EFFECTS OF LIQUID FILM MULCHING ON SOIL EVAPORATION AND COTTON PLANT GROWTH BY DRIP IRRIGATION

液体地膜覆盖对滴灌棉花土壤蒸发和作物生长的影响

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Abstract: *The feasibility of using liquid films as substitute to plastic films and the combination of liquid film mulching technique and drip irrigation were investigated to explore a solution to the increasingly serious white pollution induced by agricultural film residues in cotton fields in arid areas. With the adoption of bucket tests, five different mulching treatments (liquid film 1900 kg/hm², LFD1; liquid film 2200 kg/hm², LFD2; liquid film 2500 kg/hm², LFD3; ordinary plastic film, PFD; in bare soil, NFD) were performed on the cotton plants, and the effects of different treatments on soil moisture and temperature, as well as the growth of cotton plants and roots, were monitored and analyzed. The results indicate that liquid film spraying can promote the growth of cotton roots and affect the growth and development of cotton plant. In particular, the squaring stage was 2–5 days earlier with liquid film than that in bare land, and the yields were increased by 7.1%–14.39%. Compared with the results on the use of plastic films, soil evaporation were increased by 1.85%–6.90%; the ground temperature at 5 cm was reduced by 1°C, with a decreasing ratio of 2.5%–7.7%; the decreasing ratios of the ground temperature at 10 cm soil depth were 3.0%–6.4%; the growth stages were 1–2 days later; the yield was only reduced by 0.11%. The amount of liquid film (not less than 2500 kg/hm²) combined with the drip irrigation and plastic mulch film of cotton with drip irrigation is a water-saving and yield-increasing effect compared with the NFD, with liquid film can be degradable; hence, the proposed technique can be used in numerous applications because of these non-pollution characteristics. With the urgent need to protect the agricultural ecological environment and to conserve agricultural water, the use of liquid film can be improved on the basis of sustainable and efficient agricultural development.*

Keywords: *Cotton by drip irrigation; Liquid film mulching; Soil moisture; Soil temperature; Growth and development*

摘要： *为了探寻解决干旱区棉田日益严重的"白色污染"问题的途径，本论文研究了液体地膜代替塑料薄膜与滴灌结合的可行性。试验采用桶栽方法，设置了 5 种处理（液体地膜 1900 kg/hm²，LFD1；液体地膜 2200 kg/hm²，LFD2；液体地膜 2500 kg/hm²，LFD3；普通塑膜，PFD；裸地对照，NFD），监测和分析了不同处理对滴灌棉花土壤水分、温度及作物生长、根系的影响。结果表明，喷施液体地膜可以促进棉花根系的生长，影响棉花植株的生长和发育。特别地，喷施液体地膜后的滴灌棉花蕾期比裸地对照提前 2–5 天，产量比裸地对照增加了 7.1%–14.39%。与塑料地膜相比，土壤蒸发量增加了 1.85%–6.90%；5cm 处的地温降低了 1℃，下降 2.5% -7.7%，10cm 处的地温下降 3.0%–6.4%；生育期晚了 1–2 天；产量也只减少了 0.11%。适量液体地膜（不少于 2500 kg/hm²）与滴灌结合可以与塑料地膜膜下滴灌棉花具有相当的节水、增产效果（与 NFD 相比），液体地膜具有的可降解、无污染特点将使该技术具有较大的应用潜力。随保护农业生态环境和农业节水的迫切需要，从农业持续高效发展的角度出发，液体地膜栽培具有广阔的应用前景。*

关键词: *滴灌棉花; 液体地膜; 土壤水分; 土壤温度; 生长发育*

INTRODUCTION

Mulching for soil moisture conservation is an effective measure for saving water resources, increasing crop yields, and improving crop quality due to its capacity to effectively regulate and control soil moisture in farmlands and to enhance crop water production efficiency. Because of its remarkable function in increasing cotton yield and quality, plastic film mulching cultivation technology has currently been widely applied in Xinjiang, the largest cotton producing area in China. However, plastic films are usually used for many years, and it cannot be recycled timely and effectively, which results in an increasing amount of plastic film residues in most cotton producing farmlands in Xinjiang. Inevitably, these residues have caused serious pollution to soils and the surrounding environments. Improving cotton yield without any pollution is generally recognized as a challenge [6,7,13].

引言

覆盖保墒可对农田土壤水进行有效调控，提高作物水分生产效率，是节约水资源、提高作物产量及改善作物品质的有效措施。由于塑料地膜覆盖栽培技术能大幅度提高棉花的产量与质量， 所以在中国最重要的棉花产区-新疆被广泛采用。但塑料地膜的长年使用及回收措施的不力，造成新疆大部分棉区土壤中的地膜残留量越来越多，土壤中的残膜给土壤及生活环境带来严重的污染，这已是公认的难题[6,7,13]。

Liquid film is a kind of composite black–brown viscous liquid that is degradable, thus making it environmentally friendly. After being mixed with water and sprayed on soil, this liquid film can become a layer of black immobilizing film on soil surfaces, which can contribute significantly in enhancing soil temperature and inhibiting water evaporation [3,18].

The use of potato-dreg-based degradable liquid film can increase soil temperature and moisture content by 0.8–1.6 °C and 6.4%–17.9%, respectively [2].

Compared with the conditions on traditional bare land, the soil that is processed with liquid film mulching technology exhibits substantial improvements, particularly in the topsoil with depth of 0–25 cm, where daily mean temperature and average moisture content were increased by 2.38 °C and 2.50%, respectively, and the yield of potato tubers was increased by approximately 27.17% [4].

The soil temperature during liquid film mulching can be enhanced by 0.5–1.3 °C [5].

Liquid film mulching can increase soil temperature, especially for soil under medium-water and water-deficient treatments, where soil temperature can be increased by approximately 7.4% [8].

Both plastic film mulching and liquid film mulching exhibit favorable moisture-holding and water-promotion effects. Specifically, in topsoil with depth of 0–10 cm, plastic film mulching exhibits relatively remarkable effects, whereas in deep soil layer with depth of 30–40 cm, liquid film mulching is more preferred [12].

By using plastic films, the soil layers with depth of 0–5, 5–10, and 10–15 cm have increased their average soil temperatures by 4.92%, 3.45%, and 0.65% compared with the results using liquid films [15].

