Effect of Drip Irrigation with Magnetised Water and Fertiliser on Cotton Nutrient Absorption

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Abstract. In order to improve the nutrient absorption effect of cotton in the process of simultaneous application of water and fertiliser, this paper studied the effect of injecting magnetised water and fertiliser on cotton nutrient absorption under the production conditions of drip irrigation. In the process of integrated water and fertiliser management of cotton, the study adopted the method of magnetisation treatment —— After the water-fertiliser fusion liquid is magnetised by a magnetisation device, it is dripped on the cotton field through the drip irrigation pipe network. In this work, the water and fertiliser magnetisation device was designed, and it was combined with the drip irrigation pipe network as a test device. The nutrient absorption test of the water-fertiliser fusion liquid applied to cotton under different magnetic fields was conducted. The accumulation, absorption and distribution of cotton biomass and N, P and K elements were studied respectively. As a result of the research, we found that the magnetised water and fertiliser treatment can promote cotton nutrient absorption to varying degrees. A method of drip irrigation under a magnetised water and fertiliser film to improve the nutrient absorption effect of cotton was proposed.

1. Introduction

Drip irrigation technology is gradually popularized, which provides practical conditions and technical advantages for the simultaneous application of water and fertiliser during cotton growth. Existing research results show that both magnetised water and magnetised fertiliser have an effect on crop production. At the same time, due to the unique remanence effect, the quality of crops has also changed [1-4]. Therefore, this study applies magnetised water and fertiliser to the process of cotton water and fertiliser management, and discusses the effect on cotton nutrient absorption.

The so-called magnetised water and fertiliser is the water-fertiliser fusion liquid that flows vertically through a certain strength magnetic field at an appropriate speed. The growth process of plants requires the supply of water and nutrients. The steady-state controllable magnetic field can be generated by means of energization and excitation. By changing the magnetic field parameters, the flow speed and time of the magnetised water and fertiliser, the magnetised water and fertiliser of different strengths can be induced. Placing the water-fertiliser fusion liquid in a steady-state magnetic field will change the electrical conductivity, surface tension, viscosity and PH value of the water-fertiliser fusion liquid [5-13], which will affect the nutrient absorption and metabolism of the crop [14-19]. Irrigation with magnetised water and fertiliser shows a significant yield increase effect on most crops [20,21]. Magnetised water can also improve the quality of some crops [22-25]. The application of magnetic fertiliser has a significant yield increase effect on food crops, cash crops,
vegetables, and fruit trees [26-27].

In the current agricultural production, the simultaneous application of water and fertiliser is gradually becoming a new method of water and fertiliser management in field agricultural production. Combining this technology with magnetisation technology, research on the nutrient absorption effect of cotton and clarify it of the magnetised water-fertiliser fusion liquid on the growth process of cotton, which will provide a theoretical basis for the practical application of biomagnetic technology in cotton production.

At the moment when the field drip irrigation technology is popularized and applied on a large scale, the water and fertiliser management of cotton adopts the method of water and fertiliser together. The biological effect of the magnetic field produced by it can combine the advantages of magnetised water irrigation and magnetic fertiliser. Fertiliser is dissolved in water under the action of a magnetic field, after the water-fertiliser fusion liquid is magnetised, it has residual magnetism. After dripping into cotton through drip irrigation pipe network, the remanence effect of the water-fertiliser fusion liquid will be coupled with the fertiliser effect, which will have a series of influences on the absorption of nutrients. Therefore, this work is dedicated to combining the magnetisation device with the drip irrigation pipe network as a test device, discussing the influence of different intensity magnetic field treatments on the absorption of N, P and K elements in cotton, and the analysis of the method of the irrigation management method to enhance the nutrient absorption of the crop.

