Optimizing Water and Nitrogen Application System to Improve Nitrogen use Efficiency and Ensure Sustainable Yield of Summer Maize (*Zea mays* L.)

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Abstract

Exploring the optimal method of water and fertilizer application and N application rate for summer maize is important for achieving the high water and N efficiency in the North China Plain. We tested that the hypothesis that optimizing water and nitrogen application system could improve nitrogen (N) use efficiency and water productivity, and ensure sustainable yield of summer maize. The results showed that: the 216 kg N ha⁻¹ of drip irrigation (DI) and micro-sprinkling irrigation (SI) could obtain the high grain yield compared with 270 kg N ha⁻¹ of flooding irrigation (FI), which was achieved by maintaining a high 1000-grain weight and kernel number. However, the grain yield of 162 kg N ha⁻¹ would be decreased significantly. Irrigation methods and N application rates had significant effects on the ammonia volatilization rate and ammonia volatilization accumulation of soil, N harvest index (NHI), N partial productivity and water productivity. Compared with FI, DI and SI could reduce the ammonia volatilization rate through applying little fertilizer-N by times, and reduce the ammonia volatilization accumulation of 19.5%-54.9%. In addition, under the same irrigation method, the NHI reached the maximum when the N application rate was 216 kg ha⁻¹. Considering comprehensively, under the condition of this experiment, 216 kg N ha⁻¹ is the best N application rate under DI or SI for maize.

Full Text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the latest manuscript can be downloaded and [accessed as a PDF](#).

Tables

Table 1 Effects of different irrigation methods and nitrogen application rates on grain yields and its components of summer maize.

Year	Irrigation method	Nitrogen application rate (kg ha ⁻¹)	Harvest ear (No. ha ⁻¹)	Kernels per ear (No. ear ⁻¹)	1000-grain weight (g)	Grain yield (kg ha ⁻¹)
2017	DI	N0	67407.4a	497.2de	359.6e	9036.5d
		N162	68888.9a	516.7c	371.4cd	11699.9b
		N216	67777.8a	528.9ab	378.7ab	12316.7a
		N270	68518.5a	530.6a	381.0a	12577.5a
	SI	N0	66296.3a	496.1de	357.3e	8799.3de
		N162	68888.9a	516.2c	373.8bcd	11414.0bc
		N216	69629.6a	521.8abc	378.2abc	12208.1a
		N270	69259.3a	527.2abc	380.1ab	12301.6a
	FI	N0	67407.4a	490.2e	356.5e	8554.7e
		N162	68888.9a	504.7d	367.7d	10985.3c
		N216	68888.9a	518.8bc	373.7bcd	11467.5b
		N270	68888.9a	522.1abc	378.8ab	12160.7a
2018	DI	N0	65185.2ab	466.7f	340.0b	8756.9d
		N162	66666.7a	493.9def	359.1a	10167.5b
		N216	64814.8ab	536.7ab	366.9a	11166.1a
		N270	65185.2ab	550.1a	368.2a	11529.5a
	SI	N0	64074.1ab	504.2cde	334.6b	9319.3c
		N162	64444.4ab	519.4bcd	361.0a	10370.0b
		N216	65185.2ab	543.1ab	366.5a	11091.7a
		N270	64074.0ab	548.4a	368.2a	11495.7a
	FI	N0	62962.9b	479.1ef	338.7b	8170.6e
		N162	63333.3b	502.2de	358.3a	9091.8cd
		N216	63703.7b	518.7bcd	362.3a	10575.6b
		N270	64814.8ab	531.3abc	364.4a	11340.7a
ANOVA						
I			0.421	0.002	0.111	<0.001
N			0.029	<0.001	<0.001	<0.001
I × N			0.546	0.070	0.434	0.286

Note: Different letters in a row are significant differences among treatments in each year (P<0.05). I: Irrigation methods, N: N application rates. DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹,

N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹.

Table 2 Effects of different irrigation methods and nitrogen application rates of accumulation amounts and distribution of dry matter in pre-anthesis and post-anthesis stages of summer maize.

