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Comparison of nitrogen fertigation management strategies for center-pivot irrigated maize in the sub-humid area of China

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ABSTRACT. *In the sub-humid region of Northeast China, increasing use of center-pivot irrigation systems has caused increased interest in sprinkler fertigation technology in maize production to improve nitrogen (N) use efficiency and protect the environment. However, the lack of fertigation strategies for maize cultivation restrains the adoption of sprinkler fertigation technology. A field experiment was carried out in a sub-humid region of Northeast China on maize to determine the effect of different fertigation management strategies on plant growth, grain yield and nitrate content in the soil during the maize growing season. Three N rates (200, 160, and 120 kg N ha^{-1}) and three fertigation schedules were tested. After a uniform nitrogen fertilizer application at an early stage, the N treatments applied 100% of the remaining amount of fertilizer at the stage of vegetative (V) 14 (T1); applied 66.7% and 33.3% of the remaining amount of fertilizer at the stage of V14 and reproductive 2 (R2), respectively (T2); and applied 75% and 25% of the remaining amount of fertilizer at the stage of V14 and R2, respectively (T3). The N rates and fertigation schedules were combined to make nine treatments: T1N200, T1N160, T1N120, T2N200, T2N160, T2N120, T3N200, T3N160, and T3N120, each having three replications. Full irrigation was applied in order to minimize water stress. All treatments received the same irrigation depth in each fertigation event. Results showed that maize grain yield and above-ground biomass production increased with the increasing of N rates; N200T1 produced a higher yield (12,710 kg ha^{-1}) than the other fertigation treatments. However, there was no significant difference in yield between the N rates of 160 and 200 kg ha^{-1}($P < 0.05$), while partial factor productivity decreased with increased N application. Furthermore, the amount of the mineral nitrogen (NO_3–N) accumulated in the 0- to 100-cm layer after harvest increased as the N rates increased. At the high N level, the residual NO_3–N in the soil in T1 was 65% and 51% less than that in T2 and T3, which decreased the risk of NO_3–N leaching out of the 0- to 100-cm soil layer. Based on this research, the recommended management practice of fertigation via center-pivot irrigation systems is to apply 160 kg ha^{-1} of nitrogen (N160) to maize through two in-season fertigation events (T1), which can obtain relatively high production, meanwhile reducing the risk of nitrogen leaching in the sub-humid region of China.*

Keywords. *Fertigation strategies，Center-pivot irrigation, Grain yield, Maize, Nitrogen.*

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Introduction

Maize as one of China’s most important cereal crops, is crucial to expand grain production capacity. The region of Northeast China has the largest maize area and accounts for 28.16% of national maize production (NBSC 2015), which plays a vital role in national food security. Currently, fertigation through sprinkler or drip irrigation systems is regarded as one of the most important agricultural technologies as well as an excellent opportunity to maximize yield and minimize environmental pollution (Hagin et al., 2002). With the increasing use of center-pivot irrigation system, sprinkler fertigation technology in maize production could be a suitable fertilization methodology instead of traditional fertilizer methods. Proper nitrogen (N) fertigation management base on crop requirement is able to increase fertilizer use efficiency, minimize fertilizer application and reduce Nitrogen(N) loss to the environment (Kafkafi, et al.,2011). Results of earlier studies showed that a combination of sprinkler irrigation and N fertigation significantly reduced N leaching with only 6% reduction in crop yield in Nebraska.(Gheysari et al., 2009).

Maize require large amount of primary nutrients, especially N. An effective N management regime need to meet crop N need, improve N use efficiency and minimize N loss. The excessive application of nitrogen cannot increase the crop yield, but decrease the Nitrogen use efficiency (Barbieri et al., 2008), and cause severe environmental problems, such as greenhouse gas emissions (Burneyl et al., 2010) and groundwater contamination a result of nitrate leaching (Klocke et al., 1999). However, it has been found out that excessive application of nitrogen and improper way to apply fertilizer are common in northeast area of China. Previous studies showed that 38.9% of farmer in the Northeast China overused N fertilizer(Gao et al., 2010), and a large dose of N usually applied once per growing season when planting or at early stage via conventional fertilization practices (Zhang et al., 2007; Cui et al., 2010, and Gao et al., 2010).