2. Theoretical Analysis of Structure

2.1. Analysis of Iron Core Structure

Silicon steel is a kind of magnetic material with strong magnetic permeability. Using it to make iron core can reduce hysteresis loss. To generate a controllable electromagnetic field while facilitating the magnetisation of water and fertiliser, it is necessary to analyse the design of the iron core structure and the way the pipe penetrates the iron core. Consider the following issues:

- After energising, there is an ampere force that attracts each other at the air gap;
- In the case of a large number of coil turns and high current, ampere force reduces the air gap between the cores, and it is difficult to obtain a uniform magnetic field;
- The structure is complicated to manufacture, and the winding of the coil is cumbersome, the electromagnetic field generated is uneven and inconvenient to measure;
- The intensity of the electromagnetic field generated is small.

In summary, the shape of the water-fertiliser fusion liquid can be changed arbitrarily according to the required properties. The design uses the pipe as a medium to magnetize the water and fertiliser mixed liquid. To magnetize the water-fertiliser fusion liquid in a larger area and prevent magnetic field shielding, the pipe needs soft plastic material. According to actual needs, design the iron core and yoke into an E-shaped structure similar to the transformer.

There are air gaps on both sides of the iron core, which are used for the magnetic field generation area of water-fertiliser fusion liquid treatment.

Finally, design the outer dimension of the iron core as 800mm×1100mm×300mm, and the air gap size as 300mm×300mm×30mm. Figure 1 shows the iron core and magnetic gap structure design of the magnetic processing part of the test device.
2.2. Analysis of Coil Parameters

The E-shaped iron core is selected, and its core column is a rectangular parallelepiped, so some empirical formulas are used in the engineering to calculate. The number of turns and layers of the coil can be calculated according to the structure diagram of the core and magnetic gap.

This test requires the air gap magnetic flux density to reach 1T, mark $B_\delta = 1T$. According to the designed E-type core structure, the side length of the air gap limited cross-section is $a = b = 300mm$, and the air gap width $G = 30mm$. We can obtain the core flux density as follows:

$$B_{Fe} = \frac{\varphi_{Fe}}{S_{Fe}} = \frac{\varphi_\delta}{S_{Fe}} = \frac{B_\delta S_\delta}{S_{Fe}}$$

(1)

In equation (1), $S_\delta$ is the effective area of the air gap, $S_\delta = (300 + 30) \times (300 + 30) = 108900mm^2$, $S_{Fe}$ is the effective area of the iron core, $S_{Fe} = 300 \times 300 = 90000mm^2$. Therefore, we can obtain $B_{Fe} = 1.21T$ according to the equation.

Through the B-H curve, we can find the magnetic field intensity $H_{Fe} = 6 \times 10^{-2} \text{A/m}$.

$$NI = \sum HL = H_\delta G \times 2 + H_{Fe} L_{Fe}$$

(2)

In equation (2), $H_\delta = \frac{B_\delta}{\mu_0}$, air permeability $\mu_0 = 4\pi \times 10^{-7}$; $L_{Fe}$ is the length of the iron core magnetic circuit, $L_{Fe} = 700 \times 3 - 30 \times 2 + 800 \times 2 = 3640mm$ can be calculated from the iron core magnetic circuit structure diagram in figure 2. Therefore, we can obtain $NI = 49930$, 48A according to the equation.

![Figure 1. Iron core and magnetic gap structure.](image)
Select the enamelled wire with a diameter of 2.5mm, the rated current is 12A, coil current is $I = 4A$, so $N = NI / I = 12482.6$ turns, and the number of turns is 13,000.

According to actual requirements, the first layer line near the centre pillar: $n_1 = 600 / 2.5 = 240$ turns, so the number of layers available is $N / n_1 = 13000 / 240 = 54$ layers, and the line layer width $d = 54 \times 2.5 = 135.4 \, mm < 200 \, mm$, which meets the design requirements.

2.3. Analysis of Magnetic Field Simulation
This article uses COMSOL5.3 to simulate and analyse the main structure of the magnetic field generator. Figure 3 shows the 3D model of the main body of the closed magnetic circuit.

Figure 2. Structure diagram of iron core magnetic circuit.

