Effects of soil moisture on cotton root length density and yield under drip irrigation with plastic mulch in Aksu Oasis farmland

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Effects of soil moisture on cotton root length density and yield under drip irrigation with plastic mulch in Aksu Oasis farmland

ChengYi ZHAO, YingYu YAN, Yilihamu Yimamu, JuYan LI, ZhiMin ZHAO, LaoSheng WU

Abstract: Effects of soil moisture on cotton root length density (total root length per unit soil volume) and yield under drip irrigation with plastic mulch were studied through field experiments. The results indicate that spatial distributions of root length density of cotton under various water treatments were basically similar. Horizontally, both root length densities of cotton in wide and narrow rows were similar, and higher than that between mulches. Vertically, root length density of cotton decreased with increasing soil depth. The distribution of root length density is different under different irrigation treatments. In conditions of over-irrigation, the root length density of cotton between mulches would increase. However, it would decrease in both the wide rows and narrow rows. The mean root length density of cotton increased with increasing irrigation water. Water stress caused the root length density to increase in lower soil layers. There is a significant correlation between root length density and yields of cotton at the flower-boll and wadding stages. The regression between irrigation amount and yield of cotton can be expressed as $y = -0.0026x^2 + 18.015x - 24845$ ($R^2 = 0.959$). It showed that the irrigation volume of 3,464.4 m$^3$/hm$^2$ led to optimal root length density. The yield of cotton was 6,360.8 kg/hm$^2$ under that amount of irrigation.

Keywords: drip irrigation under plastic mulch; soil moisture; cotton; root length density

1 Introduction

Crop root growth is closely associated with soil water (Gardner, 1991; Grant, 1998; Izzi et al., 2008). The changes of soil moisture not only significantly affect the spatial distribution of crop roots and the efficiency of nutrition and water adsorption, but also directly affect the biomass of shoots. When the conditions of water and nutrient are favorable, the roots and shoots of crops would function normally and benefit each other. In contrast, their functions would be weak (Kang et al., 2002; Price et al., 2002; Woodall and Ward, 2002; Benjamin and Nielsen, 2006). Moderate water stress may induce the spread of roots in deeper layers of the soil, so that plants would obtain a larger spatial distribution from which to uptake more nutrients and water (Zhang and Wang, 1997; Yang et al., 2008). Currently, one of the most crucial issues in the application of drip irrigation under plastic mulch is to determine the appropriate parameters for drip irrigation management based on the water demand of the crops (Peter et al., 2003; Patel and Rajput, 2007). The spatial distribution of roots is the basis for determining soil moisture changes at different soil depths. Thus, it is important to understand the mechanism of the growth of roots and their spatial distribution in order to determine the appropriate irrigation method (Coelho and Or, 1999). The objectives of the study described in this paper were to measure the effects of soil moisture on the root length density and shoot growth, and to investigate the relationship between roots and shoots of cotton at differing soil moisture status under drip irrigation with plastic mulch. The quantitative rela-
tions of the root length density and yields of cotton are also discussed in this paper. The study should provide guidance in the application of water control under drip irrigation with plastic mulch in cotton fields.

2 Study area and methods

2.1 Study area

The experiments were conducted at the Aksu Water Balance Station in 2007. The site is located in the warm temperate zone with an arid climate. The average annual temperature is 11.2°C. By comparing with the places at the same latitude, the site is characterized by a hot summer, a cold winter, and that the temperature is variable in spring and autumn. It has a mean annual precipitation of 45.7 mm with a mean annual surface evaporation of 2,500 mm, a frost-free period of 207 d, annual sunshine hours of 2,940 h, and total annual solar radiation of 6,000 MJ/m². The soil in the experiments was a sandy loam with a clay layer at 40–50 cm.

2.2 Experimental design

Based on the randomized block design, four treatments with various capacities of irrigation were set as follows: (I) 2,618 m³/hm², (II) 2,947 m³/hm², (III) 3,600 m³/hm², and (IV) 4,265 m³/hm². Each treatment was repeated three times. The area of each experiment block was 389.2 m². The cotton sample used was Zhongmian 49. The cotton was planted in row spacings of 10 cm, 65 cm, 10 cm and 60 cm and plant spacing within the rows of 10 cm (Fig. 1). The cotton seeds were sowed on April 28 after applying di-ammonium hydrogen phosphate to the soil as a basal fertilizer dressing at the rate of 450 kg/hm² (17.5 kg per block). The method of irrigation of one drip irrigation pipe under each row of mulch was adopted in the experiment’s developmental stage. The frequency of drip irrigation was 7 days. The first irrigation, i.e. the first treatment, was applied on June 24 (bud stage) and there were a total of 10 irrigations through the production of the crop. At irrigations 3 and 6 respectively, urea at a rate of 450 kg/hm² (17.5 kg per block) and potassium di-hydrogen phosphate at 150 kg/hm² (5.8 kg per block) were added with the irrigation water.

