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Assessment of maize yield-increasing potential and optimum N level under mulched drip irrigation in the Northeast of China

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A R T I C L E I N F O

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A B S T R A C T

A field experiment under film mulched drip irrigation was conducted for two consecutive years (2014.5–2015.10) in the Northeast Plain of China (NEC), in order to quantify the maize yield-increasing potential and optimum nitrogen (N) level. The results showed that mulched drip irrigation significantly promoted the environmental factors, maize growth and production in the NEC ($p \leq 0.05$). Compared with the traditional rain-fed management, the total soil water storage (SWS) at ridge significantly increased by 80 mm and the topsoil accumulative temperature (TC) increased by 353 °C under mulched drip irrigation. Compared with non-mulched surface drip irrigation, the total SWS and TC also increased by 9 mm and 245–314 °C under mulched drip irrigation. The increased TC was the main reason for the promotion of crop development in the early stage, and it prolonged the duration from tasseling stage (VT) to physiological maturity (R6) and increased the yield. Furthermore, the soil total N at the root zone and N uptake also increased under mulched drip irrigation, about 0.28 g/kg and 28.41 kg/hm^2 higher than local management, respectively, which could be regarded as the second reason for the yield-increase. The third main reason for the increase in yield was that more net radiation was intercepted by maize under mulched drip irrigation. Compared with local maize cultivation, the maize yield increased by 10%-29%, and water use efficiency (WUE) increased by 10%-31% and nitrogen use efficiency (NUE) increased by 57%-84% at 230 kg/hm^2 N under mulched drip irrigation. There was no significant yield-increasing ($p > 0.05$) with N changed from 230 kg/hm^2 to 330 kg/hm^2. Therefore, N of 230 kg/hm^2 was recommended for mulched drip-irrigated maize and an increase of more than 10% of yield and WUE was validated by mulched drip irrigation experiments in the NEC.

1. Introduction

As the most important sector in China, agriculture was definitely affected by global climate changes and water security. It was reported that agriculture consumed 60% of the total water use in the world and was extremely sensitive to water shortages (Lin et al., 2012). However, unavoidable global warming had been in progress with more frequent occurrences of extreme weather, which resulted in increasing water shortages (Kang et al., 2017). Meanwhile, the potential food demand was visibly increasing with population growth and the change of diet structure. It was reported that the food demand of the world would likely increase by 70% in 2050. To balance this need, the yields of corn must increase by at least 40% in the next 40 years. Thus, sequentially exploring the yield-increasing potential was meaningful for food security in China and in the world, even for the sustainable development in China.

The NEC was one of the most important grain production regions of China. The annual maize production directly affected the food security and crop trade of China. In this region, more than 36% of the cultivated area (more than 6.0 million hm^2) was sown for maize cultivation, and the region produced approximately 31% of the national total production in 2010 (Liu et al., 2013; China Statistical Yearbook, 2011). However, a limited potential of production-increase was found with traditional management, due to the soil quality deterioration and climate change (Liu et al., 2005; Wang et al., 2015). Consequently, to further explore the yield-increasing potential and make the best use of land resources of the NEC, an 'increasing grain yield and water-saving' project was conducted in the NEC during the period from 2012 to 2015. This project developed the water-saving agriculture area of 2.5 million hm^2 and built the mulched drip irrigation agriculture area of 1.5 million hm^2.

As other literature reported, the mulched drip irrigation significantly increased the crop production and water use efficiency (WUE) in the Northwest of China (NWC; Du et al., 2008; Tian et al.,

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2017; Yang et al., 2016). The advantages of film were also reported by previous research in the NWC, i.e., maintaining higher soil water and temperature (Lü et al., 2008; Hou et al., 2010; Liu et al., 2016), reducing the evaporation and N_2O emissions (Zhang et al., 2012), and increasing crop yield and WUE (Bu et al., 2013; Zhao et al., 2012; Liu et al., 2017). However, the climatic conditions were clearly different, due to the special locations in the NEC and NWC. The black soil was rich with organic and the water resources were abundant in the NEC. However, the drought and cold spring likely led to crop failure (Yu et al., 2006). Conservation cultivation was constructive for the agricultural development and sustainability of the NEC (Li et al., 2013), but little studies of quantitative analysis for theoretical yield-increasing and optimum N application were carried out under mulched drip irrigation in the NEC. Against aforementioned background, 2-year field experiment was thus conducted during 2014–2015 to investigate the effects of mulched drip irrigation on environmental factors and growth of maize. Our study aims were as follows: (i) to investigate the soil and microclimate factors response to drip irrigation with film in the NEC; (ii) to quantify the effects of yield-increasing and water-saving under film-mulched drip irrigation; and (iii) to explore the suitable N application rate for film-mulched drip-irrigated maize in the NEC.