When the liquid film used is 225 kg/hm^2, the weed inhibition ratio of the soil is the highest, being up to 65.7%; whereas, when the liquid film used was 300 kg/hm^2, the ratio of yield increase of the soil was the greatest, up to 19.7% [16].

By using liquid films, the seeding emergence ratio of corn plant can be increased by 17%, i.e., the liquid film contributes to corn plant growth and development; the corn yield can also be increased with liquid film by 17.4% greater than without liquid film mulching [19].

Therefore, to date, few studies were made on the effects of liquid film mulching technique on the growth and development of cotton plant by drip irrigation, especially the studies in Xinjiang, where drip irrigation under mulching is widely applied. In this study, we conducted experiments on cotton plant by drip irrigation under liquid films to analyze the effects of liquid film mulching on soil moisture and temperature, as well as, on the growth of crop and underground root system. Thus, the analysis of these effects can provide theoretical and technical guidance for the scientific applications of liquid films. With the urgent need to protect the agricultural and ecological environment and to conserve agricultural water, the sustainable and efficient development of agriculture in China becomes increasingly extensive.

MATERIAL AND METHODS

Brief introduction of the test area

The tests were conducted during the period from April to October, 2014. The test field was located in the test site of Corps Key Laboratory of Modern Water-saving Irrigation (85° 59′ E and 44° 19′ N) with an elevation of 412 m. Its annual average sunshine duration is up to 2865 hours, and the frost-free period lasts for 170 days. The accumulated temperatures above 10 °C and above

液体地膜是一种复合环保型可降解黑褐色粘稠液体，兑水喷施后，可在土壤表层形成一层黑色固化膜，能够显著提高土壤温度、抑制土壤水分蒸发等[3,18]。

马铃薯渣基液体降解地膜可提高地温 0.8–1.6℃，提高土壤含水量 6.4%–17.9%[2]。

与传统裸地相比，液体地膜覆盖处理使土壤的性质得到改善，特别是使耕层土壤（0–25cm）日平均温度和平均含水率分别提高 2.38℃和 2.50%，可使马铃薯块茎产量增加 27.17%[4]。

使用液态地膜，可提高地温 0.5–1.3℃ [5]。

液膜覆盖的土壤增温效果明显，特别是中、低水分处理，增温 7.4%左右[8]。

塑料地膜覆盖和液体地膜覆盖均有较好的保水促水效应。具体来说，塑料地膜覆盖的保水促水效应在 0–10cm 表耕层较为突出，而液体地膜在 30–40cm 土层的保水促水效果则优于塑料地膜[12]。

塑料地膜在 0–5、5–10 和 10–15 cm 土层较液体地膜处理平均温度分别提高 4.92%、3.45%和 0.65%[15]。

液态地膜用量 225kg/hm^2 的处理杂草抑制率最高，为 65.7%；用量 300kg/hm^2 的处理增产率达 19.7%[16]。

液态地膜能使玉米的出苗率提高 17%，促进玉米的生长与发育，提高玉米产量，较对照高出 17.4%[19]。

因此，到目前为止，液体地膜覆盖对滴灌棉花的影响研究相对较少，特别是在膜下滴灌广泛应用的新疆。本研究通过液体地膜覆盖滴灌棉花试验，分析液体地膜覆盖对滴灌棉花土壤水分、温度及作物生长、根系的影响，从而为液体地膜的科学应用提供理论与技术指导。随保护农业生态环境和农业节水的迫切需要，从农业持续高效发展的角度出发，液体地膜栽培在中国具有广阔的应用前景。

材料与方法

研究区概况

试验于 2014 年 4 月-10 月进行，试验地点位于现代节水灌溉兵团重点实验室试验基地（85°59′E、44°19′N、海拔 412 m），年平均日照时数 2865 h，无霜期 170

15 °C were 3463.5 and 2960.0 °C, respectively. The annual average air temperature of the areas is 7.7 ± 0.90 °C. In particular, the annual highest air temperature appears in July, which averages at 25.4 ± 0.74 °C, whereas the annual lowest air temperature appears in January, which averages at −5.5 ± 2.07 °C. The annual precipitation in the area is approximately 213 ± 56.7 mm, and the annual evaporation capacity is approximately 1342 ± 413 mm [17].

d。 >10℃积温为 3463.5℃，>15℃积温为 2960.0℃。年平均气温（7.7±0.90）℃，一年中的最高气温出现在 7 月，平均气温（25.4±0.74）℃；最低气温出现在 1 月，平均气温（−5.5±2.07） ℃。年降水量（213±56.7） mm，年蒸发量（1342±413） mm[17]。

Test materials

In the tests, liquid film (Lv'ye/Greenfield; Yangling Mingrui Chemical Science & Technology Co., Ltd., Shaanxi, China) was used. These liquid films are composed of residual oils, emulators, and water, which account for 50%, 30%, and 10% of the liquid film, respectively. The early-maturing Xinlu No. 48 cotton (Huiyuan 710) was selected. Ordinary plastic films (Tianye Co., Ltd., Xinjiang) were used for comparison. These plastic films were 0.008 ± 0.0003 mm in thickness and were mainly composed of polyethylene. The adopted single-wine labyrinth drip irrigation tapes were also provided by Tianye Co., Ltd., Xinjiang, and the spacing and flow rate of drip holes were 30 cm and 2.6 L/h, respectively.

试验材料

供试液膜为明瑞牌绿野液态地膜，由中国陕西杨凌明瑞化工科技有限公司生产，各组分重量含量为：渣油（50%）、乳化剂（30%）、水（10%）及其它；棉花品种为新陆早 48 号（惠远 710）；普通塑料地膜由新疆天业公司生产，其主要成分为聚乙烯，厚度为（0.008±0.0003）mm；单翼迷宫式滴灌带由中国新疆天业公司生产，滴孔间距 30 cm，滴孔流量 2.6 L/h。

Test design

The tests were performed in plastic buckets (Fig. 1), and bucket cultivation was adopted. Fifteen plastic buckets were used in the test, and the height and inner diameters at the top and bottom of the bucket were 0.52, 0.45, and 0.35 m, respectively.