2.3 Sampling

Root samples of cotton in wide rows, narrow rows and between mulches were collected from different soil depths at various crop growth stages by a root drilling method. After being rinsed clean, the samples were scanned (using a scanner of USA design) to form a Tif image file on computer. DT-scan software was used to calculate root length (Li et al., 1999). Shoots were collected from both inside and outside rows. The dry weight of different parts was obtained. The yields of cotton were measured and other basic data were recorded after harvest.

![Fig. 1 Sketch map of cotton drip irrigation](image-url)
3 Results and discussion

3.1 Horizontal distribution of root length density of cotton

Figure 2 showed the horizontal distribution of root length density of cotton under various irrigation treatments. The distributions in wide rows and narrow rows were similar. Both of them were larger than that between mulches. It indicated that roots of cotton were mainly distributed under the mulch in the drip irrigation and few roots were between mulches. It reflected the hydrophilic properties of cotton roots. The root length density was the largest with 17.0 mm/cm³ and 16.7 mm/cm³ in the wide rows and narrow rows, respectively in the second irrigation. The largest root length density was 13.6 mm/cm³ in the fourth irrigation. The method of drip irrigation with plastic mulch has several advantages including (1) maintaining optimum soil moisture, (2) reducing water amounts between mulches, (3) inhibiting evaporation among plants, and (4) saving water sources. The horizontal distribution of cotton root length density was different in different irrigation treatments. Compared to other irrigation treatments, over-irrigation increased root length density between mulches and decreases root length density in wide rows and narrow rows. The average root length density of the whole root layer of cotton increased with increasing irrigation.

3.2 Vertical distribution of root length density of cotton

The overall trend of vertical distribution of root length density of cotton was consistent in the different irrigation treatments. The root length density decreased with increasing soil depth, as shown in Fig. 3. However, the distribution of root length density between mulches...
was discrepant. Different from other irrigation treatments, water stress irrigation decreased the root length density to 19.00 mm/cm³ at the soil layer of 10 cm and increased the density to 10.3 mm/cm³ at the soil layer of 50 cm at flower boll stage; over-irrigation treatment increased the root length density to 22.6 mm/cm³ at the soil layer of 10 cm. At the peak bolling stage, the water stress irrigation increased the root length density at both surface and deep layers. At wadding stage, the root length density was the largest at the 10 cm soil layer in the third irrigation. The increase of the root length density at deep soil layers in water stress irrigation had benefited adsorption of water and nutrients and decreased the influence of water stress on the growth of cotton.

3.3 Relationship of root length density at various growth stages and yields of cotton

The statistics of root length density of various soil layers at flower roll stage and yields of cotton illustrated that they had obvious quadratic relationships at soil depths of 0–40 cm. The regression equation is shown in Table 1. According to the relationship of root length density at soil layers of 10 cm and 30 cm and yields, there were different distributions of root length density for yield. The higher the yield was, the less the root length density changed. It indicated that the appropriate range of root length density was small at soil layers of 10 cm and 30 cm under high yield conditions. At the soil layers of 20 cm and 40 cm, yield has corresponding distributions of root length densities too. The higher the yield was, the greater the root length density changed. In other words, both high and low root length densities can increase the yields of cotton. Although a relationship between yields and the root length density at 50 cm soil depth was not built, the density was proportional to the total dry weight as a quadratic relationship. It can be found from the equation that the appropriate range of root length density at 50 cm soil depth was necessary for the high total dry weight. The change of root length density at deep soil layers influenced the accumulation of total dry weight significantly. The appropriate range of root length density for the high yield of cotton needs to be further studied.

At wadding stage, the statistics of root length density and yields indicated that the relationships between yields of cotton and the root length density possessed obvious quadratic relationships at soil layers of 10, 20, 40, 50, and 70 cm, and significant quadratic relationship at soil layers of 30, 50, and 60 cm. The regression equations are listed in Table 2. According to the relationship between the root lengths densities at the soil layers of 50 cm and yields, there were different distributions of root length density for cotton yield. The higher the yield was, the less the root length density changed. It indicated that the change range of root length density at soil layer of 50 cm was small under high yield of cotton. For the soil layers of 10, 20, 40, and 70 cm, yield of cotton corresponded to two types of root length densities. Both high and low root length densities increased the yields of cotton. It is needed to be further studied that either high or low root length density is beneficial to high yields in cotton fields.

