Effects of root pruning on the vegetative growth and fruit quality of Zhanhuadongzao trees

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Abstract

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The effects of root pruning on the vegetative growth and fruit quality of six-year-old Zhanhuadongzao (*Ziziphus jujuba* Mill.) trees were evaluated. Three root pruning treatments (severe, moderate and light degree) were conducted at the distance of 3, 5 and 7 times trunk diameter from trunk on both inter-row sides of the trees, respectively. The results showed that the severe root pruning decreased the length of primary branch by 27.9% and the number of primary branches by 12.1% in contrast to the control of no root pruning. Compared to the control, both severe and moderate root pruning had no apparent effects on nitrogen, phosphorus and potassium contents of leaves after 35 days, but had significant effects after 161 days. Severe root pruning had larger effectiveness of controlling vegetative growth than the moderate one. By root pruning, the contents of vitamin C and total sugar were increased but the content of cypermethrin was decreased in fruits and no effects were found on total acid content of fruit and yield at harvest. In the rhizosphere soil, root pruning decreased the microbial populations and enzymes activities but increased the concentrations of cypermethrin, available nitrogen, phosphorus and potassium. It is proposed that the removal of root at 3 times trunk diameter distance from trunk was feasible to regulate the vegetative growth and fruit quality of Zhanhuadongzao tree.

Keywords: Zhanhuadongzao (*Ziziphus jujuba* Mill.); root pruning; vegetative growth; yield; fruit quality; rhizosphere soil

Zhanhuadongzao, famous for its very sweet and crisp fruit, is an elite variety of *Ziziphus jujuba* Mill., which is mainly distributed in the Yellow River delta of China. One of the most important elements in jujube orchards management was vegetative growth regulation in this area due to excessive vegetative growth of Zhanhuadongzao trees. Excessive vigor is often a significant problem in deciduous tree fruit orchards, particularly in apple and peach trees, and implied a diminution in light penetration, yield and fruit quality and an increase in pruning and pest control cost (Miller 1995). Actually, shoot pruning, bark girdling and scoring were widely applied in production every year,

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which resulted in the weakness of tree vigor and liability to suffering from epiphyte and physiological diseases, and subsequently low fruit quality and frequently dead trees.

Numerous methods are available for regulating vegetative growth in deciduous fruit tree species (Miller, Tworkoski 2003). Root pruning is a common technique that can reduce vegetative growth of apple trees (Geisler, Ferree 1984; Schupp, Ferree 1990), which is a highly effective and economical method not only to assist in dwarfing, but also to stimulate the new roots necessary to sustain growth (Yashiroda 1960). To be precise, root pruning destroyed the old growth balances of trees and changed their assimilation abilities, nutrient distributions and hormone levels. Combined action of these elements may cause different promotion or control effects on growing development and fruit quality. Besides apple trees, root pruning is also reported to be used to reduce vegetative growth in a *Blanquilla* pear orchard (Asín et al. 2007). However, no research is available on the application of root pruning in jujube trees. Considering that the vegetative growth of Zhanhuadongzao is vigorous and the current methods of bark girdling and scoring have adverse effects on jujube tree, is root pruning is helpful to reduce its vegetative growth? Can root pruning be used as an alternative method for regulating vegetative growth of Zhanhuadongzao? If so, how will this method influence the yield and quality of jujube fruit? Therefore, it is desirable to determine the performances of root pruning in the production of Zhanhuadongzao.

We hypothesized that root pruning would be useful to regulate vigorous vegetative growth of Zhanhuadongzao tree. The objective of this research was to analyze the effects of root pruning at different distance from trunk on vegetative growth, yield and fruit quality of Zhanhuadongzao.

MATERIAL AND METHODS

Plant material and growth conditions

The experimental site is located in the Yellow River delta, China. The field experiment was carried out at the Zhanhuadongzao orchard, Bingzhou city, Shandong province (37°22'N, 108°02'E). The soil type in the orchard is fluvo-aquic loam; its main chemical concentrations included 10.25 g/kg organic matter, 38.74 mg/kg available nitrogen, 18.46 mg/kg available phosphorus and 125.31 mg/kg available potassium (Lu 1999). Soil pH was 8.5 (1:2.5 soil/water suspension). Six-year-old jujube trees (*Ziziphus jujuba* Mill.) were used in the experiment and the rows were planted 3 m apart with plant spacing of 3 m within each row. The mean trunk diameter and height of the jujube trees were 7.5 cm and from 2.1 m to 2.5 m, respectively.

