Apple Branch Decomposition and Nutrient Turnover in the Orchard Soil

Sansan Lyu,[a] Deguo Lyu,[a,b]* Guodong Du,[a,b,]* and Ye Yang [a]

Changes in the physical structure and nutrients contents of apple branches were explored after decomposition, and the soil quality of an orchard was evaluated after returning apple branches *in situ*. Scanning electron microscopy, X-ray diffractometry, and Fourier transform infrared spectroscopy were used to analyse the structural changes of the experimental material. The results showed that the structure of this material is obviously destroyed in the transverse sections and longitudinal sections. Collapsed cell walls had a negative effect on complete branches, which presented sharp decreases in cellulose contents and the partial removal of lignin and carbohydrate contents by the third year. In a final analysis of the nutrients in the branches, there was an obvious decline in macroelements (*e.g.*, phosphorus and potassium), whereas manganese, which is a limiting factor, increased by 4-fold compared with the control. The results indicated that the addition of mulch from branches can be used to maintain a high soil quality in the third year of decomposition.

Keywords: Apple branches; Structure; Nutrient; Orchard; Soil quality

Contact information: a: College of Horticulture, Shenyang Agricultural University, Shenyang 110866, Liaoning Province, P. R. China; b: Key Lab of Fruit Quality Development and Regulation of Liaoning Province, Shenyang Agricultural University, Shenyang 110866, Liaoning Province, P. R. China;
** Corresponding authors: shynydxgshzp@163.com (D. Lyu); guodong_du@163.com (G. Du)*

INTRODUCTION

Lignocellulosic biomass is inexpensive and abundant, and such material can promote higher productivity per hectare and require less financial input per unit of biomass produced (Hu and Ragauskas 2012). Fruit tree branches are rich in organic matter, and various inorganic nutrients are generated during the growth and development of branches, such as protein, carbohydrate, fat, nitrogen, phosphorus and potassium. These branches are regarded as valuable agricultural resources (Gao *et al*. 2010). Apple cultivation accounts for 2.5 million hectares in China, and a considerable amount of branches are pruned each year. Meanwhile, the common processing method is to clear the orchard, which results in a waste of resources. Thus, research on the decomposition of branches and nutrition turnover will provide a theoretical basis for the recycling of biological resources in the field of fruit cultivation.

Fruit tree branches are a major by-product of biomass pruning as an orchard management process. Branches present an accumulation of nutrients as compared with the fruit, leaves, and roots (Li *et al*. 2007). Under a permanent cover of branches, the carbon and minerals fixed in branches may be recycled. Most of the CO_2 and 40% of the light energy fixed by plants *via* photosynthesis are stored in lignin in woody plants, and the content of lignin may account for approximately 27% to 32% of the absolute dry weight (Fu *et al*. 2004). Aromatic rings and the various active side chain groups in lignin may exhibit various properties; they degrade slowly and chelate with rare elements, such as Fe,

Cu, and Zn, which ensures a supply of trace elements to growing plants (Kortekaas *et al*. 1998). Luo *et al*. (2003) reported that the contents of crude protein, crude fat, and crude fibre in apple branches were 3.19%, 2.11%, and 2.11%, respectively, whereas the crude fat and crude fibre contents of cornstalks were lower.

Sakamoto and Aoyama (2004) used apple pruning branches and poultry dung for compost, and eventually the material in the compost pile was transformed into a beneficial organic fertilizer for plant growth after 203 days. Grape branches can be used as raw material for organic compost due to their origin from plant products (Polprasert 2007). Their nutrient composition is suitable for the needs of crop growth, and their nutrient supply is absorbed and used synchronously in time and space. Finally, they can create and provide a vital natural ecological environment for plant growth. Nonetheless, using fruit branches and returning the materials directly to the soil is rare in agricultural ecosystems.

The investigation of wood decomposition has shown that species, growth conditions, and environmental conditions can affect the physical structure and chemical composition of wood anatomical structure (Schwarze 2007). The stoichiometric characteristics (C, N, and P) and the lignin and cellulose contents can be used to characterize wood matrix changes during decomposition (Meerts 2002; Augusto *et al*. 2008). Moreover, nutrient-limiting conditions can also indicate the direction of material circulation and energy flow. Therefore, differences in the chemical composition and physical structure of wood affect the anatomical structure of the material and the process of structural decomposition (Wardle *et al*. 2004; Wassen *et al*. 2005). Along with the degree of decomposition, Chang *et al*. (2015) showed that the C content in wood was significantly reduced. Moreover, dead tree boles and limbs serve as a major carbon pool, which influenced the in-stream dynamics of nitrogen and other nutrients (Elosegi *et al*. 2007; Thevs *et al*. 2011).

Although some researchers have shown the significance of branch decomposition and revealed aspects of the mechanism of branch to nutrient accumulation, theoretical research investigating the application of tree branches in orchards has been lacking, particularly for the characteristics of the material degradation process. The objective of this work was to investigate the changes in the composition of apple branches after returning them to the soil. A further goal was to explore structural changes of the apple branches, providing a theoretical basis for their application in agricultural production and offering a method to improve crop nutrient levels.

MATERIAL AND METHODS

Experimental Site

The experiment was conducted at the Shenyang Agriculture University, Shenyang, Liaoning Province, China. The experimental site was located in the apple orchard of Shenyang Agricultural University (41°49′ N, 123°34′ E, 76.2 m a.s.l.). The position is in the middle east direction of the Liaohe plains, and it has a warm, humid, and semi-humid continental monsoon climate with an average yearly sunshine duration of 2372 h, 146 to 163 d annual frost-free period, average air temperature of -11.7 °C in January and above 25 °C in July, and annual precipitation of 721 mm. The rainy season generally occurs from early August to September. The soil consists of loam with 15% of the clay content and <0.002 mm of the clay diameter. The depth of the plough layer is less than 60 cm and well drained.