The split application of water and N fertilizer according to crop requirement is advocated for the advantages of enhancing the yield, reducing nitrate leaching, and improving N use efficiency (Lamm, et al., 2004). It’s reported that increasing fertigation frequency maintains a constant soil moisture and nutrient concentration in the root zone (Silber et al.,2003) . For example, high fertigation frequency in season produced a greater maize yield and N uptake than fertigation only during the pre-emergence stage (Tarkalson & Payero, 2008). However, these results need to be reconsidered when apply to different climate, fertigation methods and crops, especially when there is lack of study on sprinkler fertigation technology in this region. Weekly fertigation frequency significantly increased maize yield with a subsurface drip (Lamm et al., 2001). But too frequent fertigation might not be suitable and beneficial for center pivot system, which might increase the difficulty to manage. Additionally, under sprinkler irrigation, evaporation losses were higher due to a more frequent water application (Mack et al., 2005).

Despite fertigation being an effective way to optimize N use efficiency and increase crop yield (Silber et al., 2003; Farneselli et al., 2015), lack of knowledge and insufficient information on cropping practices have been a main obstacle for the optimal sprinkler fertigation strategies used for maize cultivation.

The objectives of this study were to assess the applicability of different center-pivot fertigation strategies on maize growth, yield, N use and accumulation for developing the best management practices in the sub-humid region of Northeast China.

Materials and methods

Experiment Field Site

Field experiments were conducted in 2017 in Qiqihar (48°15’N, 125°37’E), Heilongjiang Province in Northeast China. The region has a sub-humid climate with a long-term (from 1980 to 2014) average seasonal (May to September) maximum air temperature of 23.36□, minimum temperature of 12.44□ and average seasonal rainfall of 457.13mm. The soil properties at the site were determined at five different depths, with 20 cm interval between 0 cm and 100 cm (Table 1). The bulk density at different depths were determined from undisturbed soil samples taken at each horizon (using a 100 cm^{-3} core sampler). The field capacity was measured at three locations (Veihmeyer & Hendrickson, 1949), and wilting point was determined at 1.5MPa suction by centrifugal method (CR 21GII, Hitachi, Japan). Organic matter was determined by the Walkley-Black method (Walkley & black, 1934) using the potassium dichromate dilution technique. The effective rooting depth for maize in the experimental site is 100 cm. The total available water (TAW) of the 100 cm soil profile was approximately 160mm. The weather data, including precipitation, daily maximum, minimum, and mean air temperature, relative humidity, wind speed, and sunshine radiation were collected from an automatic weather station located approximately 500 m away from the experimental field.

Table 1. Soil physical properties of the experimental field

Depth (cm)	Particle Size Distribution (%)			Texture	Soil Bulk Density (g cm^{-3})	Organic Matter Content	Field Capacity (cm^{3} cm^{-3})	Wilting Point (cm^{3} cm^{-3})
	Sand	Silt	Clay					
0-20	19.84	69.22	10.94	silt loam	1.34	6.90%	0.40	0.235
20-40	20.86	67.21	11.49	silt loam	1.33	7.20%	0.37	0.184
40-60	19.79	69.55	10.66	silt loam	1.37	4.20%	0.35	0.198
60-80	21.14	68.07	10.80	silt loam	1.45	3.70%	0.37	0.223
80-100	21.36	68.84	9.81	silt loam	1.46	4.60%	0.36	0.219

