Interactive Effects of Water Management and Controlled Release Nitrogen Fertilizer on Dry Matter and Nitrogen Accumulation and Distribution in Summer Maize (*Zea mays* L.)

Bin Zhao, Shuting Dong, Jiwang Zhang, Peng Liu, Tony J. Vyn

Agronomy College of Shandong Agricultural University / State Key Laboratory of Crop Biology, Tai'an, China

Agronomy Department of Purdue University , West Lafayette, USA

Please contact: zhaobin@sdau.edu.cn; tvyn@purdue.edu

Introduction

The total production capacity of maize has greatly advanced because of genetic improvements and management changes that have often included an increase of fertilizer inputs (Russell, 1991; Duvick, 1992; Tollenaar, 2002, 2006). Unfortunately, maize production in Huanghuaihai plain is traditionally associated with high N fertilization which has resulted in NO_3^- groundwater contamination in some areas (Mi G H, 2010). Meanwhile, maize grown in northern China is often influenced by soil water loss problems, and drought stress substantially reduces plant yield. Therefore, effective water management for agricultural production in water-scarce regions requires the application of innovative and sustainable approaches. Due to economic factors and environmental concerns, balancing fertilizer input and output has received a lot of attention. Some studies have suggested that optimum N management can improve the accumulation, transportation, and distribution rate of the dry matter of summer maize, thereby also improving the utilization rate of N (Zhao B, 2010; Teixeira, 2014; Paponov, 2005; Duan Y, 2011), which would undoubtedly increase labor input regardless of the type of N fertilizer management technique employed. Controlled-release fertilizer (CRF) is a possible alternative to common compound fertilizer (CCF) to increase N uptake efficiency and minimize N losses to the environment (Medina, 2008). Because the nitrogen release rate of slow release fertilizer can match the crop physiological requirements for N, the option of a single N application with controlled release N fertilizers can reduce labor and application costs. At the same time, slow release fertilizer can effectively increase the utilization rate of nitrogen and production efficiency (Zhang M, 2001; Zhao B, 2012). However, few studies have discussed how to coordinate the relationship between slow/controlled release fertilizer and water management, so as to increase the yields of summer maize, improve NUE, and reduce the labor input. There has been a particular gap with regard to the interactive effects of water and slow/controlled release fertilizer application amounts. Therefore, further research and development in applications of slow release fertilizer were desirable.

Objectives

- To determine interactive effects of water and N stresses on N absorption, translocation, and distribution in maize during its primary growth period, and the various relationships with yield.
- To provide information about optimum production management techniques for N fertilizer as it relates to water conservation and the production of high yields.

Materials and methods

Experimental design

Summer maize hybrid Zhengdan 958 (released in 2000) was planted during 2012 and 2013 at Shandong Agricultural University. The soil is classified as a silt loam. The study was an outdoor pot experiment with clay pots 35 cm in diameter, 45 cm high, protected with a rainout shelter used only on rainy days. Three water levels and four amounts of controlled release urea were carried out: severe water stress (W1:the moisture content was 35%±5% of the soil field capacity), mild water stress (W2: the moisture content was 55%±5% of the soil field capacity), normal water (W3: the moisture content was 75%±5% of the soil field capacity); N3 was 315 kg•ha^{-1} (N 4.68 g per pot), N2 was 210 kg•ha^{-1} (N 3.12 g per pot), N1 was 105 kg•ha^{-1} (N 1.56 g per pot) and N0 was no nitrogen. Using soil moisture meter TDR controlled to determine the amount of water. The controlled release coated urea (Nitrogen content 42% and controlled release cycle for 3 months) used in the experiment was developed by College of Resources and Environment at Shandong Agricultural University. Each treatment also received P_2O_5 at 105 kg•ha^{-1} plus K_2O at 210 kg•ha^{-1}. Maize was sown on June 18 in both years. All fertilizers were applied by hand in a band 8-cm deep and 10-cm from maize plants (in-furrow) as a basal dose.

