Effects of Different Nitrogen and Irrigation Amount on Growth, Evapotranspiration and Water and Nitrogen Use Efficiency of *Jatropha Curcas* L.

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Abstract. In order to study the effects of different nitrogen and irrigation water patterns on water and nitrogen use efficiency of *Jatropha curcas* L., three water levels (W1:100% ET (ET as evapotranspiration), W2:80% ET, W3:60% ET), and three nitrogen application levels (N1:0g.kg-1, N2:0.4g.kg-1, N3:0.8g.kg-1) were designed. The results showed that compared with T1, each organ and total dry matter of *Jatropha curcas* L. decreased in T2 and T3. Besides, nitrogen application significantly increased each organ and total dry matter of *Jatropha curcas* L. Compared with W1N3(high water and nitrogen content), W2N2 treatment saved 20% water and 50% nitrogen fertilizer. Its irrigation water uses efficiency and total amount of nitrogen uptake in per plant increased by 26% and 64.88%. Therefore, W2N2 treatment is the best irrigation and nitrogen application pattern for the growth, the use efficiency of water and nitrogen of *Jatropha curcas* L.

1. Introduction

*Jatropha curcas* L. is a plant of the genus Jatropha in Euphorbiaceae. It can survive in the environment of plateau, hilly slope, valley and barren hillside with annual precipitation of 480-2380 mm, annual average temperature of 18.0-28.5 °C and altitude of 800-1600m [1]. The height of *Jatropha curcas* L. is about 2.0-5.0m. It has the ability to grow in cold, drought and erosion environment [2-3]. *Jatropha curcas* L. is rich in nitrogen, phosphorus and potassium, which is an important raw material of organic fertilizer. The whole plant of *Jatropha curcas* L. can be processed medicines, such as its stem, leaves and bark contain a large amount of milk, which can be used as external medicines for sterilization, rheumatism analgesics and so on, as well as soap and cosmetics production. Especially its seed oil content is as high as 40-60%. It can replace diesel oil as fuel in industry, so it is called biodiesel tree. In addition, *Jatropha curcas* L. has the functions of preventing soil desertification and increasing soil organic matter [4-5]. Therefore, *Jatropha curcas* L. has great potential for development and application. Although the planting area of *Jatropha curcas* L. is relatively wide in the tropical and subtropical areas of China, most of the planting areas are facing such prominent problems as drought, water shortage, poor soil, and serious non-point source pollution caused by unreasonable fertilization, which lead to poor growth quality of *Paulownia curcas*, so that the yield is low, the quality is poor, and the water and fertilizer use efficiency is extremely low, thus seriously restricting the *Jatropha curcas* L. industry.
Scientific irrigation and fertilization are important measures to promote crop growth, save water and reduce emissions, and improve water and fertilizer use efficiency. In actual production, because of the lack of water and nitrogen management measures, many farmers blindly pursue high yields, the irrigation water and excessive nitrogen fertilizer were applied, which resulting in lower crop yield efficiency and increasing agricultural non-point source pollution [6]. Under the condition of water-nitrogen coupling, it has been found that when the irrigation amount is 80% of the field capacity, increasing nitrogen fertilizer will be more conducive to the photosynthesis of *Jatropha curcas* L. [7]. When the field water holding capacity is 80% or 60%, increasing nitrogen fertilizer significantly improves the osmotic adjustment ability of *Jatropha curcas* L. seedlings [8]. When irrigation amount was 80% of evapotranspiration, the dry matter quality, strong seedling index and water use efficiency of *Jatropha curcas* L. were significantly improved by applying nitrogen fertilizer.

Therefore, based on the nitrogen with irrigation water application mode, this study aims to improve the growth and yield of *Jatropha curcas* L., explores the integrated mode of water and nitrogen with high efficiency and provides reference for planting management of *Jatropha curcas* L.

