Effects of magnetized fresh water on seed germination and seeding growth of cotton
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ABSTRACT

Magnetized water treatment technology is usually used to improve poor quality water, and there is still a lack of study on fresh water. To understand the biological effects of different strength magnetized fresh water (MFW), seed germination and potted experiments on cotton were carried out to study the effects of MFW with different magnetic intensity (0, 100, 300, 500 mT). Results showed that the surface tension coefficient of MFW reduced by 7.3–10.5%, whilst dissolved oxygen concentrations increased by 8.8–12.7%. Germination strength indexes of cotton cultivated with MFW significantly increased, showing potential and vigor indexes of 16.8–22.4% and 47.4–78.0%, respectively. The emergence rate of cotton irrigated with MFW was faster and higher, with recorded values of 7.7–13.1%. The net photosynthetic rate ($P_n$) and instantaneous water use efficiency ($iWUE$) of cotton increased significantly, whereas the stomatal limit value ($L_s$) decreased. In all, results suggest the total biomasses of MFW irrigated cotton have significantly increased. Therefore, it is suggested that MFW may more effectively promote the utilization of water and light in cotton under magnetic field intensities of 300–500 mT. The results can provide guidance for the efficient utilization of magnetized fresh water in arid and semi-arid areas.

Key words | cotton seedling, fresh water, magnetic field intensity, photosynthesis, seed germination

HIGHLIGHTS

- Magnetized fresh water can improve the activity of water molecules and the amount of dissolved oxygen.
- The biological magnetic effect of magnetized fresh water is closely related to magnetization intensity.
- Magnetization treatment can bring into play the physiological effect of irrigation water and improve water production capacity.

INTRODUCTION

As a new type of green and pollution-free water treatment technology (Esmailinezhad et al. 2017), magnetization is simple, efficient, and low input (Luo et al. 2020). It has been widely used in wastewater treatment (Ji et al. 2010), water purification (Yao et al. 2019), scale reduction (Sohaili et al. 2016), construction (Ghorbani et al. 2019), materials (Pour et al. 2017), textiles (Lipus et al. 2013), and aquaculture (Hassan et al. 2019). The basic principle of magnetized water is that after the liquid water passes through a certain intensity magnetic field at a given flow rate, a series of changes have taken place in the physical and chemical properties of water under the influence of Lorentz force (Chibowski

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doi: 10.2166/ws.2021.051
Magnetic treatment can improve fresh water activity

J. Zhang et al.

MATERIALS AND METHODS

Overview of test area

The experimental area is in the Kunqi River alluvial plain (41°35′N, 86°10′E, and 901 m a.s.l.), the Bazhou irrigation experimental station of Xinjiang, on the edge of Tarim Basin at the southern foot of Tianshan Mountain. Lying in the middle of the Eurasian continent, it belongs to the typical dry continental climate in the warm zone, with scarce rainfall, intense positive and negative rainfall, large temperature difference between day and night, sufficient sunshine in the test area, averaging 3,056.2 h of annual sunshine (Chen et al. 2018). Average temperatures oscillate at 11.5 °C, with minimum and maximum temperatures of −30.9 °C and 42.2 °C, respectively (Yang et al. 2016). Annual precipitation falls between 53.3–62.7 mm, whilst annual evaporation, annual wind and maximum wind speed are recorded among 2,273–2,788 mm (Liang et al. 2019), 2.4 m s−1 and...
22 m s\(^{-1}\) (Li et al. 2019), in that order. The fresh water used for the test came from Kongke River with an average salinity of 0.72 g L\(^{-1}\) and pH of 7.80.