试验设计

采用桶栽试验见图 1，试验用塑料桶规格为 0.52 m×0.45 m×0.35 m（高×顶部内径×底部内径），共 15 个试验用塑料桶。

Fig.1 - Plastic bucket for testing

The plastic buckets were filled with medium loams with bulk density of 1.37 kg/m^3. In the tests, five different treatment conditions were conducted on cotton plants as follows: LFD1 (1900 kg/hm^2 liquid films), LFD2 (2200 kg/hm^2 liquid films), LFD3 (2500 kg/hm^2 liquid films), PFD (plastic films), and NFD (cotton cultivated without mulching films for comparison). Each treatment was repeated for three times. On April 21, the cotton plants were sown by dry sowing and wet germination. At the distances of 15–20 cm away from the center of buckets, equilateral triangles were drawn, and 3–4 cotton seeds were placed in each vertex. The buckets formed two columns, and two drip-irrigation tapes were used for water supply. A 450 m drip-irrigation tape was placed above the top openings of 7 buckets, while the other tape that was 510 cm long was placed above the top openings of the remaining 8 buckets. For each bucket, 2 drip holes, which are 7.5 cm away from the internal wall of top opening, were made. Pressure regulating valve, pressure gauge, and water meter were installed at the connection of each drip-irrigation tape to regulate and control

桶中装填土壤类型为中壤土，平均容重 1.37 kg/m^3。试验共设 5 个处理水平：液体地膜 1900 kg/hm^2，LFD1；液体地膜 2200 kg/hm^2，LFD2；液体地膜 2500 kg/hm^2，LFD3；普通塑料地膜，PFD；裸地对照，NFD；各处理 3 次重复。4 月 21 日采用“干播湿出”方式播种。在试验桶中心的 15–20cm 范围内画等边三角形，3 个顶点上各放 3–4 个棉籽，把桶排成 2 列，用 2 条滴灌带供水，1 条长 450 cm 的滴灌带贴着试验桶放置于 7 个桶的顶口上；另一条长 510cm 的滴灌带贴着试验桶放置于 8 个桶的顶口上，每个桶内有 2 个滴孔，滴孔距顶口内边壁各 7.5cm。在每条滴灌带的接口处安装有调压阀、压力表和水表，灌水时

pressure and irrigation. On April 22, the liquid films were sprayed, with the amounts of 1900, 2200, and 2500 kg/hm^2. The liquid films were diluted in water in the proportion of 1:2, and then evenly sprayed on the soil surfaces of the buckets by using a sprayer. For plastic films, an ordinary amount of 50 kg/hm^2 was used in the tests. The irrigations and fertilizer applications were identical under different treatment conditions. During the whole growth period, the irrigation frequency was 11, with irrigation quota and irrigation water quota of approximately 378 mm and 35 mm, respectively. The local deep fresh groundwater was adopted as the irrigation water source, with the mineralization degree of 1.3 g/L. The fertilizing amount was 832 kg/hm^2 (it should be noted that urea and potassium phosphate were applied by way of topdressing with irrigation according the ratio of 2:1). The other management measures were similar to those used in ordinary cotton fields. As stated above, drip irrigation was used in the tests. The drip holes of drip-irrigation tape were pressed closely against the soil surface, and then water was gradually permeated into the soils through capillary channels (i.e., the reserved capillary channels formed during the formation of liquid films because the evaporation of water). Therefore, drip irrigation would not cause any damage on liquid films.

Technology Roadmap

利用调压阀调控压力，利用水表控制灌水量。4 月 22 日喷施液体地膜，用量分别为：1900 kg/hm^2；2200 kg/hm^2；2500 kg/hm^2，兑水稀释 2 倍，使用喷雾器械均匀喷施于桶中土壤表面。塑料地膜用量同一般棉田用量一致，即 50 kg/hm^2。各处理灌水施肥一致，全生育期灌水次数共 11 次，灌溉定额 378 mm，灌水定额在 35 mm 左右，灌溉水源为当地深层地下淡水，矿化度 1.3 g/L，施肥量 832 kg/hm^2（尿素和磷酸钾铵按照 2:1 的比例进行滴灌随水追施），其他管理措施同一般棉田。由于采用的是滴灌方式，滴灌带的滴孔紧贴桶中土壤表面，滴孔中滴出的水经过毛细孔道（液体地膜在成膜过程中，由于水分蒸发形成并保留的毛细孔道）逐渐渗入土壤之中，所以不会对液体地膜造成破坏。