## 2. Materials and Methods

### 2.1. Site description and Materials

The experiment was carried out in greenhouse of Faculty of Modern Agricultural Engineering, Kunming University of Science and Technology. On April 15, one-year-old seedlings of Paulownia curcas were transplanted into plastic pots (Top width: 30.0 cm; Bottom width: 22.5 cm; Height: 30.0 cm). The tested soil was local dry red loam with clay loam and 13 Kg soil was filled in per pot. The soil physicochemical properties are shown in Table 1.

| Organic matter | volume weight of soil | PH | Organic matter | Total nitrogen | Total phosphorus | Total potassium | Organic matter |
|----------------|----------------------|----|----------------|---------------|-----------------|----------------|----------------|
| 13.12 g/kg     | 1.2 g/cm³            | 5.5| 13.12 g/kg     | 0.87 g/kg     | 0.68 g/kg       | 13.9 g/kg      | 13.12 g/kg     |

### 2.2. Experimental Design

Three water treatments (W1 (100% ET), W2 (80% ET), W3 (60% ET)) and three nitrogen treatments (N1 (0g/kg), N2 (0.4g/kg) and N3 (0.8g/kg)) were set up in the experiment, each treatment was repeated three times. Weighing compensation method was used to make sure the irrigation amount and the irrigation period was 7 days. The nitrogen fertilizer was 46.7% pure urea, so 0 g, 0.66 g and 1.31 g pure urea were applied in N1, N2 and N3, respectively. 0.58g potassium fertilizer and different nitrogen fertilizer were dissolved in different water and mixed evenly then poured into the soil. In order to reduce the systematic errors caused by the environment in greenhouse, the pots were rotated in the same direction every two weeks, and other management measures were consistent.

| Treatments | W₁ (mm) | F₉ (g) | Treatments | W₁ (mm) | F₉ (g) |
|------------|---------|--------|------------|---------|--------|
| Mark       | Water   | Nitrogen | Mark       | Water   | Nitrogen |
| W1N1       | W1      | N1(0g/kg) | W3N1       | W3      | N1(0g/kg) |
| W1N2       | W1      | N2(0.4g/kg) | W3N2       | W3      | N2(0.4g/kg) |
| W1N3       | W1      | N3(0.8g/kg) | W3N3       | W3      | N3(0.8g/kg) |
| W2N1       | W2      | N1(0g/kg) | W3N1       | W3      | N1(0g/kg) |
| W2N2       | W2      | N2(0.4g/kg) | W3N2       | W3      | N2(0.4g/kg) |
| W2N3       | W2      | N3(0.8g/kg) | W3N3       | W3      | N3(0.8g/kg) |
\[ W_i \] is total irrigation amount; \( F_N \) is total nitrogen amount;

### 2.3. Growth and IUE

Fresh matter and dry matter of leaves, stems and roots were measured by electronic balance. Biomass of organs was obtained on September 30. After measured the fresh matter, the organs were put into the oven at 105 \(^\circ\)C for 30 minutes, then adjust the temperature to 78 \(^\circ\)C 12hours.

\[
\text{IUE} = \frac{M_{DT}}{W_I} 
\]

(1)

Where IUE is irrigation use efficiency (g); \( M_{DT} \) is dry matter of total plant; \( W_I \) is total irrigation amount.

### 2.4. Evapotranspiration and Transpiration

Evapotranspiration and transpiration were measured on August 21 and August 22, respectively. Before measuring the transpiration of per plant, the pot surface was covered with black plastic bags and sealed them with black tape to avoid the soil evaporation.