Experimental Design

The crop was applied with three N rates (200, 160, and 120 kg N ha^{-1}) and three fertigation schedules (Table 2). After a uniform nitrogen fertilizer application at an early stage, the N treatments applied 100% of the remaining amount of fertilizer at the stage of V14 (T1); applied 66.7% and 33.3% of remained amount of fertilizer at the stage of V14 and R2, respectively (T2); and applied 75% and 25% of remained amount of fertilizer at the stage of V16 and R2, respectively(T3). The N rates and fertigation schedules were combined to nine treatments: N200T1, N200T2, N200T3, N160T1, N160T2, N160T3, N120T1, N120T2, N120T3 (Table 2). Each treatment had three replications, with the area of 135 m^{2} (15 m long and 9 m wide). All plots were placed in the third span of center-pivot irrigation system. The 200kg N ha^{-1} were based on the results of previous investigation carried out in this region under convention fertilization condition which means all fertilizer applied by broadcasting method. All treatments received same amount of phosphate and potassium (P_2O_5 44kg/ha, K_2O 68kg/ha).

Table 2. Nitrogen application rates and schedules for maize during the growing season

Number	Treatment		Nitrogen Applied (Total /Fertigated) (kg N ha^{-1})	2 May planting (kg N ha^{-1})	30 Jun V9 (kg N ha^{-1})	18 July V14 (kg N ha^{-1})	11 Aug R2 (kg N ha^{-1})
	Application schedule (V14:R2)	N rate					
1	T1 (100%)	N200	200/140	60	10	130	0
2		N160	160/100	60	10	90	0
3		N120	120/60	60	10	50	0
4	T2 (66.7%:33.3%)	N200	200/140	60	10	86.7	43.3
5		N160	160/100	60	10	60	30
6		N120	120/60	60	10	33.3	16.7
7	T3 (75%:25%)	N200	200/140	60	10	97.5	32.5
8		N160	160/100	60	10	67.5	22.5
9		N120	120/60	60	10	37.5	12.5

Cultural Practices

Prior to planting, the field was prepared with ridges spaced at 1.1 m. Two rows of maize spaced at 0.4 m were seeded on each ridge. The maize was planted on 2 May, emerged on 20 May, and was harvested on 7 October, 2017. The planting population density was 85,000 plants per ha with the direction of north-south. Herbicide, insecticide, and pesticide application followed conventional application practices in the region. The experimental field (23 ha) was irrigated and fertilized using a four-span center-pivot irrigation system (Valley Standard Pivot 8120) with a fertigation system(Yan et al., 2014). Except pre-plant granular applications, all nitrogen fertilizer was applied via this fertigation system. A readily soluble N fertilizer of urea (N- P_2O_5- K_2O, 46-0-0) was used. Desired fertigation rates were obtained by varying the application depth of water with a constant nutrient concentration. In order to exclude the effect of different water availabilities, an additional amount of water was applied to guarantee that each plot received the same amount of water at three fertigation events. Meanwhile, to avoid any yield losses due to water stress, the soil water content in the 100-cm profile was kept between 95% of field capacity (FC) and maximum allowable depletion (MAD), which is approximately 50% of total available water (TAW), with 95 mm. Finally, at each fertigation event, 10 mm, 30 mm and 15 mm depth of water were applied to each plot, respectively, with total 55 mm of water.

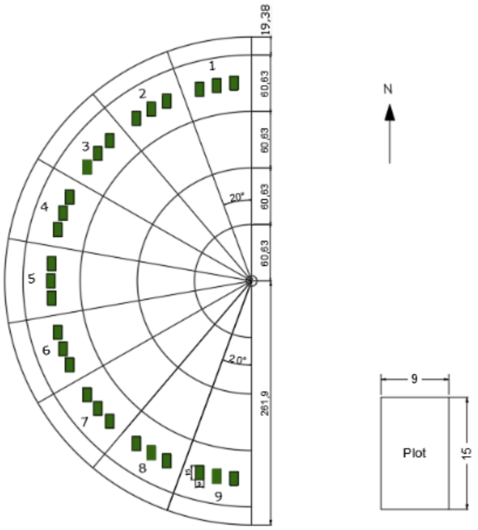

Figure 1. Diagram of experimental design and layout of plots. Numbers represent different treatments that are in consistent with the treatment showed in table 2.

