the most important factors that have been reported to influence and manifest in crop growth characteristics are chemical properties [30].

To eliminate the effects of different indicator units, some standard scoring functions were used to assign a score of between 0.1 and 1.0 to each indicator [31,32]. Standard S was used in soil indicators [33], which is described as follows:

$$F(X) = \begin{cases} 1 \\ 0.9 \times (X_{max} - X)/(X_{max} - X_{min}) + 0.1(X_{max} \geq X \geq X_{min}) \\ 0.1 \end{cases}$$

$$F(X) = \begin{cases} 1 \\ 0.9 \times (X - X_{min})/(X_{max} - X_{min}) + 0.1(X_{max} \geq X \geq X_{min}) \\ 0.1 \end{cases}$$

X_{min} and X_{max} represent the value of the minimum and maximum soil indicators, which are soil quality evaluation indicators of the threshold, respectively.

The importance of each soil quality indicator is different; usually, the weight coefficient is used to represent the degree of significance of every indicator. In this study, the principal component load, contribution rate of variance and cumulative contribution rate of variance of the soil quality index were calculated using principal component analysis in SPSS software, and then we calculated the weight in the evaluation of soil quality index in soil quality:

$$Wi = CCi/\sum_{i=1}^{n} CCi$$

CCi is the factor loading of soil quality factor for the i item.

We then applied the fuzzy weighted synthesis method in fuzzy mathematics [34,35] to build up a comprehensive evaluation of the soil quality mathematical model:

$$\text{SQI} = \sum_{i=1}^{n} Wi \times F(Xi)$$

SQI is the soil quality index parameter; Wi is the weight vector for quality factors; $F(Xi)$ is the indicator membership value; i is a soil property and n the number of soil properties. High soil quality index indicates better soil quality [36–38].

Statistical analyses were performed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA) and Excel 2003 (Microsoft, Redmond, WA, USA). The differences in the soil characteristics among treatments were examined using one-way analysis of variance (ANOVA), followed by a Tukey's honestly significant difference test at $p < 0.05$. A Pearson's correlation analysis was used to determine the meaningful soil indicators for inclusion in the SQI. Principal component analysis was also used in order to select the most appropriate soil quality indicators. Experiments performed in this study had at least three independent replications for each sample. Figures were plotted using Sigmaplot 10.0 (Systat Software Inc., San Jose, CA, USA).

3. Results

3.1. Variability of Soil Nutrient Properties

The total N content in the orchard soil significantly decreased by 18.75% and 13.79% in the 0–20 cm and 20–40 cm soil layers, respectively, 1 year after returning abandoned apple shoots compared to the controls without returning abandoned shoots (Figure 1a). However, the total N content increased significantly by 11.54% and 21.28% in the 0–20 cm and 20–40 cm soil layers, respectively, 3 years after returning abandoned apple shoots compared to the control. These results indicate that the abandoned apple shoots initially competed for N from the soil during the shoot degradation process but eventually promoted the accumulation of N in the soil as the degradable material contained in the shoots was released into the soil over 3 years.

