Postprint: Yield-Increasing Effects of Different Plastic Film Mulching Planting Patterns on Spring Maize in Dryland

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Abstract

Plastic film mulching is an important cultivation method for dryland spring maize, exhibiting significant yield-increasing effects. However, previous studies on the yield-increasing mechanisms of dryland spring maize under different plastic film mulching methods, including water utilization, root development, and lodging resistance, have been limited. Field experiments were conducted at the Qianying Experimental Station of Cangzhou Academy of Agriculture and Forestry Sciences in Hebei Province from 2013 to 2015, investigating spring maize yield and yield components, soil moisture, crop root systems, and lodging resistance under five planting patterns for three consecutive years: flat planting without mulching (CK), flat mulching with sub-film sowing (FC-SUF), flat mulching with side-film sowing (FC-FSS), ridged mulching with sub-film sowing (RC-SUF), and ridged mulching with side-film sowing (RC-FSS). The results indicated that RC-FSS, RC-SUF, FC-FSS, and FC-SUF increased yield by 24.97%, 17.75%, 11.69%, and 8.67% on average compared with CK over the three-year period, respectively, with the ridged mulching side-film sowing technique (RC-FSS) demonstrating the optimal yield-increasing effect; its water use efficiency improved by 26.27% on average compared with CK. The 0–20 cm soil water content in furrows under RC-FSS treatment increased by 30.44%–47.66% compared with CK, reaching an extremely significant difference. RC-FSS treatment exhibited the best lodging resistance, with a lodging rate of only 0.9% and a maximum lodging resistance force of 29.4 N, showing a significant difference from CK. Throughout the entire maize growth period, the 0–10 cm soil temperature under various mulching treatments increased by 0.3–2.3 °C on average compared with CK, with the most significant temperature increase observed under the RC-SUF planting pattern. At the maturity stage, root distribution diameter and root dry weight under the RC-FSS pattern were significantly superior to those under RC-SUF, FC-SUF, and CK, with all differences reaching significant levels. The study demonstrates that the spring maize ridged mulching side-film sowing technique possesses the functions of rainwater harvesting and moisture conservation, promoting root growth and robust seedlings, high lodging resistance, and yield increase and stability, offering broad application prospects in coastal plain areas with spring drought and limited rainfall.

Full Text

Yield-Increasing Effect of Film-Mulching and Planting Patterns on Spring Maize in Dryland

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Abstract

Film mulching is an important cultivation method for spring maize in dryland areas, demonstrating significant yield-increasing effects. However, previous research has paid limited attention to the yield-enhancing mechanisms of spring maize under different film-mulching methods, particularly regarding water utilization, root development, and lodging resistance. Field experiments were conducted from 2013 to 2015 at the Qianying Experimental Station of Cangzhou Academy of Agriculture and Forestry Sciences in Hebei Province to investigate five planting patterns: flat planting without film mulching (CK), flat planting with film mulching and sowing under film (FC-SUF), flat planting with film mulching and film-skirting sowing (FC-FSS), ridge planting with film mulching and sowing under film (RC-SUF), and ridge planting with film mulching and film-skirting sowing (RC-FSS). The study examined spring maize yield and its components, soil moisture, crop root systems, and lodging resistance over three consecutive years. The results showed that RC-FSS, RC-SUF, FC-FSS, and FC-SUF increased yields by 24.97%, 17.75%, 11.69%, and 8.67% compared to CK, respectively, with ridge-film mulching and film-skirting sowing (RC-FSS) demonstrating the optimal yield-increasing effect. Water use efficiency under RC-FSS improved by an average of 26.27% over CK. Soil moisture content in the 0–20 cm layer at the furrow position under RC-FSS increased by 30.44%–47.66% compared to CK, reaching highly significant differences. RC-FSS also exhibited the best lodging resistance, with a lodging rate of only 0.9% and maximum lodging resistance force of 29.4 N, significantly different from CK. Throughout the maize growth period, soil temperature in the 0–10 cm layer under film-mulching treatments increased by 0.3–2.3 °C on average compared to CK, with the RC-SUF pattern showing the most significant warming effect. At maturity, root distribution diameter and root dry weight under RC-FSS were significantly superior to RC-SUF, FC-SUF, and CK. The study demonstrates that ridge-film mulching with film-skirting sowing technology for spring maize effectively inte-

grates rainwater harvesting, soil moisture conservation, root promotion, seedling strengthening, high lodging resistance, and stable yield increase, offering broad application prospects in the coastal plain region with spring drought and limited rainfall.