Study Materials and Research Design

The experiment was conducted in 2009 using *Malus domestica* Borkh. / *M. baccata* Borkh. as the materials. The apple trees were planted based on cultivation methods in a south to the north direction at a spacing of 1.0 m (in a row) × 1.5 m (between rows). The trees grew robustly and were not impacted by disease or pests. Branches were returned to the orchard soil in May 2011. The annual branches (diameters of about 1 cm) that were pruned in early spring before emergence were used as covering materials. These materials were then cut in intervals of 10 cm and placed within a 5 cm border around the tree trunk. The area of branch coverage was 1.0 m^2, and the branch layer was 10 cm thick. Soil was then spread over the surface of branches in case they were exposed to the air. This process was repeated 5 times. In May 2014, the degradation residues of the branches were removed and regarded as treatment BR (branches returning), which were returned to the lab after cleaning the surface, drying and grinding and used to determine the branch parameters. Air-dried branches that had not been returned to the soil were designated as CK. They were collected in 2011 and stored in a valve bag.

Assay method

Scanning electron microscopy analysis

A scanning electron microscopy (SEM) analysis was performed to determine the structure of transverse sections and longitudinal sections of shoot samples using an FEI Quanta 3D FEG DualBeam microscope (FEI Company, Hillsboro, OR, USA) operated in high vacuum mode at a voltage of 5 kV. The samples were gold coated in a Denton Desk V Sputter coater (Denton Vacuum, USA) prior to analysis.

Fibre composition analysis

A cellulose, hemicellulose, and lignin analysis for the branches was performed using FIWE3/6 equipment to determine the composition of the raw fibre content (Shanghai HongJi, Shanghai, China). A paradigm (Van Soest) fibre determination method was used to determine and analyse the content of each component (Kokot *et al*. 2002).

X-ray diffractometry

X-ray diffractometry (XRD) of the branches was performed using a Bruker D8 ADVANCE X-ray diffractometer (Bruker AXS, Karlsruhe, Germany) with monochromatic CuKα radiation (λ = 0.15418 nm) generated at 40 kV and 100 mA to identify any crystallographic structures. The diffracted intensity of the samples was measured in the 2θ range between 10° and 50° at a scanning speed of 0.2°/min. The degree of cellulose crystallinity in the branches and degradation residues (expressed as the crystallinity index, CrI) was calculated from the diffraction intensities as described in Segal *et al*. (1959),

$$\mathrm{CrI} = 100 \times \left[\frac{I_{002} - I_{amorphous}}{I_{002}}\right] \quad (1)$$

where I_{002} is the intensity for the crystalline portion of cellulose at 22.5° (in most biomasses) and $I_{amorphous}$ is the minimum intensity corresponding to the amorphous portion at 18.0°.

FTIR spectroscopy

Fourier transform infrared (FTIR) analyses of the branches were performed in a PerkinElmer FTIR spectrum 100GX model (PerkinElmer, Fremont, CA, USA) to characterize their organic functional groups. The samples were ground and mixed with KBr to 0.1 wt.% and then pressed into pellets. Each spectrum represented an average of 64 scans in the IR range of 400 to 4,000 cm^{-1} at a resolution of 2 cm^{-1} (Nanda *et al*. 2014).

Branch nutrients

A representative portion of each branch sample was air dried, powdered, and passed through a 0.15-mm sieve for the nutrient content analyses. The total nitrogen content was assayed with a SKD-200 semi-micro Kjeldahl nitrogen determination apparatus (Shanghai Pei'ou Analysis Instrument Co., Ltd., Shanghai, China). The total phosphorus content was confirmed using a UV-2300 UV-Vis spectrophotometer (Shanghai Tianmei Scientific Instrument Co., Ltd., Shanghai, China) after sample digestion by H_2SO_4-H_2O_2. The total potassium, calcium, magnesium, iron, manganese, copper, and zinc contents after extraction *via* digestion were determined using an ICE-3500 atomic absorption spectrometer (Thermo Fisher Scientific, Waltham, MA, USA) (Bao 2008).

Soil quality

The soil alkali-hydrolysable nitrogen content was estimated using the alkaline hydrolysis diffusion method (Bao 2008). The soil available phosphorus content was determined *via* the method of Olsen *et al*. (1954), which involves extraction by $NaHCO_3$ and confirmation using a UV-2300 UV-Vis spectrophotometer (Shanghai Tianmei Scientific Instrument Co., Ltd.). The soil available potassium (Hanway and Heidel 1952), calcium, magnesium, iron, manganese, copper, and zinc (Lanyon and Heald 1982) were extracted by ammonium acetate and determined using an ICE-3500 atomic absorption spectrometer (Thermo Fisher Scientific).

Data and Statistical Analyses

The statistical analyses were performed using SPSS 13.0 (SPSS Inc., Chicago, USA) and Excel 2003 (Microsoft, Redmond, WA, USA) software. Differences in the soil characteristics among the treatments were examined using a one-way analysis of variance (ANOVA) followed by a Tukey's honestly significant difference test at $P < 0.05$. For the experiment in this study, at least three independent replications were performed for each sample. The figures were plotted using SigmaPlot 10.0 (Systat Software Inc., San Jose, CA, USA).