技术路线图

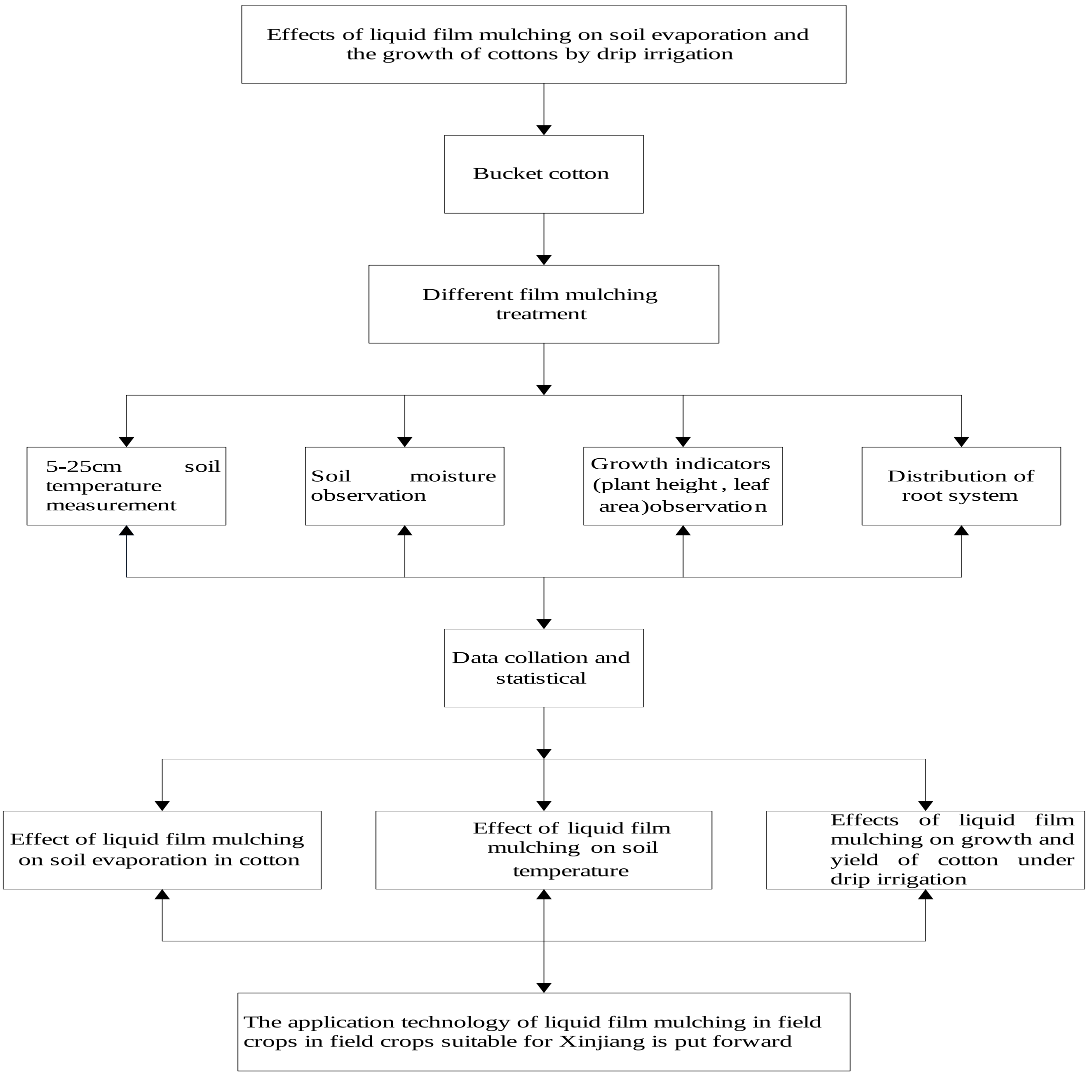


Fig.2 - Technology Roadmap

Measurement and calculation method

Measurements of soil moisture and ground temperature

In measuring soil moisture, the masses of the plastic buckets before and after irrigation were measured by using the electronic scale (XK3150), and then the soil evaporation capacity can be determined.

In measuring ground temperature (Fig. 3), five angle-stem earth thermometers were placed in each plastic bucket, and then the soil temperatures at 5–25 cm depth were measured and averaged daily during 10:00, 16:00, and 20:00.

测定和计算方法

水分和地温观测

灌前和灌后使用 XK3150(W)型电子秤称量各桶的质量，进而测定土壤蒸发量。

使用曲管地温表见图 3，每个桶放置地温计 5 支（5–25 cm），每天 10:00、16:00 与 20:00 时记载测定 5–25 cm 土层温度，求平均值。

Fig.3 - Bent stem earth thermometer

Observation and measurement of cotton roots

At the boll-opening stage, the root systems of cotton plant were used by transverse section method. Each 10 cm long root system was selected as a sampling unit. The soil samples were soaked for 24 h and then sifted by using a 0.5-mm sieve. Subsequently, all the root systems were obtained, and photographs of these were taken. Thereafter, the root length was quantified using computer-assisted image analysis technique. Finally, all these root systems were placed into the oven for 72 h at 65 °C and were weighed by using an electronic balance with precision at 0.1 mg.

The root length density (RLD) and root weight density (RWD) can be calculated by the following formulas:

棉花根系观测

在吐絮期内采用横向切片法取出根系，每 10cm 为一取样单元，将取出的土样浸泡 24 h 后过 0.5 mm 筛，捡出所有根系并拍照，用计算机图像分析技术量化总根长，之后放入烘箱，在 65℃下烘 72 h，采用精度为 0.1mg 的电子天平称其质量。

各项目计算公式：

$$RLD = \frac{TL}{V} \tag{1}$$

$$RWD = \frac{DM}{V} \tag{2}$$

where TL is the overall root length in soils, V is soil volume and, DM is the mass of dry matter of roots in unit soil column.

其中 *TL* 为土体内根系总长度； *V* 为土体体积；*DM* 为单元土柱土体内根系干物质质量。

RESULTS

Effects of liquid film mulching on soil evaporation

Soil evaporation volume can be obtained by weighing the buckets successively for six days in two irrigation periods after liquid film mulching treatment. Fig. 4 displays the variation of soil evaporations using different mulching treatments, which shows that after one-time irrigation, the evaporation volume decreased gradually with prolonged irrigation time. Compared with the condition on bare land, the soil evaporations using liquid film mulching decreased on all treatments, and the average decreasing amplitude and ratio were 0.25–3.21 mm and 4.27%–29.14%, respectively. Specifically, compared with bare land condition, when using LFD1, LFD2, and LFD3 treatments, the soil evaporation volumes were reduced by 0.25–1.82, 0.63–3.21, and

结果与分析

液体地膜覆盖对土壤蒸发量的影响

不同覆盖处理对土壤蒸发量的影响见图 4。由图 4 可以看出，在液体地膜处理后的两个灌水周期内分别选择连续的 6 天对桶进行称重。结果表明，在一次灌水后，随着时间的延长，蒸发量越来越小。液体地膜覆盖土壤蒸发量较裸地平均减少 0.25–3.21 mm，降低 4.27–29.14%。LFD1 土壤蒸发量较裸地减少 0.25–1.82 mm，降低 4.27–16.57%。LFD3 和 LFD2 土壤蒸发量较裸地分别减少

0.57–2.14 mm, respectively, with the decreasing ratios of 4.27%–16.57%, 15.44%–29.14%, and 13.85%–19.43%, respectively. Compared with the condition using plastic film mulching, the evaporation volumes of soils using LFD1, LFD2, and LFD3 increased by 0.31–1.89, 0.13–1.57, and 0.06–0.5 mm, respectively, with the increasing ratios of 9.26–25.86%, 3.70%–21.55%, and 1.85%–6.90%, respectively. The soil evaporation in the other irrigation periods exhibit similar tendency among these different treatment methods. The results indicate that, although liquid film mulching is inferior to plastic film mulching in terms of soil moisturizing effect, liquid film is superior in bare land conditions without any mulching. The evaporation in soils after liquid film mulching is the evaporation controlled by water flux profile at an extremely low level under the limitation imposed by organic thin-films; whereas, water is completely isolated when using plastic films. Apparently, the amount of liquid films also affects soil evaporation. With low application amount, the film properties are poor, whereas with high application amount, the film properties become desirable. However, these films were easily damaged when the cotton seedlings and weeds emerge from the ground. In addition, during the formation of films, the reserved capillary channels due to water evaporation became the channels for rainwater seepage after mulching. Therefore, compared with plastic films, liquid films are more beneficial to rainwater infiltration into soils.

