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Yield and Quality of Winter Jujube under Different Fertilizer Applications: A Field Investigation in the Yellow River Delta

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Abstract: Winter jujube (*Ziziphus jujuba* Mill. cv. Dongzao) is highly popular due to its attractive taste and flavor of fruits. However, its cultivation is facing a serious obstacle for the substantial decrease in fruit soluble solids contents. In this study, four commonly-used fertilization types, including organic manure application (OM), combined application of manure and NPK fertilizer (OC), NPK fertilizer application at high rate (HC) and NPK fertilizer application at low rate (LC) were selected to investigate their effects on soil and fruit properties. Results showed that fertilization influenced soil organic matter (SOM) and NPK contents. Fruit yield decreased as HC (3.37tha^{-1}) > OC (2.81tha^{-1}) > OM (2.14tha^{-1}) > LC (1.92tha^{-1}).Total soluble solids (TSS), protein contents, and the ratio of TSS to titratable acid (TA) were highest in OM, followed by OC, LC and HC. TSS and TSS/TA ratio in OM were 23.0% and 27.0% higher than those in HC. Fruit yield was significantly positively correlated with soil available N, vegetative shoot leaf N, and total topsoil P contents. TSS and TSS/TA ratio both significantly positively correlated with SOM of topsoil and leaf P contents. Combined application of organic and inorganic fertilizers should be the optimal mode for winter jujube production.

Keywords: *Ziziphus jujuba* Mill. cv. Dongzao; soil organic matter; soil available N; total soluble solids; the Yellow River Delta

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1. Introduction

Jujube is a tree fruit that can thrive in various climates and resistant to infertility and salinity of soils. Among the 135–170 jujube species reported, *Ziziphus mauritiana* Lam. (Indian jujube) and *Ziziphus jujuba* Mill. (Chinese jujube) are the two most common ones [1]. In recent decades, winter jujube (*Ziziphus jujuba* Mill. cv. Dongzao), has become one of the most popular jujube species in China due to its attractive taste, texture and nutrition of fruit [2]. It is mainly distributed across the Yellow River delta (YRD) with the planting area of ~70,000 hectares. It is becoming an important cash crop in this YRD region [3].

The fruit of winter jujube is rich in various kinds of bioactive compounds, such as vitamin C (Vc), organic acids, sugars, minerals and proteins [4]. Vc is well known for possessing the antioxidant capacity to reduce oxidative stress in human body [5,6].Organic acids, sugars, minerals, and proteins are the important attributes of jujube fruit regarding human diet, whose compositions and concentrations largely influence the fruit taste and organoleptic quality [4,7]. Sugars are indicators of fruit sweetness. Recently, firmness has also drawn increasing attention due to its working for maintaining good flavor and prolonging shelf life of jujube fruit [7]. Such quality attributes of winter jujube fruit might depend largely on factors including cultural practices, fruit maturity, genotype, soil nutrients and so on. Since few cultivars of winter jujube are available presently, farming practices adopted in jujube orchard are closely related to the fruit quality [8–10]. For example, appropriate reducing the yield and crop load of jujube fruits in the orchard can increase sensory attributes and volatile compounds contents of the fruit [11].

Recently, the fruit quality of winter jujube turned to decline substantially, because of the farmers' management practice excessively focusing on high fruit yield. Declined fruit quality did cause fruit price and farmers' income dropping by approximately 45%, leading to great challenges for the sustainable development of winter jujube fruit production [3].In the YRD, different management practices were used by farmers to produce winter jujube fruits. It is worth mentioning that to chase high yield, various types of chemical fertilizers were applied. Over fertilization, especially excess mineral N application was often occurred in orchards [12]. However, organic manure application was increasingly ignored by farmers, due to its higher cost and lower effectiveness of increasing fruit yield compared with chemical fertilization [13,14]. Jujube fruit yield and quality would be largely depended on the fertilization mode. It is of great importance to develop scientific and reasonable fertilization strategies to maintain and enhance fruit quality of winter jujube. Hence, based on the long-term different fertilization practices by farmers, the effects of fertilization mode on fruit yield and quality of winter jujube were investigated in this study. The objectives were: (1) to explore the characteristics of soil properties and leaf NPK contents under different fertilization mode; (2) to elucidate fruit yield and quality of winter jujube under different fertilization modes; and (3) to determine the correlations between the major fruit quality parameters and the status of NPK nutrients. These findings could be helpful in improving fruit quality and technological cultivation level of winter jujube.