### 2.5. Total Nitrogen Content in Plants

After crushing and sieving the dried plants, they were digested by concentrated \( \text{H}_2\text{SO}_4-\text{H}_2\text{O}_2 \) method, and the total nitrogen content was determined by Kjeldahl nitrogen analyzer. total amount of nitrogen uptake in per plant and nitrogen dry matter production efficiency were calculated by the standard formulas Eq. (2,3) [9].

\[
N_T = \sum C \times M_D 
\]

(2)

\[
E_P = M_T \times N_T 
\]

(3)

Where \( N_T \) is total amount of nitrogen uptake in per plant (g); \( C \) is the nitrogen content of each organ of the plant; \( M_D \) is dry matter of each organ of the plant; \( M_T \) is total dry matter of the plant; \( E_P \) is nitrogen dry matter production efficiency.

### 2.6. Statistical analyses

The growth and physiological data collected were analyzed by ANOVA using SPSS (20.0). Duncan (\( P=0.05 \)) method was used for multiple comparisons. The figure was completed under Excel (2010) software system.

### 3. Results

#### 3.1. Growth and irrigation irrigation water use efficiency

\( M_D \): dry matter; \( M_L \): dry leaves matter; \( M_S \): dry stems matter; \( M_R \): dry roots matter; \( M_T \): total dry matter; IUE: irrigation water use efficiency. Values are means of three replicates ± standard deviation (SD). Different letters are significantly different by Duncan(D)'s test \( (P < 0.05) \).

The results showed that the effects of different nitrogen and irrigation amount on the dry matter of leaves, stems, roots and total dry matter of \textit{Jatropha curcas} L. seedling were significant \( (P < 0.05) \). The data analysis showed that under the same nitrogen application rate, the dry matter of all organs of \textit{Jatropha curcas} L. decreased with the decrease of irrigation amount at N1 level, the total dry matter of \textit{Jatropha curcas} L. decreased with the decrease of irrigation amount at N2 level, and the roots dry matter of \textit{Jatropha curcas} L. decreased with the decrease of irrigation amount at N3 level, but the leaves dry matter, stems dry matter and the total dry matter increased at first and then decreased with the decrease of irrigation amount.
Suitable irrigation and fertilization methods can greatly improve the irrigation water use efficiency of *Jatropha curcas* L. Data analysis showed that the irrigation water use efficiency of W2 and W3 treatments increased by 13% and 6% respectively compared with W1 under the same amount of nitrogen application. Compared with N3, the irrigation water use efficiency of N1 level decreased by 23% and the irrigation water use efficiency of N2 level increased by 19%. Compared with W1N3 with high water and nitrogen, W2N2 irrigation water use efficiency increased by 25%.

### Table 3. Effects of different nitrogen and irrigation amount on dry matter and irrigation water use efficiency of *Jatropha curcas* L.

| Treatments | MD /g | IUE /g·mm⁻¹ |
|------------|-------|-------------|
|            | M_L   | M_S        | M_R   | M_T   |               |
| W1N1       | 10.86±4.43a | 57.54±6.95a | 18.43±1.82a | 86.84±6.72a | 0.282±0.06a   |
| W1N2       | 10.12±1.43a | 32.69±6.5b  | 14.43±1.19ab| 57.24±8.45b | 0.186±0.03b   |
| W1N3       | 3.81±2.15e | 16.91±2.51c | 8.87±1.35bc| 29.58±5.05c | 0.096±0.04c   |
| W2N1       | 5.89±1.41c | 20.34±4.73c | 8.81±0.07bc| 35.04±3.963c| 0.146±0.08bc  |
| W2N2       | 8.23±2.71b | 33.34±4.01b | 9.68±0.25bc| 51.24±3.13b | 0.213±0.01ab  |
| W2N3       | 5.43±2.98cd| 28.56±4.07bc| 7.13±0.36c | 41.12±5.38bc| 0.171±0.08b   |
| W3N1       | 4.5±2.14de | 18.93±2.08c | 5.23±0.65  | 28.66±2.35c | 0.158±0.05c   |
| W3N2       | 6.06±2.33c | 29.24±2.37bc| 9.86±1.21bc| 45.17±4.66bc| 0.250±0.03a   |
| W3N3       | 4.27±1.22de| 21.14±4.59c | 6.24±1.07c | 31.65±5.65c | 0.175±0.02b   |