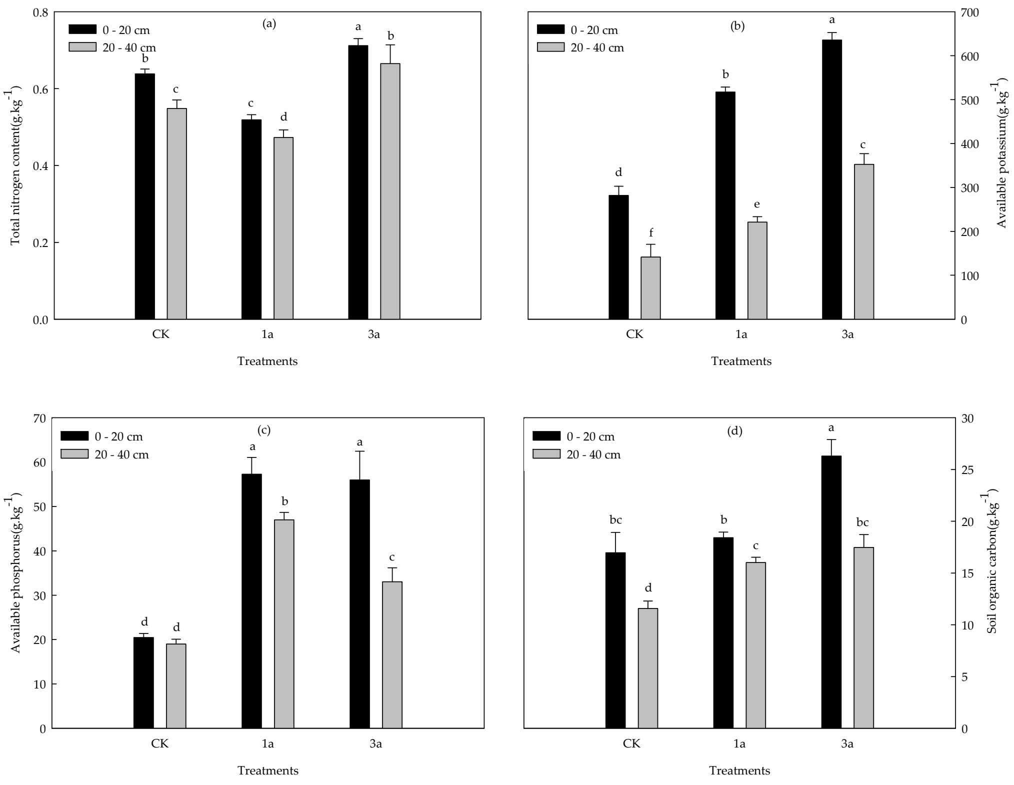

Figure 1. Effects of returning shoots on the contents of total N, organic C, available P and available K of the soil. (**a**): Total nitrogen content; (**b**): Available potassium content; (**c**): Available phosphorus content; (**d**): Soil organic carbon content; CK: control; 1a: shoots returned for 1 year; 3a: shoots returned for 3 years. Different lowercase letters in the same figure indicate significant differences at the 0.05 level.

The in situ return of abandoned apple shoots had the greatest effect on the available K content in the soil, which increased significantly in both layers compared to the control (Figure 1b). This notable contribution of returning apple shoots in situ on the available K content at different orchard soil layers was beneficial for the physiological function of the apple roots distributed among the different soil layers.

According to Figure 1c, as the in situ duration of returned apple shoots in the orchard increased, the available P content in the soil at different soil layers increased compared to the control. The available P content in the soil at each soil layer with shoots returned in situ was maximal at 1 year after return and decreased at 3 years after return. However, the decrease in the available P of the topsoil layer was not significant.

The organic C content of the orchard soil increased in both the deep soil and topsoil layers as the duration of returned apple shoots in situ increased (Figure 1d). Three years after the return of shoots in situ, the soil organic C content in each soil layer reached the maximum value and was significantly higher at the 0.05 level than the values at 1 year and in the control. These results demonstrate that returning shoots in situ increased the soil organic C content and promoted the ecological restoration of the orchard.

3.2. Variability of Soil Exchangeable Cations

After returning shoots in situ for 1 year, the exchangeable cation Na^{+} of the topsoil (0–20 cm) was 84.4% higher than the control, but the exchangeable cation Ca^{2+} and exchangeable cation Mg^{2+} were lower. Three years after return, the exchangeable cation (Na^{+}, Ca^{2+}, Mg^{2+}) content in the topsoil differed significantly at the 0.05 level. The content of

Mg^{2+} in the soil in the 20–40 cm layer increased significantly with increasing in situ time, whereas the contents of the other two cations decreased to a minimum value after 1 year but increased 3 years later (Table 2).