Figure 3. 3D model of the main body of the closed magnetic circuit.

Set the B-H curve data of the iron core material to the DR470-50 silicon steel sheet B-H curve, set
the number of coil turns, and current value, the electromagnetic field under DC voltage regulation is a constant magnetic field, solve the magnetic field type and set the static magnetic field for analysis. After running the simulation, the magnetic field intensity distribution of the main body of the magnetic circuit is obtained, as shown in figure 4.

![Figure 4](image.png)

**Figure 4.** The magnetic field intensity distribution of the main body of the magnetic circuit.

We can see from figure 4 that when the DC power supply is supplied, the magnetic lines of induction generated by the coil electromagnetic induction pass through the iron core to form a closed magnetic circuit. Combined with the legend, we can get:

- The colour distribution on both sides of the core column is the same, so we can conclude that there are the same number of magnetic lines in the core column divided into two;
- The iron cores on the left and right sides respectively form a closed magnetic circuit through the gap, so the same magnetic field strength is generated at the gap on both sides;
- When the colour of the core column is red, the intensity of the distributed magnetic field is the largest;
- The left and right magnetic field paths formed by the core column are symmetrically distributed in the centre, so the corners and the middle of the core are blue, that is, the magnetic field strength is the smallest;
- The magnetic permeability of the air at the gap is much smaller than that of the iron core. The magnetic lines of induction here will diverge and, the intensity of the formed magnetic field will decrease. Therefore, the colour of the magnetic field distribution at the air gap in the figure is blue;

The colour distribution of the magnetic field is consistent with the magnetic field intensity distribution analysed by the previous theory.

3. **Design of Test Device**

When the water-fertiliser fusion liquid is magnetised and applied to the crop through the drip irrigation device under the film, considering the influence of the flow factor on the liquid remanence, the magnetisation device is combined with the drip irrigation device to solve the control of the two variables of the flow rate and magnetisation time of the magnetised water and fertiliser problem.

3.1. **Variable Control of Flow Rate**

This test device connects the constant pressure pump with the fertiliser tank. There are two control modes, one is human control, and the other is automatic control, which does not require human intervention and executes closed-loop control by itself. The rear end of the pipeline is connected with
the constant pressure pump through a movable disassembly sleeve, and a drip irrigation control valve is installed vertically on the pipeline. The single-chip microcomputer detects and collects information from the downstream flow rate sensor, and transmits the collected information back to the upper computer. The upper computer decides and issues instructions to control the drip irrigation control valve, and realizes the control of the flow rate of the crop drip irrigation magnetised water and fertiliser.

3.2. Variable Control of Time
Regarding the issue of controlling the magnetisation time, this experiment has perfected the structure to achieve the purpose of increasing the magnetisation time. First of all, for the overall structure design, in the previous structural theoretical analysis, we chose an E-shaped structure iron core, so the magnetisation device has two air gap magnetic fields, which can perform secondary magnetisation of the water-fertiliser fusion liquid. The magnetisation device and the drip irrigation pipe network. Figure 5 shows the device combination diagram.

![Figure 5. Device integration.](image)

Secondly, for the local structural design, considering that twisting the pipe in the air gap can prolong the magnetisation time of the water-fertiliser fusion liquid in the magnetic field, it in the air gap is designed roughly as shown in figure 6.

![Figure 6. Design of the pipe in the air gap.](image)

4. Nutrient Absorption Test

4.1. Materials
The experiment was carried out in the fifth company of the fourth branch (N44.21°, E86.09°) of
Shizongchang, Shihezi City, Xinjiang, in 2019. It belongs to a typical inland desert climate, with an average annual rainfall of 290mm and an average annual frost-free period of 180 days. All ≥10°C accumulated temperature of 3300°C. The test soil was grey desert soil, and its basic physical and chemical properties were pH 8.3, organic matter 11.3g/kg, available nitrogen 58.4mg/kg, available phosphorus 24.4mg/kg, and available potassium 229mg/kg.