0.63–3.21 mm 和 0.57–2.14 mm，降低 15.44–29.14%和 13.85–19.43%。LFD1、LFD2 和 LFD3 土壤蒸发量较塑料地膜分别增多 0.31–1.89 mm、0.13–1.57 mm 和 0.06–0.5 mm，增加 9.26–25.86%、3.70–21.55%和 1.85–6.90%。另一灌水周期也有类似的规律。分析表明，液体地膜覆盖土壤保湿效应虽低于塑料地膜，但显著高于裸地。与塑料地膜相比，液体地膜覆盖地面后的蒸发，是有机薄膜限定下的极低水平水分通量剖面控制的蒸发，不同于塑料地膜完全隔绝水分。液体地膜施用量不同，对不同处理的土壤蒸发量影响程度亦有明显差异，其原因是施用量小，成膜质量较差，施用量大，成膜质量虽较高，但棉苗、杂草等出土过程中膜面受损较大。此外，液体地膜在成膜过程中，由于水分蒸发形成并保留的毛细孔道，成为覆盖后雨水渗透的通道，所以较塑料地膜更有利于雨水下渗土壤。

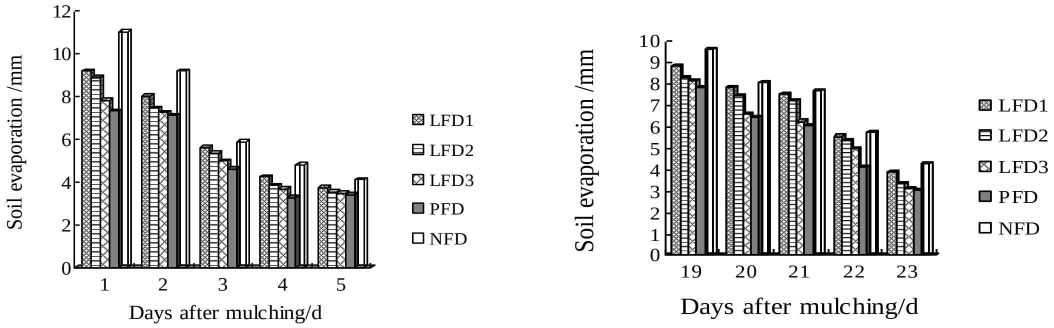


Fig.4 - Soil evaporation using different mulching treatments

Effects of liquid film mulching on ground temperature

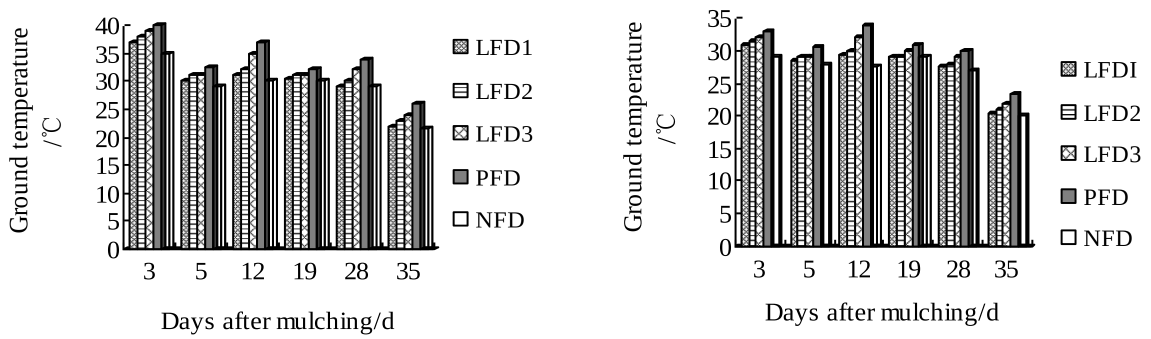
Fig. 5 displays the variation of ground temperatures with time using different mulching treatments. Fig. 6 displays the average ground temperatures at 5–25 cm depth using different mulching treatments. The ground temperatures using different processing methods differ considerably. Generally, ground temperature can be enhanced to varying degrees by applying mulching treatments, and the increasing ratio eventually decreases with soil depth and prolonged irrigation time. The ground temperatures in LFD3 treatment were the highest among all treatments. Specifically, compared with bare land conditions, the ground temperature at 5 cm depth increased by 0.5–5 °C, with the increasing ratio of 2.33%–16.67%. The ground temperature at 10 cm depth increased by 0.5–4.5 °C, with the increasing ratio of 2.50%–16.36%. Compared with the conditions when using plastic film mulching, the ground temperatures at 5 cm depth were reduced by 1–5 °C. In particular, the condition using LED3 treatment in 35 days after spraying liquid film, the ground temperature was only 1 °C below that of plastic films, with the decreasing ratio of 2.5%–7.7%. The ground temperature of soil with liquid film at 10

液体地膜覆盖对地温的影响

不同覆盖处理随时间变化对地温的影响见图 5。不同覆盖处理后 5-25cm 土层的平均地温变化见图 6。由图 5、6 可以看出，各处理不同土层间地温差异显著，各覆盖处理均不同程度提高土壤温度，且幅度随着土层的加深而减弱，随着时间的延长而变小。液体地膜处理中，LFD3 地温最高。具体地说，5cm 地温较裸地升高 0.5–5℃， 增温 2.33%–16.67%。10cm 地温较裸地升高 0.5–4.5℃，增温 2.50%–16.36%。与塑料地膜覆盖相比，在 5cm 处的地温减少 1–5℃。特别地，在 LED3 处理条件下，喷施 35 天后和塑料地膜覆盖相比，5cm 处地温只降低了 1℃，降低 2.5%–7.7%；10cm 处地温降低 3.0%–6.4%。结果表明，

cm depth exhibited the decreasing ratio of 3.0%–6.4% compared with plastic films. These results suggest that liquid films exhibit a moisturizing effect, which is primarily due to the layer of immobilizing films that formed on the soil surface after spraying. The immobilizing films have terminated the water exchange between soils and the surrounding environment. Meanwhile, these black immobilizing films can absorb a great deal of solar energy, which leads to increased soil heat flux. The increase of soil temperature directly affects microbial activities and nutrient variation in soils, thus affecting the growth and development of root systems and nutrient absorption.

