Effects of Different Irrigation Amount on the Growth of Cucumber in Plastic Greenhouses under Non-pressure Artefact Irrigation

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Abstract. In China, water-saving irrigation is a very important measure to alleviate the water resources shortage. This study investigated the changes of cucumber growth, nutrient element absorption, yield and quality under different irrigation water amount by using non-pressure artefact irrigation technology, and determined the optimal irrigation water volume under non-pressure artefact irrigation. The results showed that the plant dry weight and photosynthetic rate of cucumber under non-pressure artefact irrigation were increased compared with that under traditional irrigation. Non-pressure artefact irrigation promoted the accumulation of N, P and K, Vc content, soluble protein and soluble solid in cucumber plants, especially the irrigation amount of 246 m$^3$ 667 m$^{-2}$. In addition, microporous membrane irrigation could improve cucumber yield and water use efficiency compared with traditional irrigation methods. In conclusion, the optimal irrigation amount of cucumber under non-pressure artefact irrigation was 246 m$^3$ 667 m$^{-2}$.

Keywords: Cucumber, irrigation, microporous membrane, growth, yield.

1. Introduction

Water use is the most important factor restricting agricultural development in arid and semi-arid regions [1]. China is a country in shortage of water resources. Although China has a large amount of water resources, it has a large population, a small per capita share of water resources, uneven spatial and temporal distribution, and increasingly serious problems such as excessive exploitation and pollution of water resources. By the end of 2017, China's total water consumption was 604 million m$^3$, of which agricultural water consumption accounted for 62%, while farmland water consumption accounted for up to 90% [2]. In traditional cultivation, large amounts of water and fertilizer are often used for management, resulting in serious waste of water resources, soil salinization, and a series of problems such as reduced fruit yield and quality. Therefore, precise irrigation and fertilization technology is very necessary.

Studies have shown that compared with traditional diffuse irrigation, drip and infiltration irrigation significantly reduced the amount of irrigation water, and the deep leakage of irrigation water significantly decreased [3-4]. However, these new irrigation technologies are prone to blockage in the course of use. In addition, they require high water quality and require special equipment such as supporting pressure equipment and water conveyance pipelines, thus resulting in high cost [5-6]. Our research team has developed the integrated technology of water and fertilizer of microporous film, that is, the perforated film is laid in the ridge trench by using microporous film instead of drip irrigation belt,
drip irrigation pipe and other pipes, and cover the trench with a plastic film. Water flows between the perforated and the plastic films, and penetrates into the soil through the holes in the film, to achieve non-pressure artefact irrigation [7]. This technology not only solves the problem of blockage, but also saves irrigation equipment costs. Nevertheless, it is not clear that this water-saving irrigation technology can meet the needs of plant growth and development.

Cucumber (Cucumis sativus L.) is one of the important vegetable crops in our country whose output takes up the world total 77% of production [8]. This research adopted the non-pressure gravity irrigation, by setting the different irrigation water treatment, compared with traditional flood irrigation, studied their energy saving cucumber under the conditions of different irrigation water on cucumber growth and nutrient elements distribution, the influence of the quality and yield, and determined the optimal irrigation water amount, which provided a certain theoretical basis for the application of water-saving irrigation technology and high-yield cultivation.

2. Materials and Methods

2.1. Site Description and Experimental Materials
Cucumber (C. sativus L. cv. Jinyan No. 4) variety was chosen as plant material for the further experiments. The experiment was carried out in 2019 in the plastic greenhouses of Maozhuang Practice Base in science and Education Park of Henan Agricultural University (34°16′N, and 113°30′E). The perforated plastic film is made of agricultural film with a thickness of 0.08 mm. The length is 40 cm longer than the ridge, the width is 60 cm. In addition, each row punched 3 holes in parallel, the hole spacing is 20 cm long and 12.5 cm wide, and the hole diameter is 3 mm. Water-soluble fertilizer (18-7-20) provided by Yichuan Fufeng Plant Nutrition industry Co., Ltd.

