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Research Article

Effects of Water and Fertilizer Coupling on the Yield and Quality of Drip Irrigated Chinese Jujube in an Extreme Arid Region

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Abstract: In this study, a 2-factor and 5-level quadratic orthogonal rotated composite experimental design was employed to investigate the effects of water and fertilizer coupling on the yield and quality of drip irrigated Chinese jujube in an extreme arid region. The results showed that both water and fertilizer had significant important influences on the yield and quality of drip irrigated jujube and that reasonable and effective fertigation could bring high yield and good quality. Insufficient water would affect nutrient uptake of Chinese jujube and result in the decrease of yield. Similarly, inadequate nutrients would lead to maldevelopment of jujube and finally decrease the yield. When irrigation was at a relatively low level, reasonably increasing fertilizer application could improve the biological trails of jujube, while over-fertilization would inhibit jujube growth and decrease the yield when irrigation was at a relatively high level. Under the experimental conditions, when yield was the pursued economic goal, the suitable water and fertilizer coupling was determined as irrigation amount of 7800 m^3/hm^2, urea of 456.45 kg/hm^2 and potassium dihydrogen phosphate of 755.4 kg/hm^2; when quality was the pursued economic goal, the recommended water and fertilizer coupling was irrigation amount of 7800 m^3/hm^2, urea of 652.2 kg/hm^2 and potassium dihydrogen phosphate of 1079.25 kg/hm^2.

Keywords: Drip irrigated Chinese jujube, extreme arid region, quality, water and fertilizer coupling, yield

INTRODUCTION

Drip irrigation is a water- and fertilizer-saving irrigation technology that can keep a relatively high humidity and appropriate nutrient concentrations in the zone around crop roots by providing water locally and frequently (Xiao *et al*., 2004; Zhang *et al*., 1999). Such an irrigation technology is favorable for crop growth, which can effectively raise crop yield and quality (Feng *et al*., 1998; Lv *et al*., 1994; Yu, 1992). Especially for China, there is vast territory in the arid and semiarid zones and developing drip irrigation technology is a strategic need of achieving the sustainable development of agriculture, which has an extensive development space and a high productive potential (Sun *et al*., 2006). Currently, research on the effects of water and fertilizer coupling on yield is mainly focused on such field crops as wheat, corn and cotton. Previous studies showed that for arid agriculture, water and fertilizer had an obvious coupling relationship and the yield-increasing effect of fertilizer was not only due to fertilizer itself but also more importantly due to the interaction between fertilizer and soil water (Wang *et al*., 2011). For spring corn in semiarid regions, Nitrogen (N) fertilizer had the greatest effect on the yield, followed by Phosphorus (P) fertilizer and water had the smallest (Wang *et al*., 2008). As far as pepper yield was concerned, water, N and P had similar effects on the yield, but their pair-wise couplings presented different effects, namely, the coupling of irrigation amount and N fertilizer and the coupling of N and P fertilizers had negative effects while the coupling of irrigation amount and P fertilizer had positive effect (Liang *et al*., 2003). Although the planting area for Chinese jujube is large in Xinjiang, it has been only years since Chinese jujube was drip irrigated (Hu *et al*., 2010) and there are few studies on the effects of water and fertilizer coupling on the yield of drip irrigated Chinese jujube. As Hami Region is located in the extreme arid region of Xinjiang, Chinese jujube is a special fruit and one of the industry mainstays for that region. However, current research achievements are not adequate to provide help in water and fertilizer management for drip irrigated Chinese jujube in that region and more studies on water and fertilizer coupling are urgently needed. In this study, experiments were performed to investigate the effects of different water and fertilizer couplings on the yield and quality of the drip irrigated Chinese jujube in the extreme arid region of Hami and the suitable water and fertilizer coupling was determined for different pursued

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economic goal. The results from this study are expected to provide help in conducting reasonable and scientific fertigation for the Chinese jujube in that region.