4.2. Methods

4.2.1. Design of the Experiment. The experiment adopts a random block design. NMT: water-fertiliser fusion liquid without magnetic field magnetisation treatment; LMT: water-fertiliser fusion liquid is magnetised by an air gap magnetic field with a magnetic induction intensity of 200mT; MMT: water-fertiliser fusion liquid undergoes an air gap magnetic field with a magnetic induction intensity of 400mT Magnetisation treatment; HMT: The water-fertiliser fusion liquid is magnetised by an air gap magnetic field with a magnetic induction intensity of 600mT. The flow rate of the water-fertiliser fusion liquid after the air gap magnetic field magnetisation treatment is 2m/s, repeat three times per treatment, and the plot area is 7.2m×7m=50.4m². The terrain of each plot is flat and balanced. Nitrogen, phosphorus and potassium fertilizers drip applied throughout the reproductive period (the mass ratio of N, P²O₅, K²O is 1.0∶0.5∶0.5). The nitrogen, phosphate and potassium fertilisers in the water-fertiliser fusion liquid are respectively used with urea (Containing N 46%), superphosphate (containing P²O₅ 64%) and potassium sulfate (containing K₂O 50%) are soluble in water and form a water-fertiliser fusion liquid with water. The fertilization levels of nitrogen fertiliser, phosphate fertiliser and potassium fertiliser are respectively: N is 220kg/hm², P²O₅ is 110kg/hm², and K₂O is 110kg/hm². According to the law of fertilization during the growth period of cotton, it is applied in six times with water droplets during the growth of cotton. It is the bud stage: the blooming stage: the first blooming stage: the blooming stage: the blooming bell stage: the blooming bell stage=10%∶20%∶25%∶25%∶10%∶10%.

The tested cotton variety was Zhongmian No. 99, which was planted by drip irrigation under the mulch, with six rows in one mulch, the plant spacing was 10cm, and the width and narrow row spacing configuration were (10+66+10+66+10)cm+76cm, 2019. The seeds were sown on April 10, 2010, and the seedlings appeared on April 18, and the growth period was irrigated ten times. The irrigation quota was 3900m³/hm², and the total irrigation volume of the test plot was 20m³.

4.2.2. Measurement Index. Take cotton samples during the spitting period (September 20, 2019). Separate the collected three cotton plants into the straw, cotton fibre, and seed. They will be quenched at 105°C for 30 minutes, and then dried at 75°C. Record the dry matter weight. Crushed the dried plant samples, and analysed the nutrient absorption of different parts of the plant. The plant samples were digested with H₂SO₄-H₂O₂, the total nitrogen was determined by the Nessler colourimetric method, the total phosphorus was determined by the molybdenum antimony colourimetric method, and determination of total potassium by flame photometry.

5. Results and Discussion

5.1. Influence on the Accumulation and Distribution of Cotton Biomass

Table 1 shows that the straw, fibre, seed and total biomass of cotton are significantly less than the water-fertiliser fusion liquid treated by MMT and HMT after NMT treatment is applied to cotton. After NMT treatment and LMT treatment of water-fertiliser fusion liquid, there is no significant difference in cotton straw, fibre, seed and total biomass. The water-fertiliser fusion liquid treated by MMT and HMT can significantly increase the straw, fibre, seed and total biomass of cotton. Still, the difference between the two is not significant. Compared with NMT treatment, the straw biomass of MMT and HMT treatment increased by 10.32% and 11.28%, respectively. The fibre biomass of MMT and HMT treatments increased by 17.94% and 19.34%, respectively, compared with NMT treatment.
The seed biomass of MMT and HMT treatments increased by 12.95% and 16.06% respectively, compared with NMT treatment. The total biomass of MMT and HMT treatments increased by 12.80% and 14.51% respectively, compared with NMT treatments.