Plant Sampling and N Content Determination

Two representative plant samples were obtained from each treatment at the beginning of the blooming period and once over 10 day intervals. Samples were dried at 80℃ in a force-draft oven to a constant weight and were then weighed after they had been separated into sheath, stalk, leaf, tassel, bract, cob, and grain portions. After weighing, the samples were ground using a grinder with a 0.5 mm mesh. The N concentrations in different organs were then measured using the micro-Kjeldahl method (CN61M/KDY-9820; Beijing, China). The following parameters (Moll, 1982; Huggins, 1993) were calculated:

Plant N uptake (g plant^{-1}) = the plant N concentration × the weight of the dry plant matter

Nitrogen harvest index (NHI, %) = the grain N content/the whole-plant N content

Agronomic NUE (ANUE, kg kg^{-1}) = [grain weight (fertilizer) – grain weight (no fertilizer)]/N fertilizer applied

Apparent recovery efficiency of applied N (RE_N, %) = [N uptake at Nx – N uptake at N0]/applied N at Nx × 100%

Physiological NUE (PNUE, kg kg^{-1}) = [grain weight (fertilizer) – grain weight (no fertilizer)]/[plant N (fertilizer) – plant N (no fertilizer)]

Soil nitrogen dependency ratio (SNDR, %) = plant N (no fertilizer)/plant N (fertilizer)

Plant harvest

At the mature stage, five plants were manually harvested per treatment. Rows per ear (RE), kernels per row (KR) and kernels per ear (KE) were counted.

Results

1、Effects of water conditions and controlled release urea on grain yield and yield components in summer maize

Table 1. Effects of water conditions and controlled release urea on yield and yield components in summer maize.

Treatments	Row number	Kernels per row	Ear Length (cm)	Kernels per ear	Wt. per 1000-kernel (g)	Yield per plant (g)		
						2013	2014	Average
W1N0	15.5 cd	19.0 e	11.8d	294.5 g	277.7 c	76.9 f	85.2 f	81.1f
W1N1	18.0 ab	21.0 de	12.5d	378.0 f	253.1 d	87.0 e	105.8 e	96.4 e
W1N2	19.0 a	22.5 d	13.2c	427.5 e	244.3 e	88.4 e	107.8 e	98.1 e
W1N3	16.0 c	26.0 bc	15.0b	416.0 e	254.8 d	93.0 de	113.8 d	103.4 d
W2N0	18.0 ab	23.5 cd	13.8c	423.0 e	277.2 c	104.7 d	109.7 d	107.2 d
W2N1	18.0 ab	25.3 c	15.3b	455.9 d	310.3 a	119.3 c	126.2 c	122.8 c
W2N2	18.0 ab	26.0 bc	15.0b	468.0 cd	314.8 a	123.1 c	133.5 c	128.3 c
W2N3	18.4 a	30.5 b	15.0b	561.2 a	294.8 b	138.7 ab	156.6 ab	147.7 ab
W3N0	16.0 c	30.0 b	15.8b	480.0 c	291.6 b	118.8 c	128.7 c	123.8 c
W3N1	16.6 b	30.9 b	16.8a	512.9 b	295.6 b	130.9 b	154.7 b	142.8 b
W3N2	16.8 b	34.3 a	17.9a	576.7 a	315.5 a	144.7 a	168.0 a	156.4 a
W3N3	16.0 c	35.0 a	17.5a	560.0 a	321.7 a	144.0 a	162.0 a	153.0 a

W1: severe water stress; W2: mild water stress; W3: normal water condition; N0: no nitrogen; N1: N application of 105 kg hm^{-2}; N2: N application of 210 kg hm^{-2}; N3: N application of 315 kg hm^{-2}. In each data area, different letters within the same column indicate significant difference among treatments at *P*<0.05.

Table 2. Analysis of variance for effects of water conditions and controlled release urea on yield in summer maize.

Variation source	*SS*	*df*	*MS*	*F*-value	Significance level
Block	22.565	3	7.522	2.950*	0.04694
Water	19939.732	2	9969.866	101.640**	0.00002
Nitrogen	4125.286	3	1375.095	14.019**	0.00405
Nitrogen × water	588.539	6	98.090	38.473**	0
Error	84.135	33	2.550		

* and ** indicate significant difference at the 0.05 and 0.01 levels of probability, respectively.