Experimental design and root pruning treatments

The experiment involved a randomized, complete block design with three replications. Each block consisted of 10 trees arrayed in the same row. Prior to bud break, four treatments were applied to the examined trees on April 26, 2008:

(1) control – with intact root system,
(2) severe – removing root system at 3 times trunk diameters distance from trunk, 22.5 cm,
(3) moderate – removing root system at 5 times trunk diameters distance from trunk, 37.5 cm,
(4) light – removing root system at 7 times trunk diameters distance from trunk, 52.5 cm.

Root system was cut with a sharp spade at different distances from the trunk on both inter-row sides of jujube trees to the depth of 20 cm. The treated trees were managed in accordance with routine method.

Data collection and determination methods

At 35 days after root pruning treatments, primary branch was at the peak of vegetative growth and its length and number were measured and counted, respectively. Mature leaves were sampled in 2 to 3 trees randomly selected from each treatment. Collected leaves were rinsed twice in deionized water, put into oven to deactivate enzymes for 15 min at 105°C and then dried to constant weight at 80°C. After drying, the leaves were ground through a 30-mesh screen and analyzed for total nitrogen (N), phosphorus (P), and potassium (K). Total N content was determined using the Kjeldahl procedure. Total P content was measured as molybdovanadophosphoric acid and was read at 470 nm on a visible light spectrophotometer and total K content was determined by a flame spectrophotometer (Lu 1999).

At harvest, 161 days after root pruning treatments, samples of Zhanhuadongzao fruits were cropped and

Table 1. The length and number of primary branch of different treatments at 35 days as affected by root pruning at different trunk diameters from trunk

Treatment	Primary branch length (cm)	Number of primary branches per tree
Control	31.22[a]	98.50[a]
Severe	22.50[b]	86.56[b]
Moderate	25.51[ab]	89.29[b]
Light	29.33[ab]	96.12[a]

Within each column means followed by the same letters are not significantly different at 5%

rhizosphere soil of new roots was sampled for determination of soil enzymes activities, soil nutrients, microbial populations and pesticide residues. Rhizosphere soil was collected according to the procedures described by Wang and Zabowski (1998). Soil enzymes activities were assayed in triplicate air-dried samples as described by Guan (1986). Briefly, urease activity was determined using urea as substrate, and the soil mixture was incubated at 37°C for 24 h, the produced NH_3-N was determined by a colorimetric method, and urease activity was expressed as mg NH_3-N/g h. Invertase activity was determined using sucrose as a substrate and incubation at 37°C for 24 h, measuring the produced glucose with the colorimetric method, and invertase activity was expressed as mg glucose/g h. Alkali phosphatase activity was measured using sodium phenolphthalein phosphate as a substrate, incubation at 37°C for 24 h, and the liberated phenol was determined colorimetrically, alkali phosphatase activity was expressed as mg phenol/g h; catalase activity was measured using H_2O_2 as a substrate, shaked for 20 min and the filtrate was titrated with 0.1 mol/l $KMnO_4$, catalase activity was expressed as ml 0.1 mol/l $KMnO_4$/g h. Available N content in rhizosphere soil was determined by an indophenol blue colorimetric method; available P content in rhizosphere soil was extracted by natrii bicarbonas and measured using the ascorbic acid-ammonium molybdate method. To determine available K, rhizosphere soil was extracted by ammonium acetate and determined with a flame spectrophotometer (Lu 1999). Microbial populations were determined with dilution plate method (Zhang et al. 1983). Colonies were counted after incubation at 28°C for 7 to 10 days for growth of bacteria and actinomyces and at 25°C for 3 to 5 days for growth of fungi. Microorganisms populations were expressed as colony-forming units 1/g soil d.w. Total N, P, and K content in jujube leaves at harvest stage were determined using the same methods as those at day 35. The yield of each treatment was recorded and given as kilograms at the same time. Fruit quality was later analyzed for VC content by titration using dichloroindophenol as substrate (Liu, Yang 1996), for total sugar content with photometer using sucrose as substrate, and for total acid content, with titration using sodium hydroxide as substrate (Lu 1999). The extraction of malathion and cypermethrin in rhizosphere soil and fruits and subsequent clean-up of the extracts was in accordance with the method presented by Kumari et al. (2001) and analysis was carried out with Agilent gas chromatography system on a 6890 N model.

