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Effects of Water and Nitrogen Coupling on Yield, Quality, Water and Nitrogen Use Efficiencies of Greenhouse Muskmelon

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Abstract: The proficient supply of water and nitrogen is a key factor in facility agriculture. In order to pursue high yields, most farmers blindly irrigate and fertilize, leading to yield reduction, quality decline, soil salinization, and fertility destruction. A successive two-year greenhouse experiment was carried out on fruit quality, yield, irrigation water use efficiency (IWUE), and nitrogen use efficiency (NUE) of greenhouse muskmelon (*Cucumis melo* L.) under drip fertigation, which can provide a scientific basis for local muskmelon intensive production in Southeast China. The experiments were conducted in 2020 and 2021, with three irrigation levels 80% (W_1), 100% (W_2), and 120% (W_3) of ET_c and three N levels 60 (N_1), 95 (N_2), and 130 (N_3) kg N ha^{-1}. The amount of drip irrigation water was determined every 5 days based on crop evapotranspiration (ET_c). The seasonal irrigation amount ranged from 209.77 mm to 298.86 mm in 2020 and from 201.22 mm to 286.04 mm in 2021. The highest muskmelon yield was obtained in the treatment of W_3N_3 with an average of 27.38 t ha^{-1} in 2020 and 27.10 t ha^{-1} in 2021. Although the yield was improved by increasing nitrogen supply, there was no significant difference between N_2 and N_3 treatment in two years under the irrigation level of W_2 and W_3. The highest irrigation water use efficiency was observed in the W_1N_3 treatment in 2020 and 2021. The NUE increased with decreasing N rates at the same irrigation level. Under the same nitrogen application level, TSS and Vc under low water (W_1) were higher than that under medium water (W_2) and high water (W_3) treatment. The highest content of nitrate in low water and high nitrogen (W_1N_3) treatment was 55.41 µg/g in 2020 and 52.50 µg/g in 2021, respectively. The yield and quality of muskmelon are often incompatible, for instance, W_2N_2 treatment can obtain a higher yield, but W_1N_2 treatment maximizes Vc, TSS of muskmelon quality. Our findings suggest that the irrigation level of 1.0 *ETc*, nitrogen level of 95 N ha^{-1}, and 3500 kg·ha^{-1} of decomposed organic fertilizer was recommended as the best combination, which can improve the yield, quality, IWUE, NUE of muskmelon under drip fertigation with soil mulching in the experimental site.

Keywords: evapotranspiration; drip fertigation; dry biomass cumulative; soil mulching

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1. Introduction

Muskmelon (*Cucumis melo* L.) is a popular horticultural crop for its good taste and medicinal value, and it contains folic acid that helps to give birth to a healthy fetus and prevent osteoporosis [1]. It can also improve vision and soothe stomach ulcers [2]. It is a rich source of sugars, protein, vitamin C, vitamin B_2, and vitamin B_1. It is widely cultivated for its nutritional benefits all over the world. China produces more than half of the world's muskmelon and has the largest cultivation areas [3]. Muskmelon is mainly planted in the northwest of China, with 46% of the total production and a high level of exports.

Greenhouse cultivation, also called protected cultivation, has been widely used in most parts of China. It is highly efficient in the use of water and fertilizers. Protected cultivation can make more profit for farmers because of climate control and easily installing drip fertigation equipment while saving water and fertilizers resources. Vertical growth patterns can enhance light interception, and air circulation for greenhouse plants, which achieves higher yield than that outdoors [4]. Nowadays, a greenhouse can provide vegetables and fruits of high quality during the whole year round. Soil mulching is also practical management that can improve WUE and yield [5]. It has lots of advantages such as raising ground temperature, decreasing soil evaporation, and controlling weeds [6].

The explosive growth of the population and improvement of living standards will greatly increase the demand for water in the future [7]. The serious reduction of available water resources has become a worldwide problem. Water shortage has slowed economic growth in many areas. Efficient water-saving irrigation technologies are very important in agricultural production. Drip fertigation is the technology of delivering water-soluble fertilizers into the plant root zone by using injectors. It is considered the most effective management tool in agricultural production, especially in protected cultivation [8,9]. Irrigation management by drip fertigation equipment significantly affects quality and yield. Many studies have highlighted that muskmelon is sensitive to water stress, and severe water stress can lead to a decrease in fruit weight and yield [10]. Excessive irrigation can result in low production and bad quality [11,12]. It also might lead to nitrogen leaching, which would cause groundwater contamination. Therefore, it is vital to explore an optimum irrigation scheduling for high production and water saving of muskmelon.

Among major plant nutrients, nitrogen is a significant environmental factor in the growth and quality of greenhouse crops [13]. In order to obtain the maximum economic benefits, a large amount of fertilizer is applied to fields, and the proportion of various fertilizers is not balanced, which is easy to cause agricultural non-point source pollution. As a result of N loss, its utilization efficiency decreases considerably. Therefore, advanced N management is urgently used for crop production in agriculture. In order to gain sustainable crop production and environmentally friendly agriculture, several management practices have been suggested to increase crop yield and nitrogen use efficiency. Many scholars have demonstrated that fertilizer use efficiency could be improved by drip fertigation technology [14–17].