**Magnetizers and magnetized water devices**

Three external sintered Rufe-B CHQ permanent magnet magnetizers (Shanghai Juncai Magnetic Materials Co., LTD., China) were used with magnetic field strengths of 100, 300, and 500 mT. The effective magnetic field area was 8 cm \(\times\) 10 cm and magnetic field intensities was calibrated with a 5180-Gaussian Meter (F.W. BELL Co., USA). The magnetized water device is composed of a water box, peristaltic pump, magnetizer, water pipeline, and valves (Figure 1). Water pipelines are of PVC with a 2.5 cm diameter (cross-sectional area of 4.91 cm\(^2\)), and 10 cm of effective magnetic distance (i.e. effective pipeline length through which the magnetic field was applied). As shown in Figure 1, 100 L of fresh water placed in the water box and pipelines opened, one at a time, through manually controlled valves. A peristaltic pump (0.74–12 L h\(^{-1}\)) was used to circulate the water. A section of the circulating pipeline was placed between the two poles of the magnetizer, and the magnetic induction line was cut perpendicular to the magnetic field. The flow rate was adjusted to 0.5 m s\(^{-1}\) by the peristaltic pump, and the flow was cyclically magnetized by the magnetic field. The magnetization time was 30 min, and the retention time of the magnetized water was 8 days (Coey & Cass 2000).

**Experimental design and process**

The magnetized water device mentioned above was used to magnetize fresh water, whilst unmagnetized fresh water was used as a control. A total of four water clusters were formed, including unmagnetized fresh water (FM0), 100 mT magnetized fresh water (FM1), 300 mT magnetized fresh water (FM3) and 500 mT magnetized fresh water (FM5). A series of experiments including cotton seed germination, potted experiments in a cotton field, and physicochemical properties test were carried out for each cluster. The objective was to analyze the influence and mechanics of MFW under diversified magnetic field intensities on cotton seed germination and seedling growth.

**Experiment 1—seed germination test**

Seed germination tests were performed as described in a previous study with three repetitions (Fu et al. 2010). Fifty cotton seeds of the same size and full grain were selected and arranged evenly in a petri dish with tweezers. The petri dish was then marked and covered with a layer (1.7 mm) of fine filter paper (qualitative filter with 3 \(\mu\)m of mesh size). 20 mL of cluster water was added to the corresponding culture dish and the seeds were covered with a layer (the same as the filter paper layer described previously). After having absorbed enough water (24 h), the excess water was drained, and the seeds were placed in the culture dish in the incubator at 28 \(\pm\) 1 \(\degree\)C, with a light intensity of 800 Lx. The numbers of germinations were recorded every day, and the corresponding cluster water (5 mL) was added every day to maintain the moisture content of the filter paper. The radicle length of cotton seeds was measured on the eighth day. The germination condition was evaluated by calculating germination potential (GP), germination rate (GR), germination index (GI), and vigor index (VI) as follows (Mosse et al. 2013):

\[
GP = \frac{N_g}{N_T} \times 100\%
\]

\[
GR = \frac{N_g}{N_T} \times 100\%
\]

\[
GI = \sum \frac{G_i}{D_i}
\]

\[
VI = GI \times L
\]
where, \( N_d \) and \( N_s \) are the numbers of seeds germinated in 4 and 8 days, respectively; \( N_T \) is the total number of seeds; \( G_t \) is the number of seeds germinated at day \( t \) \((D_t)\); \( L \) is the average radicle length of seed on the eighth day.

### Experimental 2—potted experiments in a cotton field

To simulate a cotton field growth environment, all potted plants were buried, randomly divided, and repeated three times for each cluster. Saline alkali soil from 0–20 cm depth (Table 1) from the surface of the cotton field was used in the experiment. The inner diameter and height of the plastic basin used in the test were 30 and 20 cm respectively, and eight air holes with a diameter of 10 mm were set at the bottom of the basin. Each barrel was uniformly loaded with 20 kg of soil sample and fertilizer with the following composition: carbamide (N 45.4%) 6.8 g, compound fertilizer (N 12%, P 18%, K 15%) 6.4 g, organic fertilizer (organic matter >35%) 24 g. After, the fertilizer and soil were evenly mixed, 7.065 L of cluster water was irrigated to the corresponding plastic basin. Each pot was seeded with 20 cotton seeds, with a sowing depth of 2–3 cm. As in the field, the soil surface was covered with plastic film mulch after sowing.