MATERIALS AND METHODS

Outline of the study area: This study was conducted in the Second Garden, First Hongxing Form, the 13th Division of the Xinjiang Production and Construction Corps (XPCC) in the Tuha Basin from April to August in 2012. The experiment site (93°32′10.09″E, 42°49′11.23″N) is about 960 m a.s.l. and about 18 km away from the downtown of Hami City. The site has a typical continental arid climate with an average annual precipitation of merely 30 mm, an average annual evaporation as high as 3300 mm, an average annual relative humidity of 41%, an average annual sunshine duration of up to 3360 h, an average annual air temperature of 9.9°C, the accumulated temperature (>10°C) of 4260°C, an annual average wind speed of 2.8 m/sec, a maximum frozen ground depth of 1.26 m and a frost-free period of 182 days. For the experiment site, the groundwater table is at a depth of over 10 m, the average soil bulk density in the 0-100 cm soil layer is 1.50 g/cm^3 and the field water holding capacity is 11/100 g.

Experimental methods: The Chinese jujube trees had been 12 years old when our experiment was performed, which were planted with a row spacing of 5 m and plant spacing of 2 m (about 1140 plants/hm^2). Single wing labyrinth drip irrigation pipes produced by the Dayu Water-saving Co., Ltd., Xinjiang were used for the irrigation system, which had an inner diameter of 16 mm and a wall thickness of 0.18 mm. The emitter spacing was 300 mm, the lateral spacing was 60 cm (2 pipes/line) and the designed emitter flow rate was 3.0 L/h. Irrigation in each treatment was independently controlled by a ball valve so that different irrigation amounts could be applied to different treatments. A water pump was used to exert a pressure on the water supply system and a pressure gauge was connected with the front of the pipes to monitor the water pressure inside the pipe. For the laterals, sluice valves were used to adjust the water pressure inside to be 0.10 MPa.

To find out the best coupling of water and fertilizer for Chinese jujube growth in extreme arid regions, a 2-factor and 5-level quadratic orthogonal rotated composite design was employed in this study with the irrigation amount and N fertilizer amount (N:P:K = 2:1:2) as the two independent variables. There were a total of 10 treatments with 3 replicates for each treatment. The details about the experimental design are shown in Table 1. During the experiment, fertilizer was applied through the drip irrigation system (called fertigation). Nitrogen was supplied in the form of urea (total N≥46.4%) and P and potassium (K) were in the form of potassium dihydrogen phosphate (KH_2PO_4 ≥98%).

Table 1: Fertigation treatments for the Chinese jujube

Treatment	Irrigation amount (m^3/hm^2)	Urea (kg/hm^2)	Potassium dihydrogen phosphate (kg/hm^2)
D1	8400	603.30	998.25
D2	8400	505.50	836.40
D3	7200	603.30	998.25
D4	7200	505.50	836.40
D5	6600	554.40	917.40
D6	9000	554.40	917.40
D7	7800	456.45	755.40
D8	7800	652.20	1079.25
D9	7800	554.40	917.40
D10	7800	554.40	917.40

Measuring items and methods: The yields of the 10 labeled trees were recorded at the fruit mature stage using the weighing method for single fruit weight and single tree yield which was then converted to unit area yield. The Brix degree of fresh jujubes was determined using a digital refractometer (PAL-3, Atago Instruments, Tokyo, Japan). Total acidity was measured by titration and Vitamin C (Vc) content was measured by the 2, 4-dinitro-phenylhydrazine colorimetry. Data were analyzed using the SPSS 16.0 (SPSS, Chicago, USA).

RESULTS AND ANALYSIS

Effects of water and fertilizer coupling on the yield of drip irrigated Chinese jujube: Different water and fertilizer couplings would exert certain effects on the physiological traits of drip irrigated Chinese jujube and finally the yield. Jujube yield is composed of the number of fruits per tree and the hundred-fruit weight and any change in either will influence the final yield. The drip irrigated Chinese jujube yields of different treatments are shown in Table 2.