The coupling of water and fertilizer has significantly affected plant growth, yield, WUE, NUE, and quality [18]. They interact and inhibit each other. Reasonable irrigation can improve nitrogen use efficiency. Under appropriate water treatments, increasing fertilizer can improve photosynthesis and thus increase yield [19]. Proper water and fertilizer supplies can provide a good environment for the root zone of crops and promote crop growth and improve water and fertilizer utilization efficiency [20,21]. Although the effects of water and fertilizer coupling on different crops have been studied extensively, i.e., wheat [22], bell pepper [23], and watermelon [24], there is a scarcity of research on the effects of combining water applied in drip fertigation system with various N rates on the yield and quality of muskmelon under naturally ventilated greenhouse conditions. Consequently, relationships between irrigation water, N fertilization, growth, quality, and yield of muskmelon are not well documented.

Therefore, a successive two-year greenhouse experiment was carried out on greenhouse muskmelon under drip fertigation. The experiment with one commercial muskmelon, "yi pin tian xia 208", was conducted in Haining City of China in 2020 and 2021. The objectives of this work were to (1) explore the effects of different irrigation levels on the fruit yield, quality, nitrogen use efficiency (NUE), and irrigation water use efficiency (IWUE) of greenhouse muskmelon; (2) evaluate the response of yield and parameters of fruit quality to conventional and deficient N fertilization in muskmelon. We hypothesized that conventional N application, based on local fertigation practices, is excessive. Yield and fruit quality can be maintained with reduced N application; (3) determine the optimal strategy for irrigation and nitrogen management to ensure high yield and good quality under greenhouse conditions. The study aims to provide a scientific basis for local muskmelon production in Southeast China.

2. Materials and Methods

2.1. Site Description

The experiment was conducted from March to June 2020 and from April to June 2021 in a greenhouse without temperature control equipment at Yangdu Village. It is located on the east side of Xucun Town, Haining City. A suitable private family farm (108.40′ longitude, 34.18′ latitude) was chosen. Yangdu experiences a north subtropical monsoon climate, with an average annual temperature of around 15.9 °C. The average annual precipitation is approximately 1200 mm. The average annual evapotranspiration is about 800 mm. The frost-free period is 220–240 d. The soil in the greenhouse has a high infiltration rate. The main physical and chemical characteristics of the top 20 cm soil profile are shown in Table 1.

Table 1. Soil characteristics of the experiment site in 2020 and 2021.

Season	Depth (cm)	Soil Bulk Density g cm^{-3}	Field Capacity (Vw)	Electrical Conductivity (dSm^{-1})	Total Nitrogen Content g kg^{-1}	Available Phosphorus mg kg^{-1}	Available Potassium mg kg^{-1}	Organic Carbon g kg^{-1}	Texture Class
2020	0–20	1.48	24.31	0.4	0.98	74.8	135.9	16.8	Sandy loam
2021	0–20	1.43	25.11	0.4	1.02	75.7	137.7	17.3	Sandy loam

2.2. Experimental Treatments and Design

The amount of irrigation water was precisely calculated by using the modified Penman–Monteith equation. There were three irrigation levels (80% (W_1), 100% (W_2), and 120% (W_3) of ET_c at the 5-day interval) and three N levels (60 (N_1), 95 (N_2), and 130 (N_3) kg N ha^{-1} at the 10–15-day interval). There were a total of 9 treatments; each treatment had three plots. The area of the plot was 9.6 m^2 (6.0 m × 1.6 m). There were a total of 27 plots. Plots were arranged in a completely randomized block design.

The greenhouse was 60 m long in the north–south direction and 8 m wide, covered with a 0.2 mm thick thermal polyethylene sheet. Muskmelon plants were planted in wide narrow rows (1.2 m + 0.4 m) in the east–west direction (Figure 1). The whole soil bed was covered with 1.5 m wide white polyethylene film to improve soil temperature and keep weeds from growing.

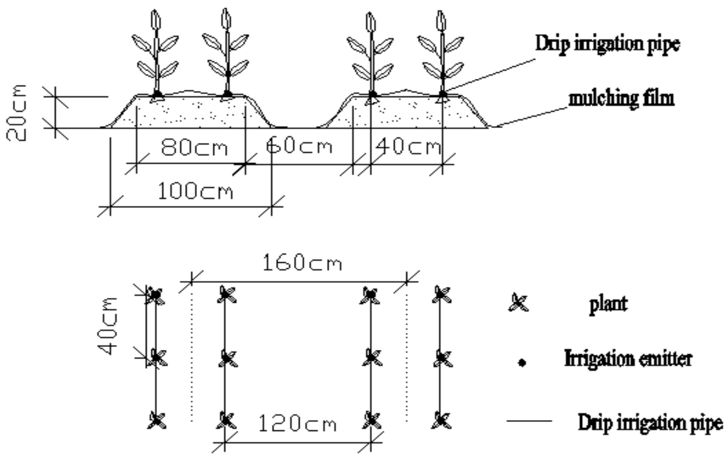

Figure 1. Drip irrigation layout and muskmelon planting pattern.

