Bangladesh J. Bot. **47**(3): 643-648, 2018 (September) Special

EFFECTS OF IRON, ZINC FERTILIZERS ON PHOTOSYNTHETIC CHARACTERISTICS, GROWTH AND FRUIT QUALITY OF PEAR-JUJUBE (*ZIZIPHUS JUJUBA* MILL.) IN THE LOESS PLATEAU, CHINA

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Key words: Iron, Zinc, Photosynthetic characteristics, Fruit quality, Pear-jujube

Abstract

A field experiment was conducted to study the effects of different concentrations of iron and zinc fertilizers application on photosynthetic characteristics, growth, fruit quality and the content of iron and zinc of pear-jujube in the Loess Plateau. The 100-leaf weight, leaf area and SPAD value of 0.6 $FeSO_4$ + 0.3% $ZnSO_4$ + N, P fertilizer (L3) were 38.32 g, 17.26 cm^2/leaf and 32.54, respectively which increased 52.8, 70.7 and 18.8% , respectively compared to the control, and difference was significant from the control ($p < 0.05$). The percentage of fruit set, fresh weight per fruit and yield kg/ha m^2 also were found maximum at L3. Iron and zinc content of jujube under the L3 treatment were 27.78 and 3.75 mg/kg which increased by 87.4 and 13.2%. The total soluble solids, Vitamin C and the flavonoid content were the highest for L3 and increased by 5.88, 23.38 and 102.7%, respectively compared to the control. In general, iron and zinc fertilizers can effectively promote the photosynthetic characteristics, growth, yield and fruit quality of pear-jujube and the 0.6 $FeSO_4$ + 0.3% $ZnSO_4$ + N, P fertilizer was found to be the most significant.

Introduction

Ziziphus jujuba Mill. belonging to the family Rhamnaceae (Yan and Lu 2010), is a unique fruit tree in China. It has a history of more than 3,000 years of cultivation (Dang *et al.* 2007). Pear-jujube belongs to fresh jujube, which is not only nutritious but also has a health-care effect (Lu *et al.* 2010). Due to the characteristic climatic conditions in northern Shaanxi, the pear jujube has uniform coloration, beautiful appearance, good quality, and high commodity value, and is obviously superior to other jujube regions (Gao *et al.* 2005). In the Loess Plateau, the development of planting pear-jujube not only promotes economy and farmers' incomes, but also greens barren hills and improves ecological environment (Yang 1999, Gao and Zheng 2004).

Lack of iron, zinc and other trace elements in plants will significantly reduce the yield and quality of plants (Velemis *et al.* 1999, Liu *et al.* 2008). Because iron, zinc and other micro-fertilizers are easily fixed by soil and unfavorable for absorption (Fawzi *et al.* 1993), extra-root spraying has become a cost-effective fertilization method. Pan *et al.* (2011) reported that after spraying different concentrations of boron fertilizer on the leaves, the content of boron in pear increased, promoting vegetative growth and improving fruit quality. A few reports are available on the fruit quality, and trace element content of pear in the Loess Plateau. Thus, in the present study an attempt was taken to analyze the photosynthetic characteristics, reproductive growth, fruit quality, iron and zinc contents of pear-jujube in the loess hilly area of northern Shaanxi Province with different concentrations of iron and zinc fertilizers under the conditions of nitrogen and phosphorus application.

The results of this findings could provide the theoretical basis and technical support for the high yield and high quality of pear-jujube and would be great significance to the local economy and ecology.

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Material and Methods

The experiment was conducted at the experimental base of red dates in Mengzi Village, Mizhi County, Shaanxi Province, where soil erosion and land desertification are serious. The average annual rainfall is 451.6 mm. The experimental soil was dominated by loess soil and was relatively poor in fertility. During the trial period, the drip irrigation quota was $135m^3/hm^2$, and irrigation was conducted on May 17 and June 12, 2013. Soil pH was 8.6, bulk density was 1.21 g/cm^3, soil available N, P, K contents were 34.73, 2.90, 101.9 mg/kg, respectively (Yan *et al.* 2008). The soil nutrients of the organic matter, total nitrogen, alkali-hydrolyzed nitrogen, and available phosphorus were very low. The effective iron content in soil which was measured by DTPA-TEA extraction AAS method was 6.13 mg/kg, the effective zinc content was 0.13 mg/kg, and the critical values of iron and zinc in loess areas in northern Shaanxi were 2.5 and 0.5 mg/kg, respectively. Zinc extremes were lacking, and the iron content was moderate (Peng and Yu 1985). But the pH in this area is higher than 7.5, which seriously restricts the absorption of iron in the soil by plants (Han and Zhao 2014). The basic physical properties of the soil are shown in Table 1.

Table 1. Basic physical characteristics of the experimental soil.