As can be seen in Table 2, the treatments of D7, D8 and D3 have a significantly higher number of fruits per tree than other treatments. Treatment D7 receives a moderate amount of irrigation and the lowest fertilizer, treatment D8 receives a moderate irrigation but the highest fertilizer and D3 receives both moderate irrigation and fertilizer. In terms of hundred-fruit weight, the treatments of D7 and D1 are significantly higher than other treatments although D1 receives moderate irrigation and fertilizer. These results clearly indicated that a higher irrigation amount or more fertilizer did not necessarily bring in a higher number of fruits or a higher hundred-fruit weight and that only a reasonable coupling of irrigation and fertilization could achieve a better effect.

As for the yield, the treatments of D3, D4 and D7 have a significantly higher yield than other treatments and D7 has the highest. This demonstrated that moderate irrigation and minimum fertilizer produced the maximum production efficiency and achieved the synergistic effect of irrigation and fertilization, which finally brought in a high yield. With respect to

Table 2: The yield of drip irrigated jujube with different water and fertilizer coupling treatments

Treatment	Fruit number per tree	Hundred-fruit weight (kg)	Yield (kg/hm^2)
D1	700A	2.14AB	15705.19ABC
D2	750AB	1.91AB	16128.50ABC
D3	1000F	1.75A	18381.95BC
D4	875DE	1.87A	18390.47ABC
D5	900E	1.70A	16084.24ABC
D6	800BC	1.91AB	16038.29ABC
D7	970F	2.35B	23085.18D
D8	1025F	1.79A	17986.88C
D9	750AB	1.68A	14135.25A
D10	820CD	1.68A	13878.20AB

Different letters within a column mean significant differences at the 0.01 level between treatments

Table 3: The components of jujube quality

Treatment	Brix degree (%)	Total acidity (%)	Vc (mg/kg)
D1	31.7Aa	0.39Aab	748.13Aa
D2	30.2Aa	0.35Aab	711.75Aa
D3	31.2Aa	0.47Aab	814.63Aa
D4	33.8Aa	0.47Aab	870.06Aa
D5	32.5Aa	0.59Ab	676.22Aa
D6	34.8Aa	0.37Aab	955.89Aa
D7	31.8Aa	0.38Aab	677.92Aa
D8	30.8Aa	0.33Aa	901.61Aa
D9	33.0Aa	0.35Aab	791.90Aa
D10	33.7Aa	0.42Aab	631.03Aa

Different capital letters in a column mean significant differences at the 0.01 level between treatments; Different lowercase letters in a column mean significant differences at the 0.05 level between treatments; while the same letters in a column indicate no significant differences

treatment D5 (minimum irrigation and moderate fertilizer), irrigation amount is too low and fertilizer cannot be effectively transported and utilized, which results in a moderate yield. But the yield in treatment D6 with the highest irrigation and moderate fertilizer is not high either, which indicates that water utilization efficiency will be decreased when fertilizer is relatively low. Therefore, only when water and fertilizer were reasonably combined, could a maximum utilization efficiency of water and fertilizer be achieved, water resource and fertilizer be saved and a high yield be obtained.

Effects of water and fertilizer coupling on the quality of drip irrigated Chinese jujube: Differences in the main quality indexes of Brix degree, total acidity and Vc content between treatments with different water and fertilizer couplings are shown in Table 3.

Brix degree is an important indicator of jujube quality and high quality jujube always displays a high Brix degree. As shown in Table 3, there are no significant differences in Brix degree between the treatments and a Brix degree of above 30% can be achieved in all the treatments. Treatment D6 has the highest Brix degree up to 34.8%, followed by D4 and D10 and treatment D2 has the lowest Brix degree, followed by D8. Considering the water and fertilizer coupling with different treatments, treatment D6 receives the highest irrigation and moderate fertilizer, while D4 and D10 receive moderate irrigation and fertilizer; D2 is moderately irrigated and receives the lowest but one fertilizer, while D8 receives a moderate irrigation but the greatest fertilizer. On the whole, the amount of fertilizer had a great effect on the Brix degree of jujube and either too much or too little fertilizer was not favorable for sugar accumulation in jujube. When the combined effects of water and fertilizer on the Brix degree were concerned, fertilization within a certain range could raise the Brix degree. Therefore, only when relatively appropriate amounts of irrigation and fertilizer were applied, could the Brix degree of jujube be raised to a relatively high level.