RESULTS

Physical Structure

The SEM imaging indicated an obvious difference between the CK (air-dried branches) and BR samples in the transverse sections and longitudinal sections. The transverse section texture of the CK was hard, compact, orderly, and regularly arranged (Figs. A-1 and A-2), whereas in this section of the BR, most of the hemicellulose and some of the lignin were removed, the surface streaks were serrated, and a large number of cracks appeared because of microbiological and environmental activity (Figs. B-1 and B-2). Obvious differences were observed between the two treatments at 2000 times

magnification. A complete structure and neat rows of cells were observed in CK (Fig. A-3), whereas BR presented a loose, disordered, and irregular structure. In addition, the texture was soft, and part of the cell wall had collapsed into the cell cavity, which caused serious structural destruction after 3 years (Fig. B-3). In the longitudinal section, CK had a relatively complete structure (Figs. A-4, A-5, and A-6). The texture of BR demonstrated that the loss of lignin in the cell wall caused crumbling of the structure in the spiral vessels and pitted vessels (Figs. B-4, B-5, and B-6).

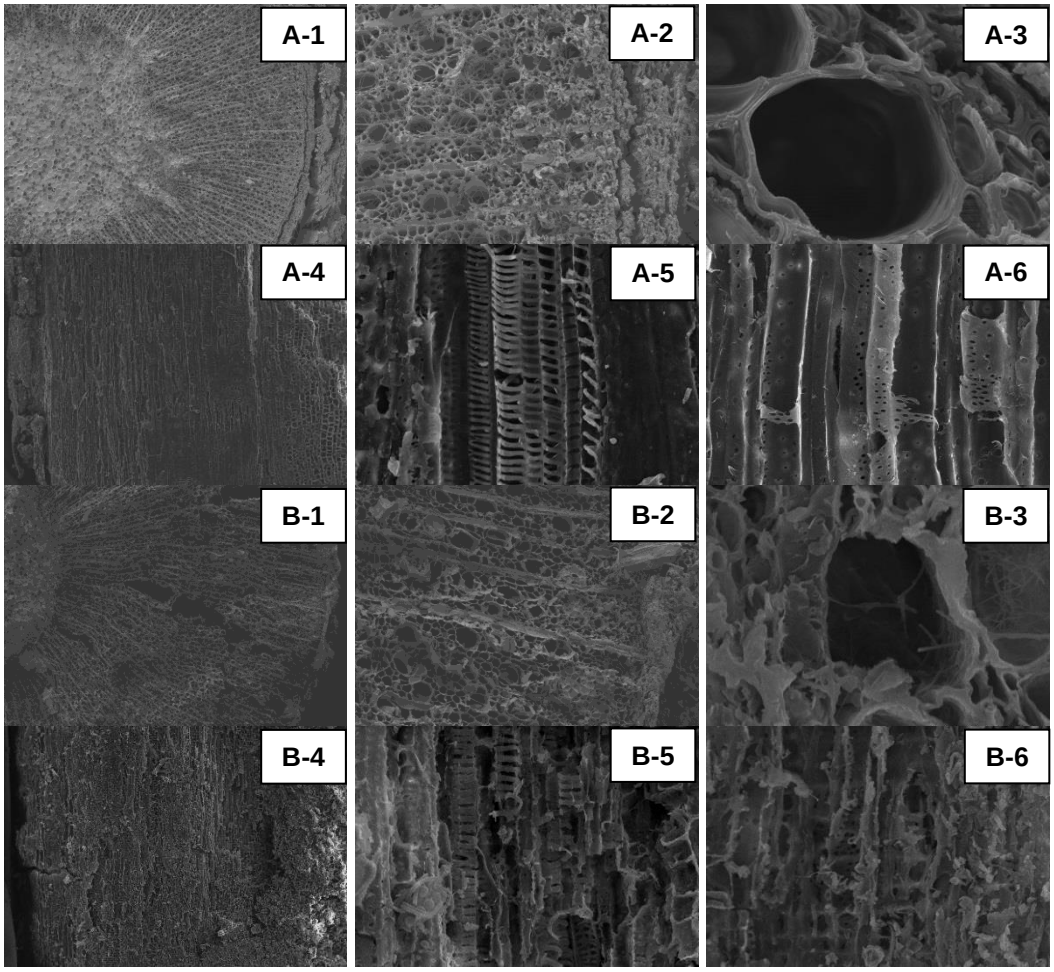

Fig. 1. SEM of apple branches after returning to orchard soil. (A-1) Transverse section of CK×50; (A-2) transverse section of CK×300; (A-3) transverse section of CK×2 000; (A-4) longitudinal section of CK×50; (A-5) longitudinal section of CK×500; (A-6) longitudinal section of CK×500; (B-1) transverse section of BR×50; (B-2) transverse section of BR×300; (B-3) transverse section of BR×2 000; (B-4) longitudinal section of BR×50; (B-5) longitudinal section of BR×500; (B-6) longitudinal section of BR×500.)

Fibre Chemical Components

The fibre components of the branches are presented in Fig. 2, and the fraction (weight percent) of different components in the CK was in the following order: cellulose < lignin < hemicellulose. However, in the 3rd year after the return of the branches, the fibre component ratio in the samples changed. The relative content of lignin noticeably increased from 30.54% in the CK to 41.11% in the BR. However, the ratio of cellulose and hemicellulose decreased from 39.04% and 19.28% to 9.71% and 16.60%, respectively.

Thus, cellulose was the first branch fibre component to degrade, and lignin degraded at a much slower rate.