Keywords: Spring maize; Dryland; Film mulching; Film-skirting sowing; Water use efficiency; Root traits; Yield-increasing effect

1. Materials and Methods

1.1 Study Area Description

The experiment was conducted from 2013 to 2015 at the Qianying Experimental Station of Cangzhou Academy of Agriculture and Forestry Sciences, located in the low plain region of the Bohai Rim (116°44 3 E, 38°14 23 N). The area features a warm temperate semi-humid continental monsoon climate and represents a typical double-cropping dryland agricultural zone. Annual precipitation ranges from 400–600 mm, with 80% concentrated in July–September. Rainfall during the spring maize growth period was 480.7 mm in 2013, 254.9 mm in 2014, and 404.2 mm in 2015. The soil is loam with an average annual temperature of 13 °C and $ 10°Caccumulatedtemperatureof4,349°C.The0–20cmsoillayercontains15.4g· kg^{-1}$ organic matter, 103.0 mg · kg^{-1} available potassium, 17.9 mg · kg^{-1} available phosphorus, and 22.3 mg · kg^{-1} alkaline-hydrolyzable nitrogen.

1.2 Experimental Design

A split-plot design was employed with tillage method as the main plot and sowing position as the subplot. The main plots included flat culture with film mulching (FC) and ridge culture with film mulching (RC). Ridge specifications were 70 cm width, 15–20 cm height, and 40 cm spacing between ridges. The subplots comprised sowing under film (SUF) and film-skirting sowing (FSS). Flat planting without film mulching served as the control (CK). All treatments used wide-narrow row planting with 70 cm wide rows, 40 cm narrow rows, 24 cm plant spacing, and a density of 75,000 plants · ha^{-1}. Each plot measured 8 m × 5 m (40 m^2) with three replications. The spring maize variety 'Zhengdan 958' was sown on May 1, 2013 (harvested August 25–30), April 25, 2014 (harvested August 26–31), and April 30, 2015 (harvested August 29–September 3). Before sowing, slow-release fertilizer (24-16-10 NPK, Tianjin Tianzheng Tian Agricultural Technology Co., Ltd.) was applied at 600 kg · ha^{-1}. A ridge-film mulching seeder developed by Cangzhou Academy was used for mulched treatments, while a conventional seeder (Nonghaha 2BY-4) was used for CK. Sowing depth was 3–3.5 cm. During the heart leaf stage, 3.75 kg · ha^{-1} of 3% phoxim granules mixed with 75 kg of fine sand was applied to the leaf whorl. Other management practices followed local conventional methods.

1.3 Measurement Items and Methods

1.3.1 Yield and Yield Components At maturity from 2013–2015, grain yield was measured from four undamaged rows (3 m length) in each plot and converted to 14% moisture content. Yield components (ear number per hectare, grains per ear, and 100-grain weight) were determined from 15 consecutive plants per plot.

1.3.2 Rainwater Harvesting Effect In September 2016, a simulated rainfall experiment was conducted with two planting patterns: (1) ridge-film mulching (70 cm ridge base, 15–20 cm ridge height, 40 cm ridge spacing, 80 cm film width) and (2) bare land control. Five simulated rainfall levels were applied: 0, 5, 10, 15, and 20 mm, creating 10 treatments with one plot each (5.5 m wide × 2 m long). Starting at the five-leaf stage, soil samples were collected at 24-hour intervals to measure soil moisture content in 0–20 cm and 20–40 cm layers using the oven-drying method.

1.3.3 Root Traits At maturity, four representative plants (96 cm length) were selected per plot. After removing aboveground parts, a 96 cm × 30 cm × 60 cm soil block was excavated to measure root distribution depth and width, count lateral roots (excluding fibrous roots), and determine root dry weight after oven-drying.

1.3.4 Soil Temperature From 2013–2015, soil temperature in the 0–10 cm layer was measured every six days from seedling to maturity stage using a WET-HH2 soil moisture, salinity, and temperature meter at five points per treatment.

1.3.5 Lodging Resistance At maturity each year, five representative plants per plot were selected. A plant lodging meter (DIK-7401, Japan) was used to measure the force required to push the plant to a 45° angle at 80 cm height, representing lodging resistance force.

1.3.6 Water Use Efficiency (WUE) Water consumption (ET) was calculated using the water balance method:

$$ET = P \pm \Delta W$$

where P is effective precipitation and ΔW is the change in soil water storage. In this dryland experiment, irrigation, surface runoff, groundwater contribution, and deep percolation were considered negligible. WUE was calculated as:

$$WUE = \frac{GY}{ET}$$

where WUE is water use efficiency ($kg \cdot ha^{-1} \cdot mm^{-1}$), GY is grain yield ($kg \cdot ha^{-1}$), and ET is water consumption (mm). Soil moisture content in the 0–100 cm profile was measured by the oven-drying method before planting and after harvest.