5、Nitrogen production and utilization efficiency in summer maize

Table 3. Effects of water conditions and controlled release urea on nitrogen use efficiency in summer maize in 2013

Treatment	Grain yield (kg hm^{-2})	NHI (%)	ANUE (kg kg^{-1} N)	RE_N (%)	PNUE (kg kg^{-1} N)	SNDR (%)
W1N0	4610 f	68.0 a				
W1N1	5220 e	69.3 a	5.8 d	30.8 b	18.9 d	74.0 a
W1N2	5300 e	65.4 b	3.3 f	24.3 d	13.5 e	64.4 b
W1N3	5580 e	69.3 a	3.1 f	20.2 e	15.3 e	59.3 c
W2N0	6280 d	66.1 b				
W2N1	7160 c	65.8 b	8.3 b	36.6 a	22.7 bc	74.5 a
W2N2	7390 c	65.1 bc	5.3 de	26.0 c	20.2 c	67.3 b
W2N3	8320 ab	63.8 c	6.5 c	26.2 c	24.7 b	57.7 c
W3N0	7130 c	63.9 c				
W3N1	8150 d	61.0 d	9.7 a	33.5 a	29.1 a	79.5 a
W3N2	8680 a	62.7 d	7.4 bc	30.9 b	24.0 b	67.7 b
W3N3	8640 a	60.5 d	4.8 e	22.9 de	20.9 c	65.3 b
Average						
W1	5180 c	68.0 a	4.1 b	25.1 a	15.9 b	65.9 b
W2	7290 b	65.2 b	6.7 a	29.6 a	22.6 a	66.5 b
W3	8150 a	62.1 c	7.3 a	29.1 a	24.7a	70.8 a
F-value						
W	111.54**	13.69**	8.36*	3.33	8.83*	6.34
F	14.61**	0.65	7.95*	15.51*	2.13	51.43**
W×F	469.19**	120.78**	87.86**	286.73**	23.06**	840.01**

Abbreviations are the same as those given in Table 1. In each data area, different letters within the same column indicate significant difference among treatments at *P*<0.05.

2、Dry matter accumulation under different water and N conditions

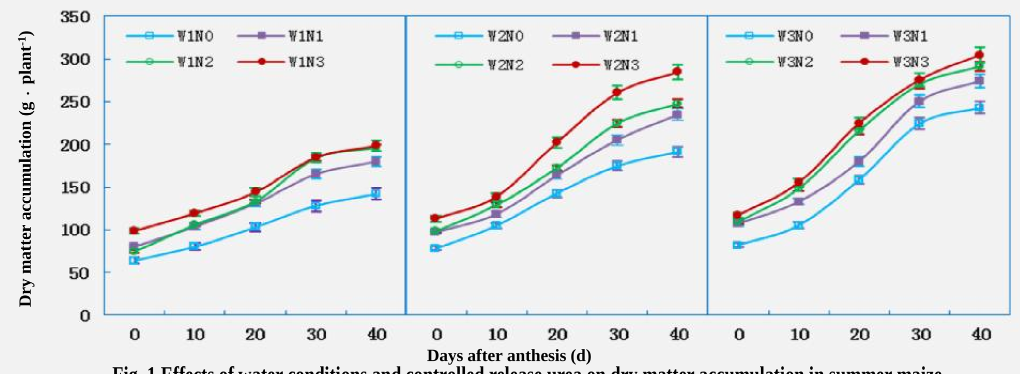

Fig. 1 Effects of water conditions and controlled release urea on dry matter accumulation in summer maize