Table 2. Effects of returning shoots on the content of exchangeable cations (mean ± SD). Different lowercase letters in the same figure indicate significant differences at the 0.05 level.

Treatment	Soil Layer (cm)	Ca^{2+} ($mg\cdot kg^{-1}$)	Na^{+} ($mg\cdot kg^{-1}$)	Mg^{2+} ($mg\cdot kg^{-1}$)
CK	0–20	420.64 ± 6.15 b	135.00 ± 10.14 c	84.92 ± 3.52 b
	20–40	444.21 ± 17.22 a	228.89 ± 17.82 b	70.69 ± 3.21 cd
1 year	0–20	394.03 ± 8.96 c	248.89 ± 11.82 b	66.99 ± 1.97 d
	20–40	407.14 ± 8.03 bc	158.33 ± 10.00 c	72.21 ± 1.49 c
3 years	0–20	439.91 ± 3.75 a	280.00 ± 8.33 a	89.84 ± 1.12 a
	20–40	414.73 ± 6.57 b	238.89 ± 10.00 b	87.13 ± 1.10 ab

3.3. Variability of Soil Neutral Sugars

Six types of neutral sugars were detected in this study (Table 3). In the 0–20 cm soil layer, glucose and xylose of plant origin increased by 3.14- and 2.68-fold, respectively, after 3 years. The levels of all other sugars were highest after 1 year and decreased after 3 years. In the 20–40 cm soil layer, the content of each neutral sugar exhibited significantly greater increases, with the exception of arabinose and rhamnose.

Table 3. Effects of returning shoots on the concentrations of neutral sugars (mean ± SD). Different lowercase letters in the same figure indicate significant differences at the 0.05 level.

Treatment	Soil Depth (cm)	Concentrations of Neutral Sugars ($mg\cdot g^{-1}$)					
		Glucose	Arabinose	Galactose	Mannose	Xylose	Rhamnose
CK	0–20	0.44 ± 0.05 d	0.82 ± 0.11 bc	0.26 ± 0.03 e	0.28 ± 0.09 c	0.38 ± 0.07 d	0.46 ± 0.11 b
	20–40	0.44 ± 0.07 d	0.91 ± 0.06 b	0.35 ± 0.02 d	0.29 ± 0.05 c	0.32 ± 0.05 d	0.49 ± 0.07 b
1 year	0–20	0.70 ± 0.11 c	1.23 ± 0.14 a	0.69 ± 0.09 bc	0.44 ± 0.07 a	0.67 ± 0.09 c	0.71 ± 0.09 a
	20–40	1.36 ± 0.07 b	0.68 ± 0.05 d	0.73 ± 0.07 b	0.38 ± 0.05 b	1.07 ± 0.15 b	0.32 ± 0.06 c
3 years	0–20	1.38 ± 0.12 b	0.74 ± 0.03 cd	0.67 ± 0.07 c	0.39 ± 0.03 ab	1.02 ± 0.11 b	0.39 ± 0.08 bc
	20–40	1.76 ± 0.25 a	0.86 ± 0.01 bc	0.90 ± 0.05 a	0.35 ± 0.04 b	1.25 ± 0.07 a	0.33 ± 0.07 c

The ratio of 6-sugar/5-sugar shows the source of carbohydrates in the soil as well as the change in SOC. The ratio (G + M)/(A + X) shows the source of carbohydrates in soil. The ratio of (G + M)/(A + X) ranged from 0.45 to 0.60 and 0.51 to 0.64 in the 0–20 cm and 20–40 cm soil layers, respectively (Figure 2). Compared to the soil without returned shoots, the ratio of (G + M)/(A + X) increased 1 year to 3 years after the return of shoots. Most of the plant residue continued to remain in the soil due to microbial assimilation, resulting in a greater contribution to the accumulation of SOC from neutral sugars originating from the soil microorganisms.