Table 1. The accumulation and distribution of cotton dry matter after the water-fertiliser fusion liquid was dripped and applied to cotton under different magnetic field treatments.

| Treatment | Straw   | Fibre   | Seed    | Total   |
|-----------|---------|---------|---------|---------|
| NMT       | 6.483   | 3.015   | 4.123   | 13.621  |
| LMT       | 6.356   | 3.125   | 4.235   | 13.716  |
| MMT       | 7.152   | 3.556   | 4.657   | 15.365  |
| HMT       | 7.214   | 3.598   | 4.785   | 15.597  |

5.2. Influence on the Absorption and Distribution of Cotton Nitrogen

Table 2 shows that after the water-fertiliser fusion liquid is treated with NMT and applied to cotton, the straw, fibre, seed and total nitrogen absorption of cotton are significantly less than that of the water-fertiliser fusion liquid after LMT, MMT and HMT. Among them, the water-fertiliser fusion liquid is treated by MMT, and the straw, fibre, seed and total nitrogen absorption of cotton are all higher than other treatments. However, when the water-fertiliser fusion liquid was treated with LMT, MMT and HMT, there was no significant difference in cotton straw, fibre, seed and total nitrogen absorption. The nitrogen uptake of LMT, MMT and HMT treatments increased by 5.04%, 5.95% and 5.62% respectively compared with NMT treatment. Compared with NMT treatment, the fibre nitrogen uptake of LMT, MMT and HMT treatments increased by 5.16%, 7.04% and 6.22%, respectively. LMT, MMT and HMT treatments increased seed nitrogen uptake by 5.09%, 6.51% and 5.74% compared with NMT treatments, respectively. The total nitrogen uptake of LMT, MMT and HMT treatments increased by 5.09%, 6.40% and 5.74%, respectively, compared with NMT treatment.

Table 2. Absorption and distribution of cotton nitrogen after the water-fertiliser fusion liquid was applied to cotton under different magnetic field treatments.

| Treatment | Straw   | Fibre   | Seed    | Total   |
|-----------|---------|---------|---------|---------|
| NMT       | 41.83   | 8.52    | 120.32  | 170.67  |
| LMT       | 43.94   | 8.96    | 126.45  | 179.35  |
| MMT       | 44.32   | 9.12    | 128.15  | 181.59  |
| HMT       | 44.18   | 9.05    | 127.23  | 180.46  |

5.3. Influence on the Absorption and Distribution of Cotton Phosphorus

Table 3 shows that after the water-fertiliser fusion liquid is dripped and applied to cotton after NMT treatment, the straw, fibre, seed and total phosphorus absorption of cotton are less than that of the water-fertiliser fusion liquid after LMT, MMT and HMT treatment. However, the water-fertiliser fusion liquid treated with LMT and HMT did not significantly increase the absorption of cotton straw, fibre, seed and total phosphorus; Only MMT treatment can increase the absorption of cotton straw, fibre, seed and total phosphorus more significantly. The phosphorus uptake of straw treated with LMT, MMT and HMT increased by 1.79%, 5.47% and 1.34%, respectively, compared with NMT treatment. The cellulose phosphorus absorption of LMT, MMT and HMT treatments increased by 0.72%, 6.46% and 1.20%, respectively, compared with NMT treatment. The absorption of seed phosphorus in LMT, MMT and HMT treatments increased by 0.67%, 5.24% and 1.06% respectively compared with NMT treatment. The total phosphorus uptake of LMT, MMT and HMT treatments increased by 1.00%, 5.47% and 1.16%, respectively, compared with NMT treatment.
Table 3. Absorption and distribution of cotton phosphorus after the water-fertiliser fusion liquid was applied to cotton under different magnetic field treatments.

| Treatment | Straw | Fibre | Seed  | Total  |
|-----------|-------|-------|-------|--------|
| NMT       | 8.96  | 4.18  | 17.93 | 31.07  |
| LMT       | 9.12  | 4.21  | 18.05 | 31.38  |
| MMT       | 9.45  | 4.45  | 18.87 | 32.77  |
| HMT       | 9.08  | 4.23  | 18.12 | 31.43  |