Year	Irrigation method	Nitrogen application rate (kg ha ⁻¹)	Biomass of R6 (t ha ⁻¹)	Pre-anthesis (t ha ⁻¹)	Post-anthesis (t ha ⁻¹)	Percentage of pre-anthesis (%)	Percentage of post-anthesis (%)
2017	DI	N0	17.43 f	6.30 b	11.12 e	36.17	63.83
		N162	20.60 d	6.83 a	13.78 c	33.17	66.83
		N216	22.13 b	7.03 a	15.10 ab	31.78	68.22
		N270	22.85 a	7.29 a	15.56 a	31.9	68.10
	SI	N0	16.67 g	6.07 b	10.61 e	36.36	63.64
		N162	20.90 cd	6.88 a	14.03 bc	32.96	67.04
		N216	22.46 ab	6.98 a	15.48 a	31.1	68.90
		N270	22.74 ab	7.01 a	15.74 a	30.8	69.20
	FI	N0	16.38 g	6.27 b	10.12 e	38.26	61.74
		N162	19.75 e	7.23 a	12.54 d	36.53	63.47
		N216	20.66 d	7.16 a	13.50 cd	34.69	65.31
		N270	21.38 c	7.30 a	14.07 bc	34.15	65.85
2018	DI	N0	15.27 f	5.70 e	9.57 f	37.39	62.61
		N162	20.19 bc	7.44 ab	12.75 cd	36.85	63.15
		N216	21.19 ab	7.53 ab	13.66 ab	35.59	64.41
		N270	21.86 a	7.77 a	14.09 a	35.55	64.45
	SI	N0	14.57 f	5.53 e	9.03 f	37.94	62.06
		N162	18.11 e	6.86 cd	11.25 e	37.86	62.14
		N216	19.73 cd	7.12 bc	12.60 cd	36.1	63.90
		N270	20.28 bc	7.29 abc	12.99 bc	35.93	64.07
	FI	N0	12.86 g	4.92 f	7.94 g	38.3	61.70
		N162	17.83 e	6.56 d	11.27 e	36.8	63.20
		N216	18.80 de	6.85 cd	11.95 de	36.45	63.55
		N270	19.76 cd	7.22 bc	12.55 cd	36.53	63.47

Note: Different letters in a row are significant differences among treatments in each year ($P<0.05$). DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹. R6: physiological maturity.

Table 3 Effects of different irrigation methods and nitrogen application rates on nitrogen accumulation and distribution in summer maize.

Year	Irrigation method	Nitrogen application rate (kg ha ⁻¹)	Nitrogen accumulation amount of VT (kg ha ⁻¹)			Nitrogen accumulation amount of R6 (kg ha ⁻¹)			
			Stem	Leaf	Plant	Stem	Leaf	Grain	Plant
2017	DI	N0	39.94 f	59.89 fgh	99.83 e	21.80 g	28.85 e	101.44 g	152.09 g
		N162	51.20 cde	64.33 def	115.53 cd	29.84 e	40.42 cd	142.70 e	212.96 e
		N216	54.72 abcd	66.65 cde	121.37 abc	33.98 bcd	43.17 bc	170.39 ab	247.54 b
		N270	56.28 ab	72.32 ab	128.60 a	37.97 a	44.82 ab	175.53 a	258.31 a
	SI	N0	41.51 f	58.01 gh	99.52 e	22.45 fg	29.04 e	98.73 g	150.22 g
		N162	51.53 bcde	64.92 def	116.44 bcd	31.82 de	38.68 d	144.45 de	214.95 de
		N216	55.35 abc	66.94 bcde	122.29 abc	32.82 cd	45.18 ab	161.96 c	239.96 c
		N270	57.58 a	68.82 abcd	126.40 a	36.57 ab	47.40 a	164.30 bc	248.27 b
	FI	N0	38.54 f	56.26 h	94.80 e	24.54 f	27.21 e	96.38 g	148.13 g
		N162	47.70 e	62.82 efg	110.52 d	33.56 cd	39.20 d	128.01 f	200.77 f
		N216	50.39 de	71.03 abc	121.42 abc	35.15 bc	40.58 cd	145.90 de	221.62 d
		N270	51.51 bcde	73.68 a	125.18 ab	38.97 a	45.04 ab	150.12 d	234.14 c
2018	DI	N0	27.89 e	46.11 e	74.00 e	16.86 g	20.91 c	76.96 e	114.73 f
		N162	46.20 cd	58.29 cd	104.48 cd	24.68 ef	30.63 b	129.60 bc	184.91 d
		N216	46.38 cd	64.78 abc	111.15 abc	26.43 de	35.92 a	158.87 a	221.22 ab
		N270	49.12 bc	67.42 ab	116.54 a	29.79 ab	38.20 a	160.00 a	227.99 a
	SI	N0	25.26 ef	40.91 ef	66.17 ef	16.54 g	17.32 d	78.15 e	112.01 f
		N162	43.98 d	54.92 d	98.90 d	22.38 f	32.37 b	131.55 bc	186.30 d
		N216	51.21 ab	61.13 bcd	112.34 abc	24.92 de	36.00 a	151.58 a	212.51 bc
		N270	54.09 a	61.12 bcd	115.21 ab	27.25 cd	37.92 a	157.15 a	222.31 ab