2. Materials and methods

2.1. Experimental site

The study area was located in the Irrigation Experiment Station of the Heilongjiang Institute of Water Resources Technology Research (125°45′ E, 45°22′ N) in Harbin city of Heilongjiang province, China. The elevation was 220 m. The study area had a sub-humid climate, with a cold and dry winter and a hot and rainy summer. The experimental area was 1.2 hm^2 with black silt soil. The average bulk density was 1.48 g/cm^3, the average field capacity was 0.35 cm^3/cm^3 and the saturation capacity (SC) was 0.466 cm^3/cm^3. The organic matter was 25.94 g/kg, EC was 111.08 μs/cm and the Ph was 8.69 in the upper 1.0 m of the soil profile (Table 1). From 1980 to 2012, the average annual precipitation and temperature were approximately 543 mm and 4.8 °C, respectively (Liu et al., 2015). Field experiments were conducted during 2014–2015, with lower precipitation and temperature than the average of sixty years (1951–2013, Fig. 1) during the maize growth periods, especially in July 2014.

Before seeding, the study area was covered with heavy snow and ridged with alternate parallel ridges and furrows after the snow melted. The ridges and furrows were 1.0 m and 0.3 m wide, respectively. After ridging, the maize plots were fertilized with N 50 kg/hm^2, P_2O_5 150 kg/hm^2, and K_2O 80 kg/hm^2.

2.2. Experimental description

The experiments were conducted with seven treatments (Table 2). Treatments 1–4 applied different N fertilizers under the film-mulched drip irrigation system. According to the investigation of local N management (N applied and application time), the total N applied was 330 kg/hm^2. It was also proven that maize yield varied linearly with N increasing from 80 kg/hm^2 to 200 kg/hm^2 under mulched drip irrigation (Liu et al., 2015). In this paper, the controlled total N was applied at rates of 330, 280, 230 and 180 kg/hm^2 (referred to as MN330, MN280, MN230 and MN180, respectively). After planting, the remaining N source was urea (46% N), which was applied via drip fertigation during 60–105 days after sowing (Table 3, V6 and VT stages). The fertilizer was applied at 60% at V6 and 40% at VT. The fertilizer was applied on 29 June and 23 July, 2014, as well as on 7 July and 25 July, 2015.

For treatment 5, the total N fertilizer applied was 330 kg/hm^2 (referred to as N330) under surface drip irrigation system. The schedule of the fertilizer application was the same as the above description.

Treatments 6 and 7 were rain-fed. In accordance with local management, the applied total N fertilizer was 330 kg/hm^2 for treatment 6 (referred to as CK1), and the additional urea was spread on 9 July 2014 and 22 July 2015 (V12 stage of maize). A total of 0 kg/hm^2 of N fertilizer was applied after planting in treatment 7 (referred to as CK2).

Every treatment had three replications with random arrangements. For treatments 1–4, every plot area was 5.2 m × 20 m. For treatments 5–7, every plot area was 11 m × 20 m. Maize was seeded on 26 April 2014 and 25 April 2015 by machine in all of the treatments. Two rows

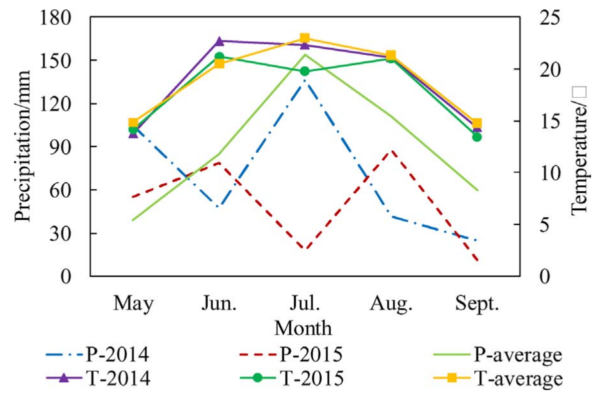

Fig. 1. Distribution of precipitation and temperature during 2014–2015 experimental period and comparison with the average values of 1951–2013. (P meant precipitation and T meant temperature).

Table 2
Treatments of the field experiments in 2014 and 2015.

Treatments	Irrigation management	N supplied ($kg\ hm^{-2}$)	Irrigation date (2014)	Irrigation date (2015)
MN330	film-mulched drip irrigation	330	3 May, 2 June, 29 June, 23 July, 8 August	1 May, 8 May, 7 July, 25 July, 6 August
MN280	film-mulched drip irrigation	280		
MN230	film-mulched drip irrigation	230		
MN180	film-mulched drip irrigation	180		
N330	surface drip irrigation	330		
CK1	rain-fed	330		
CK2	rain-fed	50		

Table 1
Basic properties of initial soil profile.

Soil layers (cm)	Soil texture	Soil bulk density ($g\ cm^{-3}$)	Saturation capacity ($cm^{-3}\ cm^{-3}$)	Field capacity ($cm^{-3}\ cm^{-3}$)	Organic matter ($g\ kg^{-1}$)	PH	EC ($\mu s\ cm^{-1}$)
0–10	silt loam	1.372	0.474	0.349	31.63	8.36	123.50
10–30	silt loam	1.309	0.515	0.321	28.57	8.48	100.65
30–50	silt loam	1.552	0.456	0.375	25.5	8.76	98.35
50–80	silt loam	1.516	0.461	0.360	25.94	8.90	121.75
80–100	silt loam	1.630	0.424	0.356	18.07	8.96	111.15
Average		1.48	0.466	0.35	25.94	8.69	111.08