Measurements of Plant Growth

During the growing season, plant height, leaf area index (*LAI*), and aboveground plant biomass were measured at six growth stages, a total of six sampling dates were collected. For each sampling location, three representative plants were chosen and used for plant height measurements, LAI determination and aboveground plant biomass. LAI were estimated by McKee method (1964) that record the length and maximum width of each green leaf.

The aboveground biomass was measured by clipping the aboveground plant at the soil surface, then oven-dried the stalks, leaves and grains separately at 70 □ until they reached a constant weight and then recorded. The oven-dried samples were then ground into fine powder to pass through a 1-mm sieve and used Kjeltec Analyzer (Kjeltec 2300, Foss, Denmark) to measure total N content for each sample. The plant N uptake was determined by the product of the aboveground plant biomass and the total N content. At the final harvest, four rows of five meters long plants in each plot were chosen to determine grain yield, air dried and then grains were converted to a standard moisture content of 14% (Chinese Standard, 2009).

Measurements of Soil Water and Nitrogen Content

Soil water status were monitored by gravimetric method, using a 4-cm diameter hand-held auger to collect soil samples in each plot. Soil samples were collected regularly at 2 weeks interval. Sampling were also done a day before and 2-3 days after irrigation of 100 cm soil layer at 20 cm intervals. The data was used both to determine irrigation initiation and to monitor soil total available water (TAW). Same soil samples that were collected after fertigation event, including final harvest, were used to obtain the seasonal change of NO_3-N content in the soil. 10 g of air-dried soil that passed through a 2-mm sieve. The extraction was carried out with 100 mL of 1 mol^{-1} KCl (Soil Science Society of China, 1999), and the nitrate-N content was determined using an Auto Analyzer □ (Bran+Luebbe, Germany). The NO_3-N content of each soil layer were determined at final harvest from soil sample, the same automatic analyses used for the analyses of soil N content.

Partial factor productivity from applied N (PFP_N, kg ha^{-1}) is calculated as follows (Dobermann & Cassman, 2005).

$$\mathrm{PFP_N} = \frac{\mathrm{Y_T}}{\mathrm{F_N}} \qquad (1)$$

Where Y_T =the total grain yield (kg ha^{-1}) at certain level of fertilizer N applied (F_N, kg ha^{-1}).

Statistical Analysis

An analysis of variance (ANOVA) with three replicates was used to test whether the rates of nitrogen and application schedules had a significant effect on plant growth and yield at the probability levels of 0.05. The least significant difference was also calculated on all treatments.

Results

Weather Conditions

The daily precipitation, effective precipitation, accumulated precipitation and accumulated ET_0 after emergence are shown in Fig.2. A total of 407.47 mm of precipitation was received from May 20 to October 7, 10.9% below the long-term precipitation value (1980 to 2014), and effective precipitation was determined to be 380 mm. A total depth of 55 mm of irrigation was applied over the three fertigation events. The mean air temperatures were 17.67 ℃, with maximum air temperature of 23.06 ℃ and minimum air temperature of 11.5 ℃. The reference evapotranspiration (ET_0) was calculated from the weather data recorded by the weather station for the whole growing season (Allen et al., 1998). The ET_0 was 1.00 to 8.99 mm d^{-1}, and the seasonal ET_0 was 472 mm. The accumulated ET_0 was higher than precipitation. Thus, irrigation played a significant role in meeting the evaporative demand during the crop season.