2. Methods and Materials

2.1. Study Region and Sampling

This investigation was conducted in Zhanhua District(37°42′ N, 117°54′ E), Binzhou City, Shandong Province, China, which was located in the Yellow River Delta. In this region, winter jujube orchards cover an area of about 30,000 hectares. It has a humid temperate continental monsoon climate, with mean annual precipitation of 600 mm, evaporation of 1800 mm and temperature of 12.5 °C. Soil salinization frequently occurs due to the shallow level and high salinity of ground water. Soil salinity (0–20 cm) in winter jujube orchard of studied area is 1.0–2.0 g kg^{-1}.The soil has a sandy loam texture, and is classified as Aquic Inceptisol. Commonly used fertilization modes by farmers at the jujube orchards in this region mainly include organic fertilization (OM), Organic and inorganic fertilization (OC), inorganic fertilization at high rate (HC), and inorganic fertilization at low rate (LC) (Table 1).

Table 1. Fertilizer applied rates in different fertilization modes.

Fertilization Mode	Fertilizer	Application Rate (kg ha^{-1})			
		Organic Manure	N	P	K
OM	Organic manure	7.5~10.0 × 10^3	100~150	35~45	85~125
OC	Organic manure + NPK compound fertilizer	3.0~4.5 × 10^3	OF: 40~70 CF: 335~380	OF: 14~20 CF: 86~115	OF: 34~60 CF: 216~250
HC	NPK compound fertilizer at high rate	0	540~600	165~200	375~450
LC	NPK compound fertilizer at low rate	0	150~225	65~100	100~125

OF, organic fertilizers; CF, chemical fertilizers.

Four typical jujube orchards with each fertilization mode were selected as sampling sites. The orchards we selected covered >2000 m^2, and were all with relatively single and stable fertilizer mode for more than 5 years and the ages of the jujube trees were about

8 years old showing excellent fruiting performances (Figure 1).Organic fertilizer used was commercial manures containing ~45% organic matter, ~2.0% N, ~1.0% P, and ~2% K nutrients. Inorganic N and P fertilizers were urea and diammonium phosphate. Inorganic K fertilizer was potassium sulfate. During the cultivation of winter jujube, organic fertilizer was used as basal fertilizer in November. As for NPK fertilizers, 30% of them were used as basal fertilizer, and 40% and the remaining 30%were used as supplemental fertilizer in July; and August, respectively.

Figure 1. The typical jujube orchard selected in this study.

Soil and leaf samplings were conducted in September 2020.Three jujube trees in each targeted orchard were randomly selected and associated soils, and leaves from fruit-bearing and vegetative shoots were collected. Under each tree, topsoil samples (0–20 cm) and subsoil samples (20–40 cm) were collected using a soil auger. In each tree within different fertilization mode, three fruit-bearing and vegetative shoots were randomly selected, and ten jujube leaves were collected from each shoot. Thus a total of thirty leaves from fruit-bearing/vegetative shoot mixed to one leaf sample. After air drying and sieving, soil samples were detected for physic-chemical properties in laboratory. Leaf samples were first dried at 105 °C for 30 min, then dried at 80 °C for 10 h, finally smashed and stored in desiccator until NPK contents analysis. In October, jujube fruit yield of each orchard was measured, and 100 jujube fruits were collected from each early-sampled tree. After clearing using deionized water, jujube fruits were stored at 5 °C until quality analysis.

2.2. Analysis of Soil and Leaf Samples

Soil pH was determined in a soil-water suspension (1:2.5). Soil organic carbon (SOC) content was measured using a vario EL III analyzer (Elementar, Hanau, Germany) after inorganic C of the soils being removed by 1 N HCl. Soil organic matter (SOM) content was calculated as SOC × 1.724 [15]. Soil available P and K were extracted by 0.5 M $NaHCO_3$ and 1 M CH_3COONH_4, respectively. To measure the total P and K, soil samples were digested using aqua regia and HF. P and K contents in extracted and digested solutions were determined by an Optima 8000 ICP-OES (PerkinElmer, Waltham, MA, USA) [15]. Soil available N was extracted with 2 M KCl and analyzed using a segmented flow AA3 analyzer (Seal, Norderstedt, Germany) [15]. Total N content in soil and leaf samples was measured using a vario EL III analyzer (Elementar, Hanau, Germany).P and K contents of leaf samples were measured according to method by Lu [15]. Briefly, 0.15 g of leaf sample was mixed with 5 mLH_2SO_4 in digestion tube. After overnight, the mixture was heated from 240 °C to 380 °C. When digestion solution turned to be brownish black, the tube was cooled and added 5–10 drops of H_2O_2. The solution was boiled for 10–15 min, and added 5 drops of H_2O_2 after cooling. This step was repeated until digestion solution turned to be colorless. P and K contents in digestion solution were determined by an Optima 8000 ICP-OES (PerkinElmer, Waltham, MA, USA).