3.4. Variability of the Total Water-Soluble Free Amino Acids Content in the Orchard Soil

The total water-soluble free amino acid content decreased by 16.4% in the 0–20 cm soil layer 1 year after returning shoots and was lower than the control in the 20–40 cm soil layer, although this difference was not significant. Three years after returning shoots, the soil amino acid content was significantly increased in the 0–20 cm and 20–40 cm layers, by 1.08- and 1.16-times that of the control soil, respectively. The changes in amino acid content are likely attributable to the abundance of neutral amino acids (Figure 3).

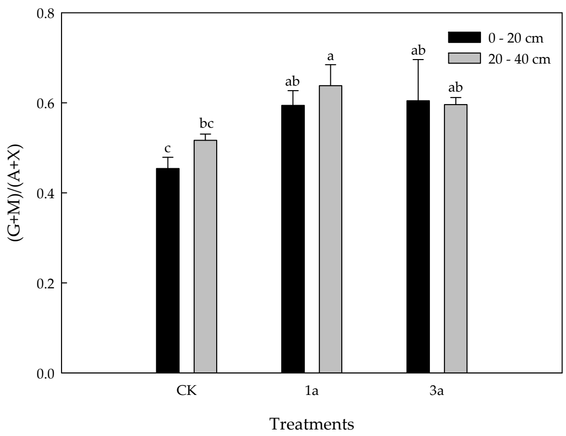

Figure 2. The effects of treatment on the ratio of (G + M)/(A + X). G means galactose; for the ratio >2, neutral sugars come from microorganisms; for the ratio <0.5, neutral sugars come from plants. CK: control; 1a: shoots returned for 1 year; 3a: shoots returned for 3 years. Different lowercase letters in the same figure indicate significant differences at the 0.05 level.

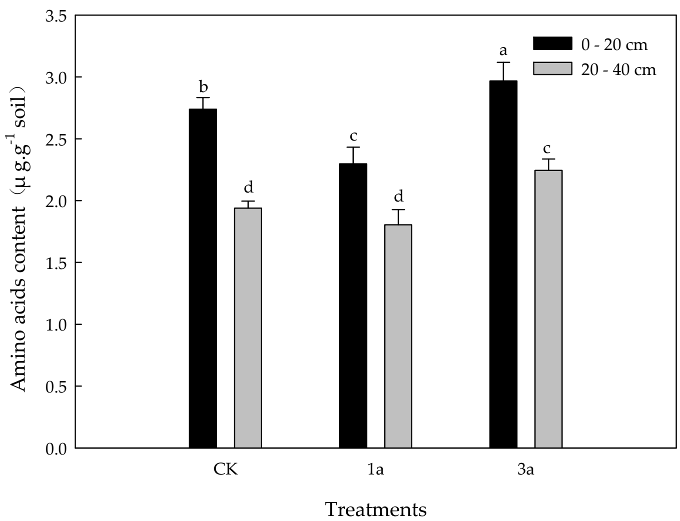

Figure 3. Effects of returning shoots on the soil amino acids content. CK: control; 1a: shoots returned for 1 year; 3a: shoots returned for 3 years. Different lowercase letters in the same figure indicate significant differences at the 0.05 level.

3.5. Correlation Coefficients between Various Soil Nutrient Indices

Pearson correlation analysis of the soil quality indices demonstrated that the SOC content had a significant correlation ($p < 0.05$) with soil total N, glucose, and xylose content and a highly significant correlation ($p < 0.01$) with the available P, available K, exchangeable Mg^{2+} and water-soluble free amino acid contents. The contents of soil total N, available P, and available K are important indicators of soil fertility. The total N content in the soil had a significant positive correlation (0.802) with the total amino acid content and significant correlations with the available P and available K contents (0.759). There were various connections among the other orchard soil nutrient indices (Table 4). The correlations among SOC, N, P, and K, key indicators of soil quality or fertility, indicate coordination of growth and decline, and could be used to assess soil quality.