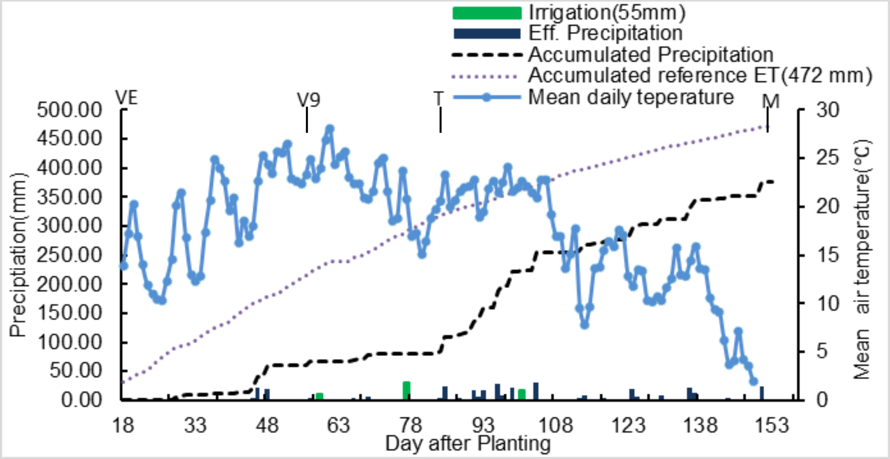

Figure 2. Effective precipitation, irrigation, accumulated ET_0 and mean air temperature during maize growing season. The annotations VE, V9, T, and M identify emergence, vegetative 9, tasseling, and maturity dates, respectively.

Variation of Soil Water Content

The soil water content within the 0- to 100-cm layer over all nine treatments for the whole growing season are shown in figure 3, which were influenced by growing stage as well as soil depth. The variations of soil moisture condition in the shallow layers were larger than deep layer, and soil water depletion decreased with soil depth (Djaman & Irmak, 2012). In general, mean values of soil water state within the 100-cm profile were all above 50% TAW, which showed that crop didn't experience obvious water stress. During the later stage, large rainfall produced the soil moisture in the 100-cm profile over field capacity.

Growth Analysis

The plant height and LAI of three growth stages and final above-ground dry matter were chosen to be analyzed (Table 3). Generally, the plant height, LAI and the above-ground dry matter after harvest increased with N application rate. The N200 treatments produced a significantly greater plant height and dry matter. Significant influences on plant height and LAI among different N rate treatments were observed on 25 July ($P \leq 0.05$), while for later growing stage, only N120 showed a significantly low plant height compared to the N200 treatment. The effects of the three different fertilizer schedule treatments were observed in plant height. T1 showed a significant advantage, 7.1% and 4.7 % greater than T2 and T3, which applied 100% of the remaining amount of fertilizer at the V14 stage. For a given fertigation scheme, the above-ground dry matter after harvest increased with N applicated rate. For example, the final above-ground biomass averaged over the three

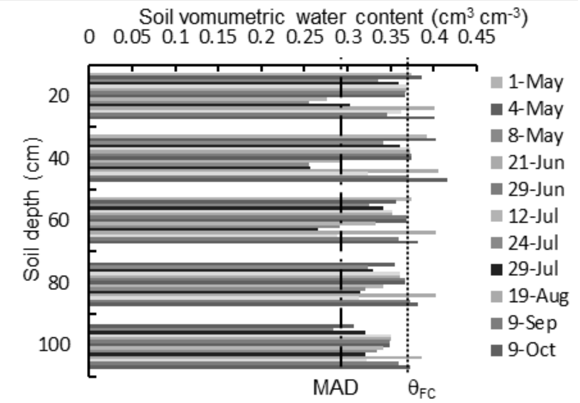

Figure 3. Variation of soil water condition along the depth of soil profile during the growing season. Values at each depth are the average of all nine treatments.

fertigation schemes increased from 16.7 to 20.09 Mg ha^{-1} as the application rate increased from 120 to 200 kg ha^{-1}. There was a significant difference between N200 and N120.