2.3. Fruit Quality Analysis

Vitamin C (Vc) content was measured by 2, 6-dichloroindophenol sodium salt method, and soluble protein content was measured with Coomassie brilliant blue method [16]. Fruit firmness was measured with GY-1 type fruit sclerometer (Beijing Channel Scientific Instruments Co., Ltd., Beijing, China), which performed in 30 replications for each jujube orchard. Titratable acid (TA) was determined by titration with 0.1 mol L^{-1} NaOH, and results were expressed as mg malic acid equivalent per gram fresh weight [11]. The content of total soluble solids (TSS) was measured with a Master 53T refractometer (Atago Co., Ltd., Toyoto, Japan).

2.4. Statistical Analysis

Data are presented as arithmetic means (n = 4) in the tables and figures. One-way ANOVA was used for testing differences of soil properties, leaf NPK contents and fruit quality among different fertilization modes. Pearson's correlation coefficients and curve regression analysis were conducted to describe the correlations between soil properties/leaf NPK contents and fruit quality. All significant differences reported were $p < 0.05$ unless otherwise noted. Data analysis was performed using SPSS v20.0 software (IBM SPSS, New York, NY, USA).

3. Results

3.1. Soil Properties and NPK in Leaf Samples

The properties of the soils from winter jujube orchards under different fertilization modes are shown in Table 2. It could be observed that pH in topsoils (0–20 cm) was significantly lower than that in the subsoils (20–40 cm) ($p < 0.05$). SOM, total N, total P, total K, available P, and available K contents were significantly higher in topsoils than those in subsoils ($p < 0.05$). In topsoils, the highest contents of SOM, total N, total K, and available K were observed in OM group, which were significantly greater than those in HC and LC groups ($p < 0.05$). Soil total P and available N contents in the HC mode were 10.9~50.5% and 23.5~62.5% higher than those in other fertilization modes ($p < 0.05$). While available P content in OC was significantly higher than in other three fertilization modes. With exception of total P, similar trends of soil properties were also available in subsoils.

Table 2. Soil main properties in different fertilization modes.

Soil Layer	Fertilization Mode	pH	SOM ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	TP ($g\ kg^{-1}$)	TK ($g\ kg^{-1}$)	AN ($mg\ kg^{-1}$)	AP ($mg\ kg^{-1}$)	AK ($mg\ kg^{-1}$)
0–20 cm	OM	7.93 ^{a}	16.1 ^{a}	0.56 ^{a}	0.057 ^{bc}	0.96 ^{a}	29.1 ^{c}	25.7 ^{b}	265 ^{a}
	OC	7.90 ^{a}	15.0 ^{b}	0.55 ^{a}	0.065 ^{ab}	0.93 ^{a}	38.2 ^{b}	42.7 ^{a}	264 ^{a}
	HC	8.02 ^{a}	12.3 ^{c}	0.45 ^{b}	0.072 ^{a}	0.86 ^{b}	47.2 ^{a}	28.5 ^{b}	185 ^{b}
	LC	7.96 ^{a}	13.0 ^{c}	0.43 ^{b}	0.048 ^{c}	0.86 ^{b}	31.0 ^{bc}	23.8 ^{b}	167 ^{b}
20–40 cm	OM	8.26 ^{a}	9.85 ^{a}	0.48 ^{a}	0.043 ^{a}	0.89 ^{a}	19.1 ^{c}	16.1 ^{a}	223 ^{a}
	OC	8.26 ^{a}	9.23 ^{a}	0.42 ^{a}	0.042 ^{a}	0.85 ^{ab}	33.6 ^{b}	20.5 ^{b}	198 ^{a}
	HC	8.25 ^{a}	6.50 ^{b}	0.35 ^{b}	0.041 ^{a}	0.76 ^{b}	40.7 ^{a}	13.1 ^{bc}	138 ^{b}
	LC	8.28 ^{a}	7.04 ^{b}	0.38 ^{b}	0.042 ^{a}	0.76 ^{b}	20.2 ^{c}	11.3 ^{c}	135 ^{b}