Statistical analysis

Data were analyzed by the Statistical Analysis System (SAS Institute, Inc., 1996). One-way ANOVA was carried out to evaluate the effects of root

Table 2. Total N, P and K contents in jujube leaves of different treatments at 35 and 161 days as affected by root pruning at different trunk diameters from trunk

Treatment	N (g/kg)		P (g/kg)		K (g/kg)	
	35	161	35	161	35	161
Control	33.630[ab]	21.863[a]	4.024[b]	11.786[a]	11.932[a]	12.854[a]
Severe	31.754[b]	9.332[d]	3.353[c]	10.730[c]	10.704[b]	11.957[b]
Moderate	32.180[b]	14.271[c]	3.583[bc]	11.035[b]	11.497[b]	12.033[b]
Light	38.197[a]	19.280[b]	4.693[a]	9.848[d]	12.267[a]	12.839[a]

Within each column means followed by the same letters are not significantly different at 5%

Table 3. Enzymes activities in rhizosphere soil of different treatments at 161 days as affected by root pruning at different trunk diameters from trunk

Treatment	Invertase (mg glucose/g h)	Catalase (ml 0.1 mol/l $KMnO_4$/g h)	Phosphatase (mg phenol/g h)	Urease (mg NH_3-N/g h)
Control	0.665^a	0.108^a	0.162^a	0.006^a
Severe	0.234^c	0.367^c	0.107^c	0.004^c
Moderate	0.505^b	0.545^b	0.139^b	0.005^b
Light	0.615^a	0.931^a	0.163^a	0.005^b

Within each column means followed by the same letters are not significantly different at 5%

pruning treatment on different variables measured regarding the vegetative growth, yield and fruit quality of Zhanhuadongzao.

RESULTS

The length and number of primary branches

Primary branch is the new one sprouting in the spring, which can reflect the vegetative growth of a mature jujube tree. The influence of root pruning on the length and number of primary branches at 35 days after treatments is presented in Table 1. Compared to the control, the length and number of primary branches were significantly decreased by 27.9% and 12.1% after severe root pruning treatment, respectively. The inhibition effects of root pruning on primary branch growth were gradually decreased with the increase of pruning distance from trunk. No significant difference between light root pruning and the control was noticed. The obtained results indicated that appropriate root pruning could distinctly reduce the vegetative growth of Zhanhuadongzao tree.

Total N, P and K contents in the leaves

Table 2 shows total N, P and K contents in the leaves of jujube trees at 35 and 161 days after root pruning. After 35 days, both severe and moderate root pruning treatments decreased the contents of total N, P and K in leaves relative to the control; severe root pruning treatment caused a decreased by more than 5.6%, 10.9%, 10.3%, respectively. Unlike severe and moderate root pruning, the light one showed a reverse trend. The contents of total N, P and K in leaves of jujube trees treated with light root pruning were increased by 13.5%, 16.6% and 2.7% over control, respectively.

After 161 days, there was a similar pattern of variation for total N, P and K contents among different treatments as at 35 days. The results indicated that root pruning of different intensities had entirely different effects on the mineral nutrient status of Zhanhuadongzao trees.

Enzymes activities in rhizosphere soil

The enzymes activities of rhizosphere soil, sampled from approximately 0 to 4 mm away from the root surface, were significantly influenced by living root system of jujube tree (Table 3). The activities of four enzymes, namely invertase, catalase, phosphatase and urease, were declined in rhizosphere soil as affected by severe or moderate root pruning in contrast to those of the control, which was possibly due to the damage of root system resulted from pruning. Among all the treatments, the activities of invertase, catalase, phosphatase and urease were the lowest in rhizosphere soil of severely root-pruned jujube trees. The results indicated that enzymes activities were affected by root pruning and severe root pruning could contribute to evident reduction of enzymes activities in rhizosphere soil.

Available N, P and K concentrations in rhizosphere soil

The nutrient status of rhizoshpere soil mainly depended on fertilizer added in current season, and was also affected by microorganism mineralization and enzymatic reaction. Fig. 1 shows that compared to the control, the concentrations of available N, P and K in rhizoshpere soil of severely or moderately root-pruned jujube trees were higher than those of the control, the highest of which were obtained in moderate root pruning treatment. The results

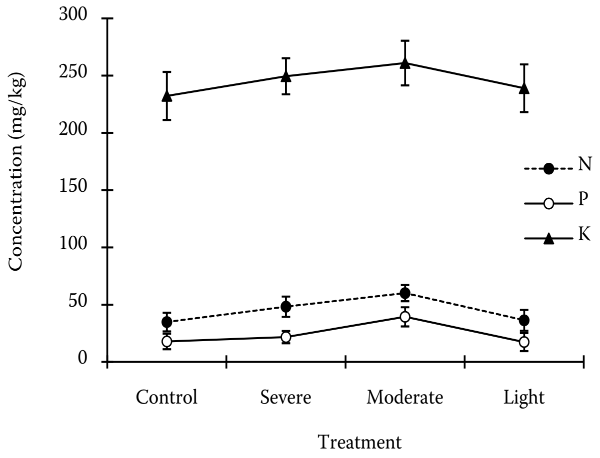

Fig. 1. Available N, P and K concentrations in rhizosphere soil of different treatments at 161 days after root pruning

of ANOVA analysis indicated that root pruning caused significant changes of nutrient status of rhizosphere soil.

