Supplementary information

Application of Blended Controlled-Release and Normal Urea with Suitable Maize Varieties to Achieve Integrated Agronomic and Environmental Impact in a High-Yielding Summer Maize System

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Plant and fertilizer measurement and analysis

The ear numbers, grain numbers, and hundred-grain weight (HGW) and aboveground N uptake were determined according to previous research (Guo et al., 2017). The nitrogen release of CRU was measured using a static water (25°C) releasing test in the laboratory (Yang et al., 2009) and the buried bag method in the farmfield (Kaneta et al., 1994). In the laboratory method, 10 g of CRU samples with three replications were placed in a 100-mesh nylon bag in a plastic bottle with 500 mL deionized water in it. Solution samples were collected at 1, 3, 7, 14, 28, 42, 56, and 84 days, and the released N was tested using ultraviolet spectrophotometry. In the maize field, 39 mesh bags with 10 g CRU were buried in a field with the same soil conditions as those used for the maize growing stage, and 3 bags were randomly collected every 20 days after seeding. The bags were washed with deionized water to remove the soil, then the CRU particles were placed in a vacuum oven at 60°C for 48 h, and then the particles were weighed to determine the nitrogen release rate of CRU (Kaneta et al., 1994, Wilson et al., 2009).

Data collection and Nr losses model establishment

To ensure the accuracy of the Nr losses based on the LCA method, site-specific Nr losses (e.g., NH_3 volatilization, N leaching, and N_2O emission) were collected from peer-reviewed publications in the North China Plain (NCP).

To minimize bias, the studies needed to meet to the following criteria:

i. Indicators were measured in field experiments with replications.
ii. Nr losses were measured during the entire growth stage (from the seeding stage to harvest stage).
iii. The experiments included the CRU plots and common urea plots under the same N application rate, and the other management practices were the same for the two N type plots.
iv. The N_2O emissions were measured with the closed chamber method, and NH_3 volatilization was measured with either the micrometeorological method or the wind tunnel method. Using collected localized databases, Nr loss models were developed based on the relationships between N_2O emissions, NH_3 volatilization, and N application rate (there were not enough available data for N leaching). A linear or exponential regression analysis

was chosen to identify the best-fit curve, and the adjusted R^2 values were used for the model selection.