Values are means using the same fertilization mode (n = 4). Different letters in each column within the same soil layer indicated significant difference(LSD test, $p < 0.05$).OM, organic fertilization; OC, organic and inorganic fertilization; HC, inorganic fertilization at high rate; LC, inorganic fertilization at low rate. SOM, soil organic matter; TN, soil total N; TP, soil total P; TK, soil total K; AN, soil available N; AP, soil available P; AK, soil available K.

NPK contents in leaf samples are shown in Figure 2. In the four fertilization modes, N contents in the vegetative shoot were significantly higher than those in the fruit-bearing shoot (t test, $p = 0.003$). P and K contents were higher in the fruit-bearing shoot than that in the vegetative shoot but not at the significant levels. Among the different fertilization modes, highest leaf N contents were both in HC. Leaf P contents varied slightly with the highest values in fruit-bearing and vegetative shoot observed in OC and OM, respectively. Leaf K contents of fruit-bearing shoot in OM and OC were significantly higher than those in HC and LC ($p < 0.05$). In vegetative shoot, little difference in leaf K contents was observed among different fertilization mode.

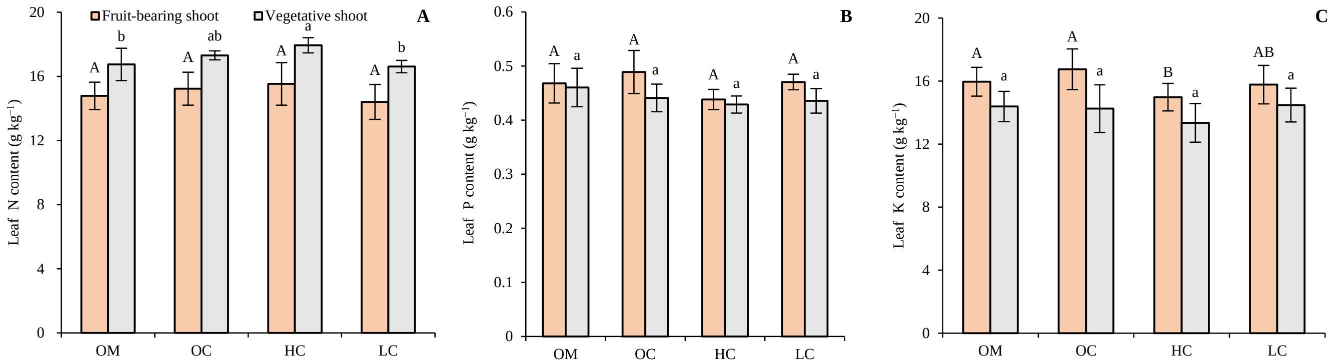

Figure 2. Leaf N (**A**), P (**B**), and K (**C**) contents in fruit-bearing and vegetative shoots of different fertilization modes. Columns represent the mean ($n = 4$), and bars represent standard deviation (SD). Different uppercase (lowercase) letters within the fruit-bearing (vegetative) shoot group indicated significant difference (LSD test, $p < 0.05$). OM, organic fertilization; OC, organic and inorganic fertilization; HC, inorganic fertilization at high rate; LC, inorganic fertilization at low rate.

3.2. Fruit Yield and Quality

Fruit yield of winter jujube under the four fertilization modes decreased as HC > OC > OM > LC (Table 3). Compared with those in OC, OM, and LC, fruit yield in the HC mode increased by 20.0%, 57.4%, and 75.3%, respectively ($p < 0.05$). As for the fruit quality, the highest TSS content was in the OM mode, 9.0%, 11.0%, and 23.0% higher than that in OC, LC and HC, respectively. The highest Vc content was in LC, 9.0% and 10.5% higher than those in HC and OC ($p < 0.05$). The protein content in HC was significantly lower than those in other three fertilization modes ($p < 0.05$). The highest TA content was in HC, which was significantly greater (7.0%) than that in OC ($p < 0.05$). Values of fruit firmness were much higher in HC and LC ($p < 0.05$). Great values of the ratios of TSS to TA were observed in OM and OC, and that in HC was 13.3~27.0% lower than the others ($p < 0.05$).