3.6. Soil Quality Index (SQI) Parameter

3.6.1. Weight, Eigenvalue and Contribution Rates of the Evaluation Index

For 14 chemical-property indices of soil quality, the first four principal components (SOC, TN, AP, AK) were all greater than 1, and the cumulative contribution of the variance was greater than 91.25% (Table 5), thus reflecting variation of the system [39]. The contribution rate of their variance indicated that the impact power of each principal component on assessing soil quality followed the order principal component 1 > principal component 2 > principal component 3 > principal component 4, and the main soil quality factors were soil amino acids, soil total N, exchangeable Mg^{2+} and organic carbon.

3.6.2. Soil Quality Comprehensive Index

The set weighted synthesis method was adopted to establish a comprehensive evaluation model of soil quality. According to Figure 4, the return of abandoned shoots had an obvious impact on orchard topsoil (0–20 cm) quality, which increased 5.7% and 8.6% 1 and 3 years after return, respectively. However, the soil quality comprehensive index exhibited smaller changes in the 20–40 cm soil layer. Thus, as the return time increases, the improvement to orchard topsoil quality is greater than that for deeper soil.

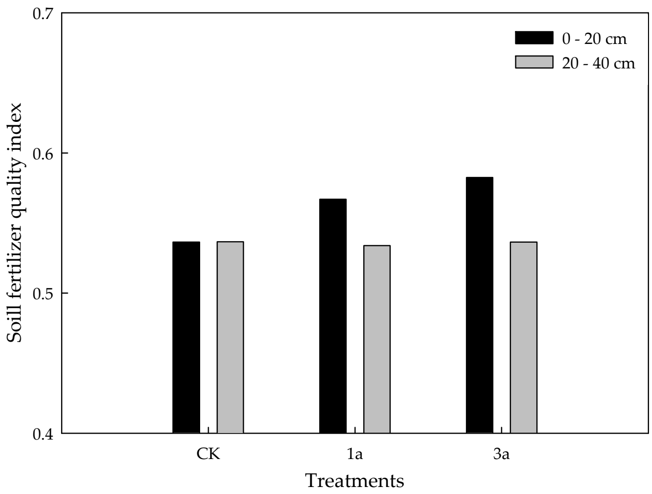

Figure 4. Soil quality comprehensive index after returning shoots for different times. CK: control; 1a: shoots returned for 1 year; 3a: shoots returned for 3 years.

Table 4. Correlation coefficients between various soil nutrient indices (* $p < 0.05$; ** $p < 0.01$).

	SOC	TN	AP	AK	ACa	ANa	AMg	Rhamnose	Arabinose	Mannose	Glucose	Galactose	Xylose	Amino Acids
SOC	1													
TN	0.562 *	1												
AP	0.605 **	−0.074	1											
AK	0.746 **	0.495 *	0.759 **	1										
ACa	0.126	0.448	−0.376	−0.094	1									
ANa	0.342	0.450	0.432	0.664 **	0.265	1								
AMg	0.608 **	0.880 **	−0.093	0.354	0.361	0.188	1							
Rhamnose	−0.293	−0.119	−0.067	0.121	−0.154	−0.079	−0.342	1						
Arabinose	−0.396	−0.223	0.151	0.229	−0.355	0.332	−0.529 *	0.694 **	1					
Mannose	0.411	−0.154	0.877 **	0.663 **	−0.422	0.413	−0.207	0.029	0.317	1				
Glucose	0.533 *	0.241	0.472 *	0.326	−0.103	0.344	0.383	−0.760 **	−0.360	0.440	1			
Galactose	0.381	0.021	0.622 **	0.400	−0.376	0.377	0.093	−0.503 *	0.009	0.681 **	0.906 **	1		
Xylose	0.583 *	0.221	0.542 *	0.382	−0.248	0.265	0.376	−0.693 **	−0.332	0.491 *	0.975 **	0.914 **	1	
Amino acids	0.660 **	0.802 **	0.168	0.695 **	0.269	0.322	0.691 **	0.255	−0.065	0.087	−0.058	−0.167	−0.016	1

Table 5. Rotated factor capacity, weight, eigenvalue and contribution rates in principal component analysis of soil quality factors.