液体地膜具有一定的保温效应。其原因是液体地膜喷施后，于土壤表面形成一层黑色固化膜，该膜阻隔了土壤与外界的部分水分交换，黑色固化膜也能吸收较多的吸收太阳能，最终使土壤热通量增大。土壤的增温直接影响土壤微生物的活动及养分的变化，从而影响作物根系生长发育和养分吸收。



At 5 cm soil depth
At 10 cm soil depth

Fig.5 - Ground temperatures using different mulching treatments

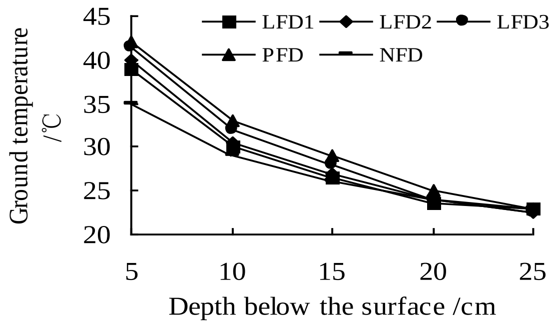


Fig.6 - Ground temperatures at different soil depth using different mulching treatments

Effects of liquid film mulching on the cotton's growth and development

Table 1 illustrates the growth of cotton plants in different mulching treatments, which shows that the growth of cotton plants after mulching was faster than in bare land. For the cotton plants using LFD3 and LFD2 treatments, 10 and 11 days were required from sowing to emergence of seedlings, and the lengths were shortened by 4 and 3 days compared with that in bare land, respectively. The cotton plants in liquid films entered the squaring stage that was 2–5 days earlier than that in bare land, whereas the cotton plants in plastic films entered the initial flowering stage that was 5 days earlier than that in bare land. Apparently, the amount of liquid films affected the growth and development of cotton plants, i.e., with the increasing amount of liquid films, the early growth periods began earlier. However, with the increase of the amount of liquid film, the cotton plants were more likely to be senile at later growth periods. The primary reason is that liquid films can contribute to the preservation of soils moisture and the temperature increase. These effects are more apparent in topsoil, and

液体地膜覆盖对棉花生长发育的影响

不同覆盖处理对棉花生长发育的影响见表 1。由表 1 可以看出，各覆盖处理棉花发育进程都快于裸地对照。LFD3 从播种到出苗需要 10d，比裸地早 4d。LFD2 从播种到出苗需要 11d，比裸地早 3d。现蕾期，喷施液体地膜比裸地对照提早 2–5d。初花期，塑料地膜覆盖仅比裸地对照提早 5d。不同覆盖处理基本在同一时间到达吐絮期。滴灌条件下液体地膜用量大小影响棉花的生育期进程，即随着液体地膜用量的加大，棉花的前期生育期随之提前。但据观察：随着液体地膜用量增大，棉花在生长后期易出现早衰现象。其原因是由于液体地膜具有保墒增温性能，这种效

thus the cotton plants have difficulty rooting, which is related to the information that the water and nutrients in deep soils cannot be fully utilized at the later growth stages of cotton plant.

应在土壤表层影响较明显，从而导致棉株根系不易下扎，于生育后期不能充分利用土壤深层水肥有关。

Table 1

Effects of different mulching treatments on the growth and development of cotton plant

Treatment	Month–day				
	Sow	Seedling	Squaring stage	Initial flowering stage	Boll opening stage
LFD1	4-21	5-3	6-18	7-3	8-19
LFD2	4-21	5-2	6-17	7-1	8-18
LFD3	4-21	5-1	6-15	6-30	8-18
PFD	4-21	4-30	6-13	6-29	8-17
NFD	4-21	5-5	6-20	7-4	8-19

Effects of liquid film mulching on the root length density of drip-irrigation cotton plants

Significantly positive correlations exist among the biomass of leaf area per plant, the biological yield above the ground, and the number of reproductive organs [9–11,14]. Root length density is the overall length of root systems per a unit volume of soils, which reflects the number of capillary roots and directly reflects the extension and intensity of root systems to absorb water and nutrients. Fig. 7 displays the root length densities of the drip-irrigation cottons in different mulching treatments. Compared with the data using the treatment of NFD, the root length densities of the soils at 20–30 cm depth in the LFD1 and LFD2 treatments increased by 405.063 and 851.974 m/m^3, respectively. The root length density of the soils in LFD3 was 915.803 m/m^3 higher than that in NFD, but 63.823 m/m^3 lower than that in PFD. These results indicate that the liquid film application at an appropriate amount can contribute to the root system growth of cotton plant, which lays solid foundations for growth and development, and finally, to achieve high yield. In addition, all of the root length densities in different treatments initially increased and then decreased with increasing soil depth. The root systems beneath the plough layer, although its density is fairly small, play quite important roles in absorbing and utilizing the nutrients and water in subsoil.

液体地膜覆盖对滴灌棉花根长密度的影响

棉花根系生物量与单株叶面积、地上部生物学产量及生殖器官产量之间均存在显著的正相关[9-11,14]。根长密度表示单位土体内根系总长度，反映根系毛细根数量，也间接反映了根系吸收水分、养分的范围和强度。液体地膜覆盖对滴灌棉花根长密度的影响见图 7。由图 7 可以看出，在 20–30cm 土层内，LFD1 和 LFD2 的根长密度较 NFD 分别增加 405.063 m/m^3 和 851.974 m/m^3。LFD3 的根长密度较 NFD 增加 915.803m/m^3，较 PFD 减少 63.823 m/m^3。结果表明，适量的液体地膜覆盖促进了棉花根系的生长，亦为地上部良好的生长发育及获得较高的产量奠定了良好基础。棉花根长密度在不同土层中变化趋势来看，各处理下的根长密度分布都是随土层深度的增加先增大后减小，耕层以下土层中的根系，其量虽然少，但对于吸收和利用下层土壤中的养分、水分起着重要的作用。

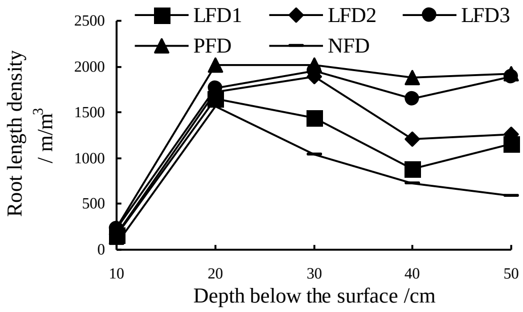


Fig.7 - Root length densities in different mulching treatments

Effects of liquid film mulching on the root weight density of drip-irrigation cotton plants