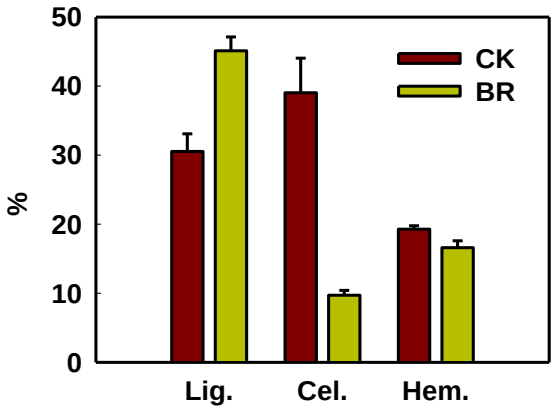

Fig. 2. Change of fiber contents of apple branches under returning to orchard soil. Lig., lignin; Cel., cellulose; Hem., hemicellulose

X-ray Diffraction

The XRD patterns of the branches are shown in Fig. 3. The diffraction analysis demonstrated that returning the branches to the soil produced a greater amount of small and sharp peaks in the branches, indicating the presence of miscellaneous minerals. This result indicated that a small amount of crystallization is generated or redirected during the decomposition process. Cellulose I was detected in the CK, and cellulose II was detected in the BR because the peaks at 15.5° (d-space ~5.51 Å) and 21.7° (d-space ~3.96 Å) are assigned to cellulose I and cellulose II, respectively (Nanda *et al*. 2014). The crystallinity index (percentage) for the branches also decreased from 28.29% to 20.19% after the branches had been returned for 3 years.

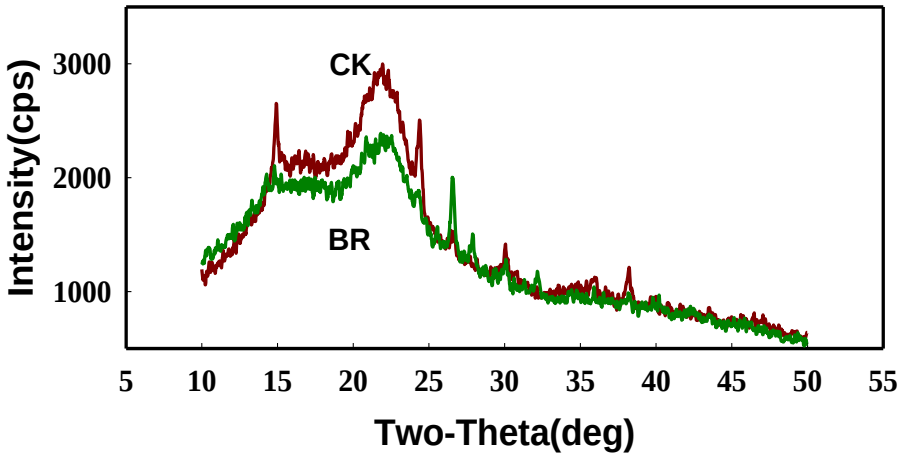

Fig. 3. X ray diffraction pattern of apple branches under returning to orchard soil

FTIR Spectra

The FTIR spectra of the branches after returning are shown in Fig. 4. The spectra revealed a number of sorption peaks, indicating the complex nature of the branches. The major peaks are tabulated in Table 1 and indicate the different associated compounds and bond types available in these fractions.

The region between 4000 and 400 cm^{-1} was investigated because it is the most sensitive to structural changes in the branches. A strong hydrogen bonded (O-H) stretching absorption was observed at 3400 cm^{-1}, and a prominent C-H stretching absorption was observed at 2927 cm^{-1}. These peaks are caused by the presence of cellulose, hemicellulose, and lignin, which indicates that obvious compositional changes occurred between the CK and BR. In addition, many well-defined peaks were observed in the fingerprint region between 1800 and 600 cm^{-1}. Here, the intensities of the carbohydrate bands at 1738, 1375, 1320, and 898 cm^{-1} increased as decay proceeded to the third year after the branches had been returned to the soil. However, the intensities of the lignin absorption bands at 1505, 1511, 1425, and 1048 cm^{-1} decreased as the decay progressed, with the band at 1505 cm^{-1} showing the lowest intensity (near zero) after returning for 3 years.

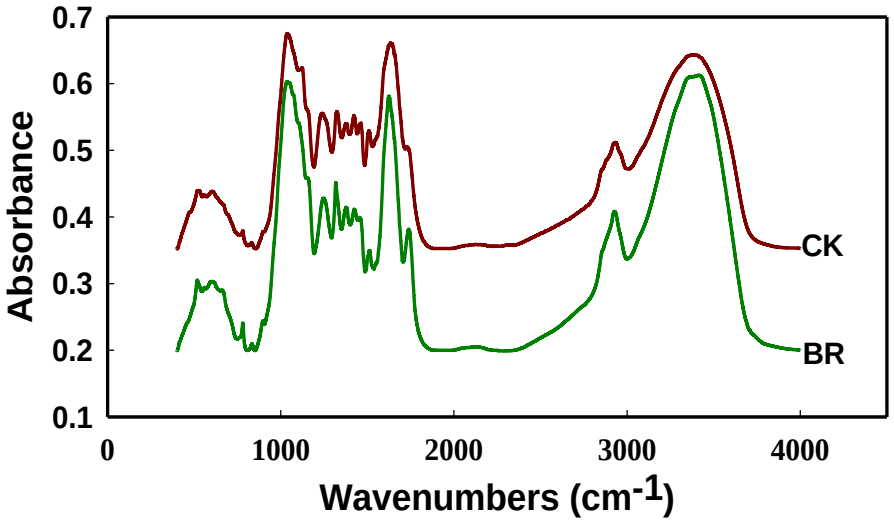

Fig. 4. Fourier infrared spectrum of apple branches under returning to orchard soil

Table 1. Assignment of Absorption Bands in FTIR Spectrum of Apple Branches under Returning to Orchard Soil

Band Position (cm^{-1})	Assignment and Representative Compounds
3400-3356	(O-H) Carbohydrates, protein, amides
2925	(CH_2) Carbohydrates, aliphatic compounds
1738/1734	Unconjugated C = O in xylans (hemicellulose)
1650	Absorbed O–H and conjugated C–O
1596 and 1505/1511	Aromatic skeletal in lignin
1425	C–H Deformation in lignin and carbohydrates
1375	C–H Deformation in cellulose and hemicellulose
1330/1320	C–H Vibration in cellulose and C ı –O vibration in syringyl derivatives
1268	Guaiacyl ring breathing, C–O stretch in lignin and for C–O linkage in Guaiacyl aromatic methoxyl groups
1244	Syringyl ring and C–O stretch in lignin and xylan
1048	C–O Stretch in cellulose and hemicellulose
898	C–H Deformation in cellulose.

