Effects of Different Irrigation Methods on Growth, Fruit Quality and Yield of Apple Trees

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Abstract Water-saving irrigation is an important way to realize the sustainable development of the apple industry. In order to screen the best irrigation pattern for apple, taking 9-year-old 'Yanfu 10' Fuji/*Malus robusta* apple as the material, the effects of different irrigation methods (drip irrigation, sprinkling irrigation, and flood irrigation) on the growth, fruit quality, and yield of apple trees were studied. The results showed that compared with the flood irrigation, drip irrigation and sprinkling irrigation significantly increased the spring shoot length by 14.8% and 9.1%, respectively, and decreased the autumn shoot length by 11.7% and 8.8%, respectively. Drip irrigation and sprinkling irrigation significantly increased the leaf area, chlorophyll content, and leaf weight, the leaf area increased by 3.0% and 1.9%, respectively, the chlorophyll content increased by 13.9% and 11.5%, respectively, and the leaf weight increased by 5.8% and 5.1%, respectively. Drip irrigation and sprinkling irrigation could slightly increase the single fruit weight and fruit shape index, significantly increase the coloring index and smoothness index. The single fruit weight increased by 3.2% and 1.9%, the coloring index increased by 6.1% and 4.1%, the smoothness index increased by 4.7% and 2.8%, and the proportion of red fruit increased by 4.2% and 2.2%, respectively. The content of soluble solids in drip irrigation and sprinkling irrigation was significantly higher than that in flood irrigation, which was 13.0% and 2.6% higher than CK, respectively. The fruit hardness in drip irrigation and sprinkling irrigation was 7.9% and 2.2% higher than CK, respectively, and that in drip irrigation increased significantly. The yield in drip irrigation and sprinkling irrigation was 12.1% and 8.2% higher than CK, respectively. In conclusion, drip irrigation and sprinkling irrigation could promote the growth of apple trees, improve the fruit quality, and increase the yield of apple trees, and the effect of drip irrigation is better than sprinkling irrigation.

Key words Apple, Irrigation method, Growth, Fruit quality, Yield

1 Introduction

At present, most of the orchards in China still apply the traditional flood irrigation method. This irrigation method greatly wastes water and fertilizer, but also causes nutrient leaching and soil compaction, reduces soil permeability, destroys soil microbial flora, reduces microbial diversity and activity, and also inhibits root respiration of fruit trees, leads to poor growth and functional decline of root system, reduces nutrient absorption and transport efficiency, and seriously affects the normal growth and development of fruit trees and improvement of fruit quality, and it has become an outstanding issue restricting the sustainable and healthy development of fruit tree industry[1]. Water-saving irrigation technology is a modern and cost-effective technology that can improve the irrigation water use efficiency[2-3]. Therefore, it is required to develop and implement new scientific and water-saving irrigation methods such as drip irrigation and sprinkling irrigation[4-5]. As advanced water-saving irrigation methods, drip irrigation and sprinkling irrigation have received more and more attention. People have carried out extensive studies on water-saving irrigation of fruit trees and the effects on fruit quality and physiological indicators. Compared with the traditional irrigation model, the irrigation uniformity of sprinkling irrigation is higher, it can not only reduce the water loss in the orchard transportation process, but also the soil leakage loss after irrigation, but also can improve the fruit quality[6]. Drip irrigation can reduce a large amount of water loss and save 49% compared with surface irrigation. Different irrigation methods have great effects on root crown biomass, root system activity and leaf physiological functions[7]. Besides, soil microbial traits and soil enzyme activity are also regulated by irrigation treatment[8]. Zhang Xueqin *et al.*[9] found that different irrigation methods have great effects on root growth and soil enzyme activity during fruit swelling period. In addition, irrigation and fertilization of plants through drip irrigation can increase the fertilizer utilization rate, thereby promoting the improvement of fruit yield and quality[10-13]. At present, the apple tree planting area continues to expand, irrigation water consumption continues to increase, and the conflict of water shortage has become increasingly prominent. Therefore, it is required to vigorously develop water-saving irrigation technique to replace traditional irrigation methods. Taking traditional flood irrigation as the control, we studied the effects of drip irrigation and sprinkling irrigation on the growth, fruit quality and yield of apple trees, and selected the best irrigation method, to provide technical support for establishing scientific water-saving fruit tree cultivation system.

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2 Materials and methods

2.1 General situation of experimental area The experiment was carried out in the apple orchard in Dahuangjia Village, Chaoshui Town, Penglai City, Shandong Province. The orchard area was 0.4 ha, the terrain was flat, the soil was sandy soil, pH was 6.7, organic matter content was 0.9%, and the management level was moderate.