2.2. Experiment Design
In this experiment, the cucumber seedlings with 3 leaves and 1 heart stage, consistent growth and strong strength were selected for transplanting on March 20, 2019, and were pulled on July 6, 2019. Before transplanting, dried chicken manure (750 kg 667 m−2) and ternary compound fertilizer (15-15-15, 35kg 667 m−2) were applied as basal fertilizers. Cucumber was cultivated in one row and two rows, with east-west row. Twenty-five plants were transplanted in each plot with an area of 4.9 m2. After 3 weeks of transplanting, six different irrigation amount treatments began, including CK: traditional irrigation fertilization method, A: 377 m3 667 m−2, B: 334 m3 667 m−2, C: 290 m3 667 m−2, D: 246 m3 667 m−2, and E: 203 m3 667 m−2. The traditional irrigation fertilization method was used as the control treatment (CK), and the actual irrigation amount was 300 m3 667 m−2 and the fertilizer amount was 125 kg 667 m−2; For other treatments, microporous film was laid between the ridges, and integrated water and fertilizer technology of microporous film was adopted. See Table 1 for the specific arrangement of irrigation amount. Each treatment was repeated 3 times and randomly grouped. Seven plants were randomly selected for marking in each treatment. After transplanting, plant morphology including plant height, stem diameter and number of leaves were measured every 20 days for a total of 4 times, and fruit quality of the third panicle was determined.

2.3. Measurement of Plant Morphology
The plant height (from stem base to growing point of cucumber) was measured by measuring tape. The stem diameter (cotyledons 1 cm below) was measured by vernier caliper. Leaf numbers growing longer than 5 cm was counted. Root, stem, and leaf fresh weights were measured by analytical balance. Then, roots, stems, leaves were dried at 75°C until weight constancy and weighed.

2.4. Determination of Photosynthetic Parameters
The photosynthetic parameters of fully expanded leaves in the middle of cucumber plants were determined by a portable photosynthetic apparatus with transparent leaf Chambers installed at 9:00-11:00 a.m. on a sunny day. The flow rate was set at 500 μmol m−2 s−1, and the natural environmental conditions were light, CO2 concentration and temperature. Determination of 5 plants per treatment.
Table 1. Amounts of watering and fertilization after cucumber transplanting.

| Weeks after transplanting | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---------------------------|---|---|---|---|---|---|---|----|----|----|----|----|
| Weeks#day                 | 3#1| 4#4| 5#4| 6#4| 7#7| 8#6| 9#5| 10#4|11#6|12#5|13#4|14#3 |
| Top-dressing amount       | 14| 7 | 7 | 9 | 9 | 11| 9 | 5  | 6  | 4  | 3  | 7  |

CK: The actual irrigation water and fertilizer amount is 300 m³·667 m⁻² and 125 kg·667 m⁻².

A

| Irrigation water treatment (ton·time⁻¹·667 m⁻²) | 18| 20| 20| 20| 20| 15| 12| 12| 12| 12| 12| 12|
|------------------------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|
| CK                                             | 377| 15| 16| 22| 21| 18| 20| 20| 15| 12| 12| 12|
|                                                     | 20| 17| 17| 17| 17| 17| 17| 17| 17| 17| 17| 11|
| C                                              | 290| 11| 12| 18| 18| 14| 15| 15| 14| 15| 11| 10| 10|
|                                                     | 14| 13| 13| 13| 12| 13| 12| 12| 12| 12| 10| 10| 10|
| D                                              | 246| 10| 11| 15| 15| 12| 12| 12| 12| 12| 12| 10| 8 |
|                                                     | 10| 10| 10| 10| 10| 10| 10| 10| 10| 10| 8 | 8 | 8 |
| E                                              | 203| 8 | 9 | 13| 12| 10| 10| 10| 10| 10| 10| 7 | 7 |
|                                                     | 10| 10| 10| 10| 10| 10| 10| 10| 10| 10| 7 | 7 | 7 |

2.5. Analysis of Nutrient Element Contents
Before treatment, basic soil samples were taken at 0-20 cm, 20-40 cm and 40-60 cm depth. After treatment, soil samples were taken at 0-20 cm, 20-40 cm, 40-60 cm depth, and the roots, stems and leaves of dried plants were taken [9]. The sample was used to measure the contents of nutrient elements. The nitrogen (N) content was measured as described in Kjeldahl. The phosphorus (P) content was analyzed by vanadium molybdate colorimetry, and the potassium (K) content was determined by flame photometric method [10].