Nutrient Release

The analyses detected nine nutrient variables in the branches, as displayed in Table 2. Compared to K, N, Mg, and Fe, there is a relative higher level of total P, Zn, Ca, Mn, and Cu in the air-dried branches from apple trees. A similar pattern was observed as has been reported in the case of straw, which is rich in alkaline elements as they are readily taken up from the soil (Jensen *et al.* 2000).

The chemical characteristics of the branches in terms of their inorganic phases varied between the CK and BR treatments. Remarkable increases in N were observed in the 3rd year after returning, and the value was 36.67% higher than the CK. This increase occurred because decomposers must absorb N from the external environment for growth; thus, apple branches with high C/N are decomposed, which results in N accumulation in the decomposed litter.

The Mg, Fe, Mn, and Cu concentrations in the apple branches were similar to that of N, which were higher after returning. However, the release of P, K, and Ca was higher, and the levels of P, K, and Ca were 34.12%, 39.44%, and 27.90%, respectively, lower in the BR than in the CK.

Table 2. Analysis of Nutrient Contents of Branches under Returning to Orchard Soil

Content	Branches	
	CK	BR
N (g/kg)	5.29±0.13b	7.23±0.30a
P (mg/kg)	331.98±6.96a	218.72±1.48b
K (g/kg)	9.33±0.99a	5.65±0.66b
Ca (g/kg)	40.22±4.53a	29.00±2.10b
Mg (g/kg)	2.37±0.27b	3.43±0.18a
Fe (g/kg)	0.56±0.01b	1.61±0.02a
Mn (mg/kg)	29.25±1.24b	156.54±4.22a
Cu (mg/kg)	21.63±0.29b	32.07±0.64a
Zn (mg/kg)	42.36±0.25a	41.97±2.58a

Note: The values presented in the table are average values taken from three replicate measurements.

Soil Quality

The soil with returned branches had much higher AN, AP, AK, AFe, AMn, and ACu statuses than the CK branches, which were 3.42%, 91.85%, 37.84%, 12.35%, 17.59% and 19.80%, respectively (Table 3). The effect of returning branches on the soil quality was noticeable at the AP level, which was nearly twice that of the CK. However, the levels of ACa, AMg, and AZn decreased by 3.32%, 12.50%, and 10.69%, respectively.

The data in Table 2 and Table 3 show that the nutrients released from the apple branches after decomposition accumulated in the soil, especially AP and AK. Simultaneously, returning branches to the soil had a positive effect on plants that utilize ACa and AZn.

Table 3. Analysis of Available Nutrient Contents of Orchard Soil

Content	Soil	
	CK	BR
AN (g/kg)	91.88±2.63a	95.02±2.98a
AP (mg/kg)	100.39±1.41b	192.60±11.03a
AK (g/kg)	0.37±0.01b	0.51±0.01a
ACa (g/kg)	3.01±0.02a	2.91±0.05a
AMg (g/kg)	0.48±0.01a	0.42±0.01b
AFe (g/kg)	67.18±3.08b	75.48±2.55a
AMn (mg/kg)	54.53±2.45b	64.12±2.20a
ACu (mg/kg)	6.92±0.26b	8.29±0.11a
AZn (mg/kg)	7.39±0.26a	6.60±0.30b

Note: The values presented in the table are average values taken from three replicate measurements.

DISCUSSION

Cellulose, hemicellulose, and lignin are the principal components of plant cell walls. The cellulose is organized into microfibrils, which act as a skeleton in the cell walls; hemicellulose and lignin act as binders and filler material between the cytoskeletons. The three components intertwine to form multiple thin layers that hold plant cell walls together (Davis and Spackman 1964; Novaes *et al*. 2010). Similar to other woody biomass, apple branches have a secondary cell wall that is lignified and contains sclerenchyma tissue (fibres and sclereids), and it acts as a strengthening material for the plants in addition to conducting gases and metabolites (Beakbane *et al*. 1939; Prasad *et al*. 2007; Bajus 2010). Based on the results, the structure of the apple branches was loose, disordered, and irregular after decay. Moreover, the texture was soft, and the cell wall crumbled, which resulted in considerable structural decomposition.

The peak at 16.0° (d-space ~5.51 Å) indicated whewellite (Ca oxalate monohydrate), which is characteristic of certain wood species (Vassilev *et al*. 2012). This substance is formed in plants as a result of biogenic processes, such as photosynthesis and mineral adsorption. The peak at 24.5° (d-space ~3.61 Å) represents gypsum, and in the branches, gypsum can act as a soil conditioner to enhance soil fertility. Peaks at 14.9° and 24.5° were observed in the CK XRD patterns, suggesting its potential as a biofertilizer for enhancing soil quality. With the decay process, the peak at 24.5° weakened; otherwise, a diffraction peak at 26.6° developed because of a small amount of crystalline redirection. The weakening of broad peaks near 24.5° (d-space ~3.62 Å) in the BR branches indicated the release of turbostratic carbon crystallites (Kim *et al*. 2011) after returning for 3 years.