2.2 Experimental materials The main cultivar was 'Yanfu 10' Fuji/*Malus robusta* apple, the pollination variety was 9-year-old Gala with spacing in the rows and spacing between rows of 3 m × 5 m.

2.3 Experiment methods

2.3.1 Using a randomized block design, we set three treatments: drip irrigation, sprinkler irrigation, and flood irrigation (CK), and 15 plants for each treatment, and repeated three times. Each treatment was first irrigated during the dormant period of apple trees in 2013. For three consecutive years from 2014 to 2016, irrigation was carried out one time in the germination, flowering, new shoot growing, flower bud differentiation, fruit expansion, fruit maturation, and dormancy stages. The irrigation amount, determined on the basis of water demand of apple growth and development, was 375, 300, 375, 225, 375, 375, and 375 m^3/ha, respectively. Other field management methods were the same as traditional irrigation methods.

2.3.2 Measurement items and methods.

(i) New shoot length. In the middle of June and late of September, we randomly selected 30 new shoots outside the crown, and measured the length of spring shoots and autumn shoots.

(ii) Leaf traits. In late September, we selected 100 mature leaves from the middle of spring shoots outside the crown, measured the chlorophyll content using SPAD-502 PLUS chlorophyll meter, measured the leaf area using YMJ-B leaf area meter, and weighed the 100-leaf weight using JA2003N balance.

(iii) Fruit traits. When the fruit became mature in late October, we selected single representative plant in each treatment, picked all fruits and weighed, made a statistic of the yield of single plant, and converted into the per unit area yield. Then, we randomly selected 30 fruits, weighed the single apple weight using the balance, measured the vertical and horizontal diameters of the fruits with a digital caliper, measured the peeling hardness of the fruit using GY-1 type fruit hardness tester,, and measured the content of soluble solids using ATAGO PAL-1 digital display. We randomly selected 50 fruits, counted the number of fruits with whole red surfaces, calculated the proportion of whole red fruit (the total number of red fruits / 50 × 100%), classified the color area and smoothness of the fruit surface (Table 1), and calculated the coloring index and smoothness index:

The coloring index = ∑(number of each level of fruits × representative level value)/(total number of fruits × max level value) ×100.

The smoothness index = ∑(number of each level of fruits × representative level value)/(total number of fruits × max level value) ×100.

2.3.3 Data processing. With the aid of Microsoft Excel 2010 and DPS 7.5, we carried out statistical analysis of the data, and carried out the significance test using Duncan's new multiple range method. Then, using the mean value of three years of indicators, we evaluated the overall effects of different irrigation methods.

Table 1 Color index and smoothness classification criteria for apple fruits

Level	Coloring area//%	Smoothness//%
0	0 – 5	0 – 10
1	5 – 25	10 – 30
2	25 – 50	30 – 60
3	50 – 75	60 – 85
4	75 – 100	85 – 100

3 Results and analysis

3.1 Effects of different irrigation methods on growth of apple trees

3.1.1 Effects on the growth of new shoots. The average spring shoot length of drip irrigation and sprinkling irrigation was significantly higher than that of CK, which was 14.8% and 9.1% higher than that of CK, respectively. Among them, the index value of drip irrigation treatment was significantly higher than that of the sprinkling irrigation treatment; the average length of autumn shoot was significantly less than that of CK, which was 11.7% and 8.8% shorter, but the difference in index values between the two treatments was not significant (Table 2). This indicates that the drip irrigation and sprinkling irrigation can significantly promote the growth of spring shoots and inhibit the growth of autumn shoots. Among them, the effect of drip irrigation on the growth of spring shoots is significantly better than that of sprinkling irrigation.

Table 2 Effects of different irrigation methods on growth of new apple shoots (cm)

Treatment	2014		2015		2016		Mean value of 3 years	
	Length of spring shoots	Length of autumn shoots	Length of spring shoots	Length of autumn shoots	Length of spring shoots	Length of autumn shoots	Length of spring shoots	Length of autumn shoots
Drip irrigation	32.4 a	12.3 b	32.9 a	11.7 b	32.6 a	12.1 b	32.6 a	12.0 b
Sprinkling irrigation	30.3 a	12.4 b	31.3 a	11.9 b	31.5 b	12.0 b	31.0 b	12.4 b
Flood irrigation (CK)	27.8 b	13.9 a	28.9 b	13.2 a	28.6 c	13.8 a	28.4 c	13.6 a

Note: different small letters denote significant difference at 0.05 level, the same as below.