Fourteen days after sowing, the rate of emergence was measured and only 4 cotton plants were kept in each pot, with the remaining seedlings being removed. The length of cotton seedlings was then measured, the dust on the surface removed, and fresh weight of the seedling measured after washing and drying. For that purpose, seedlings were placed in an oven at 105 °C for 1 h and dried at 75 °C. The dry weight of the seedling was measured after cooling down. Plant height, stem diameter at cotyledon node, number of leaves per plant, and area of single leaf of potted cotton were measured. The stem diameter was measured with an electronic vernier caliper with an accuracy of 0.01 mm. The number of leaves was counted manually. Plant height, leaf width, and vein length were measured with measuring tape with an accuracy of 1 mm. The area of a single leaf was calculated with the formula \( \text{length} \times \text{width} \times 0.84 \) (Tan et al. 2017). The growth indexes of potted cotton seedlings were measured every 10 days. Thirty days after final singling, the net photosynthetic rate \((P_n)\), stomatal conductance \((G_s)\), intercellular CO2 concentration \((C_i)\), and transpiration rate \((T_r)\) of the main functional leaves (from the top to the bottom of the fourth leaf) of cotton seedlings were measured using LC Pro SD full-automatic portable photosynthetic instrument (UK ADC) equipped with an LED artificial light source. Then, the stomatal limit \( L_x = 1 - C_i/C_a \) (\( C_a \) is atmospheric CO2 concentration) and instantaneous water use efficiency \( WUE = P_n/T_r \) were calculated (Liu et al. 2017). When determining the photosynthesis parameters of cotton seedlings, according to the meteorological environment conditions during 10:00–12:00 am in a cotton field, the light intensity was set as 1,100 \( \mu \text{mol m}^{-2} \text{s}^{-1} \), the concentration of CO2 was 36 \( \mu \text{mol mol}^{-1} \), and the temperature was 30 °C. The SPAD value of chlorophyll in cotton seedling leaves was measured using the SPAD-502 Plus Chlorophyll Meter (Konica Minolta, China). Forty days after final singling, the cotton seedlings were removed slowly. The cotton branches were then cut with fruit scissors, the dust was removed from the surface, the cotton branches were washed and dried, and the dry weight of each part was weighed.

### Determination of physicochemical properties of magnetized water

In order to clarify the mechanism, the physicochemical properties of magnetized water, including surface tension, dissolved oxygen content, electrical conductivity (EC), and

| Soil texture | Depth/cm | \( \gamma_0/\text{g cm}^{-3} \) | \( \theta_v/\text{cm}^2 \text{cm}^{-2} \) | FC/(cm2 cm-2) | PWP/\% cm2 cm-2 | ECE / (ds m-1) |
|-------------|----------|-----------------|----------------|--------------|----------------|----------------|
| Sandy loam  | 0–5      | 1.60            | 0.396          | 0.197        | 0.05           | 5.52           |
|             | 5–10     | 1.62            | 0.394          | 0.195        | 0.05           | 5.49           |
|             | 10–15    | 1.63            | 0.396          | 0.196        | 0.04           | 5.45           |
|             | 15–20    | 1.67            | 0.395          | 0.194        | 0.06           | 5.43           |
| average     | 1.63     | 0.395           | 0.196          | 0.05         | 5.47           |

\( \gamma_0 \), \( \theta_v \), \( \text{FC} \), \( \text{PWP} \), and \( \text{K_s} \) represent soil bulk density, saturated volume water content, field capacity, wilting coefficient, and extract conductivity, in that order.

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**Table 1**: Soil physical properties in experimental cotton field
pH were measured. The surface tension was determined by a SCZL202 automatic tension tester (Zibo Shengkang Electric Co., Ltd, China), and the dissolved oxygen content was measured by HQ40 portable dissolved oxygen meter (HACH, USA). EC and pH were determined by DDS-307 electrical conductivity meter and PHSJ-4A pH meter, respectively (Shanghai INESA Scientific Instrument Co., Ltd, China).