Layers (cm)	Sand (1-0.05 mm)	Fine sand (%) (0.05-0.001 mm)	Clay (%) (< 0.001mm)	Physical clay (%) (<0.01mm)
0-20	27.67	68.98	2.51	17.70
20-40	29.17	68.19	2.44	16.46
40-60	31.22	65.75	2.46	16.07

A ten-year-old dwarf planted *Ziziphus jujuba* (*Zizyphus jujuba* Mill.cv. Lizao) with uniform vigor and well growing conditions was selected. Under the conditions of drip irrigation, base fertilizers N, P, K and different concentrations of iron and zinc fertilizer were sprayed on the leaves. In the bud stage, basal fertilizer 1/2 urea (237.5 g/plant), superphosphate (2273 g/plant), analytically pure and potassium sulfate (245 g/plant) were applied once and during fruit enlargement urea was applied as topdressing. During the budding leaf stage, iron and zinc fertilizers were sprayed according to Table 2 (Peng and Yu. 1985, Fawzi *et al.* 1993). Five test groups were set up which were 0.3 $FeSO_4$ + 0.3 $ZnSO_4$ (L1), 0.3 $FeSO_4$ + 0.6 $ZnSO_4$ (L2), 0.6 FeSO + 0.3 $ZnSO_4$ (L3), 0.6 FeSO + 0.6% $ZnSO_4$ (L4) and control group (CK) which contained only nitrogen and phosphorus fertilizers. Each tree was sprayed with 4 L of solution, so the amount of fertilizer applied was 12 and 24 g/plant, respectively and sprayed three times at 10 days interval. Each treatment was repeated five times. Protection trees were selected on both sides of each test tree. The area of the plot was about 500 m^2.

Table 2. Trial treatment of fertilization on Jujube tree.

Treatment	CK	L1	L2	L3	L4
$FeSO_4$	0	0.3%	0.3%	0.6%	0.6%
$ZnSO_4$	0	0.3%	0.6%	0.3%	0.6%

At the fruit ripening stage, 100 leaves were randomly picked from tree and their leaf area was determined with MSD-971, the thickness of the louver was measured with a vernier caliper; the weight of the louver was measured by balance with 0.1×10^{-5} accuracy. The number of fruits was counted in the middle of July, and the fruit setting rate was calculated; 24 mature fruits were collected from each tree on october 8, 2013 for quality determination. Chlorophyll content was determined using CCM 200. The canopy index was determined by Canopy analysis of Wins Canopy 2005a (Gao *et al.* 2006). Fruit quality was determined according to Gao (2006). Fruit moisture content was measured by atmospheric heating and drying; soluble solids were measured using 2WAJ-Abbe refractometer; titratable acid was titrated with 0.1mol/l NaOH standard solution. Reduced-vitamin C was measured by 2,6-dichloro-indophenol titration; vitamin C oxidase and polyphenol oxidase activity were measured.

The dried fruits were comminuted through 0.2 mm sieves and digested with HNO_3 (65%): $HClO_3$ (72%) = (4 : 1). Finally, the content of each element was determined using an atomic absorption spectrophotometer (Zhang *et al.* 2008). Unless specified, five trees were treated in each test and number of replication was three. Test data were analyzed using Microsoft Excel 2003 and SPSS17.0 and the average of each process as the final result was considered.

Results and Discussion

There was no significant difference in 100 leaves thickness in any treatment with the control (Table 3). The 100 leaf weight and the leaf area of all the treatments were significantly different from the control ($p < 0.05$). Among them, L3 had the best effect which were 38.32 g and 17.26 cm^2/leaf. Hundred leaf weights and leaf area of L3, and L4 increased by 52.8 and 70.7%, respectively compared to CK. Foliar application of iron and zinc can significantly increased the growth of leaves, with L3 and L4 being the most significant.

Table 3. The effect of Fe, Zn fertilizer treatment on the leaf growth of pear-jujube.

Treatment	Hundred leaf weight (g)	Hundred leaf thickness (mm)	Leaf area (cm 2/leaf)
CK	25.08 ± 0.79 c	259.50 ± 25.98 a	10.11 ± 0.33 c
L1	32.44 ± 1.05 b	269.36 ± 27.2 a	13.98 ± 0.51 b
L2	33.05 ± 1.25 b	256.31 ± 25.4 a	14.32 ± 0.48 b
L3	38.32 ± 0.85 a	268.33 ± 25.5 a	17.26 ± 0.53 a
L4	36.61 ± 0.85 a	269.82 ± 27.1 a	16.99 ± 0.57 a

Values followed by different letters in a column are significant among treatment at the 5% level (Same as below).