There were three drip irrigation systems in the greenhouse. Each irrigation system was independent in terms of irrigation and fertilization. The system consisted of a water tank (800 L), a fertilizer tank (300 L), and eighteen drip tubes (two tubes per plot). A booster pump was fixed to the outlets of two tanks to maintain the operational water pressure (0.1 MPa) in the drip irrigation system. Irrigation water was applied with drip emitters whose constant discharge rate was 3.0 L h^{-1} under the operational pressure of 0.1 Mpa. The distance between two drip emitters was 40 cm.

2.2.1. Irrigation Application LI-COR, Lincoln, NE, USA

The crop evapotranspiration (ET_c) was calculated using Equation (1) [25]. ET_0 was calculated by the modified Penman–Monteith Equation (2) [26]. A micro-weather station (U30-NRC-SYS-PRO, Onset HOBO, Bourne, MA, USA) installed in the center of the greenhouse automatically collected daily meteorological factors, including temperature, humidity, air pressure, and solar radiation. The crop coefficient (K_c) were 0.5, 1.05, and 0.75 for the initial stage, the mid-season stage, and the end of the season stage according to FAO56, respectively [27].

$$ET_c = ET_0 \times K_c \tag{1}$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{1713}{T+273}(e_a - e_d)}{\Delta + 1.64\gamma} \tag{2}$$

where ET_0 is the reference crop evapotranspiration (mm·d^{-1}); Δ is the slope of the saturated vapor pressure curve (Kpa·°C^{-1}); R_n is the net radiation at the crop surface (MJ·m^{-2}·d^{-1}); G is the soil heat flux density (MJ·m^{-2}·d^{-1}); γ is the psychrometric constant (Kpa·°C^{-1}); ET_c is the actual crop water requirement; K_c is the crop coefficient of muskmelon.

2.2.2. Nutrient Application

Prior to muskmelon planting, all of the phosphorus (80 kg P_2O_5 ha^{-1}) and potassium sulfate (150 kg K_2O ha^{-1}) were applied to the soil. Decomposed organic fertilizer (3500 kg·ha^{-1}) was evenly added to the test site at one time. During the growing season, N fertilizer was applied at about two-week intervals in coordination with irrigation. Five equal doses of nitrogen fertilizer were applied during the whole growth period. There are three stages in the operation of drip fertigation systems, the first stage is to irrigate water without fertilizer, the second stage is to irrigate water with fertilizer together, and the third stage is to irrigate water without fertilizer.

2.2.3. Plant Management

The tested crop was "yi pin tian xia 208", a local variety of muskmelon. After 2 days of sprouting at 28 °C, muskmelon seeds were sown in cultivating plates (the ratio of vermiculite:perlite:peat is 1:1:2). Six-week-old muskmelon plants were transplanted in the greenhouse on 28 March 2020, and on 1 April 2021. The whole growth circle of muskmelon is about 117 days to reach maturity. In order to successfully pass the slow seedling period to ensure their survival rate, 30 mm water was applied to all treatments after transplanting. The scheduled irrigation amounts were then applied in different treatments based on the corresponding ET_c. When there were about 28 leaves in the main stem, the main stem tips were cut, leaving 3 lateral branches between the 12th and 16th burls. A muskmelon plant retains only one healthy fruit.

2.3. Measurements and Calculations

2.3.1. Above-Ground Dry Matter Accumulation

Three plant samples of each treatment were taken at the ripe stage. Firstly, the stems, leaves, and fruits of muskmelon were separated and placed into different paper bags and then placed into an oven at 105 °C for a quarter of an hour. Finally, those were dried at 70 °C to a constant weight. Dry matter weights of the sample were determined by a scale (JCS-1000, KAIFENG GROUP, Jinhua, China).

2.3.2. Fruit yield, IWUE, and NUE

About 30 days after pollination, muskmelon fruits were harvested. Each muskmelon was weighed to calculate the mean fruit weight of plots. Fruit yield per hectare was then obtained by multiplying the fruit weight by the fruit number per square.

Irrigation water use efficiency (IWUE) is the yield that can be harvested per unit volume of irrigation volume, which is the ratio of the total output of each treatment to the total irrigation volume, and its unit is kg m^{-3}.

NUE (kg/kg) refers to the crop yield that can be produced per unit of fertilizer nitrogen input, that is, NUE = Y/F, Y is the yield obtained after nitrogen application, and F is the input of nitrogen fertilizer.