2.6. Determination of Yield and Quality
The yield of cucumber in each plot was counted and irrigation water use efficiency (IWUE) was calculated according to the following equation: IWUE=Y/I, Y is total fruid yield (kg·667 m⁻²), I is the irrigation water amount (m³·667 m⁻²) in the growth period.
In the middle stage of fruit development, the quality indexes of cucumber fruits were determined: vitamin C content was measured by molybdenum blue colorimetric method; soluble sugar content was measured by anthrone colorimetric method; soluble solids were measured by glucose meter; soluble protein was measured by Coomassie bright blue G-250 method.

2.7. Statistical Analysis
SPSS 22.0 (SPSS Inc., Chicago, USA) was used to analyse data. Treatment means were analysed using Tukey’s honestly significant difference (HSD) post-hoc test whenever the analysis of variance (ANOVA) indicated significant differences (P< 0.05).

3. Results
3.1. Morphological Changes in Cucumber under Different Irrigation Amount
Under different irrigation amount treatments, all growth parameters of cucumber plants, including plant height, stem diameter, and leaf number, showed increasing trends with increased transplanting time. Additionally, compared with CK, other treatments showed no significant difference (data not shown). As shown in Figure 1, there was no significant difference in fresh weights of root, stem, leaf, and whole...
plant among treatments. The dry weights of leaf and whole plant of treatment D were significantly higher than those under CK. There was no significant difference between the dry weights of root and stem of treatment A, B, C, D, and E and CK. These results show that the suitable irrigation amount can improve the dry weight of crops under the condition of microporous membrane.

![Figure 1](image1.png)

**Figure 1.** Effects of different irrigation amount on fresh and dry weights of cucumber plants. The same letter for each sampling location under different treatments indicates no significant difference \((P=0.05)\).

### 3.2. Photosynthetic Parameters in Cucumber under Different Irrigation Amount

Photosynthetic gas exchange parameters can directly reflect the situation of plant photosynthesis. Treatment A, B, C, and E showed significantly higher \(P_n\) than CK but showed no significant difference compared with D (Figure 2). In addition, \(T_r\) and \(G_s\) showed no significant differences among treatments. Moreover, the \(C_i\) of treatment A, B, D, and E was significantly lower than CK, and there was no significant difference among them (Figure 2).

![Figure 2](image2.png)

**Figure 2.** The effect of different irrigation amount on photosynthetic parameters of cucumber leaves. The same letter for each sampling location under different treatments indicates no significant difference \((P=0.05)\).

### 3.3. Nutrient Characteristics in Cucumber and Different Layers under Different Irrigation Amount

All treatments had significantly effect on the N content in all layers compared with basic soil samples (Figure 3A). Compared with CK, the N content of treatment B, C and D in 0-20 and 20-40 cm soil layers were significantly higher, especially treatment D. Compared with CK, the P content of treatment A, B, C, D and E in 0-20 cm soil layer was lower, where compared with basic soil samples, it was higher. Compared with basic soil samplers, the P content of all treatments in 20-40 cm soil layer and treatment B, C and D in 40-60 cm soil layer was lower, but there was no significant difference from CK. The K content of treatment A, B, C in 0-20 cm soil layer, treatment B, C in 20-40 cm soil layer and all treatments in 40-60 cm soil layer was significantly lower than basic soil samplers and CK.
Compared with CK, the N content in the roots, stems and leaves of cucumber plants treated with A, B, C and D was significantly higher (Figure 3B). Compared with CK, the P content in the roots, stems and leaves of cucumber plants treated with B, C and D was significantly higher. In addition, compared with CK, the K content in the roots, stems and leaves of cucumber plants under all treatments was significantly higher. These results showed that treatment B, C and D were beneficial to the accumulation of N, P and K in cucumber plants, especially the treatment D.

Figure 3. Effects of different irrigation amount on N, P and K contents of (A) soil and (B) cucumber plants. J: basic soil samples. The same letter for each sampling location under different treatments indicates no significant difference (P=0.05).