Table 3. Yield and quality of fresh jujube fruit in different fertilization modes. Values are means of the average of four jujube orchards using same fertilization mode ($n = 4$). Different letters in each column indicated significant difference (LSD test, $p < 0.05$).

Fertilization Mode	Yield (t ha^{-1})	TSS (mg g^{-1})	Vc (mg g^{-1})	Protein (mg g^{-1})	TA (mg g^{-1})	Firmness (N cm^{-2})	TSS/TA
OM	2.14 ^{c}	195.9 ^{a}	2.23 ^{ab}	3.62 ^{a}	3.39 ^{ab}	8.54 ^{b}	5.79 ^{a}
OC	2.81 ^{b}	179.8 ^{b}	2.14 ^{b}	3.51 ^{a}	3.28 ^{b}	8.73 ^{b}	5.50 ^{a}
HC	3.37 ^{a}	159.3 ^{c}	2.17 ^{b}	2.96 ^{b}	3.51 ^{a}	9.18 ^{a}	4.56 ^{c}
LC	1.92 ^{c}	176.5 ^{b}	2.36 ^{a}	3.45 ^{a}	3.42 ^{a}	9.33 ^{a}	5.17 ^{b}

OM, organic fertilization; OC, organic and inorganic fertilization; HC, inorganic fertilization at high rate; LC, inorganic fertilization at low rate. TSS, total soluble solids; Vc, vitamin C; TA, titratable acid; TSS/TA, ratio of TSS to TA.

3.3. Correlation between Fruit Quality and Leaf NPK Contents and Soil Properties

Results of correlation analysis were shown in Table 4. It could be observed that fruit yield of winter jujube was significantly positively correlated with topsoil total P, soil available N, and N of vegetative shoot leaf, and significantly negatively correlated with SOM of topsoil ($p < 0.05$). TSS of jujube fruit was significantly positively correlated with topsoil SOM and available K, and P of vegetative shoot leaf, and negatively significantly correlated with soil available N ($p < 0.05$). Similarly, fruit protein and ratio of TSS to TA were also significantly negatively correlated with soil available N, and significantly positively correlated with topsoil available K ($p < 0.05$). Winter jujube leaf P content from fruit-bearing shoot significantly positively correlated with the ratio of TSS to TA ($p < 0.05$). Total N of topsoil and leaf P content from fruit-bearing shoot were both significantly negatively correlated with TA, and total P of subsoil positively significantly correlated with TA ($p < 0.05$). Leaf N content from fruit-bearing shoot and total P of subsoil significantly positively correlated with fruit firmness, and leaf P content from fruit-bearing shoot significantly negatively correlated with fruit firmness ($p < 0.05$).

Table 4. Correlation analysis between soil properties, leaf NPK contents, fruit yield and quality.

Parameter		Yield	TSS	Vc	Protein	TA	Firmness	TSS/TA
0–20 cm soil	SOM	−0.500 *	0.748 **	−0.200	0.644 **	−0.371	−0.236	0.835 **
	TN	−0.116	0.363	−0.228	0.638 **	−0.484*	−0.055	0.610 **
	TP	0.720 **	−0.362	0.017	−0.306	0.342	0.285	−0.477
	TK	−0.077	−0.011	−0.283	0.011	−0.332	−0.319	0.201
	AN	0.831 **	−0.719 **	0.013	−0.656 **	0.418	0.245	−0.824 **
	AP	0.299	0.065	−0.038	0.397	−0.170	0.050	0.170
	AK	−0.212	0.609 **	−0.032	0.572 *	−0.131	−0.110	0.571 *
20–40 cm soil	SOM	−0.411	0.334	−0.025	0.561 *	−0.223	−0.298	0.414
	TN	−0.328	0.464	0.182	0.356	−0.114	−0.249	0.468
	TP	0.025	0.180	0.419	−0.095	0.522*	0.497 *	−0.142
	TK	−0.210	0.245	−0.065	0.382	−0.368	−0.420	0.407
	AN	0.851 **	−0.629 **	−0.153	−0.617 **	0.234	−0.099	−0.651 **
	AP	−0.311	0.374	0.062	0.490 *	−0.164	−0.175	0.417
	AK	−0.410	0.384	−0.106	0.570 *	−0.239	−0.237	0.468
Vegetative shoot	N	0.613 **	−0.061	−0.199	−0.467	0.179	−0.305	−0.135
	P	−0.283	0.528 *	0.237	−0.002	−0.046	−0.214	0.471
	K	−0.203	0.268	−0.041	0.420	−0.224	0.108	0.391
Fruit-bearing shoot	N	0.194	−0.256	0.421	0.188	0.194	0.586 *	−0.276
	P	−0.432	0.400	−0.011	0.480	−0.545 *	−0.493 *	0.650 **
	K	−0.094	0.332	0.042	0.231	−0.163	0.230	0.404