Malathion and cypermethrin residues in rhizosphere soil

During the period of this experiment, malathion and cypermethrin were used for leaf spraying five times. In order to examine whether root pruning exerted a certain effect on pesticide residues, the concentrations of malathion and cypermethrin in rhizosphere soil were determined. Fig. 2 shows that only cypermethrin was detected and the significant interactions between root pruning and cypermethrin residue were observed. Compared with the control, cypermethrin concentrations in the rhizosphere soils of severely and moderately root-pruned jujube trees were increased, which indicated that the two root pruning treatments accelerated the transformation of cypermethrin into soil. The data also proved that cypermethrin concentration in rhizosphere soil was decreased with the increase of root pruning distance from trunk.

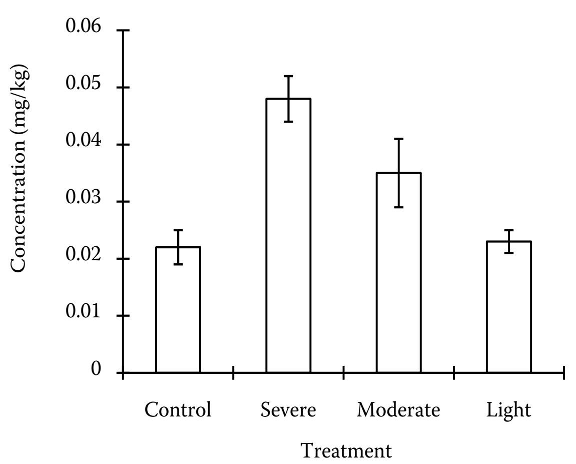

Fig. 2. Cypermethrin concentrations in rhizosphere soil of different treatments at 161 days after root pruning

Microbial populations in rhizosphere soil

In the experiment, the populations of bacteria, fungi and actinomyces in rhizosphere soil were tested at 161 days after root pruning. The effects of root pruning on microbial populations are presented in Table 4. Compared with the control, the amounts of bacteria and fungi were significantly reduced by severe and moderate root pruning but unaffected by light pruning treatment. For actinomyces, no significant differences were found among all treatments. The amounts of microorganism population ranged from 1.100×10^7 to 2.917×10^7/g soil d.w. and differed apparently between treatments. The results demonstrated that root pruning could have remarkable impacts on microbial populations in rhizosphere soil of Zhanhudongzao trees and the effects were dependent on root pruning strength.

Fruit quality and yield

The yield of Zhanhuadongzao was slightly enhanced by root pruning, but it did not reach statistically significant level. In recent years, there was an increasing focus on the quality of Zhanhuadongzao, especially on pesticide residues in fruits. The contents of vitamin C and total sugar in fruits were increased by root pruning. However, differences in yield and total acid between treatments were not seen at harvest, even though there was an elevated trend as observed in Table 5. Only cypermethrin was detected and its concentration was lowest in severe root pruning treatment.

DISCUSSION

In the experiment, a portion of fine roots was removed more or less through root pruning, which resulted in some variations in physiology and biochem-

Table 4. Microbial populations in rhizosphere soil of different treatments at 161 days as affected by root pruning at different trunk diameters from trunk (×10^7/g soil d.w.)

Treatment	Bacteria	Actinomyces	Fungi	Total
Control	2.276[a]	0.585[a]	0.0284[a]	2.889[a]
Severe	0.514[c]	0.579[a]	0.0069[c]	1.100[c]
Moderate	1.491[b]	0.580[a]	0.0181[b]	2.089[b]
Light	2.313[a]	0.575[a]	0.0288[a]	2.917[a]

Within each column means followed by the same letters are not significantly different at 5%

istry of Zhanhuadongzao trees. The experimental results indicated that severe root pruning could effectively inhibit the length and number of primary branches. The reason probably was that Zhanhuadongzao trees were unable to uptake adequate water and nutrients for the growth of aboveground organs due to decreased existing root surface areas by roots pruning. It is also likely that severe root pruning caused an imbalance in the root to shoot ratio, however, it is not likely that plant can support rapid new root development and maintain consistent shoot growth at the same time but initially expend more resources on root growth rather than shoot growth (Farmer, Pezeshki 2004). With time extension, the inhibition effect was slightly weakened.