3.2. Evapotranspiration and Transpiration

Figure 1 showed that transpiration is directly related to plant metabolism. Under the same nitrogen application, the transpiration of *Jatropha curcas* L. at T1 level was the largest; under the same nitrogen application, the transpiration of *Jatropha curcas* L. at N3 level was the largest, followed by N2 and N1 was the smallest. The ratio of transpiration to evapotranspiration showed that the maximum value was obtained under treatment T1N1, and the proportion of transpiration per unit evapotranspiration of *Jatropha curcas* L. reached 57%, followed by that under treatment T2N2 was 54%.

![Figure 1. Effects of different nitrogen and irrigation amount on Evapotranspiration and Transpiration of *Jatropha curcas* L.](image-url)
3.3. Total Nitrogen Content in Plants

Table 4. Effects of different nitrogen and irrigation amount on nitrogen content, total amount of nitrogen uptake in per plant and nitrogen dry matter production efficiency of *Jatropha curcas* L.

| Treatments | CN/(g·kg⁻¹) | NT/(mg·plant⁻¹) | EP/(g·g⁻¹) |
|------------|-------------|-----------------|-------------|
|            | C_L         | C_S             | C_R         |
| W1N1       | 14.92±0.04c | 9.27±0.03c      | 6.54±0.05c  | 803.1±51.79ab | 107.93±1.95a |
| W1N2       | 29.1±0.08b  | 15.52±0.04b     | 13.29±0.13b | 967.16±136.91a | 59.06±0.48b |
| W1N3       | 36.24±0.04a | 17.26±0.11ab    | 16.39±0.22ab | 561.83±102.63c | 53.14±1.25b |
| W2N1       | 14.44±0.13c | 9.26±0.03c      | 6.42±0.08c  | 324.68±34.32d | 107.72±0.9a |
| W2N2       | 32.17±0.02b | 16.7±0.1ab      | 13.87±0.04b | 927.01±54.46a | 55.3±1.31b |
| W2N3       | 38.52±0.09a | 18.7±0.02a      | 17.67±0.09a | 849.89±125.53ab | 48.7±1.25b |
| W3N1       | 14.73±0.05c | 9.29±0.03c      | 6.39±0.08c  | 270.75±21.2d | 105.85±1.67a |
| W3N2       | 31.02±0.06b | 15.81±0.01b     | 12.73±0.16b | 759.42±86.99b | 59.67±0.78b |
| W3N3       | 36.39±0.07a | 17.99±0.02a     | 16.84±0.03ab | 627.34±107.26bc | 50.23±0.79b |

CN: nitrogen content; C_L: nitrogen content of leaves; C_S: nitrogen content of stems; C_R: nitrogen content of roots; NT: total amount of nitrogen uptake; EP: nitrogen dry matter production efficiency.

It showed that there was no significant difference in the effects of different nitrogen and irrigation amount on total nitrogen in leaves, stems and roots of *Jatropha curcas* L. seedlings. Data analysis showed that, compared with W1, the C_L, C_S and C_R increased by 6%, 6% and 4% at W2 level, increased by (+) and decreased by (-): 2%, 2% and - 7% at W3 level. Compared with N1 level, the C_L, C_S and C_R increased by 107%, 71% and 107% at N2 level, respectively ($P < 0.05$) and increased by 151%, 93%, 162% at N3 level, respectively ($P < 0.05$). Compared with W1N3 with high water and nitrogen, CL, CS and CR decreased by 11%, 3% and 15% under W2N2 treatment ($P < 0.05$).

With the increase nitrogen of fertilization, the NT increased at first and then decreased. The NT of W1N2 and W2N2 were 967.16 and 927.01mg/plant, which were higher than other treatments. Compared with W1N3 with high water and nitrogen, NT increased by 64.88% under W2N2 treatment ($P < 0.05$). Besides, the EP in N1 was higher than N2 and N3 and there was no significant difference between N2 and N3 levels.