*, significant level at $p < 0.05$; **, significant level at $p < 0.01$. SOM, soil organic matter; TN, soil total N; TP, soil total P; TK, soil total K; AN, soil available N; AP, soil available P; AK, soil available K; TSS, total soluble solids; Vc, vitamin C; TA, titratable acid; TSS/TA, ratio of TSS to TA.

4. Discussion

4.1. Effect of Fertilization Mode on Soil Properties

In the present study, differences of soil properties were observed among different fertilizer applications indicating long-term single fertilization modes would affect the soils in varying degrees. SOM contents tended to be much lower in soils without organic manure application (Table 2, $p < 0.05$) showing single input of chemical fertilizers could result in the relative shortage of SOM, as well as organic manure supply was an effective way to maintain and improve SOM level. The accumulation of SOM in orchard largely depended on the balance of input and mineralization of organic matter in soils. Chemical fertilization can enhance the bioavailability of soil nutrients, especially N (Table 2), which would cause an increase in mineralization of native SOM and then decrease in SOM content [17]. Similar result was also reported that inorganic fertilization increased olive yield, but reduced SOM in comparison to organic amendments [18].SOM can enhance bioavailability of nutrients, and improve soil physicochemical and biological properties, which are closely linked to the yield and quality of fruits [19,20].

Fertilizer could affect the nutrients with varying degrees in the soils of the orchards. It could be observed that, in the present study, total N increased with SOM, which might be due to the great portion of organic N (~90%)to total N in the soils [21]. So, under the current fertilization mode, organic fertilizer would contribute to the great amounts of total N as well as inorganic fertilizers provide more available N. Available P contents in soils varied little with application rate and great values were observed in modes received both organic and chemical fertilization. Application of organic manure efficiently prevented the conversion of added fertilizer P into recalcitrant P [22].Hence, organic fertilization was a feasible way to increase the availability, and reduce fixation of P added in soils. Available K content was significantly higher in organic added modes indicating organic manure application was conducive to improve the bioavailability of K in soils [23].

4.2. Effect of Fertilization Mode on Fruit Yield and Quality

As mentioned above, soil nutrients and SOM were mainly controlled by fertilization mode in fruit orchards, which directly influenced the yield and quality of fruits. Based on our results, organic fertilization tended to improve the fruit quality indexes of winter jujube including contents of TSS and protein and TSS/TA ratio, and chemical fertilization at high applied rate would contribute to high fruit yield (Table 3). This was in accordance with a previous study report by Reche et al. [13]. TSS, protein, and TSS/TA ratio are the important fruit flavor attributes [24]. In this study, SOM in topsoil was positively correlated with TSS, protein, and TSS/TA ratio, and significantly negatively correlated with fruit yield ($p < 0.05$, Table 4). Therefore, topsoil SOM level, or organic input played important role in improving fruit flavor quality of winter jujube. The reasons might be: (1) Organic fertilization would increase soil water content and improve soil structure and nutrient availability, especially in the rhizosphere, which was helpful to meet water and nutrient demands during jujube growth [14,25]; (2) organic fertilization could provide a larger amounts of available nutrients (macro- and micronutrients) to plants [26], which would facilitate root growth and increase chlorophyll content of the plants, and then accelerate the accumulation of photosynthesis products in plants [13,19]; (3) low fruit yield probably meant a sink strength of fruit yield per unit, facilitating more sugars and other flavor compounds transport from sources to jujube fruits relatively [11].