3.1.2 Effects on the leaf traits. The average leaf area, chlorophyll content and 100-leaf weight were not significantly different

between drip irrigation and sprinkler irrigation, but both index values were higher than CK. The average leaf area increased by 3.0% and 1.9%, respectively, and there was no significant difference with CK. The chlorophyll content increased by 13.9% and 11.5%, respectively, and the average 100-leaf weight increased by 5.8% and 5.1%, respectively, both significantly higher than CK (Table 3). This indicates that both drip irrigation and sprinkling irrigation can promote the increase of apple leaf area, and obviously increase the chlorophyll content and 100-leaf weight. Among them, the effect of drip irrigation treatment is slightly better than that of sprinkling irrigation.

Table 3 Effects of different irrigation methods on growth of apple leaves

Treatment	2014			2015			2016			Mean value of 3 years		
	Leaf area//cm^2	SPAD	100-leaf weight//g	Leaf area//cm^2	SPAD	100-leaf weight//g	Leaf area//cm^2	SPAD	100-leaf weight//g	Leaf area//cm^2	SPAD	100-leaf weight//g
Drip irrigation	34.2 a	59.6 a	87.3 a	34.1 a	59.9 a	87.7 a	33.9 a	59.3 a	88.1 a	34.1 a	59.6 a	87.7 a
Sprinkling irrigation	33.8 a	58.2 a	86.9 a	33.7 a	58.3 a	87.2 a	33.6 a	58.5 a	87.1 a	33.7 a	58.3 a	87.0 a
Flood irrigation (CK)	33.1 a	52.6 b	82.6 b	32.8 b	52.1 b	82.9 b	33.3 a	52.2 b	83.1 b	33.1 a	52.3 b	82.8 b

3.2 Effects of different irrigation methods on quality of apple fruit

3.2.1 Effects on the appearance quality. The average single fruit weight, fruit shape index, coloring index, smoothness index and the index of drip irrigation and sprinkling irrigation were not significantly different, but both index values were higher than CK, and the average fruit weight increased by 3.2% and 1.9% respectively. The average fruit shape index was slightly higher, and there was no significant difference with CK; the average coloring index increased by 6.1% and 4.1%, the average smoothness index increased by 4.7% and 2.8% respectively, and the average proportion of whole red fruit increased by 4.2% and 2.2% respectively, significantly higher than CK (Table 4). This indicates that drip irrigation and sprinkling irrigation can significantly improve the appearance quality of the fruit, and the effect of the drip treatment is slightly better than the sprinkling irrigation treatment.

Table 4 Effects of different irrigation methods on appearance quality of apple fruit

Treatment	2014					2015					2016					Mean value of 3 years				
	Single fruit weight g	Fruit shape index	Coloring index %	Smoothness index %	Whole red %	Single fruit weight g	Fruit shape index	Coloring index %	Smoothness index %	Whole red %	Single fruit weight g	Fruit shape index	Coloring index %	Smoothness index %	Whole red %	Single fruit weight g	Fruit shape index	Coloring index %	Smoothness index %	Whole red %
Drip irrigation	328.3 a	0.92 a	97.9 a	93.7 a	91.4 a	332.5 a	0.92 a	98.8 a	93.5 a	92.7 a	336.2 a	0.93 a	97.9 a	92.9 a	91.6 a	332.3 a	0.92 a	98.2 a	93.4 a	91.9 a
Sprinkling irrigation	326.5 a	0.91 a	96.3 a	91.1 a	89.1 a	328.3 a	0.92 a	96.3 a	92.1 a	91.1 a	329.4 a	0.92 a	96.5 a	91.6 a	90.1 a	328.1 a	0.92 a	96.4 a	91.6 a	90.1 a
Flood irrigation (CK)	319.1 a	0.90 a	92.2 b	88.3 b	87.1 b	321.7 a	0.91 a	93.2 b	90.5 b	89.1 b	324.9 a	0.91 a	92.2 b	88.6 b	88.3 b	321.9 a	0.91 a	92.5b	89.1 b	88.2 b

3.2.2 Effects on the internal quality. The average content of soluble solids of drip irrigation and sprinkling treatments were significantly higher than CK, which was 13.0% and 2.6% higher than that of CK, respectively. Among them, the index value of drip irrigation treatment was significantly higher than sprinkling irrigation treatment; the average fruit hardness was higher than CK, and the index value of drip irrigation was the highest, there was no significant difference with the sprinkling treatment but it was significantly higher than CK (Table 5). The results showed that drip irrigation and sprinkling irrigation could significantly improve the internal quality of the fruit. The effect of the drip treatment was better than the sprinkling irrigation treatment. The content of soluble solids of the fruit was significantly higher than that of the sprinkling irrigation treatment.