1.4 Data Processing and Analysis Data were organized using Microsoft Excel 2007 and analyzed statistically using SPSS 16.0 software.

2. Results

2.1 Effects of Different Planting Patterns on Spring Maize Growth Stages

As shown in , film mulching advanced emergence by 2–4 days compared to CK. Under the same planting pattern, film-skirting sowing extended the emergence period by 2 days compared to sowing under film. Compared with CK, FC-FSS had no effect on vegetative growth duration, while RC-FSS shortened it by 2 days, and both FC-SUF and RC-SUF shortened it by 3 days. Under flat culture (FC), SUF shortened vegetative growth by 3 days compared to FSS, whereas under ridge culture (RC), SUF shortened it by only 1 day. Film mulching extended reproductive growth by 2–9 days compared to CK, with consistent trends across years. FC-SUF showed the shortest extension (2–7 days), while RC-FSS showed the longest (7–9 days). Under FC, SUF extended reproductive growth by 0–3 days compared to FSS, while under RC, SUF shortened it by 0–2 days.

2.2 Effects of Different Planting Patterns on Spring Maize Yield

shows that FC-SUF, FC-FSS, RC-SUF, and RC-FSS significantly increased yield by 8.67%, 11.69%, 17.75%, and 24.97% compared to CK, respectively. Both FC and RC patterns significantly increased yield by 10.2% and 21.4% over CK, with RC outperforming FC by 11.2% across years. Additionally, FSS increased yield by 5.12% over SUF. Ridge-film mulching with film-skirting sowing (RC-FSS) demonstrated the highest yield and optimal technical performance. Analysis of yield components revealed that the four planting patterns had no significant effect on ear number per hectare or 100-grain weight; yield differences were primarily manifested in grains per ear. Across three years, RC and FC patterns increased grains per ear by 17.5% and 10.3% compared to CK, respectively, with RC exceeding FC by 6.56%.

2.3 Effects of Different Planting Patterns on Water Use Efficiency

As shown in , RC treatments improved water use efficiency by 16.45%–34.30% compared to other planting patterns. Over three years, RC-FSS increased WUE by 34.30%, 21.47%, and 23.04% compared to CK, consistently outperforming other treatments. In higher rainfall years (480.7 mm in 2013 and 404.2 mm in 2015), WUE ranged from 20.17–25.53 $kg \cdot ha^{-1} \cdot mm^{-1}$, with RC increasing WUE by 7.24%, 11.83%, and 11.84% over FC. In the lower rainfall year (254.9 mm in 2014), WUE ranged from 35.18–40.56 $kg \cdot ha^{-1} \cdot mm^{-1}$. All RC treatments showed significant differences from CK, indicating that ridge-film mulching substantially improves water use efficiency in rain-fed dryland areas.

2.4 Rainwater Harvesting Effect of Ridge-Film Mulching with Film-Skirting Sowing

demonstrates that RC-FSS provides significant rainwater harvesting benefits compared to FC. Under simulated rainfall of 5, 10, 15, and 20 mm, soil moisture content in the 0–20 cm layer at the furrow position under RC-FSS increased by 4.04%, 5.69%, 6.36%, and 7.22% over CK, representing increases of 30.44%, 41.81%, 43.68%, and 47.66%, respectively (highly significant differences). In the 20–40 cm layer, soil moisture increased by 2.31%, 3.40%, 4.63%, and 5.85% over CK, representing increases of 16.39%, 23.50%, 31.24%, and 38.01%, respectively (highly significant differences). The 0–20 cm cultivated layer under RC-FSS showed more pronounced moisture increases.

2.5 Soil Warming Effects of Different Planting Patterns

indicates that film-mulching treatments increased soil temperature by 0.3–2.3 °C compared to CK. Under both FC and RC patterns, SUF increased soil temperature by 1.13 °C and 1.28 °C over FSS, respectively ($P<0.05$), with RC-SUF showing the most significant warming effect. The warming effect of film mulching gradually decreased with advancing growth stages, with the most pronounced decline observed under sowing-under-film treatments.