FI	N0	24.27 f	37.61 f	61.88 f	15.97 g	18.83 cd	68.67 e	103.48 f
	N162	44.56 d	57.38 d	101.95 d	29.57 abc	30.77 b	111.13 d	171.47 e
	N216	45.17 d	61.87 bcd	107.05 bcd	28.99 bc	32.22 b	125.61 c	186.83 d
	N270	43.66 d	69.93 a	113.59 ab	31.62 a	38.01 a	137.96 b	207.58 c

Note: Different letters in a row are significant differences among treatments in each year ($P < 0.05$). DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹. VT: tasseling, R6: physiological maturity.

Table 4 Nitrogen translocation efficiency and contribution of post-tasseling to grain as affected by the different irrigation methods and nitrogen application rates.

Year	Irrigation method	Nitrogen application rate (kg ha ⁻¹)	N translocation (kg ha ⁻¹)	N translocation efficiency (%)	Contribution of N translocation to grain (%)	N assimilation (kg ha ⁻¹)	Contribution of N assimilation to grain (%)
2017	DI	N0	49.18 a	48.96 a	48.51 a	52.26 e	51.49 b
		N162	45.27 ab	39.16 bcd	31.76 b	97.43 cd	68.24 a
		N216	44.22 ab	36.34 cd	25.93 b	126.17 a	74.07 a
		N270	45.82 ab	35.63 cd	26.11 b	129.71 a	73.89 a
	SI	N0	43.05 ab	45.32 ab	44.65 a	53.33 e	55.35 b
		N162	37.76 b	34.06 cd	29.63 b	90.25 d	70.37 a
		N216	45.70 ab	37.48 cd	31.30 b	100.20 cd	68.70 a
		N270	41.17 ab	32.85 d	27.41 b	108.96 bc	72.59 a
	FI	N0	48.03 ab	48.11 a	48.60 a	50.70 e	51.40 b
		N162	45.94 ab	39.36 bc	31.87 b	98.51 cd	68.13 a
		N216	44.30 ab	36.19 cd	27.40 b	117.66 ab	72.60 a
		N270	42.43 ab	33.53 cd	25.85 b	121.87 a	74.15 a
2018	DI	N0	36.23 cd	48.98 a	47.08 a	40.73 f	52.92 f
		N162	49.17 ab	47.06 ab	37.96 bcd	80.43 de	62.04 cde
		N216	48.80 ab	43.75 abcd	30.91 ef	110.07 a	69.09 ab
		N270	48.55 ab	41.42 cd	30.52 f	111.45 a	69.48 a
	SI	N0	27.08 e	43.69 abcd	39.50 bc	41.60 f	60.50 de
		N162	41.60 bc	40.80 cd	37.56 bcde	69.52 e	62.44 bcde
		N216	45.83 ab	42.81 bcd	36.49 bcdef	79.79 de	63.51 abcde
		N270	43.97 abc	38.67 d	31.86 def	93.99 bc	68.14 abc
	FI	N0	32.31 de	48.79 a	41.32 ab	45.84 f	58.68 ef
		N162	44.15 abc	44.53 abc	33.51 cdef	87.40 cd	66.49 abcd
		N216	51.42 a	45.74 abc	33.87 cdef	100.16 abc	66.13 abcd
		N270	50.05 a	43.46 abcd	31.88 def	107.10 ab	68.12 abc