3.4 Relationship between drip irrigation demand and yields of cotton

The yields of cotton were obviously different under different irrigation treatments. The influence of water on yields of cotton obeyed the Law of Diminishing Returns; either water stress treatment or over-

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Regression equations</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>( y = -670.97x^2 + 28073x - 286717 ) (x: root length density; y: yields)</td>
<td>0.999**</td>
</tr>
<tr>
<td>10–20</td>
<td>( y = 69.308x^2 - 2735.9x + 30956 ) (x: root length density; y: yields)</td>
<td>0.794*</td>
</tr>
<tr>
<td>20–30</td>
<td>( y = -50.549x^2 + 1896.7x - 11158 ) (x: root length density; y: yields)</td>
<td>0.898*</td>
</tr>
<tr>
<td>30–40</td>
<td>( y = 144.21x^2 - 2626.8x + 15855 ) (x: root length density; y: yields)</td>
<td>0.833*</td>
</tr>
<tr>
<td>40–50</td>
<td>( y = -121.5x^2 + 1317.2x + 3842.1 ) (x: root length density; y: the total dry weight)</td>
<td>0.992**</td>
</tr>
</tbody>
</table>

Notes: * \( P<0.05 \) and ** \( P<0.01 \) are indicated
irrigation treatment would decrease yields of cotton, the number of bolls, and the weight of bolls. The influence of water stress on the yield of cotton was more serious than that of over-irrigation. Based on the statistics, the relationship between drip irrigation and yields of cotton possessed a significant quadratic relationship ($R^2 = 0.9592$), as shown in Fig. 4. The maximum yield calculated by the equation was 6,360.8 kg/hm$^2$ and the corresponding irrigation capacity was 3,464.4 m$^3$/hm$^2$.

Table 2 The relationship between root length density at wadding stage and yields of cotton

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Regression equations</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>$y = 4.0459x^2 + 246.21x + 3891.2$ (x: root length density; y: yields)</td>
<td>0.974**</td>
</tr>
<tr>
<td>10–20</td>
<td>$y = 8E-06x^2 - 0.0907x + 260.11$ (x: yields; y: root length density)</td>
<td>0.997**</td>
</tr>
<tr>
<td>20–30</td>
<td>$y = 1E-06x^2 - 0.0284x + 220.6$ (x: the total weight; y: root length density)</td>
<td>0.905*</td>
</tr>
<tr>
<td>30–40</td>
<td>$y = 561.34x^2 - 8799.3x + 38896$ (x: root length density; y: yields)</td>
<td>0.917**</td>
</tr>
<tr>
<td>40–50</td>
<td>$y = -1951.8x^2 + 18888x - 37641$ (x: root length density; y: yields)</td>
<td>0.999**</td>
</tr>
<tr>
<td>50–60</td>
<td>$y = 14381x^2 - 90688x + 155580$ (x: root length density; y: the total dry weight)</td>
<td>0.844*</td>
</tr>
<tr>
<td>60–70</td>
<td>$y = 28013x^2 - 139684x + 178807$ (x: root length density; y: yields)</td>
<td>0.893*</td>
</tr>
</tbody>
</table>

Notes: * $P < 0.05$ and ** $P < 0.01$ are indicated

The maximum yield calculated by the equation was 6,360.8 kg/hm$^2$ and the corresponding irrigation capacity was 3,464.4 m$^3$/hm$^2$.

3.5 Optimum distribution of root length density of cotton

By calculating the maximum yields of cotton based on the equations in Tables 1 and Table 2, the optimal distribution of root length densities at various soil layers at flower boll and wadding stages was calculated (Fig. 5). The distribution of root length density at flower boll stage has two trends. The trend with higher root length density was more consistent with the experimental results. However, it is still unclear what distribution range of roots is good for the growth of cotton and if the larger distribution range of roots is better for high yields. The research of Li et al. (1992) showed that the relationship between yields and distribution of roots in cotton fields under irrigation was linear. The yields can be improved significantly by a large amount and good distribution of roots. For non-irrigated cotton fields, the relationship between yields and amounts of roots showed a logarithmic relationship and the increase of the amounts of roots was necessary for the improvement of yields. The large distribution range of roots is necessary to obtain high yield in non-irrigated cotton fields. Li et al. (1999) found that the amounts of roots in high yielding cotton fields were much larger than those in low yielding fields. In the cotton fields with low yields, the amounts of roots, as well as the distribution of roots in deep soil, were small, which were the major hindrance factors to obtaining high yields. However, it is unclear yet what is the relationship between the root length density of cotton and yields and the appropriate range of root length density for high yields of cotton. Thus, a further study should focus on how big roots are needed for the better growth of cotton, whether the bigger roots are needed for high yields, and how to determine the suitability of root sizes.