Total acidity is also an important index of jujube quality. In contrast to the Brix degree, a low total acidity is often what people want. Table 3 demonstrates that treatment D8 is significantly (at the 0.01 level) lower in total acidity than other treatments and there are no significant differences between other treatments, which indicates that the water and fertilizer coupling applied in D8 is most favorable for decreasing the total acidity and consequently more favorable for sugar accumulation. The treatments of D3, D4 and D5 have a total acidity of over 0.45% while other treatments do not differ much in total acidity. Considering the water and fertilizer coupling, D3 and D4 receive both moderate irrigation and fertilizer while D5 receives the lowest water and moderate fertilizer, suggesting that irrigation, fertilization and their coupling have fairly obvious effects on total acidity. Notably, fertilizer application especially N and K fertilizer application could effectively lower the total acidity. Yet, it was not that more N and K fertilizers can result in a lower total acidity but that an appropriate range of N and K should be used. As for irrigation amount, it had a positive correlation with total acidity, namely, irrigation could increase the total acidity but was not good for improving jujube quality.

In addition, a high Vc content is also an important trait of high quality jujube. The data in Table 3 reveals that the treatments of D6 and D8 have the highest Vc content nearly over 900 mg/kg, which is significantly larger than those of other treatments. Under the experimental conditions of this study, the Vc content in other treatments expect D6 and D8 is in the range of 631.03-870.06 mg/kg, which is not much different from the mean value. Considering the water and fertilizer coupling, D6 receives the highest irrigation and moderate fertilizer, while D8 is moderately irrigated but receives the highest fertilizer. This indicates that under certain conditions, increasing the amount of either irrigation or fertilizer can effectively raise the Vc content in jujube. Therefore, only when reasonable amounts of irrigation and fertilizer were applied could the utilization efficiency of water and fertilizer be effectively raised.

To sum up, the treatments with different water and fertilizer couplings showed fairly apparent differences in the quality indicators of jujube. Under the experimental conditions of this study, treatment D8 could effectively raise the sugar content and Vc content of Chinese jujube but decrease the total acidity to the minimum. Therefore, the water and fertilizer coupling in D8 was considered to be relatively reasonable. It needs to be pointed out that not only fertigation but also jujube cultivar, soil texture and local climate can affect the growth and development of jujube (Wang *et al*., 2013). The soil in the study area is sandy gravel which is very poor in basic nutrients and soil background fertility has an effect on crop yield. Therefore, the effects of water and fertilizer coupling on drip irrigated jujube should be further investigated on different soil textures, in different regions and with different cultivars so that more universal conclusions can be drawn.

CONCLUSION

The results from this study indicated that water and fertilizer coupling had important effects on both the yield and quality of drip irrigated Chinese jujube. Insufficient water negatively affected nutrient uptake and subsequently the yield of jujube. Inadequate nutrients caused maldevelopment of jujube and inhibited water uptake by jujube, which led to yield drop. Reasonable and effective fertigation could bring in a high yield and good quality of jujube in an extreme arid region. Under the experimental conditions in this study, when jujube yield was the pursued economic goal, the suitable water and fertilizer combination was determined as irrigation amount of 7800 m^3/hm^2, urea of 456.45 kg/hm^2 and potassium dihydrogen phosphate 755.4 kg/hm^2. When jujube quality was the pursued economic goal, the appropriate water and fertilizer combination was irrigation amount of 7800 m^3/hm^2, urea of 652.2 kg/hm^2 and potassium dihydrogen phosphate 1079.25 kg/hm^2.

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