Soil Property	Rotated Factor				Common Factor Variance	Norm Value	Weight
	1	2	3	4			
SOC	0.775	0.357	0.408	−0.018	0.896	2.054	0.070
TN	0.875	0.120	−0.208	0.275	0.900	2.117	0.070
AP	0.134	0.216	0.882	0.180	0.876	1.569	0.069
AK	0.620	−0.008	0.664	0.390	0.978	1.874	0.077
ACa	0.378	0.034	−0.695	0.340	0.743	1.505	0.058
ANa	0.280	0.144	0.192	0.905	0.955	1.215	0.075
AMg	0.855	0.338	−0.224	−0.048	0.898	2.138	0.070
Rhamnose	−0.021	−0.934	0.191	0.066	0.914	1.754	0.072
Arabinose	−0.350	−0.584	0.370	0.528	0.879	1.586	0.069
Mannose	−0.021	0.163	0.887	0.265	0.885	1.537	0.069
Glucose	0.139	0.919	0.300	0.149	0.977	1.805	0.076
Galactose	−0.082	0.735	0.572	0.245	0.934	1.689	0.073
Xylose	0.167	0.867	0.425	0.035	0.962	1.794	0.075
Amino acids	0.940	−0.268	0.126	0.089	0.978	2.274	0.077
Eigenvalue	5.521	3.402	2.787	1.063			
Contribution rate of variance (%)	39.44	24.30	19.91	7.59			
Cumulative (%)	39.44	63.74	83.65	91.25			

4. Discussion

In recent years, plant residues have been returned to orchard soil as an organic material to efficiently increase SOC [40,41]. Zhao et al. [42] reported that covering the ground with straw efficiently increases SOC content in farmland. Moreover, higher organic carbon accumulation in the soil contributes to straw decomposition and can reduce the loss of soil nutrients due to leaching. Further research indicated that straw is a C source for microbial activity and provides a nucleation center for aggregation; the resultant enhanced microbial activity induces the binding of the residue and soil particles into macroaggregates that contribute to the accumulation of labile C [41]. The abandoned shoots of fruit trees are recommended as a type of available organic residue to improve soil nutrition and maintain the balance of soil nutrient output and input [11,43]. In our study, returning shoots to the orchard increased the organic carbon content in the topsoil layer (0–20 cm), but there was no significant difference compared to the control after shoots were returned in situ for 1 year. The C/N ratio of apple shoots is relatively high, and thus the return of apple shoots to the soil might stimulate the ability of microbes to utilize the soil N and simultaneously generate a positive priming effect, thus enhancing the mineralization of SOC [44,45]. Thus, the N content in the soil decreased, whereas the SOC content increased to a lesser extent. Three years after returning the shoots, N residues in the soil and substances that are difficult to decompose underwent slow and complicated changes to form difficult-to-decompose humic substances, whose decomposition depends on the action of microorganisms to improve SOC content and affect the types of SOC [46,47]. Eventually, these changes resulted in a significant increase in the SOC content in the surface ($p < 0.05$). Compared to the surface, the external environment had less of an influence on the deeper soil layer (20–40 cm), which exhibited a slowly increasing trend year by year. Thus, the return of apple shoots to the orchard can be considered an effective measure to improve soil fertility.