Root weight density is the gross mass of the dry matters in roots, which directly reflects the mass of root systems and indirectly reflects the extension and intensity of root systems to absorb water and nutrients. Fig. 8 displays the root length densities of drip-irrigation cottons

液体地膜覆盖对滴灌棉花根重密度的影响

根重密度表示单位土体里面根系干物质总质量，反映根系质量，也间接反映根系吸收水分、养分的范围和强度大小。液体地膜覆盖对滴灌棉花根重密度的影响见图 8。由

determined by using different processing methods, which shows a negative exponential function between cotton root weight density and soil depth. At 10–20 cm soil depth, the root densities in the LFD1 and LFD2 treatments increased by 0.1335 × 10^{-4}g/cm^3 and 0.4496×10^{-4}g/cm^3, respectively, compared with that in NFD. The root weight density using LFD3 was 1.3645 × 10^{-4}g/cm^3 being greater than that in NFD, but 0.4429 × 10^{-4}g/cm^3 lower than that in PFD. These results indicate that liquid films, in the appropriate amount, can be comparable with plastic films in terms of root weight density. More importantly, the white pollution caused by plastic film residues can be thoroughly eliminated.

图 8 可以看出，棉花根重密度与土层深度呈负指数关系，以地表层的根重密度最大。在 10–20cm 土层内，LFD1 和 LFD2 较 NFD 分别增加 0.1335×10^{-4}g/cm^3 和 0.4496×10^{-4}g/cm^3。LFD3 的根重密度较 NFD 增加 1.3645×10^{-4}g/cm^3，较 PFD 减少 0.4429×10^{-4}g/cm^3。结果表明，适量的液体地膜覆盖效果已接近塑料地膜，从另一方面来说，也可以彻底消除“白色污染”。

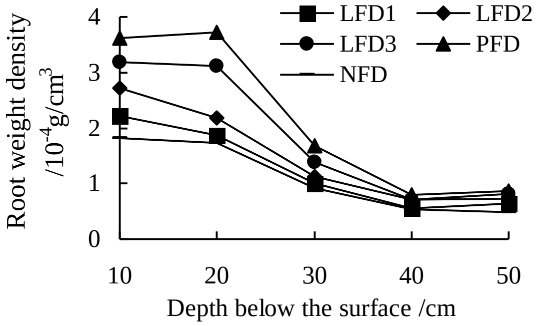


Fig.8 - Root weight densities using different mulching treatments

Effects of liquid film mulching on the yield of drip-irrigation cotton plants

Table 2 presents the yield structures of cotton plants in different mulching treatments, showing that the boll number per plant was increased by 0.31–0.67 compared with that in bare land. After liquid film spraying, the yields were approximately 4980–5317 kg/hm^2, which were increased by 7.1%–14.39% relative to the results in bare land. However, compared with the result using plastic films, the yields were reduced by 28–365 kg/hm^2, with the decreasing ratio of yield of 0.11%–7.4%. Notably, the yields of the cotton plants in LFD3 treatment were considerably close to that in plastic films. Conclusively, the cotton yields by drip irrigation in liquid films, although lower than that in plastic films, were apparently higher than the yield on bare land. From the perspective of ecological sustainability, liquid film spraying is of great application value. Practices proved that premature seedling is the key for a high cotton yield, which also requires a favorable soil environment. Therefore, liquid films can contribute to the enhancement of boll numbers and the improvement of boll quality.

液体地膜覆盖对滴灌棉花产量的影响

不同覆盖处理对棉花产量结构的影响见表 2。由表 2 可以看出，喷施液体地膜比裸地对照单株铃数增加 0.31–0.67 个。液体地膜覆盖产量为 4980–5317kg/hm^2，比裸地增产 7.1%–14.39%。液体地膜覆盖相对塑料地膜减产 28–365kg/hm^2，减产率 0.11%–7.4%，但 LFD3 产量已接近塑料地膜。由此说明，滴灌条件下液体地膜覆盖棉花产量虽次于塑料地膜，然而适量液体地膜覆盖棉花产量明显高于裸地，从生态可持续角度也具有可应用价值。实践证明，壮苗早发是棉花获取高产的关键，而棉花早发需要一个较好的土壤环境，液体地膜覆盖有利于促进棉花增结铃数、提高铃质量。

Table 2

Yield structures of cotton plants in different mulching treatments

Treatment	Boll number per plant	Single boll weight (g)	Seed cotton yield (kg/hm^2)	Growth ratio compared with the condition without mulching (%)
LFD1	4.87	5.09	4980	7.10
LFD2	5.21	5.25	5196	11.79
LFD3	5.23	5.28	5317	14.39
NFD	4.56	4.77	4648	—
PFD	5.24	5.31	5345	14.50

Discussion

Currently, many similar research results on the role of liquid film in preservation of soil moisture and enhancement of soil temperature were presented. However, the research regarding the combination of liquid film mulching cultivation technique and drip irrigation and their effects on soil moisture and temperature, as well as cotton growth and root systems, is still quite rare. In the present work, not only the effects of liquid film mulching on cotton growth and development, as well as the root systems, were analyzed, but also the effects on soil moisture and temperature. The results indicate that, after liquid film spraying on drip-irrigation cotton plants, the soil temperature can be remarkably enhanced, and simultaneously the soil evaporation capacity can be significantly reduced, i.e., the absorption and synthesis capacity of the root systems can be improved. The elevated root activity can also provide solid foundations for promoting the growth and development of over ground cotton plants and achieving high yields, which are characterized by premature growth of cotton plants, greater mass of cotton bolls, and significant increase in yield. Moreover, different amounts of liquid film also exhibited different degrees of mulching effects. A favorable soil ecological environment is an important prerequisite for high yield of cottons, since it firstly affect the growth and development of underground roots and then the growth of over ground cotton plants, and finally leads to a high cotton yield. Although the liquid film is inferior to plastic film in the aspects of soil moisture preservation and yield growth, it can be beneficial to the seepage of rainwater into soils, deeper rooting, the increase of the ratio of root weight beneath the soils, and the maintenance of strong absorption and synthesis capacity of the cotton root at the later growth stages. In addition, by using liquid films, the premature senility of cotton plants can be effectively prevented. After liquid film spraying, the boll numbers per cotton plant increased by 0.31–0.67 compared with the values on bare land; the average cotton seed yields were enhanced by 7.1%–14.39% compared with the values on bare land, but were reduced by 0.11%–7.4% compared with the values using plastic films. These results are slightly inconsistent with the previous research results. In further studies, we should expand the test range of liquid film mulching. In particular, we should conduct tests in farmland and probe into the effects of intensity and frequency of liquid film spraying on drip-irrigation cotton plants. Moreover, a related technical specification of liquid film mulching should be established and improved.