3、Treatment influences on N accumulation in the total plant

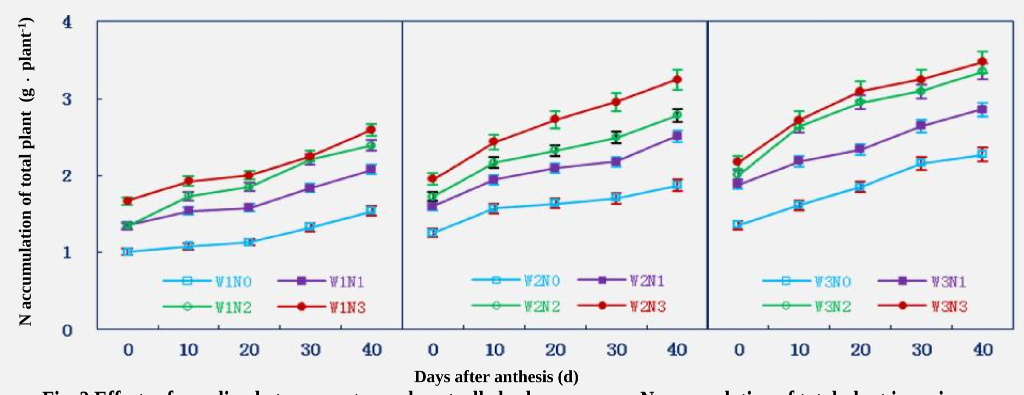

Fig. 2 Effects of coupling between water and controlled release urea on N accumulation of total plant in maize

4、Nitrogen accumulation and proportion of total plant N in different organs

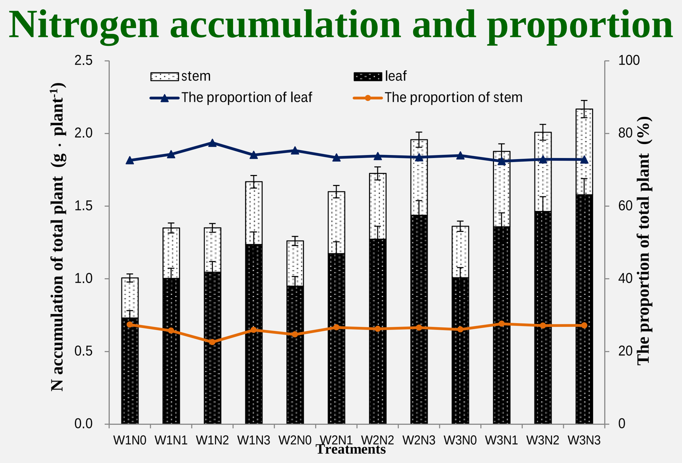

Fig. 3 N accumulation and proportion of leaf and stem in the total plant at tasseling

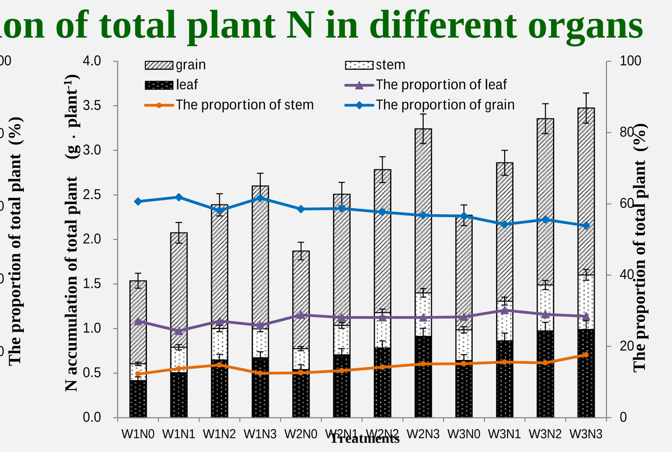

Fig. 4 N accumulation and proportion of leaf , stem and grain in the total plant at mature stage

Conclusion

- Controlled release urea and water had significant interactive effects on N absorption, translocation, distribution, and efficiency in summer maize, and water was the main factor.
- Optimum management of both water and N improved N accumulation in summer, and coordinated N distribution and accelerated N translocation to the ears, increased the dry matter accumulation and yield in summer maize, especially the yield components of kernels per ear and weight per 1000-kernel.
- This study found that the controlled release urea N application rate of 210 kg ha^{-1} was the best treatment when the soil moisture content was 75%± 5% of the field capacity. We suggest that a coupling of controlled release urea N application rate of 315 kg ha^{-1} with maintaining soil moisture content of 55%± 5% of field capacity is optimal.

Acknowledgments

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