3.4. Cucumber quality under Different Irrigation Amount
As shown in table 2, the VC content of cucumber in each treatments was significantly increased, compared with CK, especially D, which was 81.36% higher than that of CK. In addition, compared with CK, the soluble content of cucumber in all treatments was increased, and D was the highest, which was 15.6% higher than CK. Compared with CK, the soluble protein content of cucumber treated with A significantly decreased, while that of cucumber treated with B, C, D, and E showed no significantly difference. The soluble solid content of cucumber fruit showed a consistent trend with the content of VC. The content of soluble solid in all treatments was significantly higher than that in CK, and D was the highest, 63.63% higher than that in CK. These results indicated that compared with the traditional irrigation and fertilization methods, the microporous membrane irrigation conditions were more conducive to the formation of cucumber fruit quality, among which D showed the best performance.

Table 2. Effects of different irrigation amount on cucumber quality

| Treatments | VC content (mg·100 g⁻¹) | Soluble sugar content (%) | Soluble protein content (g·100 g⁻¹) | Soluble solid (%) |
|------------|-------------------------|---------------------------|-------------------------------------|------------------|
| CK         | 2.36±0.20b              | 3.01±0.01c                | 0.74±0.05a                          | 2.20±0.12b       |
| A          | 3.21±0.53a              | 3.35±0.03b                | 0.25±0.22b                          | 3.40±0.21a       |
| B          | 3.36±0.55a              | 3.36±0.02b                | 0.68±0.01ab                         | 3.50±0.12a       |
| C          | 3.45±0.31a              | 3.35±0.01b                | 0.75±0.02a                          | 3.47±0.03a       |
| D          | 4.28±0.15a              | 3.48±0.03a                | 0.83±0.01a                          | 3.60±0.26a       |
| E          | 3.36±0.67a              | 3.34±0.01b                | 0.70±0.06ab                         | 3.43±0.15a       |

Note: The different letter in the same column denotes significant (P<0.05) by Tukey’s multiple range test.

3.5. Cucumber Yield and Water Use Efficiency under Different Irrigation Amount
The yield per plant and yield of cucumber under other treatments except for treatment E were significantly higher than CK, and there was no significant difference between treatment E and CK (Table 3). The water use efficiency of treatment C, D, and E was significantly higher than CK, 38.72%, 53.61%,
and 51.21% higher than CK, respectively. These results showed that microporous membrane irrigation could improve cucumber yield and water use efficiency compared with traditional irrigation methods.

Table 3. Effects of different irrigation amount on cucumber yield and water use efficiency.

| Treatments | Yield per plant (kg) | Yield (kg 667m⁻²) | Irrigation water use efficiency (kg·m⁻³) |
|------------|----------------------|-------------------|----------------------------------------|
| CK         | 3.09±0.27b           | 10521.72±904.30b  | 35.05±3.01c                            |
| A          | 3.94±0.17a           | 13393.72±585.52a  | 35.53±1.55c                            |
| B          | 4.04±0.04a           | 13724.51±147.11a  | 41.09±0.44bc                           |
| C          | 4.15±0.02a           | 14098.44±65.89a   | 48.62±0.23ab                           |
| D          | 3.90±0.20a           | 13243.42±674.92a  | 53.84±2.74a                            |
| E          | 3.23±0.04b           | 10971.21±138.54b  | 53.00±0.68a                            |

Note: The different letter in the same column denotes significant (P<0.05) by Tukey’s multiple range test.

4. Discussion

This research team of microporous membrane fertigation device can replace drip tube, drip irrigation, micro injection to achieve uniform, quantitative fertigation, there will not be "blocked" phenomenon, do not need special drip irrigation fertilizer, don't need to water pressure, save time, fertigation irrigation fertilization membrane have keep moisture to prevent compaction effect, to transform traditional agriculture "flood irrigation", "a lot of fertilization methods play an important role. In this study, compared with traditional flood irrigation, all treatments under microporous membrane irrigation improved significantly in terms of photosynthesis, yield, quality and water use efficiency. Photosynthesis is an important determinant of plant growth and crop yield, and different water management is an important way to improve photosynthesis and increase crop yield [11]. In this experiment, compared with the traditional irrigation method, the photosynthesis of all treatments under the condition of microporous membrane irrigation increased significantly (Figure 3). Furthermore, the yield of treatments except for treatment E was significantly increased (Table 3). In addition, compared with the control group, the water use efficiency of treatment C, D and E was significantly increased (Table 3). It can be seen that although the water use efficiency (WUE) of treatment E is very high, the yield is not high. In other words, the relationship between yield and WUE is not linear. This is consistent with the results of Condon et al. [12].