2.3.3. Quality and Shape Index of Muskmelon Fruit

Young muskmelon fruits with the same pollination date, the same node, and similar size were marked at each plot. Three representative muskmelon fruits were used for analysis among the labeled fruits in each treatment. The fruit flesh samples (skin and seeds removed) were made into liquid by a blender and the liquid extract was immediately used to measure the total soluble solids (TSS), vitamin C, and nitrate content. Total soluble solids were estimated using a hand-held refractometer. Vitamin C and nitrate content were estimated by the method of Li et al. [28]. The fruit shape index (the ratio of fruit longitudinal and transverse diameter) was determined after weighing.

2.4. Data Analysis

Analysis of variance (ANOVA) was conducted using the SPSS software package (SPSS V18.0). All treatment means were compared using the least significant differences (LSD) at 5% significant level.

3. Results

3.1. Amount of Applied Irrigation Water

Figure 2 showed that the irrigation event was initiated on 28 March and ended on 14 June 2020, and started on 1 April and ended on 11 June 2021, respectively. Muskmelon was irrigated 16 times in 2020 and 15 times in 2021. The total ET_0 value was 253.1 mm during the whole experimental period in 2020 and the mean daily value was 3.24 mm. The three irrigation treatments of W_1, W_2, and W_3 received 209.8 mm, 254.3 mm, and 298.9 mm of water, respectively. The total ET_0 value was 233.3 mm during the whole experimental period in 2021 and the mean daily value was 3.28 mm. The three irrigation treatments of W_1, W_2, and W_3 received 201.22 mm, 243.63 mm, and 286.04 mm of water, respectively.

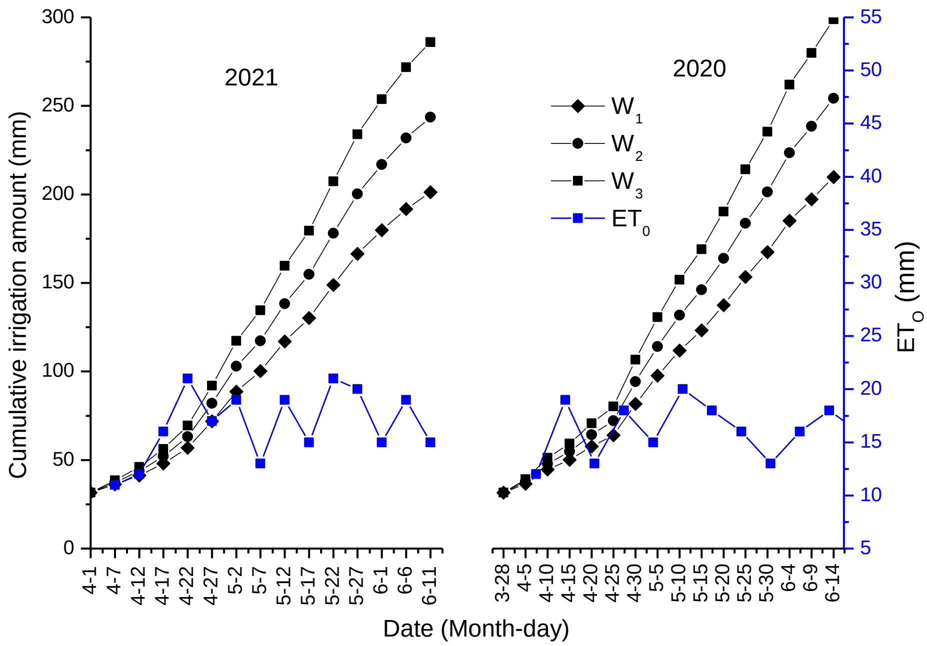

Figure 2. Irrigation treatments in the whole cultivation period in 2020 and 2021.

3.2. Dry Matter Accumulation (DMA)

According to the source-sink theory, plant yield is positively correlated with its dry matter mass. As shown in Figure 3, different water and nitrogen treatments of greenhouse muskmelon had a significant effect on the whole dry matter accumulation, but the enhanced water and nitrogen amount did not translate linearly into increased DMA. The distribution ratio of DMA of muskmelon after maturity showed that fruits were the accumulation center of dry matter, followed by leaves, stems, and petioles, accounting for 62.90%, 24.31%, 8.23%, and 4.56% of the total DMA (two-year average). Under the same nitrogen treatment condition, the DMA of all above-ground organs (leaves, petioles, stems, and fruits) increased with the increase in irrigation amount. The total DMA of the whole plant under W_3 treatment was higher than that of W_1 and W_2, which was 16.96%, 1.44% (2020), and 16.52%, 1.84% (2021) higher on average, and there is no significant difference with W_2 in 2020. Under the same water treatment conditions, the DMA of N_3 treatment was higher than that of N_1 and N_2, which was 10.51%, 1.00% (2020) and 16.15%, 1.10% (2021) higher on average, and the difference between N_2 and N_3 treatment was not significant in both of years.