In this study, soil available N content significantly positively correlated with fruit yield of winter jujube, and significantly negatively correlated with TSS, protein, and TSS/TA ratio ($p < 0.05$, Table 4). It is well known that N is essentially important for crop growth, and many physiological metabolic processes in plants are related to N supply [27]. Enough N supply is essential for photosynthesis and subsequent distribution of photoassimilates towards crop fruit [28]. However, excessive N input could improve the synthesis of organic acid, causing elevated consumption and reduced accumulation of sugars and protein in fruit [29]. This could be supported by the higher TA content in HC mode and the positive correlation between available N in topsoil and TA in this study (Tables 3 and 4). Thus, over N supply might lead to low quality of jujube fruit. Previous studied ever reported the threshold value of N input was >300 kg ha^{-1} for tomato grown in greenhouse [29].

In this study, elevated total P content in topsoil was conducive to boost fruit yield. As an essential macroelement for plants growth, P is required for photosynthesis, synthesis and decomposition of carbohydrates [30]. So, P supply was indispensable for the ensurance of fruit yield and quality. Soil P content was weakly correlated with the quality indexes. However, leaf P content of vegetative shoot significantly positively correlated with TSS, and leaf P content of fruit-bearing shoot significantly positively correlated with TSS/TA ratio, and significantly negatively correlated with TA and firmness. In view of the complexity of P transformation in soil, leaf P content from vegetative and fruit-bearing shoot maybe the more suitable indicator to assess the fruit quality attributes of winter jujube. P addition could increase fruit sink strength which contributed to attract more sugars from leaves into fruits as well as decrease the enzymatic activities involved organic acid synthesis [31,32]. Therefore, P supply can increase fruit sugar contents and decrease organic acid contents, thus enhance the ratio of TSS and TA [32].

In this study, available K content in topsoil was significantly correlated with TSS, protein, and TSS/TA ratio ($p < 0.05$, Table 4). K has the great impact on quality attributes of fruit that determine fruit marketability, consumer preference, and the concentration of phytonutrients associated with human-health [33]. The reason was that K was involved in transportation of photoassimilates from sources to sink tissues, enzyme activation, and other biochemical and physiological processes vital to plant growth, yield, and quality formation [34]. Since the improvements in the availability and abundance of soil K were not just depended on the increasing inorganic K fertilizer input [35], combined organic manure application, foliar spraying and other optimal fertilized technologies should be developed during winter jujube cultivation.

4.3. Fertilization Strategy for Winter Jujube Cultivation

It is important to get a balance between fruit yield and quality of tree fruit since traditional pursuit of great amounts of fruit would bring both quality and price reductions [3,36]. Irrational field management such as excessive supply of chemical fertilizers might lead to poor flavor and taste attributes, i.e., TSS, Vc, and TA contents, and firmness, which has been the bottleneck restricting sustainable development of winter jujube cultivation [3,32].Our results did show the fertilization directly associated with the yield and quality of jujube fruits. The status of soil nutrients were of utmost importance for fruit quality [9,37,38]. Presently, conventional farming management mainly focuses on the chemical fertilization, and ignored organic inputs. Excessive N supply is the other outstanding disadvantage. Both management practices have resulted in the high fruit yield with poor quality [3], and environmental issues, such as N/P losses through leaching and runoff [39,40]. To improve profits of farmer from jujube production, rational fertilization should integrate fruit yield with quality effectively.

In this study, higher fruit yield, TSS and protein contents, and TSS/TA ratio were formed in OC mode (Table 3), indicating benefits of combined organic and inorganic fertilization. This was also conformed in a 3-year field experiment of kiwifruit cultivation, which showed that organic matter addition along with NPK chemical fertilizers efficiently maintained fruit yield, and markedly enhanced fruit sugar contents, compared to chemical NPK fertilization [41]. Thus, the combined application of manure and chemical fertilizers maybe the optimal management strategy for winter jujube production in studied region.

5. Conclusions

Based on the field investigation, fertilization directly influenced jujube tree growth, fruit yield and quality, and rational fertilization practices should balance the relation between fruit yield and quality. Fruit yield in HC was 57.4% higher than that in OM, but TSS and TSS/TA ratio were lower (22.9% and 27.0%, respectively). Combined application of organic and inorganic fertilizers, i.e., OC, might be the optimal fertilization mode, which could bring about high fruit yield with good quality relatively.TSS and TSS/TA ratio significantly positively correlated with SOM of topsoil and leaf P contents. Hence, SOM and leaf P contents could be used as effective indexes to evaluate jujube fruit quality. To meet the requirements, further researches should be carried out to determine the threshold of SOM and accurate supply amount of nutrients, especially N, P, and K, during jujube fruit yield and quality formation.

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