Data processing and analysis

Data were recorded in Excel 2016 and analyzed using SPSS 22.0 software (IBM Corp. USA). The least significant difference (LSD) method ($P < 0.05$) was used for comparison of multiple values.

RESULTS AND DISCUSSION

Germination characteristics of cotton seeds

$GP$, $GR$, $GI$, and $VI$ are important indicators to reflect seed germination strength (Kumar et al. 2011). $GP$ and $GR$ directly reflect the initiation of the metabolic process, while $GI$ and $VI$ reflect the seed’s potential for rapid and uniform emergence. Compared with FM0, the $GP$, $GR$, $GI$, and $VI$ of cotton irrigated with MFW were significantly increased ($P < 0.05$), in the ranges of 22.2–26.3%, 16.8–22.4%, 22.2–27.0%, and 47.4–78.0%, respectively (Table 2). The increased range of $GP$ was greater than that of $GR$, while the amplitude of $VI$ was greater than that of $GI$, indicating that fresh water magnetization could significantly improve seed strength and enhance the germination potential of cotton. This is consistent with the results of studies on the application of magnetized water to promote the germination of wheat seeds (Massah et al. 2019). As reported, smaller water cluster structure and higher dissolved oxygen after magnetization of fresh water were found, which provide good water and gas environments for seed germination and are conducive to improved seed germination (Surendran et al. 2016). Comparing cotton seeds cultivated with fresh water against those under different magnetized intensities, the results suggested that $GI$’s cotton seeds cultivated by FM3 improved the most, whereas $GP$, $GR$, and $GI$ of cotton seeds treated with FM1 were slightly larger than FM5. At the same time $VI$ was slightly smaller than FM5, but none of them was significant ($P > 0.05$).

Effect of MFW on the emergence rate of cotton

High seedling emergence rate and seedling uniformity are the guarantees for high and stable yield (Mo et al. 2017). The emergence of cotton seeds started 3 days after sowing (Figure 2). With the increase of emergence time, the emergence rate of cotton gradually increased and tended to stabilize. As shown in Figure 2, the emergence rate of cotton under MFW irrigation was faster and higher when compared to freshwater irrigated seeds. The emergence rate and full seedling formation of cotton irrigated with FM0 was 77.3% and 8 d, respectively, while the emergence

| Treatment | $GP$ (%) | $GR$ (%) | $GI$ (%) | $VI$ (%) |
|-----------|---------|---------|---------|---------|
| FM0       | 53.3 ± 1.2b | 71.3 ± 1.2c | 17.6 ± 0.7b | 26.4 ± 0.8c |
| FM1       | 66.0 ± 2.0a | 86.0 ± 2.0ab | 21.6 ± 0.5a | 38.9 ± 1.3b |
| FM3       | 67.3 ± 3.1a | 87.3 ± 1.2a | 22.4 ± 0.8a | 47.0 ± 2.5a |
| FM5       | 65.3 ± 1.2a | 83.3 ± 2.3b | 21.5 ± 0.5a | 41.6 ± 1.4b |

$GP$, $GR$, $GI$, and $VI$ represent germination potential, germination rate, germination index, and vigor index, in that order. Different letters within a column indicate significant differences among all treatments at $P < 0.05$. 