5.4. Influence on the Absorption and Distribution of Cotton Potassium

Table 4 shows that after the water-fertiliser fusion liquid is dripped and applied to cotton after NMT treatment, the straw, fibre, seed and total potassium absorption of cotton are less than that of the water-fertiliser fusion liquid after the air gap magnetic field magnetisation treatment. However, the difference in cotton stalks, seed and total potassium absorption was not significant, only cotton fibre potassium absorption changed significantly. Compared with the treatment of LMT, MMT and HMT of water-fertiliser fusion liquid, the change of the magnetic induction intensity of the air gap magnetic field failed to have a significant effect on the change of cotton straw, seed and total potassium absorption. The potassium uptake of straw treated with LMT, MMT and HMT increased by 0.88%, 1.51% and 1.24%, respectively, compared with NMT treatment. The cellulose potassium absorption of LMT, MMT and HMT treatments increased by 3.77%, 8.45% and 9.66%, respectively, compared with NMT treatment. The potassium absorption of the seed of LMT, MMT and HMT treatments increased by 0.75%, 1.19% and 1.57% respectively compared with NMT treatment. The total potassium uptake of LMT, MMT and HMT treatments increased by 0.96%, 1.69% and 1.70% respectively compared with NMT treatment.

Table 4. Absorption and distribution of cotton potassium after the water-fertiliser fusion liquid was applied to cotton under different magnetic field treatments.

| Treatment | Straw | Fibre | Seed  | Total  |
|-----------|-------|-------|-------|--------|
| NMT       | 8.96  | 4.18  | 17.93 | 31.07  |
| LMT       | 9.12  | 4.21  | 18.05 | 31.38  |
| MMT       | 9.45  | 4.45  | 18.87 | 32.77  |
| HMT       | 9.08  | 4.23  | 18.12 | 31.43  |

6. Conclusions

After experimental research, different magnetic intensity treatments can have a certain effect on cotton N, P and K elements absorption. Using the whole processed cotton plant as a subject, we can draw the following conclusions:

- In the magnetic intensity of 200mT, 400mT, and 600mT, the treatment of 200mT magnetised water and fertiliser drip irrigation has no significant effect on the dry matter biomass and absorption of cotton plants;
- For cotton treated with magnetised water and fertiliser with the magnetic intensity of 200mT, 400mT, and 600mT, the N content and absorption of cotton plants were higher than the control;
- The cotton treated with magnetised water and fertiliser of various magnetic strengths can increase the P content and absorption of plants, and the treatment of 400mT magnetised water and fertiliser drip irrigation has a significant effect on the P content of plants;
- As the magnetic induction intensity of the magnetisers used for the three treatments increased, the K content of cotton plants showed an increasing trend. The absolute K absorption of cotton plants treated with each magnetic intensity was also higher than that of the control.

Taking cotton stalk, fibre, and seed as separate subjects, we can draw the following conclusions:
Each magnetic intensity treatment can increase the content of N, P and K elements in straw, fibre and seed;

Magnetised water and fertiliser treatment had no regular effect on the K content and absorption of cotton plants;

Each magnetic intensity treatment can increase the dry matter biomass in fibre and seed, and the 400mT and 600mT magnetic intensity treatment can increase the dry matter biomass in straw, fibre and seed;

Analysing the distribution of the absorption of nutrients in cotton stalks, fibre, and seed among the plants, we can see that: Magnetised water and fertiliser treatments with magnetic intensities of 400mT and 600mT had significant effects on the dry matter biomass and absorption of cotton plants. Except for the 200mT magnetic water and fertiliser treatment, the other magnetic water treatments can increase the nutrient content distribution in the leaves. The content and absorption of N and P in the straw, fibre and seed of cotton treated with various magnetic water and fertilisers were higher than that of the control, and the treatment with the magnetic intensity of 400mT performed best.

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