Liquid film, a novel cover material for cultivation in farmlands, is highly efficient, nontoxic, innocuous, and can be changed into organic fertilizers through biodegradation and light degradation [1]. Liquid films are not only applied in the cultivation of grains and cotton in fields, but also are applicable for the growth and development of fruits and vegetables in orchards. However, liquid film mulching technique should be further improved in terms of degradation characteristics and rain-wash resistance performances. As a consequence, these liquid films can be completely degraded within the mulching period, and moreover, they cannot be degraded very prematurely to lose their mulching effect. As the plastic films are commonly used for many years, the film residues causes severe contamination in cotton fields. Liquid films, owing to their low costs, strong adaptability to geographic and geomorphic conditions, favourable emergency, and ecological effects, can remarkably enhance the economic and ecologic benefits of cotton fields.

讨论

液体地膜覆盖的保墒增温特点与已有众多研究结果类似，但液体地膜覆盖与滴灌结合，从而改变或影响滴灌棉花土壤水分、温度及作物生长、根系，已有研究成果相对较少。本论文不仅分析了液体地膜覆盖对滴灌棉花生长发育和根系的影响，同时也分析了液体地膜覆盖对土壤水分、温度的影响。结果表明，液体地膜覆盖滴灌棉花可提高土壤温度并显著降低土壤蒸发量，从而促进棉株根系吸收与合成能力，而根系活力的增强，亦为地上部棉株生长发育及获得较高的产量奠定了良好基础。表现为棉株早发，铃质量大，增产效果显著。液体地膜不同用量覆盖效应存在一定差异。其原因是良好的土壤生态环境是棉花获得高产的重要基础，它首先影响到棉株地下部根系的发育，进而影响到地上部棉株的生长，最终才能实现棉花高产。这些效应表现虽然是液体地膜覆盖低于塑料地膜，但液体地膜更有利于雨水下渗土壤、棉花根系下扎，提高土壤下层根量比例，维持中后期棉株根系较强的吸收与合成能力，从而有效防止棉花早衰。喷施液体地膜比裸地对照单株铃数增加 0.31–0.67 个。液体地膜覆盖平均籽棉产量较裸地增长 7.1%–14.39%，较塑料地膜降低 0.11%–7.4%，这一点与前人研究结果不太一致。在以后的科研工作中，逐步扩大液体地膜的试验范围，尤其是大田试验，深入研究液体地膜喷施强度、喷施频率等对滴灌棉花的影响，形成并完善液体地膜配套应用技术规程。

液体地膜是一种新型的农田栽培覆盖材料， 高效、无毒无害，可以由生物和光降解转化为有机肥[1]，不仅适用于大田粮、棉等作物，也适用于果园、蔬菜及其它作物生长需要，但对其性能、防雨水冲刷等方面需要在工艺上进一步完善，使其在有效覆盖期内，既能被完全降解，又不致于过早降解而失去应有的覆盖效应。随塑料地膜的长年应用，残膜严重污染棉田。而液体地膜成本低廉、对地形地貌适应能力强，应急性好，也具有良好的生态效应，可显著提高棉田的经济效益和生态效益。

CONCLUSIONS

(1) By spraying liquid films on drip-irrigation cotton plants, the soil evaporation capacity can be reduced by 4.27%–29.14%, and the soil temperatures at 5 cm depth can be enhanced by 2.33%–16.67% compared with the values on bare land. Liquid film spraying can promote the growth of cotton roots and affect the growth and development of cotton plant. In particular, the squaring stage of cotton plants in liquid films was 2–5 days earlier than that in bare land and the yields were increased by 7.1%–14.39%. The mulching effect using an appropriate amount of liquid films was comparable with the results using plastic films, that is, soil evaporation was increased by 1.85%–6.90%. The ground temperatures at 5 cm depth were 1°C lower than the values using plastic films, with the decreasing amplitude of 2.5%–7.7%. The decreasing amplitudes of the ground temperature at 10 cm depth were 3.0%–6.4%. The growth stages were 1–2 days later, and finally, the yield was only reduced by 0.11%.

(2) For the cotton cultivation by drip irrigation in arid areas, the spraying of an appropriate amount of liquid films can achieve a favorable mulching effect that is comparable with plastic films. Moreover, the liquid films can thoroughly eliminate increasing white pollution caused by film residues in farmlands, and thus contribute to the sustainable development of ecological environment in farmlands. Liquid film mulching is a feasible technique in cotton production by drip irrigation. With the urgent need to protect the agricultural ecological environment and agricultural water conservation, the sustainable and efficient development of agriculture in China is more extensive.

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结论

（1）液体地膜喷施在滴灌棉花上，可以使土壤蒸发量减少 4.27%–29.14%，在 5cm 处的地温较裸地对照提高 2.33%–16.67%，喷施液体地膜可以促进棉花根系的生长，影响棉花植株的生长和发育。特别地，喷施液体地膜后的滴灌棉花蕾期比裸地对照提前 2–5 天，产量比裸地对照增加了 7.1%–14.39%。与塑料地膜相比，土壤蒸发量增加了 1.85%–6.90%；5cm 处的地温降低了 1℃，下降 2.5% -7.7%，10cm 处的地温下降 3.0%–6.4%；生育期晚了 1–2 天；产量也只减少了 0.11%。

（2）在干旱区滴灌棉田，喷施适量的液体地膜，可以达到和塑料地膜相当的覆盖效果。另外，使用液体地膜可以彻底消除残留在农田的“白色污染”，从而可使农田生态环境得到可持续发展。在滴灌棉花生产中采用液体地膜覆盖是一项可行技术。随保护农业生态环境和农业节水的迫切需要，从农业持续高效发展的角度出发，在中国更具有广泛的发展潜力。

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