Wang *et al*. (2005) utilized FTIR spectroscopy to analyse the characteristics of vineyard pruning during composting. The relative changes in the OH, CH_3, CH_2, CO, COO, and PO groups indicated that the aliphatic compounds decreased, while the aromatic compounds increased. Thus, FTIR provides valuable information on the material transformation mechanism, which was also suggested by Cao and Tan (2004). The absorption peak position and relative intensity of the FTIR results reflected changes in the cellulose, hemicellulose, and lignin components in different functional groups (Francioso

et al. 2011). Rodrigues *et al*. (1998) used FTIR spectroscopy to quantitatively determine the amount of lignin in *Eucalyptus globulus*, and they concluded that the best calibration fit was obtained using peak height ratios at 1505 and 1158 cm^{-1} for lignin and carbohydrates, respectively. In this study, the intensities at 1505 and 1158 cm^{-1} decreased and were almost absent after returning for 3 years, which likely indicates that part of the lignin and carbohydrates were removed. The decrease at 1247 cm^{-1} indicated that the ester bonds of hemicellulose and lignin interactions in apple branches were destroyed. The band at 1424 cm^{-1} occurred because of CH_2 shear vibrations in the crystalline cellulose; after being returned to the orchard for 3 years, the lower cellulose content in the BR samples was indicated by the weaker band at 1424 cm^{-1}. These data were also in accordance with Fig. 2.

The translocation and distribution of mobile elements in the trees kept pace with the metastasis of the growth centres (Deng *et al*. 1989). Dynamic studies on the N contents of trees have shown that in autumn and winter, N is mainly stored in perennial structures, such as stems and roots (von Fircks *et al*. 2001). Thus, fruit tree branches are rich in organic matter, and various inorganic nutrients suitable for crop growth (Zhang *et al*. 2013). Pruning removes the mineral nutrients. The presented analyses of the released nutrients indicated that the K content was higher than the P content, and the N content was the lowest relative to the nutrients released during the degradation of straw (Li *et al*. 2009; Dai *et al*. 2010). The final analysis of the parameters showed an obvious decrease in the P content and K content compared with the CK, which presented the same decomposition trends as straw. The C/N ratio of the apple branches was relatively high (The average value of C/N ratio which we tested was 110), and returning apple branches to the soil might stimulate the degradation ability of plant microbes that utilize soil N. Thus, the relative N content in the branches increased. Among the other elements detected, the alkaline elements (Zn and Ca) were reduced. However, the relative Mn content was up to 5 times higher than CK because Mn content has a highly significant positive relationship with the limit value for decomposition (Berg 2000).

Plant residues determine the nutrient cycle and balance and maintain the ecosystem functions of agriculture and forestry ecosystems (Li *et al*. 2007). For example, forest residue decomposition and nutrient release affect the storage characteristics of soil nutrients and improve the soil nutrient supply capacity (Hyvönen *et al*. 2000; Merilä *et al*. 2014). Organic management has been advocated to improve the sustainability of apple production systems (Reganold *et al*. 2001). The results of this research, which are similar to those of previous studies on plant residue nutrient release (Muvengwi *et al*. 2015; Ndagurwa *et al*. 2013), demonstrate that the contents of AN, AP, AK, AFe, AMn, and ACu in the BR treatment increased compared with the CK treatment, in which branches were not returned to the orchard soil. The contents of N, P, and K are essential for C fixation during photosynthesis and the functions of the symplast, which is the interconnected network of live cell contents in the outer wood and inner bark from the root tip to the foliage (Walter *et al*. 2015). The K content is a key indicator and contributes 17% towards the soil quality index (Sharma *et al*. 2005). Thus, allowing branches to decompose for 3 years would have a vital impact on the quality of the orchard soil. However, 3 years represents a relatively long time for residues on the surface of an orchard, and the overall state and influence of the residues on material circulation within ecological systems requires in-depth research.

CONCLUSIONS

1. Through the observation of the transverse sections and longitudinal sections, the internal structures of apple tree branches are destroyed after 3 years' decomposition. In addition, the cellulose, hemicellulose, and lignin exhibit good decomposition, as measured by X-ray diffractometry and Fourier transform infrared spectroscopy. It can be concluded that apple branches returned to the orchard can cycle lignin back into the soil environment.
2. Apple branches can be regarded as a recycled biological resource in the field of fruit cultivation because they contain N, P, K, and microelements, which are absorbed in the soil. The addition of mulch from branches can be used to maintain a high soil quality in the third year of decomposition. Returning the material to the soil can also reduce the use of some trace elements, improve the nutrient mineralization, and allow for nutrient turnover in the apple orchard itself.

ACKNOWLEDGEMENTS

This work was supported by the China Agriculture Research System (Grant No. CARS-28), the National Key Research and Development Program of China (Grant No. 2016YFD0201115), and the Institutions of Higher Learning Fruit Tree Cultivation and Physio-Ecology Innovation team of Liaoning Province (No. LT2014014).

REFERENCES CITED

Augusto, L., Meredieu, C., Bert, D., Trichet, P., Porté, A., Bosc, A., and Ranger, J. (2008). "Improving models of forest nutrient export with equations that predict the nutrient concentration of tree compartments," *Annals of Forest Science* 65(8), 808-821. DOI: 10.1051/forest:2008059

Bao, S. D. (2008). *Soil Chemical Analysis*, China Agricultural Press, Beijing, China.

Bajus, M. (2010). "Pyrolysis of woody material," *Petroleum and Coal* 52(3), 207-214.

Berg, B. (2000). "Litter decomposition and organic matter turnover in northern forest soils," *Forest ecology and Management* 133(1), 13-22. DOI: 10.1016/S0378-1127(99)00294-7

Cao, Y., and Tan, H. (2004). "Structural characterization of cellulose with enzymatic treatment," *Journal of Molecular Structure* 705(1), 189-193. DOI: 10.1016/j.molstruc.2004.07.010

Chang, C. H., Wu, F. Z., Yang, W. Q., Tan, B., Xiao, S., Li, J., and Gou, X. L. (2015). "Changes in log quality at different decay stages in an alpine forest," *Chinese Journal of Plant Ecology* 39(1), 14-22. DOI: 10.17521/cjpe.2015.0002 (in Chinese)

Dai, Z. G., Lu, J. W., Li, X. K., Lu, M. X., Yang, W. B., and Gao, X. Z. (2010). "Nutrient release characteristic of different crop straws manure," *Transactions of the Chinese Society of Agricultural Engineering* 26(6), 272-276. DOI: 10.3969/j.issn.1002-6819.2010.06.047 (in Chinese)

Davis, A., and Spackman, W. (1964). "The role of the cellulosic and lignitic components of wood in artificial coalification," *Fuel* 43, 215-224.