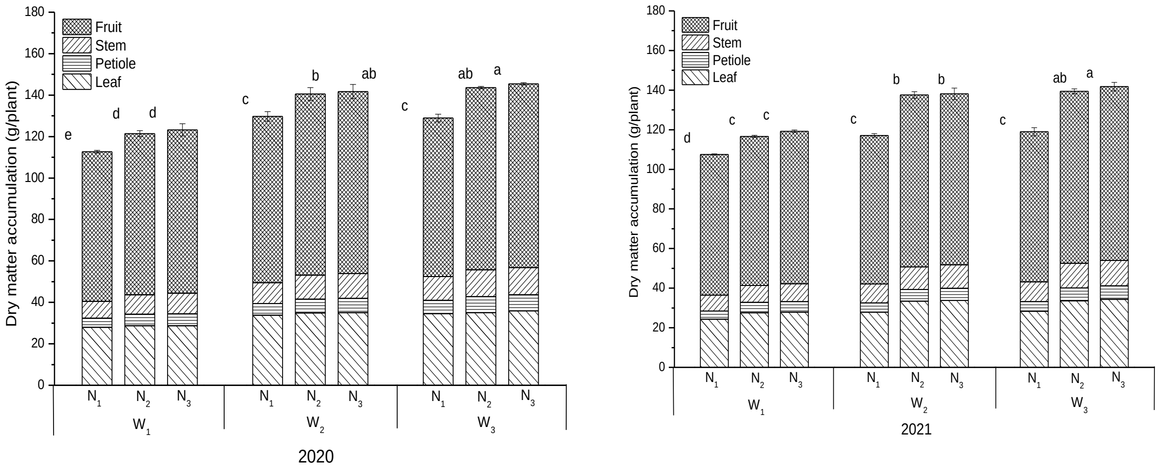

Figure 3. Effects of different water and nitrogen supplies on the above-ground dry matter accumulation (DMA) of muskmelon in 2020 and 2021. Note: Without the same small letters mean significant difference among treatments at 0.05 level.

3.3. Yield, IWUE, NUE

Mean fruit weight, mean muskmelon marketable yield, irrigation water use efficiency (IWUE), and nitrogen use efficiency (NUE) were obtained for each treatment during the two years and summary statistics are shown in Table 2. As shown in Table 2, the fruit yield of muskmelon varied widely at different irrigation and nitrogen levels. The marketable fruit yield ranged from 22.31 t ha^{-1} to 27.38 t ha^{-1} in 2020 and from 21.95 t ha^{-1} to 27.10 t ha^{-1} in 2021, respectively. At the same irrigation level, increasing the nitrogen application rate could improve melon yield. The yield of medium nitrogen N_2 was slightly lower than that of high nitrogen N_3, there was no significant difference between N_2 and N_3 treatments in two years under the irrigation level of W_2 and W_3. Under the same nitrogen application level, muskmelon yield increased with the increase in irrigation amount. Compared with water stress (W_1), the yield of excessive water supply (W_3) and normal water supply (W_2) increased by 10.59%, 10.13% (2020), and 12.10%, 10.45% (2021), respectively. The results showed that the combination of normal water supply (W_2) and reduced fertilization (N_2) had an obvious effect on increasing yield. The effects of irrigation and nitrogen levels on mean fruit weight were as significant as for marketable fruit yield. Since a plant retained only one fruit, the variation trend of yield and mean fruit weight was the same. The mean fruit weight in different treatments ranged from 713.90 g to 876.26 g in 2020 and from 702.47 g to 867.09 g in 2021.

Table 2. Effects of different irrigation and nitrogen levels on mean fruit weight (MFW), marketable fruit yield (MFY), irrigation water use efficiency (IWUE), and nitrogen use efficiency (NUE) in 2020 and 2021.

Experiment Treatment		2020				2021			
Irrigation Level	Nitrogen Level	MFW (g)	MFY (t ha^{-1})	IWUE (kg m^{-3})	NUE (kg kg^{-1}N)	MFW (g)	MFY (t ha^{-1})	IWUE (kg m^{-3})	NUE (kg kg^{-1}N)
	N_1	713.90 d	22.31 d	17.02 b	371.83 b	702.47 e	21.95 e	17.46 c	365.87 b
W_1	N_2	768.52 bc	24.02 bc	18.32 a	252.80 d	743.65 d	23.24 d	18.48 b	244.62 d
	N_3	778.75 b	24.34 b	18.56 a	187.20 f	760.87 c	23.78 c	18.91 a	182.90 f
	N_1	758.10 c	23.69 c	14.90 c	394.84 a	741.01 d	23.16 d	15.21 d	385.95 a
W_2	N_2	864.07 a	27.00 a	16.99 b	284.23 c	843.16 b	26.35 b	17.30 c	277.35 c
	N_3	868.38 a	27.14 a	17.07 b	208.75 e	853.37 ab	26.67 ab	17.51 c	205.14 e
	N_1	755.59 c	23.61 c	12.64 d	393.54 a	748.60 cd	23.39 cd	13.08 e	389.90 a
W_3	N_2	869.03 a	27.16 a	14.54 c	285.86 c	857.65 ab	26.80 ab	14.99 d	282.12 c
	N_3	876.26 a	27.38 a	14.66 c	210.64 e	867.09 a	27.10 a	15.15 d	208.43 e

Note: Without the same small letters mean significant difference among treatments at 0.05 level. The below table is the same.