Table3. Effects of different fertigation schedules and rates on plant height, leaf area index (LAI), above-ground biomass

Treatment		Plant height (cm)			L AI			Above-ground biomass (Mg/ha)
		25-Jul	8-Aug	7-Sep	25-Jul	8-Aug	7-Sep	7-Oct
T1	N200	224.20	223.58	218.97	4.41	4.53	4.11	20.59
T1	N160	210.98	209.11	208.80	4.39	4.58	3.64	19.35
T1	N120	192.70	211.44	207.72	4.19	3.97	3.38	18.00
T2	N200	209.48	206.29	217.47	4.50	4.30	4.34	18.94
T2	N160	194.66	205.03	205.33	4.35	4.28	4.37	18.13
T2	N120	181.84	201.96	208.53	4.28	4.25	3.90	16.27
T3	N200	214.16	211.89	207.33	4.41	4.15	3.98	20.74
T3	N160	205.41	213.68	218.72	4.26	4.49	3.98	19.36
T3	N120	180.24	202.31	200.67	4.03	4.34	4.03	16.64
Summary Statistics								
N rate	N200	215.94a[a]	213.92a	214.60a	4.49a	4.33a	4.14a	20.09a
	N160	203.68b	209.27ab	210.95ab	4.29ab	4.45a	3.99a	18.95ab
	N120	184.926c	205.24b	205.64b	4.19b	4.26a	3.77a	16.97b
Application schedule	T1	209.29a	214.711a	211.83a	4.43a	4.44a	3.71b	19.31a
	T2	195.33b	209.29b	210.44a	4.37a	4.32a	4.20a	17.78a
	T3	199.94b	204.43ab	208.91a	4.12b	4.27a	4.0ab	18.91a

[a] Treatments with the same letter in the column are not significantly different at the P = 0.05 level.

NO_3-N Concentration and Residual Mineral N Content

The changes in the soil nitrate content during the growing season are shown in figure 5. Nitrate content in the soil showed more variability at the 0- to 40-cm layer compared to the 40- to 100-cm layer. The result was consistent with the study of (Sui, et., 2015). A noticeable increase generated following almost every fertigation event. This trend was observed especially at 0- to 40-cm soil layer. For N application rates of 200 and 160 kg ha^{-1}, concentrations of NO_3-N measured at 100-cm soil profile for T1 were lower than T3 and T2. However, lower N residuals were found in the T1 treatment after harvest. For example, T1 was 40% lower than T2 and 33% than T3 at high N level (N200) in the 0-100 cm depth (figure 4). Meanwhile, differences existed among different fertigation treatments such that residual mineral N content appeared to be higher at the high N rate.