Figure 2 | The effect of different strengths of magnetized fresh water irrigation on the emergence rate of cotton.
The growth indexes of cotton enlarged with time, and a small difference between growth indexes of cotton irrigated with magnetized and unmagnetized fresh water was observed, 10 d after final singling. The longer the time of growth, growth indexes for both cotton irrigated with magnetized and unmagnetized fresh water gradually increased (Figure 3). In the same growth period, plant height, stem diameter, leaf number, and single leaf area of cotton irrigated with MFW were larger than those of FM0. After 10–40 d of final singling an average growth rate (slope of plant height growth curve) of 0.46 cm d$^{-1}$ was recorded for FM0, with a peak growth rate on plant height between 10–20 d after final singling. At the same time the average growth rates of cotton plant height under FM1, FM3, and FM5 were 0.56, 0.70, and 0.65 cm d$^{-1}$, respectively. All peaks of plant height growth rate occurred between 30–40 d after final singling. 40 d after seedling, plant height of cotton irrigated with FM1, FM3, and FM5 increased by 21.5%, 51.1%, and 33.0%, respectively, compared to FM0 (Figure 3(a). After 10–40 d of final singling, an average growth rate (slope of stem diameter growth curve) of 0.11 mm d$^{-1}$ was recorded for FM0, with a peak growth rate on stem diameter between 20–30 d after final singling. Meanwhile the average growth rates of cotton stem diameter under FM1, FM3 and FM5 were 0.15, 0.17, and 0.14 cm d$^{-1}$, respectively. All the peaks of stem diameter growth rate occurred between 30–40 d after final singling. 40 d after seedling, the number of cotton leaves irrigated with FM1, FM3, and FM5 increased by 27.8%, 47.3%, and 28.0%, respectively, compared to FM0 (Figure 3(b)). In addition, 40 d after final singling, the number of cotton leaves irrigated with FM1, FM3, and FM5 increased by 20.0%, 46.7%, and 26.7% (Figure 3(c)), respectively, while the single leaf area increased by 20.1%, 47.0%, and 35.8% (Figure 3(d)), respectively, compared to FM0. Generally speaking, FM3 had the greatest promoting effect on cotton growth, followed by FM5 and FM1.

### Effect of MFW on cotton morphological development

The growth indexes of cotton enlarged with time, and a small difference between growth indexes of cotton irrigated withFM1, FM3 and FM5 were 80.8%, 88.6%, and 84.4% respectively, with full seedling formations of 8 d, 7 d, and 8 d, in that order. Compared with FM0, the emergence rate of cotton irrigated with MFW increased by 7.7–13.1%, and the full seedling formation of cotton irrigated with FM3 was advanced by 1 d. Similarly, Moussa (2011) applied magnetized water irrigation to improve the emergence rate of snow peas and chickpeas. In general, the most remarkable seeding emergence was by FM3, followed by FM5 and FM1.

The seedling strength was analyzed by seedling length, young root length, seedling fresh weight, seedling dry weight, and seedling water content. The cotton seeds were removed 14 days after sowing and seedling activity indexes were measured and analyzed (Table 3). Compared to FM0, the activity of cotton seedlings under MFW irrigation was significantly increased ($P < 0.05$), and the seedling length, root length, fresh weight, dry weight, and water content increased by 4.0–8.0%, 20.3–35.5%, 40.1–73.1%, 18.7–34.4%, and 2.7–4.3%, respectively. Among them, the seedling root length and seedling fresh weight increased considerably while the water content of the seedling showed moderate intensification, indicating that MFW mainly improves seedling vitality and ensures the seedling health by promoting root growth and boosting fresh weight. The effects of MFW on the activity of cotton seedlings were significantly different ($P < 0.05$). By and large FM5 had a greater promoting effect on root length, fresh weight, and dry weight, while FM3 had the greatest promotion effect on length and water content.

### Table 3 | Characteristics of seedling activity of cotton under magnetized and unmagnetized fresh water

| Treatment | Seedling height (cm) | Seedling root length (cm) | Fresh weight (g) | Dry weight (g) | Seedling water content (%) |
|-----------|---------------------|--------------------------|------------------|---------------|--------------------------|
| FM0       | 7.5 ± 0.1c          | 4.6 ± 0.2c               | 5.89 ± 0.11d     | 0.87 ± 0.02d  | 85.17 ± 0.04d            |
| FM1       | 7.8 ± 0.1b          | 5.5 ± 0.3b               | 8.25 ± 0.15c     | 1.04 ± 0.02c  | 87.43 ± 0.04c            |
| FM3       | 8.1 ± 0.1a          | 5.9 ± 0.2ab              | 9.57 ± 0.28b     | 1.07 ± 0.03b  | 88.81 ± 0.06a            |
| FM5       | 7.9 ± 0.2b          | 6.2 ± 0.4a               | 10.19 ± 0.12a    | 1.17 ± 0.01a  | 88.49 ± 0.09b            |

Different letters within a column indicate significant differences among all treatments at $P < 0.05$. 