Deng, X., Weinbaum, S. A., DeJong, T. M., and Muraoka, T. T. (1989). "Utilization of nitrogen from storage and current-year uptake in walnut spurs during the spring flush of growth," *Physiologia Plantarum* 75(4), 492-498. DOI: 10.1111/j.1399-3054.1989.tb05614.x

Elosegi, A., Diez, J., and Pozo, J. (2007). "Contribution of dead wood to the carbon flux in forested streams," *Earth Surface Processes and Landforms* 32(8), 1219-1228. DOI: 10.1002/esp.1549

Francioso, O., Sanchez-Cortes, S., Bonora, S., Roldán, M. L., and Certini, G. (2011). "Structural characterization of charcoal size-fractions from a burnt *Pinus pinea* forest by FT-IR, Raman and surface-enhanced Raman spectroscopies," *Journal of Molecular Structure* 994(1), 155-162. DOI: 10.1016/j.molstruc.2011.03.011

Fu, W., Liao, X. R., Wang, J. F., and Du, J. F. (2004). "The lignin in plant," *Bulletin of Biology* 39(2), 12-14.

Gao, D. T., Guo, J. N., Wei, Z. F., and Yang, C. X. (2010). "Effect of orchard mulch on soil quality, growth and development of apple trees," *Journal of Fruit Science* 27(5), 770-777. DOI: 10.13925/j.cnki.gsxb.2010.05.021

Hanway, J. J., and Heidel, H. (1952). *Soil Analysis Methods as Used in Iowa State College (Agricultural Bulletin No. 57)*, Soil Testing Laboratory, Iowa State College, Ames, Iowa, USA.

Hu, F., and Ragauskas, A. (2012). "Pretreatment and lignocellulosic chemistry," *Bioenergy Research* 5(4), 1043-1066. DOI: 10.1007/s12155-012-9

Hyvönen, R., Olsson, B., Lundkvist, H., and Staaf, H. (2000). "Decomposition and nutrient release from *Picea abies* (L.) Karst. and *Pinus sylvestris* L. logging residues," *Forest Ecology and Management* 126, 97-112. DOI: 10.1016/S0378-1127(99)00092-4

Jensen, P. A., Frandsen, F. J., Dam-Johansen, K., and Sander, B. (2000). "Experimental investigation of the transformation and release to gas phase of potassium and chlorine during straw pyrolysis," *Energy Fuels* 14(6), 1280-1285. DOI: 10.1021/ef000104v

Kim, P., Johnson, A., Edmunds, C. W., Radosevich, M., Vogt, F., Rials, T. G., and Labbe, N. (2011). "Surface functionality and carbon structures in lignocellulosic-derived biochars produced by fast pyrolysis," *Energ. Fuel* 25, 4693-4703. DOI: 10.1021/ef200915s

Kokot, S., Czarnik-Matusewicz, B., and Ozaki, Y. (2002). "Two dimensional correlation spectroscopy and principal component analysis studies of temperature dependent infrared spectra of cotton-cellulose," *Biopolymers* 67(6), 456-469. DOI: 10.1002/bip.10163

Kortekaas, S., Wijngaarde, R. R., Klomp, J. W., Lettinga, G., and Field, J. A. (1998). "Anaerobic treatment of hemp thermomechanical pulping wastewater," *Water Research* 32(11), 3362-3370. DOI: 10.1016/S0043-1354(98)00120-1

Lanyon, L. E., and Heald, W. R. (1982). "Magnesium, calcium, strontium, and barium," in: A. L. Page, R. H. Miller, and D. R. Keeney (eds.), *Methods of Soil Analysis. Part 2: Chemical and Microbiological Methods* (2nd Ed.), American Society of Agronomy, Madison, WI, pp. 247-262.

Li, F. Y., Sun, X. F., Feng, W. Q., Qin, Y. S., Wang, C. Q., and Tu, S. H. (2009). "Nutrient release patterns and decomposing rates of wheat and rapeseed straw," *Plant Nutrition and Fertilizer Science* 15(2), 374-380. DOI: 10.3321/j.issn:1008-505X.2009.02.018 (in Chinese)

Li, H. T., Yu, G. R., Li, J. Y., Liang, T., and Chen, Y. R. (2007). "Dynamics of litter

decomposition and phosphorus and potassium release in Jinggang Mountain region of Jiangxi Province, China," *Chinese Journal of Applied Ecology* 18(02), 233-240. DOI: 1001-9332(2007)02-0233-08 (in Chinese)

Li, X., Zhang, L. J., Liu, W. S., Yang, J. M., and Ma, Z. Y. (2007). "On nutrient accumulation and distribution in plum tree as well as nutrient dynamic changes in plum leaves," *Soil* 39(6), 982-986. DOI: 10.13758/j.cnki.tr.2007.06.028

Luo, H. D., Mao, Y. Y., Niu, X. W., Mu, X. M., Liu, Y. P., Wang, F., Ren, K. L., and Tian, H. (2003). "Caragana feed sheep digestion test," *China Herbivores* 1, 104-106.