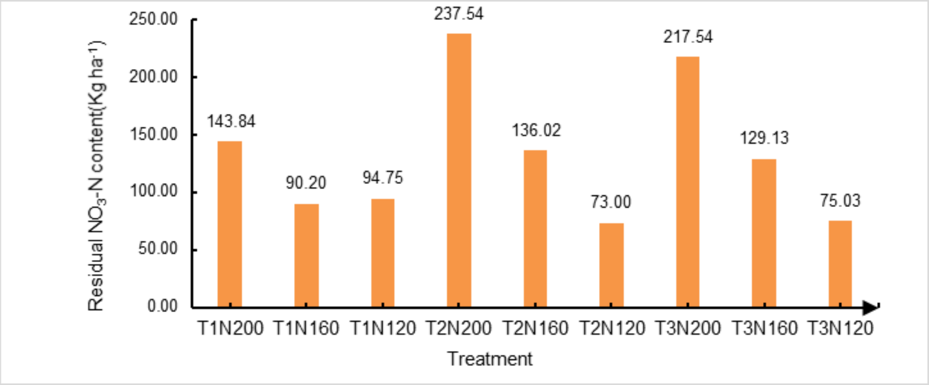

Figure 4. Soil residual NO_3–N content in 0-100 cm profile

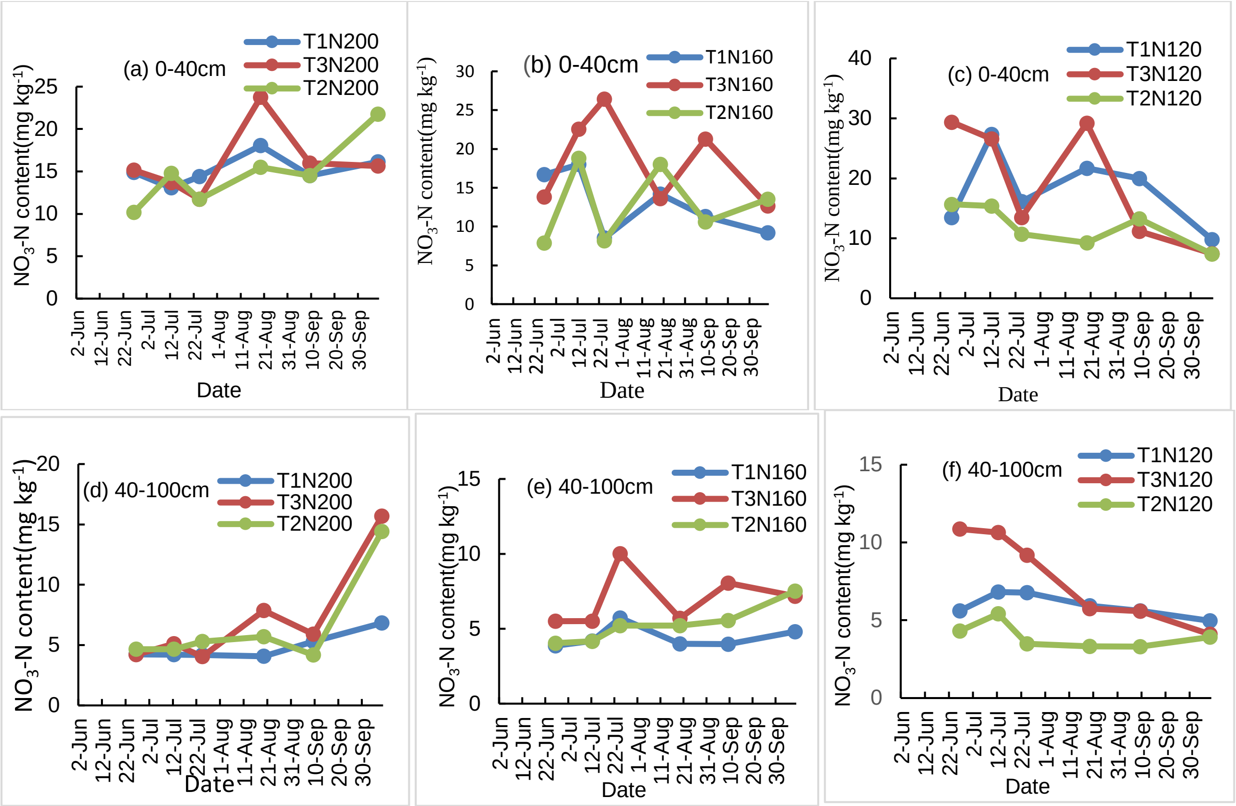

Figure 5. Change in soil nitrate content during the growing season.

Yield

Effects of the fertigation schedules and rates on maize yield and nitrogen use efficiency (PFP_N) are given in table 4. Maize yield was significantly affected by N rate ($p \leq 0.01$), while the fertigation schedules had no significant effect on maize yield. Meanwhile, there was no interaction between fertigation schedules and N rates. The mean yield generated by N200 and N160 were 9.8% and 7.3% greater than N120, but no significant difference in yield existed between N200 and N160. T1N200 had the highest yield. The T2N120 and T3N120 treatments had a significantly lower yield than all N160 and N200 treatments. The PFP_N decreased with increasing N rates, which was consistent with the report by Dobermann et al (2004). Within the same nitrogen application level, T1 showed a slight advantage in PFP_N. Even through N120 had a higher PFPN, N120 caused the significant reduction of grain yield. Therefore, N160 is the recommended N rate that grants grain yield and meanwhile increases N productivity.