2.6 Effects of Different Planting Patterns on Maize Root Traits

Measurements at maturity showed that RC-FSS significantly improved root distribution diameter, root dry weight, and lateral root number compared to CK, though differences in root length were not significant. Therefore, ridge-film mulching with film-skirting sowing promotes root development, particularly increasing root diameter and dry matter weight, which represents an important mechanism for yield increase ().

2.7 Effects of Different Planting Patterns on Maize Lodging Resistance

As shown in , film-skirting sowing demonstrated clear advantages in lodging resistance compared to sowing under film, while CK showed the poorest lodging resistance. RC-FSS exhibited the best lodging resistance with a lodging rate of only 0.9% and maximum lodging resistance force of 29.4 N, significantly different from RC-SUF, FC-SUF, and CK, but not significantly different from FC-FSS.

3. Discussion

In the rain-fed dryland region of the Bohai Rim low plain, low spring temperatures and limited rainfall often result in uneven, weak, and slow seedling emergence in traditional spring maize cultivation due to constraints of air temperature, soil temperature, and moisture conditions. Drought and limited rainfall in May–June frequently cause "neck drought" during the critical trumpet stage when water and nutrient demands are highest, leading to yield reduction and severely restricting spring maize production. Previous research has demonstrated that plastic film mulching technology can increase soil temperature, reduce evaporation, improve soil hydrothermal conditions, enhance soil biological activity, suppress salt accumulation and weed growth, and promote crop growth and early maturity, with yield increases of 30%–60% for maize. This study confirms that film-mulching sowing improves soil temperature and moisture, enhances hydrothermal conditions, promotes plant height, leaf area, and dry matter accumulation, and increases grain yield through higher grain number and weight, consistent with previous findings.

This research clarifies the technical effects of different film-mulching sowing patterns in the Bohai Rim low plain rain-fed dryland region and identifies ridge-film mulching with film-skirting sowing as the optimal pattern, effectively addressing the "neck drought" problem during the critical growth stage. The rainwater harvesting effect of this pattern converts small, frequent, ineffective spring rainfall into effective moisture for maize growth, significantly improving soil moisture conditions in the root zone and enhancing water use efficiency. Additionally, ridge-film mulching with film-skirting sowing solves the problem of soil looseness and lodging susceptibility during late-season rains associated with traditional under-film sowing, improving production stability.

4. Conclusion

1. Ridge-film mulching significantly increases spring maize yield, with ridge-film mulching patterns increasing yield by 11.37% over flat-film mulching. Specifically, ridge-film mulching with film-skirting sowing increased yield by 24.97% compared to CK and 13.3% compared to ridge-film mulching with under-film sowing.

2. Ridge-film mulching with film-skirting sowing demonstrates significant rainwater harvesting effects, increasing soil moisture content in the 0–20 cm layer at furrow positions by 30.44%, 41.81%, 43.68%, and 47.66% under different rainfall levels, with highly significant differences. The moisture increase was more pronounced in the 0–20 cm cultivated layer under RC-FSS.

3. Ridge-film mulching substantially improves water use efficiency by 16.45%–34.30%, with RC-FSS increasing WUE by an average of 26.27% over CK and outperforming all other planting patterns, showing a positive correlation with yield increase.

4. Ridge-film mulching effectively promotes root development and significantly reduces lodging rate. Compared to CK, RC-FSS significantly increased root distribution width, lateral root number, and root dry weight while enhancing lodging resistance, achieving a lodging rate of only 0.9% and maximum lodging resistance force of 29.4 N.

5. The ridge-film mulching with film-skirting sowing pattern developed in this study integrates rainwater harvesting, moisture conservation, root promotion, seedling strengthening, lodging resistance, and stable yield increase, effectively addressing production challenges associated with low spring temperatures and limited rainfall in the Bohai Rim low plain region, and offering broad application prospects for spring maize production in this area.

References

[1] Liu M, Tao H B, Wang P, et al. Effect of sowing date on growth and yield of spring-maize[J]. Chinese Journal of Eco-Agriculture, 2009, 17(1): 18—23

[2] Tang X M, Li S Z, Fan T L, et al. Effects of different plastic film mulching modes on growth and yield of dry land maize[J]. Journal of Maize Sciences, 2011, 19(4): 103-107

[3] Kong W P, Cheng Z Y, Zhang R, et al. Effects of different covers modes and cropping patterns on water and heat in early stage and seeding rates of maize in dry land[J]. Journal of Irrigation and Drainage, 2014, 33(3): 119-121

[4] Sun S J, Fan Y M, Xu Z H, et al. Effects of planting density on soil moisture and corn yield under plastic film mulching in a rain-fed region of northeast China[J]. Chinese Journal of Ecology, 2014, 33(10): 2650-2655