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Magnetic treatment can improve fresh water activity

J. Zhang et al.

[1] Magnetic treatment can improve fresh water activity

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Effect of magnetized fresh water irrigation on photosynthetic parameters of cotton

The $P_n$ of cotton irrigated with FM3 and FM5 increased by 33.9% and 32.8%, respectively, nevertheless there was no significant difference between FM1 and FM0 (Figure 4(a)). The $T_r$ of cotton irrigated with FM1 was slightly smaller than FM0, and the $T_r$ of cotton irrigated with FM3 and FM5 was slightly increased, but not significant (Figure 4(b)). The $G_s$ of cotton irrigated with FM3 and FM5 increased by 69.6% and 40.2%, respectively; however, there was no significant difference between FM1 and FM0 (Figure 4(c)). The $C_i$ of cotton irrigated with FM3 and FM5 increased by 51.3% and 37.9%, respectively, yet there was no significant difference between FM1 and FM0 (Figure 4(d)). Compared with FM0, the $iWUE$ of cotton irrigated with FM3 and FM5 increased by 24.4% and 22.3% (Figure 4(e)), while $L_a$ decreased by 21.5% and 25.9% (Figure 4(f)). In general, the most remarkable photosynthetic characteristic parameters were by FM3, followed by FM5 and FM1. The results indicated that MFW could effectively improve stomatal conductance of cotton, reduce stomatal limitation and increase the supply of CO$_2$, thus improving the photosynthetic carbon assimilation capacity and enhancing the utilization efficiency of light energy and water (Qiu et al. 2014). This is consistent with the results of Hasan et al. (2017). As reported, magnetization can improve the activity of related enzymes in plants and increase the metabolism rate of crops (ul Haq et al. 2016). Free water increased in magnetized crop cells, the photochemical activity of chlorophyll increased, the rate of photophosphorylation accelerated, and the net photosynthetic rate increased (Huuskonen et al. 1998).
Effects of magnetized fresh water irrigation on cotton biomass and its distribution

The cotton biomass showed a significant difference between magnetized and unmagnetized fresh water, but not a significant difference among different magnetization intensities (Table 4). Compared with unmagnetized fresh water, leaves, root dry weight and total dry matter of cotton irrigated with MFW increased by 10.7–12.5%, 22.9–33.3%, and 10.3–15.1%, respectively, which conformed to the results of Yusuf & Ogunlela (2015). The stem weight of cotton irrigated with FM5 increased by 18.8% compared with FM0; however, FM1 and FM3 had no significant difference from FM0. In addition, the stem weight ratio of cotton irrigated with FM5 increased by 3.1% compared to FM0, yet FM1 and FM3 decreased slightly. The leaf weight ratio of

Table 4 | Biomass and its distribution of cotton irrigated with magnetized and unmagnetized fresh water

| Treatment | Stem (g) | Leaf (g) | Root (g) | Total dry weight (g) | Stem weight ratio (%) | Leaf weight ratio (%) | Root shoot ratio (%) |
|-----------|----------|----------|----------|----------------------|-----------------------|----------------------|----------------------|
| FM0       | 5.76 ± 0.12b | 11.49 ± 0.20b | 1.57 ± 0.12b | 18.82 ± 0.42b | 30.61 ± 0.21ab | 61.06 ± 0.33a | 9.10 ± 0.57a |
| FM1       | 5.90 ± 0.18b | 12.93 ± 1.12a | 1.94 ± 0.13a | 20.76 ± 1.25a | 28.44 ± 0.91bc | 62.21 ± 1.76a | 10.35 ± 1.10a |
| FM3       | 6.11 ± 0.12b | 12.83 ± 0.15a | 1.93 ± 0.09a | 20.87 ± 0.18a | 29.28 ± 0.33b | 61.47 ± 0.18a | 10.2 ± 0.62a |
| FM5       | 6.84 ± 0.58a | 12.72 ± 0.48a | 2.09 ± 0.12a | 21.66 ± 0.98a | 31.55 ± 1.4a | 58.76 ± 0.54b | 10.73 ± 1.06a |