Table 4. Effects of the number of fertigation schedule and rates on maize yield

Treatment		Mean yield（kg/ha）	PFP_N
T1	N200	12489.60a [a]	62.45
T1	N160	11865.92ab	74.16
T1	N120	11482.55bc	95.69
T2	N200	12128.11ab	60.64
T2	N160	11939.11ab	74.62
T2	N120	10822.40c	90.19
T3	N200	12028.65ab	60.14
T3	N160	11870.96ab	74.19
T3	N120	11060.28c	92.17
ANOVA[b]			
N		*(P=0.00)	
T		NS(P=0.17)	
N×T		NS(P=0.515)	

[a] Treatments with the same letter in the column are not significantly different at the P = 0.05 level.

[b] N and R represent the N application rates and fertigation schedules, respectively. NS= not significant at p= 0.05level, *= significant at the p= 0.05 level.

Discussion

The results for grain yield, above-ground biomass, plant height, and LAI confirmed that maize growth was mainly related to N rate. This was widely reported in the literature (Lamm et al., 2004; Li et al., 2017; Silber et al., 2003 and Zhao et al., 2006).The N use efficiency (PFP_N) and residual soil NO_3-N need to be considered as well. Three different fertigation schedules (T1, T2 and T3) had significant effect on plant height at early stage and on LAI at late stage (Table 3). That can be explained that T1 applied highest amount of N at the V14 stage when the plant was more sensitive to nutrient, sufficient N supply is crucial for plant growth and this trend maintained at the peak of plant growth. Compared with the decrease of LAI in T1, T2 and T3 showed a higher value of LAI at late stage. This was in agreement with previous findings that N applied at late stage maintain the content of chlorophyll in leaves and then postpone the plant senescence (Liu et at., 2011). Based on the advantage of split fertigation reported before, we expected difference showed in grain yield. However, no remarkable difference was observed in grain yield and above-ground biomass among T1, T2 and T3. In other worlds, the three times fertigation event (T2 and T3) didn't show a statistical advantage compared with two times in-season fertigation in grain yield. Meanwhile we recorded a noticeable residual NO_3-N content in T2 and T3 after harvest (Figure 4), especially at high N level. It should be noted that T2N200 and T3N200 had a considerable increasement of NO_3-N content mainly due to the precipitation event at the end of growing season. Soil NO_3 concentration and subsurface drainage water generated by irrigation are two important factors that control NO_3 leaching (Tamini & Mermoud, 2002). NO_3-N leaching increased in response to any additional N, crop growth stage and crop N uptake. Therefore, additional fertigation at late stage result in higher residual NO_3-N content, greatly increasing the possibility of N leaching.

Conclusions

The results of this study indicated that grain yield and biomass production increased with increasing N rates. The N200T1 treatment produced a higher yield (12,710 kg ha^{-1}) than the other fertigation strategies. However, statistically significant differences in yield didn't occur between the nitrogen rates of 160 and 200 kg ha^{-1}($P \leq 0.05$), while PFP_N decreased with increasing N application. The amount of the mineral nitrogen (NO_3–N) accumulated in the 0- to 100-cm layer after harvest increased as the N rates increased. At the high N level, the residual NO_3–N in the soil in T1 was 65% and 51% less than that in T2 and T3. This decreased the risk of NO_3–N leaching out of the 0- to 100-cm soil layer. The fertigation schedule T1 also had more advantage in promoting plant growth at early stage.

Based on this research, the recommended management practice of fertigation via center-pivot irrigation systems is to apply 160 kg ha^{-1} of nitrogen (N160) to maize through 2 in-season fertigation events (T1), which can obtain relatively high production while reducing the risk of nitrogen leaching in the sub-humid region of China.

Acknowledgements

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