Meerts, P. (2002). "Mineral nutrient concentrations in sapwood and heartwood: A literature review," *Annals of Forest Science* 59,713-722. DOI: 10.1051/forest:2002059

Merilä, P., Mustajärvi, K., Helmisaari, H. S., Hilli, S., Lindroos, A. J., Nieminen, T. M., Nöjd, P., Rautio, P., Salemaa, M., and Ukonmaanaho, L. (2014). "Above-and below-ground N stocks in coniferous boreal forests in Finland: Implications for sustainability of more intensive biomass utilization," *Forest Ecology and Management* 311, 17-28. DOI: 10.1016/j.foreco.2013.06.029

Muvengwi, J., Ndagurwa, H. G. T., and Nyenda, T. (2015). "Enhanced soil nutrient concentrations beneath-canopy of savanna trees infected by mistletoes in a southern African savanna," *Journal of Arid Environments* 116, 25-28. DOI: 10.1016/j.jaridenv.2015.01.017.

Nanda, S., Azargohar, R., Kozinski, J. A., and Dalai, A. K. (2014). "Characteristic studies on the pyrolysis products from hydrolyzed Canadian lignocellulosic feedstocks," *BioEnergy Research* 7(1), 174-191. DOI: 10.1007/s12155-013-9359-7

Ndagurwa, H. G. T., Dube, J. S., and Mlambo, D. (2013). "The influence of mistletoes on nitrogen cycling in a semi-arid savanna, south-west Zimbabwe," *Journal of Tropical Ecology* 29(02), 147-159. DOI: 10.1017/S0266467413000096.

Novaes, E., Kirst, M., Chiang, V., Winter-Sederoff, H., and Sederoff, R. (2010). "Lignin and biomass: A negative correlation for wood formation and lignin content in trees," *Plant Physiology* 154, 555-61. DOI: 10.1104/pp.110.161281

Olsen, S. R., Cole, C. V., and Watanabe, F. S. (1954*). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate (Circular no. 939),* United States Department of Agriculture, Washington, D.C.

Polprasert, C. (2007). *Organic Waste Recycling: Technology and Management*, IWA Publishing, London, UK.

Prasad, S., Singh, A., and Joshi, H. C. (2007). "Ethanol as an alternative fuel from agricultural, industrial and urban residues," *Resources Conservation Recycling* 50, 1-39. DOI: 10.1016/j.resconrec.2006.05.007

Reganold, J. P., Glover, J. D., Andrews, P. K., and Hinman, H. R. (2001). "Sustainability of three apple production systems," *Nature* 410, 926-930. DOI: 10.1038/35073574

Rodrigues, J., Faix, O., and Pereira, H. (1998). "Determination of lignin content of *Eucalyptus globulus* wood using FTIR spectroscopy," *Holzforschung* 52, 46-50. DOI: 10.1515/hfsg.1998.52.1.46

Sakamoto, K., and Aoyama, M. (2004). "Comparison of coarsely shredded and finely shredded apple prunings in composting with poultry manure and calcium cyanamide," *Japanese Journal of Soil Science and Plant Nutrition* 75(5), 583-591.

Schwarze, F. W. (2007). "Wood decay under the microscope," *Fungal Biology Reviews* 21(4), 133-170. DOI: 10.1016/j.fbr.2007.09.001

Segal, L. G. J. M. A., Creely, J. J., Martin, A. E., and Conrad, C. M. (1959). "An

empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer," *Textile Research Journal* 29(10), 786-794. DOI: 10.1177/004051755902901003

Sharma, K. L., Mandal, U. K., Srinivas, K., Vittal, K. P. R., Mandal, B., Grace, J. K., and Ramesh, V. (2005). "Long-term soil management effects on crop yields and soil quality in a dryland Alfisol," *Soil and Tillage Research* 83(2), 246-259. DOI: 10.1016/j.still.2004.08.002

Thevs, N., Buras, A., Zerbe, S., Kuehnel, E., Abdusalih, N., and Ovezberdiyeva, A. (2011). "Structure and wood biomass of near-natural floodplain forests along the Central Asian rivers Tarim and Amu Darya," *Forestry* 85, 193-202. DOI: 10.1093/forestry/cpr056

Vassilev, S. V., Baxter, D., Andersen, L. K., Vassileva, C. G., and Morgan, T. J. (2012). "An overview of the organic and inorganic phase composition of biomass," *Fuel* 94, 1-33. DOI: 10.1016/j.fuel.2011.09.030

von Fircks, Y., Ericsson, T., and Sennerby-Forsse, L. (2001). "Seasonal variation of macronutrients in leaves, stems and roots of *Salix dasyclados* Wimm. grown at two nutrient levels," *Biomass and Bioenergy* 21(5), 321-334. DOI: 10.1016/S0961-9534(01)00045-9

Wang, Y. Q., Schuchardt, F., Zhang, R. Z., Sheng, F. L., and Cao, Z. Y. (2005). "Biochemical changes and characteristics of organic matter transformation during composting process of vineyard prunings," *Journal of Fruit Science* 22(2), 115-120. DOI: 10.13925 /j.cnki .gsxb.2005.02.007

Wardle, D. A., Walker, L. R., and Bardgett, R. D. (2004). "Ecosystem properties and forest decline in contrasting long-term chronosequences," *Science* 305, 509-513. DOI: 10.1126/science.1098778

Wassen, M. J., Venterink, H. O., and Lapshina, E. D. (2005). "Endangered plants persist under phosphorus limitation," *Nature* 437, 547-550. DOI: 10.1038/nature03950

Zhang, N. W., Dong, C. X., and Xu, Y. C. (2013). "Nutrient amounts removed by the pruning branches and the fruit harvest from the pear tree," *Journal of Nanjing Agricultural University* 36, 37-42. DOI: 10.7685/j.issn.1000-2030.2013.04.007 (in Chinese)

Article submitted: December 2, 2016; Peer review completed: February 19, 2017; Revised version received and accepted: March 2, 2017; Published: March 8, 2017.
DOI: 10.15376/biores.12.2.3108-3121