Chlorophyll is an important factor affecting the absorption and conversion of light energy. Li *et al.* (2012) showed that the chlorophyll content and SPAD value in leaves are significantly positively correlated, indicating that the SPAD determined by CCM200 can represent the leaching chlorophyll content in leaves. Fig. 1 shows that the chlorophyll content of the leaves of the jujube tree during different growth stages increased significantly. Under the condition of foliar spraying, the chlorophyll content of L3 treatment increased significantly, and the maximum chlorophyll content was 32.54, which was 18.8% higher than that of CK ($p < 0.05$). The SPAD values of L1, L2, and L4 treatments reached 32.49, 30.65, and 31.58 and increased by 15.0, 11.9 and 15.3%, respectively, compared with CK. The results showed that the foliar spray significantly promoted the SPAD value of leaves, and the SPAD value of L3 had the most significant effect. Foliar spraying significantly increased the leaf louver weight, leaf area and chlorophyll content and application of L3 had the best effect.

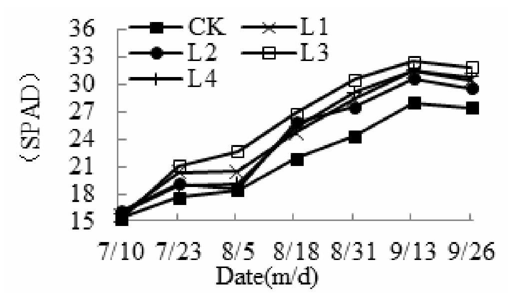

Fig. 1. Effects of Fe and Zn fertilizer treatments on chlorophyll contents of pear-jujube.

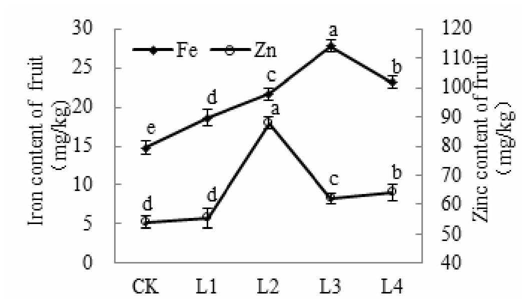

Fig. 2. Effects of Fe and Zn fertilizer treatments on iron and zinc content of pear-jujube.

The number of elements in the leaves directly affects the intensity of photosynthesis and the number of photosynthetic products (Hui *et al.* 2004). It is apparent from Fig. 2 that the different fertilization methods have significant effect on the content of trace elements in the growth process of pear-jujube. The iron content in different treatments had a turning point on July 10 (Fig. 3). The content of total iron in different treatments showed a slow rising state before July 10. The content of iron in leaves treated with CK decreased rapidly after July 10 and changed to a steady state after August 4. The content of total iron in the treated leaves increased generally, and the increase of total iron content in leaves of pear-jujube treated with L4 was the most significant, followed by L3 treatment. The contents of total zinc in leaves of pear-jujube during different fertilization treatments showed a turning point on August 4th, which turned from a rising to a downward trend. Foliar application significantly increased total zinc content in the leaves, and the trend of L2 and L4 treatments was consistent. After August 29, it tended to be stable; however, the trends of L1 and L3 treatment continued to decline after 4 August. Different treatments significantly affected the contents of iron and zinc in leaves of pear-jujube. Among them, the increase of total iron content in leaves of pear-jujube treated with 0.6% $FeSO_4$ + 0.6% $ZnSO_4$ was the most significant.

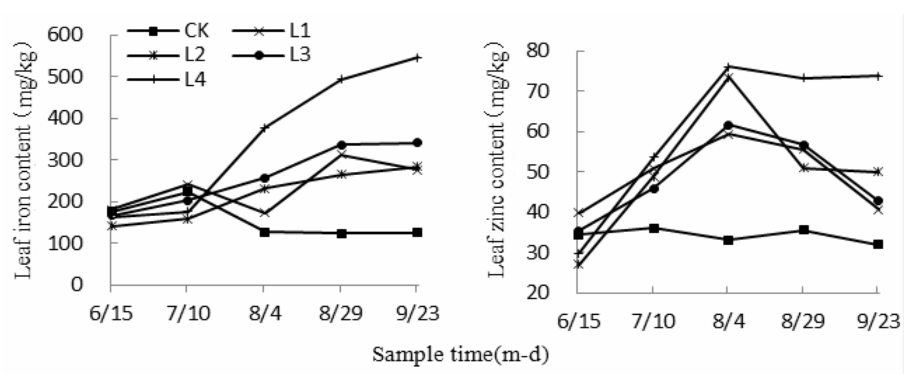

Fig. 3. Effects of Fe and Zn fertilizer treatments on leaf iron and zinc content of pear-jujube.