Theoretically, at wadding stage, a root length density larger than 50 mm/cm$^3$ or less than 10 mm/cm$^3$ at 10 cm soil depth is favorable to high yields. However, it is very difficult to have a root length density larger than 50 mm/cm$^3$ at wadding stage. More researches are needed to understand whether the large root length density affects the growth of shoot organs and re-
Some research has indicated that the roots in shallow layers decrease and the roots at deep layers increase just before the wadding stage. This is caused by a natural death of the roots. The roots at shallow layers grew earlier; therefore, the mortality rate was large (Zhang et al., 2005). The root length density at shallow layers is favorable to high yields. A possible reason is that the newly dead and rotting roots improve the soil environment and accelerate the absorption of water and nutrients. The mechanism of yield formation affected by root length density needs further study.

Fig. 5 Vertical distribution of cotton optimal root length density at (a) flowering and bolling stage, and (b) boll opening stage

4 Conclusions

The horizontal distribution of roots in soil was non-uniform and obviously hydrophilic. The root length densities in wide rows and narrow rows were similar under various irrigation treatments, and were larger than those between mulches. The root length density between mulches increased in the over-irrigation treatment, while both root length densities in wide rows and narrow rows decreased. The average root length density of the entire root layers increased with increasing irrigation. Water significantly affected the vertical distribution of root length density of cotton. Water stress increased the root length density at deep layers of roots.

The optimal root length density can be obtained under the irrigation treatment of 3,464.4 m³/hm². The best yield of cotton was 6,360.8 kg/hm². Thus, it is the appropriate irrigation capacity.

At the highest yield of 6360.8 kg/hm², the root length densities at various soil depths were calculated. The results showed that the vertical distribution had two trends at flower boll stage. The trend with larger root length density is more consistent with the measured values. Thus, the further study should focus on how big roots are needed for good growth of cotton, whether the bigger roots are needed for high yields, and how to determine the suitable size of roots. At wadding stage, the root length density larger than 50 mm/cm³ or less than 10 mm/cm³ at the soil depth of 10 cm were both favorable on high yields. However, it is very difficult to have the root length density larger than 50 mm/cm³ at wadding stage. More research is needed to understand if the large root length density affects the growth of shoot organs and restraints the cotton yield. The stated root length densities at shallow soil depths were favorable to high yields. It was unclear if the rotten roots, which were formed at an early growth stage and died at wadding stage, improved the soil environment and accelerated the adsorption of water and nutrients. The mechanism of yield formation affected by root length density should be studied further in future.

Acknowledgements

The study was supported by the National 973 project (2009CB421302), the National Project (2007BAC03A0604) and the key National Natural Science Foundation (40830640). We are grateful to Prof. Tao YANG in Heai University of Nanjing for his hard work on language revision.
References


The first Editorial Board meeting of Journal of Arid Land in 2010 was held in Urumqi

On Sep. 5, 2010, the first Editorial Board meeting of Journal of Arid Land (JAL) was held in Urumqi. The director of Xinjiang Institute of Ecology and Geography (XIEG), Chinese Academy of Sciences (CAS) and the editor-in-chief of JAL, Professor Chen Xi, another editor-in-chief, Professor Li Bailian, University of California, Riverside, the associate editor-in-chief, Professor Michael F. Allen, University of California, Riverside, a member of Editorial Board, Professor Roman Jashenko, Institute of Zoology, Kazakhstan, and the director assistant Yue Lingsheng, Periodical Publishing Center of Science Press, were invited to attend the meeting. Academician Qin Dahe, as a consultant of JAL, had a conversation with Professor Chen Xi and the editor staff of JAL before the meeting. He commended JAL and gave good suggestions to JAL.

Professor Tian Changyan, the deputy director of XIEG presided over the meeting. Firstly, Professor Chen Xi, on behalf of the Institute, expressed his congratulation to the meeting and appreciation to the members of Editorial Board. Chen Xi indicated that the JAL played an important role in the international scientific communication of Central Asia countries. He wished that the journal could be better and better under the support of all members of Editorial Board. Subsequently, Professor Li Bailian briefly introduced the plans of collaboration with the international press organization and the optimization of editorial staff of JAL. Mr. Yue Lingsheng said that Science Press would further propagate JAL and promote the development of JAL. Executive associate editor-in-chief, Professor Qian Yibing, reported the publication progress of JAL, the main problems existed in the development of JAL, the planning of JAL, and the rights and obligations of the member of the Editorial Board, etc. The members of the Editorial Board gave many good suggestions in the aspects of the development, publicization, improving the impact of JAL, and SCI Index of journals.