China is a country short of water resources, so the research of water-saving technology is very meaningful. In this study, compared with the traditional irrigation method, the water use efficiency of treatment C, D and E was increased by 38.72%, 53.61%, and 51.21% (Table 3). Previous studies have found that compared with diffuse irrigation, drip irrigation generally saved 30% - 50% water [13-14], indicating that the water-saving technology of microporous membrane is equivalent to that of drip irrigation. The input of drip irrigation equipment is 27,000 yuan /hm², with a lifetime of 5 years [15]. In this study, the technology had a low cost of input because it can be used with undamaged waste shed film. Therefore, the non-pressure artesian irrigation system can be popularized and applied in production as an effective water-saving irrigation technology.

5. Conclusion

In general, the optimal irrigation amount was 246 m³ 667 m⁻² under non-pressure artefact irrigation.

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References

[1] Ferreira T, Carr M, 2002. Response of potatoes (Solanum tuberosum L.) to irrigation and nitrogen in a hot, dry climate: I. Water use. Field Crops Research 78: 51–64
[2] National bureau of statistics 2018 China statistical yearbook (Beijing: China statistical press)
[3] Román R, Caballero R, Bustos A 1999 Field water drainage under traditional and improved irrigation schedules for corn in central Spain Soil Science Society of America Journal 63: 1811—1817
[4] Yang L J, Zhang Y L, Xu H, et al. 2004 Effect of irrigation methods on soil water loss and water use efficiency of tomato in greenhouse Journal of Irrigation and Drainage 23(3): 49—51
[5] Li N, Kang Y H, Li X B, et al. 2019 Lateral flushing with fresh water reduced emitter clogging in drip irrigation with treated effluent Irrigation Science 37(5):1-9
[6] Mostafa H M S, El-Nady R, Awad M, et al. 2018 Drip irrigation management for wheat under clay soil in arid conditions Ecological Engineering 121:35-43
[7] Wang J Q, Zhao Y P, Shi J T, et al. 2020 An uniform and quantitative irrigation equipment: China, ZL 2017 1 0751922.X
[8] FAO 2016 FAOSTAT Domains/Production/Crops. Available online at: http://www.fao.org/faostat/en/#data/QC (Accessed December 19, 2016).
[9] Bremner J M 1960 Determination of nitrogen in soil by the Kjeldahl method Journal of Agricultural Science 55(1): 11-33
[10] Burcea M, Cretu D, Musat M, et al. 2016 Study regarding the influence of NPK fertilizers on the total nitrogen content from tomato (Lycopersicum esculentum) Romanian Biotechnological Letters 21 (1): 11144-11148
[11] Xing Y Y, Zhang F C, Zhang Y, et al. 2015 Effect of irrigation and fertilizer coupling on greenhouse tomato yield, quality, water and nitrogen utilization under fertigation. Scientia Agricultura Sinica 48(4): 713-726
[12] Condon A G, Richards R A, Rebetzke G J, et al. 2002 Improving intrinsic water use efficiency and crop yield Crop Science 42, 122–131
[13] Fan Z B, Liu M J, Zhang X M, et al. 2011 Effect of dripper fertigation on tomato yield and apparent N balance in a greenhouse Plant Nutrition and Fertilizer Science 17(04): 970-976
[14] Nasiraei J R, Ansari H, Esmaeili K, et al. 2018 Effect of irrigation timing on the eggplant performance under drip irrigation Crop research 53 (1&2) : 81-87
[15] Fan Z B, Lin S, Chen Q, et al. 2015 Effect of drip fertigation on water and nitrogen use efficiency and nitrate residues in a greenhouse Journal of China Agricultural University 20(01): 135-143