4. Discussion

Roots can absorb water continually to promote the growth of roots when water is sufficient. In This study, it found that root growth was significantly related to the amount of nitrogen application. Under high water condition, root dry matter decreased with the increase of nitrogen application, which indicated that excessive nitrogen application inhibited root growth. Moreover, under medium and low water conditions, root dry matter increased at first and then decreased with the increase of nitrogen application, which indicated that excessive nitrogen application inhibited root growth. In addition, the redundancy of crop growth can be reduced in W2N2 and W3N2 treatments, there growth of leaves and roots of crops is reduced compared with that of W1N2.

The results showed that W2N2 and W3N2 had more leaves, larger transpiration and higher irrigation water use efficiency (Table3 and Figure 1). This was because with the decrease of irrigation amount, the growth of leaves decreased, transpiration rate of leaves decreased, transpiration and transpiration also decreased significantly[11]. At the same time, a more favorable growth environment and root micro-environment with suitable soil moisture content for *Jatropha curcas* L. was createdat W2 and W3 levels. However, the high soil moisture content of W1 level inhibited root respiration [12], which was not conducive to the growth of root and canopy of *Jatropha curcas* L. Therefore, the irrigation water...
use efficiency of *Jatropha curcas* L. was significantly improved by W2N2 and W3N2 treatments. In addition, compared with N2 level, the difference between transpiration and evapotranspiration of *Jatropha curcas* L. at N3 level was the largest, it indicated that more water evaporated from soil surface and ineffective evapotranspiration consumption increased. At the N2 level, the soil water potential was improved, thereby the effectiveness of soil water was improved, more water was absorbed by plant’s root and the evaporation of water from the soil surface reduced. Therefore, W2N2 and W3N2 treatments promoted significantly the irrigation water use efficiency of *Jatropha curcas* L. compared with W1N2 treatments.

It was also found that total nitrogen in leaves, stems and roots increased with the increase of nitrogen application and total nitrogen in stems and roots increased first and then decreased with the decrease of irrigation (Table 4). The results showed that under serious water deficit condition (W3), excessive increase of nitrogen application rate was not conducive to the absorption of nitrogen by the trees. For example, under high nitrogen level (N3), the concentration of soil solution was higher, and the dry matter, water use efficiency and nitrogen use efficiency of roots significantly reduced, possibly because the concentration of soil nitrogen was too high, which reduced the water potential of soil [13]. The difference between leaves water potential with different part leaves were reduced, so the absorption and utilization of nutrients and water were inhibited.

When the amount of nitrogen was suitable, with the increase of irrigation, the amount of nitrogen absorbed by crops increased, but nitrogen was leached to the lower part of the root density when the irrigation amount was too much. In addition, this study also found that although the drought resistance of *Jatropha curcas* L. was very strong, but it belonged to shallow-rooted plants, which was also the direct reason for the more irrigation, the less absorption and utilization of nitrogen fertilizer by *Jatropha curcas* L. trees. Furthermore, with more irrigation water, ammonium nitrogen in soil volatilized with higher evaporation on the soil surface, which made it difficult to be used for *Jatropha curcas* L., that was consistent with the research of Liu Shiquan [14] on pumpkins.

5. Conclusion

Compared with W1N3 treatment with high water and nitrogen, W2N2 treatment could save 20% of water and 50% of nitrogen, but the growth and dry matter quality of *Jatropha curcas* L. did not decrease significantly (*P* > 0.05), irrigation water use efficiency, evapotranspiration, transpiration and the total nitrogen uptake of *Jatropha curcas* L. were significantly improved (*P* < 0.05). Therefore, under the experimental conditions, the best irrigation nitrogen application mode was W2N2 treatment.

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