Note: Different letters in a row are significant differences among treatments in each year ($P < 0.05$). DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹.

Table 5 Effects of different irrigation methods and nitrogen application rates on the nitrogen use efficiency indicators in summer maize.

Year	Irrigation method	Nitrogen application rate (kg ha ⁻¹)	NHI (%)	NUE (%)	AE _N (kg kg ⁻¹)	PFP _N (kg kg ⁻¹)
2017	DI	N0	66.73 abc	-	-	-
		N162	67.01 abc	38.28 bcd	25.95 bcd	73.58 a
		N216	68.83 a	45.02 a	32.52 a	58.10 c
		N270	67.96 ab	40.08 bc	27.96 bc	47.46 e
	SI	N0	65.71 bcde	-	-	-
		N162	67.20 abc	40.71 bc	28.76 ab	71.79 a
		N216	67.49 ab	42.33 ab	29.83 ab	57.59 c
		N270	66.18 bcd	37.00 cde	24.74 cd	46.42 e
	FI	N0	65.08 cde	-	-	-
		N162	63.76 e	33.11 ef	19.89 e	69.09 b
		N216	65.79 bcde	34.67 def	23.36 de	54.09 d
		N270	64.12 de	32.46 f	20.28 e	45.89 e
	DI	N0	67.16 b	-	-	-
		N162	70.09 a	44.14 ab	33.11 ab	63.95 a
		N216	71.80 a	50.23 a	38.63 a	52.67 c
		N270	70.16 a	42.74 ab	31.34 bc	43.51 e
2018	SI	N0	69.79 a	-	-	-
		N162	70.63 a	46.73 ab	33.59 ab	65.22 a
		N216	71.34 a	47.40 ab	34.64 ab	52.32 c
		N270	70.68 a	41.62 ab	29.81 bc	43.38 e
	FI	N0	66.37 bc	-	-	-
		N162	64.81 c	42.76 ab	26.70 c	57.18 b
		N216	67.23 b	39.32 b	26.86 c	49.88 d

Note: Different letters in a row are significant differences among treatments in each year ($P < 0.05$). DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹. AE_N: agronomic efficiency of applied N, NHI: N harvest index, NUE: N use efficiency, PFP_N: N partial factor productivity.

Figures

Figure 1

The daily average air temperature and precipitation of the growth stages for summer maize in 2017 and 2018.

Figure 2

Effects of different irrigation methods and nitrogen application rates on ammonia volatilization in 2017 and 2018. DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹

Figure 3

Effects of different irrigation methods and nitrogen application rates on ammonia volatilization accumulation of soil. Different capital or small values are significant differences among treatments in each N application rate at the 5% level. DI: Drip irrigation, SI: Micro-sprinkler irrigation, FI: Flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹.

Figure 4

Effects of different irrigation methods and nitrogen application rates on water productivity (WP) in summer maize. Different capital or small values are significant differences among treatments in each N application rate at the 5% level. DI: drip irrigation, SI: micro-sprinkler irrigation, FI: flooding irrigation. N0: 0 kg N ha⁻¹, N162: 162 kg N ha⁻¹, N216: 216 kg N ha⁻¹, N270: 270 kg N ha⁻¹.