Table 2 showed changes in the IWUE of greenhouse muskmelon under different water and nitrogen supplies. Under the same nitrogen level, IWUE increased with decreasing water amount in the two-year experiment, with a maximum at W_1 treatment in both years. Under the same water level, the irrigation water use efficiency was increased by improving N application in both seasons. In 2020, IWUE ranged from 12.64 to 18.56 kg m^{-3}, which observed the maximum value (18.56 kg m^{-3}) at W_1N_3 treatment, and there was no significant difference between W_1N_3 and W_1N_2. In 2021, IWUE ranged from 13.08 to 18.91 kg m^{-3}, which also observed the maximum value (18.91 kg m^{-3}) at W_1N_3 treatment. Compared with low nitrogen N_1, the nitrogen application rate increased from 95 to 130 kg ha^{-1}, and the increase in IWUE was not obvious in 2020 and 2021.

The changes in NUE of greenhouse muskmelon under different water and nitrogen supplies are shown in Table 2. The NUE ranged from 187.20 kg kg^{-1} N to 394.84 kg kg^{-1} N in 2020 and from 182.90 kg kg^{-1} N to 389.90 kg kg^{-1} N in 2021. Under the same irrigation level, NUE increased with decreasing N rates. The highest NUE was obtained in the W_2N_1 treatment (394.84 kg kg^{-1} N) in 2020 and the W_3N_1 treatment (389.90 kg kg^{-1} N) in 2021. Under the same nitrogen level, compared with the W_1 level, the nitrogen use efficiency of the W_2 level significantly increased with increasing irrigation water amount in the two-year experiment, but there was no significant difference between W_2 and W_3.

3.4. Quality and Shape Index of Muskmelon Fruit

Muskmelon is one of the vital sources of soluble sugar, protein, and vitamin C, which can determine the taste and quality of muskmelon, and the concentration of nitrate in greenhouse fruits is higher than that of open field fruits, which is harmful to the body's health. Total soluble solids refer to the general term for water-soluble compounds in fruits, including sugars, acids, proteins, etc., which can reflect fruit quality to some extent. Therefore, the contents of total soluble solids, vitamin C, and nitrate were usually used in evaluation indexes of muskmelon quality.

As can be seen from Table 3, the maximum value of total soluble solids was obtained in the W_1N_2 treatment in both years. Under the same nitrogen treatment condition, the total soluble solid content decreased gradually with the increase in irrigation amount, and the total soluble solid content under W_1 treatment was higher than that of W_2 and W_3, 11.84% and 19.24% higher on average in 2020, 9.70% and 23.63% higher on average in 2021, respectively. Under the same water level, the total soluble solids increased first and then decreased with the increase in nitrogen application rate. The soluble solids content under N_2 treatment was 11.13% and 9.53% higher than on average in 2020, was 12.45% and 10.22% higher than N_1 and N_3 on average in 2021, respectively.

Table 3. Effects of different irrigation and nitrogen levels on fruit total soluble solids (TSS), vitamin C (Vc), concentrations of nitrate, and fruit shape index (FSI) during two seasons.

Experiment Treatment		**2020**				**2021**			
Irrigation Level	**Nitrogen Level**	**TSS (%)**	**Vc mg/kg**	**Nitrate μg/g**	**FSI**	**TSS (%)**	**Vc mg/kg**	**Nitrate μg/g**	**FSI**
	N_1	11.29 b	33.26 b	36.98 e	0.94 a	10.80 b	32.63 b	34.78 d	0.94 a
W_1	N_2	12.49 a	37.97 a	45.06 c	0.95 a	12.04 a	35.26 a	41.19 c	0.95 a
	N_3	11.36 b	32.65 b	55.41 a	0.94 a	11.32 b	31.14 c	52.50 a	0.94 a
	N_1	10.16 e	30.15 cd	29.09 g	0.94 a	9.97 c	29.57 ef	30.67 e	0.94 a
W_2	N_2	11.00 bc	37.27 a	39.42 de	0.94 a	11.18 b	31.54 bc	40.74 c	0.94 a
	N_3	10.26 de	31.63 bc	51.01 b	0.94 a	9.99 c	30.06 de	48.32 b	0.94 a
	N_1	9.27 f	29.07 d	23.22 k	0.95 a	8.78 d	28.53 f	22.10 f	0.94 a
W_3	N_2	10.65 cd	31.36 bcd	32.93 f	0.94 a	10.01 c	29.42 ef	29.48 e	0.94 a
	N_3	9.55 f	30.90 bcd	41.47 d	0.94 a	8.84 d	29.45 ef	41.48 c	0.94 a