It was observed that the different fertilizer treatments increased the total iron content in pear-jujube fruit (Fig. 3). The trend of total iron content was L3 > L4 >> L2 > L1 > CK, and the total iron content in L3 treatment was the highest (27.78 mg/kg), followed by L4 treatment (23.18 mg/kg), which were 87.4 and 56.4% higher than CK respectively, and significantly different from

CK ($p < 0.05$). Different treatments affected the content of total zinc in pear-jujube fruit. The content of total zinc at L2 was the highest, which was 87.91 mg/kg. After spraying Fe fertilizer, the total Fe content in pear-jujube increased significantly, but with the increase of Zn fertilizer concentration, the total Fe content in pear-jujube decreased. This may be due to the plant's role in the absorption of trace elements Zn and Fe (Yan and Xiong 2000).

Table 4 shows that fruit setting rate, the single fruit weight, and yield of pear-jujube after treatment with Fe and Zn fertilizer increased than those in the control. Among them, L3 treatment had the most significant effect on the reproductive growth of pear-jujube ($p < 0.05$); Different fertilization treatments significantly improved the fruit setting rate of pear-jujube, among which the highest rate of fruit set with L3 (18.13%), which was 133.9% higher than that of CK, and the difference was significant ($p < 0.05$). The yield of pear-jujube treated with foliar spray was significantly higher than that of the control. Different micro-fertilizer treatments had different degrees of influence on the reproductive growth of pear-jujube in mountainous areas. When the above indicators were integrated, L3 had been found to have the most significant effect.

Table 4. The effect of Fe and Zn fertilizer treatments on reproductive growth of pear-jujube.

Treatment	Fruit setting rate (%)	Weight/fruit(g)	Yield (kg/hm2)
CK	7.75±0.45 c	19.78±0.81 b	10023.22±609 c
L1	14.66±0.74 ab	23.95±1.52 a	12802.68±794 a
L2	16.53±1.03 a	25.64±1.41 a	14413.08±889 a
L3	18.13±0.93 a	26.17±1.20 a	18076.74±989 b
L4	16.16±1.06 a	25.75±1.18 a	13728.66±899 a

Table 5. The effect of Fe and Zn fertilizer treatments on nutrient quality of pear-jujube.

Treatment	FWC (%)	TSS (%)	TA (%)	TSS/TA	Vc (mg/g)	Flavones (mg/g)
CK	78.20 ± 0.26 d	16.95 ± 0.51 c	1.22 ± 0.07 a	13.89 ± 0.09 e	2.31 ± 0.11 b	1.49 ± 0.11 e
L1	79.93 ± 0.42 c	19.27 ± 0.82 b	1.10 ± 0.03 b	17.52 ± 0.13 d	2.38 ± 0.03 b	1.81 ± 0.15 d
L2	80.87 ± 0.59 bc	20.13 ± 0.77 b	0.87 ± 0.02 c	23.09 ± 0.21 b	2.40 ± 0.07 b	2.05 ± 0.06 c
L3	82.33 ± 0.32 a	22.83 ± 0.73 a	0.85 ± 0.02 c	26.88 ± 0.26 a	2.85 ± 0.07 a	3.02 ± 0.04 a
L4	81.6 ± 0.44 ab	20.55 ± 0.69 b	1.12 ± 0.10 b	18.33 ± 0.22 c	2.50 ± 0.04 bb	2.28 ± 0.09 b

FWC = Fruit water content, TSS = Total soluble solid, TA = Titratable acid.

Table 5 revealed that the water content of pear-jujube fruit with different fertilization treatments was higher than that of the control; L3 increased by 4.13% compared to CK and were significantly different from CK ($p < 0.05$), in which the water content of fruits treated with L3 was the maximum. Different treatments effectively increased the content of total soluble solids, solid-acid ratio, vitamin C and total flavonoids in pear-jujube fruit. Among them, the effect of vitamin C was most significant with L3, which was 2.85 mg/g, and it was 23.4% higher than that of CK, and the difference was significant ($p < 0.05$). The content of titratable acid (TA) in different micro-fertilizer treatments was found lower than that of the control, TA with L3 treatment was the lowest followed by L2 treatment. The study showed that the content of total iron and total zinc in different treated pear-jujube increased significantly; at the same time, it effectively improved the nutritional quality of the fruit, and the treatment of 0.6% $FeSO_4$ + 0.3% $ZnSO_4$ was found to be the most effective.

Comprehensive analysis of the treatment of 0.6% $FeSO_4$+ 0.3% $ZnSO_4$ was relatively best and can provide theoretical basis and reference for the scientific fertilization of the production of organic special pear dates in the loess hilly region. In addition, further research may be continued with fertilization treatment for the improvement of the yield, quality, and iron and zinc content of other fruit trees. This findings would be of great significance to the local economy and ecology as well.

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(Manuscript received on 16 July, 2018; revised on 10 September, 2018)