[5] Ren X M, Sun D B, Wang Q S. Effects of plastic film mulching and plant density on yield and evapotranspiration of rainfed spring maize[J]. Transactions of the Chinese Society for Agricultural Machinery, 2017, 48(1): 206-211

[6] Gao X, Gong D Z, Gu F X, et al. Inhibiting soil respiration and improving yield of spring maize in fields with plastic film mulching[J]. Transactions of the CSAE, 2014, 30(6): 62-70

[7] Xu L X, Duan X M, Liu R L. The effect of different ridge and furrow planting pattern on the physical and chemical characteristics of soil and efficient utilization of water[J]. Journal of Shanxi Agricultural University: Natural Science Edition, 2017, 37(2): 83-88

[8] Zhang J P, Sun J S, Liu Z G, et al. Effect of moisture and mulching on filling characteristics and yield of summer maize[J]. Chinese Journal of Eco-Agriculture, 2010, 18(3): 501-506

[9] Li J, Xie R Z, Wang K R, et al. Variations in maize dry matter, harvest index, and grain yield with plant density[J]. Agronomy Journal, 2015, 107(3):

829-834

[10] Antonietta M, Fanello D D, Acciaresi H A, et al. Senescence and yield responses to plant density in stay green and earlier-senescing maize hybrids from Argentina[J]. Field Crops Research, 2014, 155: 111-119

[11] Zhou L M, Li F M, Jin S L, et al. How two ridges and the furrow mulched with plastic film affect soil water, soil temperature and yield of maize on the semiarid Loess Plateau of China[J]. Field Crops Research, 2009, 113(1): 41-47

[12] Bruns H A, Abbas H K. Ultra-high plant populations and nitrogen fertility effects on corn in the Mississippi Valley[J]. Agronomy Journal, 2005, 97(4): 1136-1140

[13] Li R, Hou X Q, Jia Z K, et al. Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rained area of the Loess Plateau, China[J]. Agricultural Water Management, 2013, 116: 101-109

[14] Zhou L M, Jin S L, Liu C A, et al. Ridge-furrow and plastic-mulching tillage enhances maize-soil interactions: Opportunities and challenges in a semiarid agroecosystem[J]. Field Crops Research, 2012, 126: 181-188

[15] Xu L, An W, Hao J P. The effect of water-osmosis plastic membrane on physiology、yield component and yield for drought maize[J]. Journal of Arid Land Resources and Environment, 2010, 24(8): 180-185

[16] Li H X, Wu B Z. Summary of polythene mulch on physiological index of maize[J]. Journal of Maize Sciences, 2004, 12(S1): 66-69

[17] Liu X W, He B L, Guo T W. Effects of full mulching on double ridges with different mulching methods on soil water content and maize yield in dryland[J]. Acta Agriculturae Nucleatae Sinica, 2012, 26(3): 602-608

[18] Gao Y H, Niu J Y, Yan Z L, et al. Effects of different plastic-film mulching techniques on maize (Zea mays L.) dry matter accumulation and yield[J]. Chinese Journal of Eco-Agriculture, 2012, 20(4): 440—446

[19] Jiang X D, Li Z J, Hou L T, et al. Impacts of minimum tillage and no-tillage systems on soil NO3—-N content and water use efficiency of winter wheat /summer corn cultivation[J]. Transactions of the CSAE, 2005, 21(7): 20-24

[20] Hou L T, Jiang X D, Han B, et al. Effects of different mulching treatments on the gas exchange parameters and water use efficiency of winter wheat[J]. Transactions of the CSAE, 2006, 22(9): 58-63

[21] Zhang X H. Application of the technique of water-collecting with plastic film in corn cultivation in dry-land[J]. Journal of Anhui Agricultural Sciences, 2006, 34(23): 6151-6153

[22] Wang Y L. Cultivation Techniques of High Yield and Early Maturity for Peanut, Maize, Cotton and Watermelon Plastic Film Mulching[M]. Beijing:

Golden Shield Press, 1988: 66-69

[23] Ma J H, Tian E P, Wang Y C. Preliminary report on application effect of mulch film technology in maize in autumn[J]. Ningxia Agriculture and Forestry Science and Technology, 2007, (5): 31-39

[24] Xing S L, Wei Y A, Li S X. Present status and prospect of film-mulching cultivation of crops in Shaanxi Province[J]. Agricultural Research in the Arid Areas, 2002, 20(1): 10-13

Note: Figure translations are in progress. See original paper for figures.