It can be seen from Table 3 that the changes in vitamin C and total soluble solids were consistent under different water and nitrogen supply. The content of vitamin C in medium nitrogen treatment (N_2) was higher than that of low nitrogen treatment (N_1) and high nitrogen treatment (N_3), was 11.13% and 9.53% higher on average in 2020, 15.27% and 12.00% higher on average in 2021, which indicate that proper nitrogen application could improve vitamin C. Nitrogen deficiency and excessive nitrogen application were not conducive to the synthesis of vitamin C. When the nitrogen rate was N_2 and the irrigation rate was W_2, the content of vitamin C reached the maximum, 37.97 mg/kg in 2020, and 35.26 mg/kg in 2021, respectively. Under W_2 and W_3 treatment, vitamin C content decreased, indicating that high irrigation water was not conducive to vitamin C formation in fruit pulp. Under the same nitrogen application level, the vitamin C content under low water treatment (W_1) was higher than that under medium water treatment (W_2) and high water treatment (W_3), with an average increase of 11.84% and 19.24% in 2020 (4.88% and 13.74% in 2021).

Nitrate content is an important index to evaluate fruit safety and quality, which affects human health. As can be seen from Table 3, the effects of water and nitrogen on the nitrate of greenhouse muskmelon were significant. Under the same irrigation amount, the nitrate content of muskmelon increased gradually with the increase in nitrogen application amount. Under the same nitrogen, the content of nitrate decreased gradually with the increase in irrigation amount, and the highest content of nitrate in low water level and high nitrogen (W_1N_3) treatment was 55.41 μg/g in 2020 and 52.50 μg/g in 2021, respectively.

The fruit appearance data are also presented in Table 3. Fruit shape is the major index of muskmelon appearance quality, which can directly affect consumers' desire to buy and is usually called the fruit shape index (the ratio of longitudinal diameter and transverse diameter). The irrigation and nitrogen were not significant for the fruit shape index in both seasons, which is due to the fact that the fruit shape index mainly depends on muskmelon varieties.

4. Discussion

4.1. Amount of Applied Irrigation Water

There is no rainfall inside the greenhouse, and there will be no deep leakage and surface runoff by using drip fertigation technology. If soil moisture change is not taken into account, evapotranspiration is equal to irrigation water [29]. To ensure good growth of seedlings before the scheduled drip fertigation was initiated, 30 mm of water amount was applied to all treatments after transplanting. Zeng et al. found that seasonal evapotranspiration of glasshouse muskmelon varied from 80.9 mm to 173.3 mm of pan evaporation measured by a standard 0.2 m diameter pan [30]. Li et al. reported that seasonal evapotranspiration of glasshouse muskmelon varied from 120.1 mm to 178.6 mm [31]. Our experiment showed that seasonal irrigation amounts ranged from 209.77 mm to 298.86 mm in 2020 and from 201.22 mm to 286.04 mm in 2021. The amount of water applied in this experiment is more than their results, and the main reasons for the differences are the period of cultivation, the region, and the variety of muskmelon.

4.2. Dry Matter Accumulation

Nitrogen application rate and irrigation amount are two very important factors in agricultural production. Dry matter accumulation in plants will be affected at different growth stages or under different water and fertilizer supplies [32]. Many studies have shown that a lack of water may do serious harm to dry matter accumulation, while high nitrogen levels tend to be conducive to DMA. The independent effects of water and fertilizer on muskmelon growth and dry matter accumulation have been reported [33,34]. Lin et al. conducted soilless cultivation experiments on muskmelon in a greenhouse, and the results showed that the total dry matter mass of muskmelon at maturity was about 136 g [35]. Xu et al. showed in soilless cultivation that the dry matter accumulation of muskmelon at maturity was about 140 g/plant [36]. The effects of different water and nitrogen treatments on the DMA of muskmelon were significant, increasing the irrigation amount and nitrogen application rate were beneficial to plant growth. However, with the increase in irrigation amount and nitrogen application amount, the increased trend of dry matter weight of muskmelon slowed down obviously. This study found that the DMA was about 129.09 g/plant, the maximum value was obtained under W_3N_3 treatment at the maturity stage, which was 145.42 g/plant in 2020, 141.75 g/plant in 2021. The results of this experiment are slightly inconsistent with the results of the former study, which may be mainly related to the cultivation method, planting density, varieties, and sampling time of melon.

4.3. Yield, IWUE, NUE

Table 2 showed that the maximum muskmelon yield was reached at irrigation levels of 120% *ETc*, but there was no significant difference from 100% treatment. The results of Cabello et al. [37] indicated that excessive irrigation water did not produce a higher fruit yield. Similar results have been reported by Fabeiro et al., who obtained maximum yields at irrigation levels of 100% *ETc* [38]. Dogan et al. [39] obtained maximum yields of 43.8 and 38.9 t ha^{-1} with 70% and 100% of the class A pan evaporation rate, respectively. Regulated deficit irrigation could improve IWUE and realize the high yield of mango at the maturity stage [40]. Our study found that low water during the whole growth stage reduced muskmelon yield. In fact, it is sensitive to soil moisture during the expanding periods of muskmelon. Reasonable fertilization practices could increase crop yield by more than 40% [41]. Excessive fertilization results in insignificant yield [42], it will have a negative effect on production if the fertilization continues to improve [43]. In our case, a yield increase of 12.3% (2020), and 11.5% (2021) was obtained by increasing nitrogen from 60 to 95 kg N ha^{-1}, then the yield increased by 0.09% (2020), 1.5% (2021) from 95 to 130 kg N ha^{-1} in the two-year experiment.