Different letters within a column indicate significant differences among all treatments at P < 0.05.
cotton irrigated with FM5 reduce by 3.8% compared to FM0. For root shoot ratio, there was no significant difference between magnetized and unmagnetized irrigated cotton. Results indicated that magnetization could promote the overall development of cotton plants by promoting the growth and development of seedling roots.

Changes of physicochemical properties of magnetized fresh water

The surface tension is a macroscopic expression of liquid micro molecular structure, and its change can reflect the change of internal molecular structure (Wang et al. 2013; Amor et al. 2017), which can be described by the surface tension coefficient (STC). The STC of FM0 was 0.069 N m$^{-1}$, while the STCs of MFW were 0.062–0.064 N m$^{-1}$, which reduced by 7.3–10.5% compared to FM0 (Figure 5(a)). The reduced surface tension of MFW was similar to the results of Pang & Deng (2008), which seemed that the internal structure changed (Toledo et al. 2008), the average distance between water molecules increased (Wang et al. 2013), the hydrogen bonds weakened (Cai et al. 2009), the number of free monomer water molecules and dimer water molecules increased (Kney & Parsons 2006), and the chemical bond angle and the radius of water ion gel decreased (Moosavi & Gholizadeh 2014). The dissolved oxygen content (DO) of FM0 was 7.46 mg L$^{-1}$, while the DOs of MFW were 8.12–8.41 mg L$^{-1}$, which increased by 8.8–12.7% compared to FM0 (Figure 5(b)), which also verified the results of Lee et al. (2019). The electrical conductivity (EC) of FM0 was 0.200 ds m$^{-1}$, and the ECs of MFW increased slightly but not significantly (Figure 5(c)). The pH of FM0 was 7.86, while the pH of MFW decreased slightly but not significantly (Figure 5(d)). In all, MFW had a great influence on the STC and DO, and FM3 had the best magnetization effect on STC and DO, followed by FM5 and FM1.

CONCLUSIONS

The surface tension coefficient of magnetized fresh water (MFW) decreased by 7.3–10.5%, the dissolved oxygen content increased by 8.8–12.7%, and the water molecular activity was significantly improved. The emergence rate of cotton irrigated with MFW was 7.7–13.1%, and the seedling vigor indexes were significantly increased ($P < 0.05$). MFW could improve the emergence and seedling vigor of cotton by increasing GP and VI of seeds. The $P_o$ and $iWUE$ of cotton irrigated with MFW were increased by 32.8–33.9% and 22.3–24.4%, respectively, and MFW promoted
morphological development and biomass by improved cotton photosynthesis and water use efficiency. The water molecular activity of MFW with 300–500 mT magnetic field intensity was best, which was beneficial to the growth of cotton seedlings. The results can provide guidance for the efficient utilization of MFW in arid and semi-arid areas. However, this study only focused on the magnetization of fresh water quality and its effect on the growth of early cotton seedlings, while the effects of magnetized water with different water quality on the physiological growth characteristics, yield, and quality of cotton at the later growth stage need to be further studied.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (41830754, 51239009 and 41907010), Basic research plan of Natural Science of Shaanxi Province (2020JQ-616).

DECLARATION OF COMPETING INTEREST

The authors declared that they have no conflicts of interest to this work.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 19 January 2021; accepted in revised form 8 February 2021. Available online 17 February 2021.