Terrestrial plants are supplied with water and nutrients by their roots (Eshel et al. 2001). Plant roots can induce changes in nutrient composition in the rhizosphere solution directly through root uptake and indirectly through their effects on rhizosphere microorganisms (Drever, Vance 1994). A higher population of microorganism can increase the decomposition of organic matter and therefore may increase nutrient concentrations of the rhizosphere solution (Wang, Zabowski 1998). Compared to the control, the nutrient concentrations in rhizosphere soil of severe and moderate root pruning treatments were higher; it possibly correlated with the fact that the nutrients of N, P and K in rhizosphere soils were less absorbed by damaged root system after root pruning. Although higher nitrogen, phosphorus and potassium concentrations in rhizosphere soil could accelerate plant growth, severe and moderate root pruning reduced the large size of root system and hence lowered competitive ability for water and mineral uptakes (Ma et al. 2008), which resulted in lower N, P and K contents in leaves and consequently inhibited Zhanhuadongzao tree growth.

The role of the rhizosphere microorganisms in processing and retention of nutrients in plant-soil systems was considered in general terms and in relation to broad attributes of ecosystem functioning (O'Neil, Reichle 1980). At the same time, microorganisms can secrete enzymes into soil in their process of propagation (Chen 1996) to promote matter transformation. Because Zhanhuadongzao roots were cut, the capabilities of the root system in physiological metabolization and secretion were weakened, the root exudation serving as an important carbon and energy source for microorganisms contained in the rhizosphere (Quian et al. 1997) and shed matters on root surface were decreased, which jointly resulted in lower microbial populations and enzymes activities compared to the control. No differences of actinomyces were found between the treatments shown in Table 4, probably because different classes of microorganisms selectively utilize carboxyl acids and amino acids,

Table 5. Fruit quality and yield of different treatments at harvest (161 days) as affected by root pruning at different trunk diameters from trunk

Treatment	Vitamin C (mg/100 g)	Total sugar (%)	Total acid (mg/100 g)	Yield (kg)	Malathion (mg/kg)	Cypermethrin (mg/kg)
Control	155.319[c]	14.012[d]	0.461[a]	12.970[a]	not detected	0.096[a]
Severe	233.387[a]	16.394[a]	0.495[a]	13.860[a]	not detected	0.020[c]
Moderate	224.861[b]	15.475[b]	0.475[a]	14.320[a]	not detected	0.039[b]
Light	158.124[c]	14.886[c]	0.463[a]	14.050[a]	not detected	0.085[a]

Within each column means followed by the same letters are not significantly different at 5%

and therefore different plant species have different growing provocations on microbial classes in the rhizosphere (Grayston et al. 1988).

Due to root pruning, Zhuanhuadongzao trees would allocated more photosynthates into the root system to support its farther growth and development, and simultaneously speed up malathion and cypermethrin residues to be lavishly transported into roots and degraded in soil resulting in lower pesticide residues in fruits. This result suggests that root pruning can be considered as an additional method to obtain optimal fruit quality. Malathion is extremely decomposed (Chen 1996), so it was not detected in rhizosphere soil and fruit. However, obvious raise of cypermethrin residue in rhizosphere soil and reduction of it in fruit were found in root-pruned trees.

Some researchers concluded that root pruning could reduce the yields of fruit trees because the trees were unable to supply sufficient photosynthates to maximize production (Khan et al. 1998). The others believed that root pruning provided appropriate growth control and produced the highest yield due to an important increase in return bloom (Asín 2007). In the study, no significant difference was observed but there was a little increase in yield, partly owing to the recovery of root system and subsequent higher nutrient uptake for jujube tree in the later growth stage. For mature Zhanhuadongzao trees, the length and number of primary branches are signs whether vegetative growth is vigorous or not. In the research, severe and moderate root pruning showed distinct inhibitory effects on the length and number of primary branches. That is to say, the vegetative growth of Zhanhuadongzao tree was reduced in the first year by severe and moderate root pruning, although Khan et al. (1998) reported that root pruning showed no effects in reducing vegetative growth of apple trees in the first year after treatments but significant effects in the second year.

The results reported here are induced only from the experiment in the first fruiting year and it is insufficient to state whether a distinct degree of root pruning is the optimum selection. In order to convincingly and roundly evaluate the effects of root pruning on the vegetative growth and fruit quality of Zhanhuadongzao tree, the experiment should be continued in the second year or longer.

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