Treatments with higher irrigation water amounts constantly have lower IWUE, in accordance with the results by Agbna et al. in tomato [44], suitable deficit irrigation can improve IWUE and yield [45]. Al-mefleh et al. [46] found that excessive or insufficient irrigation would lead to yield decline. The results of this study showed that muskmelon yield decreased significantly under severe water stress, mainly due to the weakened photosynthesis caused by water shortage, slowing growth, and reducing dry matter accumulation, which affected the final yield. Erdem et al. [47] found that excessive irrigation amount would lead to low irrigation water efficiency, probably because excessive irrigation increased the moisture area of soil and resulted in an increase in ineffective soil moisture evaporation. Our study found that the irrigation water was used more efficiently at the lower irrigation levels, which was consistent with the results of Erdem's study, reaching the maximum value under low water and high nitrogen (W_1N_3) treatment.

An increase in nitrogen rate results in a decrease in NUE and an increase in soil nitrate content [48–52]. Excessive nitrogen application leads to much nitrate nitrogen in the soil, affecting crop growth. In the two-year experiment, it was found that NUE could be significantly increased when the irrigation level increased from W_1 to W_2 ($p < 0.05$), but there is no significant difference when the irrigation level increased from W_2 to W_3. The most efficient treatment was a low nitrogen level (N_1), which is in accordance with the results of Zotarelli et al. [53]. That is because crops assimilate mineral nitrogen from the soils in the lower nitrogen treatments.

4.4. Quality

Fresh melon contains soluble solids, vitamin C, organic acids, and other nutrients, and the content of the TSS is an important index for the effective evaluation of fruit quality [54]. Previous studies confirmed that fruit quality is related to irrigation amount and nitrogen application amount to a certain extent. Nitrogen application rate affects protein and organic acid in fruits. Appropriately increasing the nitrogen application amount can improve the contents of vitamin C and soluble sugar in fruits, while excessive nitrogen application amount will decrease fruit quality [55]. It was found in this experiment that TSS and Vc showed a trend of increasing and decreasing with the increase in nitrogen level when nitrogen application rates increased from N_1 to N_3, appropriately increasing the application rate of nitrogen fertilizer can promote the absorption of phosphorus and potassium in the muskmelon root zone, delay fruit ripening, prolong photosynthesis time, and increase the content of sugar of fruit, despite nitrate content increased slightly. Excessive nitrogen fertilizer resulted in crop physiological abnormalities and inhibition of muskmelon photosynthesis, decreasing the content of sugar in fruit. Water is the key factor affecting fruit quality, especially in the late-ripening stage. Although studies have shown that appropriate water deficit can improve fruit quality [56], it can reduce fruit yield. Yield and quality have always been the main contradiction in fruit production. The results of this two-year experiment showed that under the same irrigation quantity, the Vc and TSS of medium nitrogen (N_2) were the best. Under the same nitrogen application level, the Vc and TSS under low water (W_1) were higher than that under medium water (W_2) and high water (W_3) treatments. Other researchers have also found no effects of the irrigation water amount on TSS contents [57,58]. These results show that excess N can lead to poorer fruit quality. However, some researchers found that different N levels had little or no effects on total soluble solids [59,60]. The results showed that reasonable water and nitrogen supply can improve water and nitrogen utilization efficiency and control nitrate content within a certain range and maximize the TSS and Vc of muskmelon.

5. Conclusions

In this study, the experiment of variable irrigation and fertilization showed that the dry matter accumulation and yield of greenhouse muskmelon were the highest when the nitrogen application rate was N_3 (130 kg N ha^{-1}) and irrigation amount was W_3 (120% ET_c), but the yield did vary significantly between N_2 and N_3 treatments in two years under the irrigation level of W_2 and W_3. The nitrogen application rate increased from N_2 to N_3, the increase in IWUE was not obvious. Compared with N_3, the N_2 treatment of reduced nitrogen application (35 kg N ha^{-1} reduction) can improve NUE and quality, but muskmelon yield did not decrease significantly. Although the quality parameters (Vc and total soluble solids) of muskmelon were the best under the W_2N_2 treatment, the yield also decreased significantly, affecting the local farmers' net income. Therefore, the irrigation level of 1.0 ET_c, nitrogen level of 95 N ha^{-1}, and 3500 kg·ha^{-1} of decomposed organic fertilizer was recommended as the best combination. As we all know, fruits can achieve the best quality under water stress conditions. So, the yield and quality of muskmelon should be studied by different water deficit treatments at different growth stages in the future.

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