Table 5 Effects of different irrigation methods on internal quality of apple fruit

Treatment	2014		2015		2016		Mean value of 3 years	
	Content of soluble solids//%	Fruit hardness kg/cm^2	Content of soluble solids//%	Fruit hardness kg/cm^2	Content of soluble solids//%	Fruit hardness kg/cm^2	Content of soluble solids//%	Fruit hardness kg/cm^2
Drip irrigation	15.5 a	9.8 a	15.6 a	9.2 a	15.8 a	9.9 a	15.6 a	9.6 a
Sprinkling irrigation	14.4 b	9.3 a	15.1 a	9.2 a	14.6 a	8.9 b	14.7 b	9.1 ab
Flood irrigation (CK)	14.1 b	8.7 a	14.2 b	8.9 a	13.2 b	9.1 ab	13.8 c	8.9 b

3.3 Effects of different irrigation methods on yield of apple trees The average yield of drip irrigation and sprinkling treatments was significantly higher than CK for 12.1% and 8.2%, respectively, but the difference between the two treatments was not significant (Table 6). This indicates that drip irrigation and sprinkling irrigation can significantly increase the yield of the apple trees and the effect of the drip treatment is slightly better than the sprinkling irrigation treatment.

Table 6 Effects of different irrigation methods on yield of apple trees

(kg/ha)

Treatment	2014	2015	2016	Mean value of 3 years
Drip irrigation	74 389.5 a	77 035.5 a	76 474.5 a	75 966.0 a
Sprinkling irrigation	73 090.5 a	74 164.5 a	72 715.5 b	73 323.0 a
Flood irrigation (CK)	681 40.5 b	70 099.5 b	64 999.5 c	67 746.0 b

4 Conclusions and discussions

At different growth stages, fruit trees have different sensitivity to water. Through using irrigation methods to regulate plant root and shoot growth and water, it is able to realize the purpose of controlling the growth of fruit trees, reduce the amount of pruning, accordingly increase the accumulation of nutrients, and promote differentiation of flower bud[14]. Reasonable irrigation methods can increase the water use efficiency of plants and realize water saving and efficient water use[7]. Studies have shown that irrigation affects the leaf water content, shoot growth, trunk diameter, and photosynthetic characteristics of fruit trees[2, 15]. According to results of our study, compared with the flood irrigation, drip irrigation and sprinkling irrigation significantly promoted the growth of spring shoots. The results of drip irrigation tests conducted in mountain orchards also showed that the average length of fruit shoots increased by 10% and 33%, respectively, compared with border irrigation and non-irrigation[16].

Irrigation affects the chlorophyll content of apple leaves[17], which in turn affects the photosynthetic capacity of the leaves[18]. The results of this study showed that both drip irrigation and sprinkling irrigation promoted the increase of apple leaf area, and significantly increased the 100-leaf weight and chlorophyll content. The index value of drip irrigation treatment was slightly higher than that of sprinkling irrigation treatment, but the two treatment index values were not significantly different. This indicates that the two kinds of irrigation methods significantly enhanced the photosynthesis of the leaves, and the drip irrigation treatment was slightly better than the sprinkling irrigation treatment.

Irrigation methods affect apple fruit growth rate and yield[19]. The results of this study showed that the yield of apple trees of drip irrigation and sprinkling irrigation was significantly higher than that of flood irrigation, and the effect of drip irrigation treatment was slightly better than that of sprinkling irrigation treatment. Under the same fertilization conditions, drip irrigation can significantly increase apple yield and improve the fruit quality compared with traditional surface irrigation[20]. In this study, compared with the flood irrigation, the single fruit weight of drip irrigation and sprinkling irrigation increased, and the proportion of whole red fruit, the coloring index, the smoothness index, and the content of soluble solids were all significantly increased.

From the above analysis, it can be seen that selecting suitable irrigation methods is favorable for the growth and development of apple trees, and favorable for improving the fruit quality and increasing the yield. In this study, the effects of drip irrigation and sprinkling irrigation are better than those of flood irrigation. The overall effect of drip irrigation treatment is better than sprinkling irrigation treatment.

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(To page 68)

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(From page 57)

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