Plant residue plays an important role in determining nutrient cycling, balance and maintaining the ecosystem functions of agriculture and forestry ecosystems [48]. Forest residue decomposition and nutrient release not only affect the storage characteristics of soil nutrients but also improve the soil nutrient supply capacity [49,50]. The results of our study, which are similar to those of previous studies of plant residue nutrient release [51,52], demonstrated that the contents of available P, available K, glucose, galactose, mannose, and xylose increased compared to the control 1 year after returning shoots to the orchard soil. The slow degradation of the nutrient-rich shoot residue under the natural environment is likely the main reason for the changes in the soil nutrient content. Over time, in addition to exchangeable Ca, arabinose and rhamnose, the soil nutrient index in the orchard with returned shoots was significantly higher than that in the orchard without returned shoots. Increases in soil mineral elements and neutral sugar content can change the soil exchange site number, biochemical processes and the activity of biological communities [9]. During the return of shoots into the orchard, the soil available K content increased by 1.83- and 2.25-fold after 1 year and 2.49- and 1.56-fold after 3 years in the 0–20 cm and 20–40 cm soil layers, respectively. The reduction of N content in the soil in the early period of return may also be due to antagonism between high concentrations of K and soil NH_4^+ in competition for the soil exchange area. Three years after return, the structural stability of the shoots was destroyed, and a large number of elements were released back into the soil; thus, the inhibitory effect on nutrients was abated, and there was a significant difference between the nutrient contents in the treated soil compared to the control [53]. In addition, because the apple shoots were covered with topsoil, the changes in nutrients were more significant closer to the surface.

Soil quality depends on a large number of physical, chemical, and biological properties, of which the chemical index is the dominant factor [54]. The SQI (soil quality comprehensive index method) is one of the most commonly used methods to evaluate soil quality [31,36]. Ngo-Mbogba et al. [55] assessed soil quality under different land cover types and their relationship in South Cameroon using the SQI and determined that groundcover led to significant increases in the comprehensive quality of the soil compared to the secondary forest and primary forest. Moreover, the organic matter, available P, Ca, and pH, which in combination accounted for 88.5% of the variation of soil quality, were considered the main contributors to soil quality. Sharma et al. [2] concluded that the soil-available K content was a key factor in determining the quality of soil and rated its contribution as 17%. In the present study, Pearson correlation analysis revealed that all parameters used to assess soil quality, except exchangeable Ca and rhamnose, were significantly correlated with soil organic matter, total N, available P and available K. These results indicate that the soil quality index can reflect the soil nutrient supply characteristics. Principal component analysis (PCA) was used to select the most appropriate indicators controlling soil quality, which demonstrated that soil total N, amino acids, exchangeable Mg, and organic carbon were the main driving factors of soil quality. Soil amino acids, which were the first principal component factor with a loading that reached 0.940, were significant in the soil quality evaluation system. SQI analysis demonstrated that 1 and 3 years after returning shoots, the soil quality of the orchard's surface soil (0–20 cm) was increased by 5.7% and 8.6%, respectively, compared to the control. Thus, returning shoots to the orchard soil effectively improved the soil chemical properties and enhanced the comprehensive soil quality of the orchard, with more obvious effects as the duration of return increased. However, in this research, only the soil chemical index was used to assess the comprehensive soil quality in the orchard; comprehensive analyses of the associated biological and physical indices are still lacking, and further studies are needed.

5. Conclusions

Returning apple shoots to the orchard increased the topsoil nutrient content in the surface layer (0–20 cm) but had no obvious effect on the 20–40 cm soil layer. The results of the analysis of the soil quality index by the comprehensive quality assessment system revealed that in the 0–20 cm soil layer, the soil comprehensive quality increased with time after the return of shoots, whereas the soil quality of the deeper soil layer had no obvious change. Returning abandoned apple shoots to the orchard is an important supplementary measure for increasing the soil carbon pool and contributes to increasing the soil nutrient contents and soil quality, thus improving the soil conditions of the apple root system.

Author Contributions: E.Z. compiled the original manuscript. S.L. performed most of the experiments, analyzed the data, and compiled the original manuscript. G.D. and D.L. designed the experiments and reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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