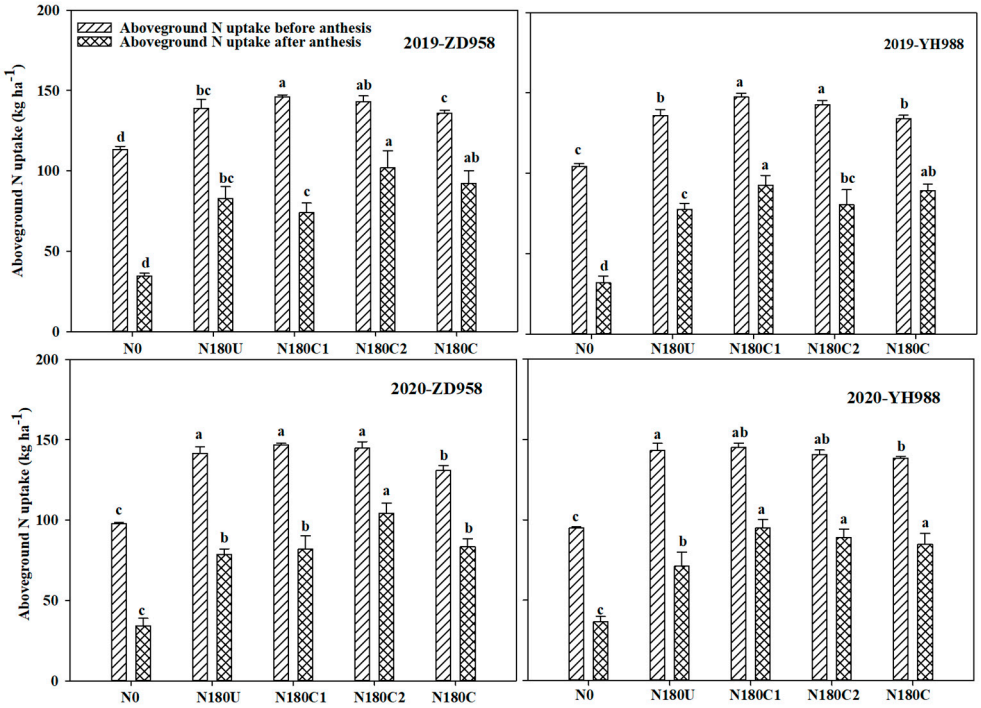

Figure S1. Aboveground N uptake before and after anthesis under different N rates and resources for varieties ZD958 and YH988 in 2019 and 2020. N0, no N; N180U, urea-N, 180 kg N ha^{-1}, applied twice before seeding and at the 6-leaf stage; N180C1, ratio of controlled release nitrogen to urea nitrogen is 1:2, 180 kg N ha^{-1}; N180C2, ratio of controlled release nitrogen to urea nitrogen is 2:1, 180 kg N ha^{-1}.

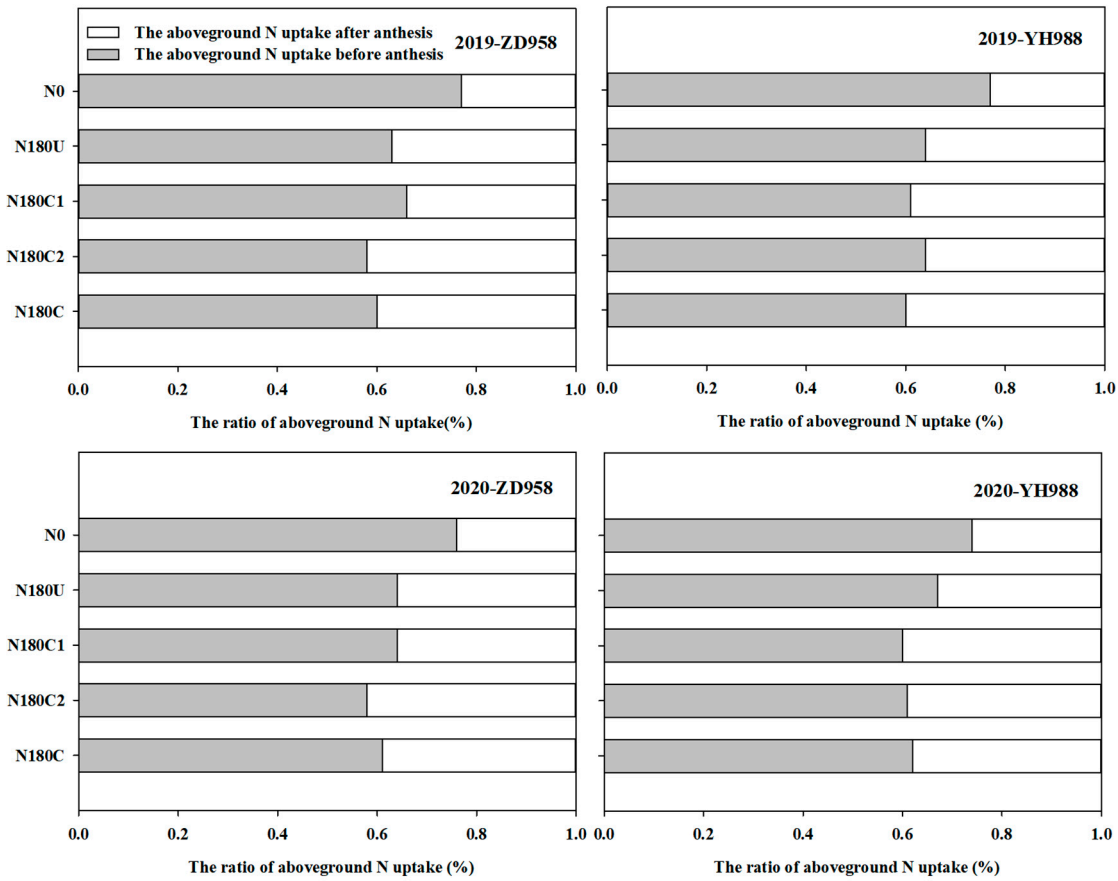

Figure S2. Percentage of aboveground N uptake before and after anthesis under different N rates and resources for varieties ZD958 and YH988 in 2019 and 2020. N0, no N; N180U, urea-N, 180 kg N ha^{-1}, applied twice before seeding and at the 6-leaf stage; N180C1, ratio of controlled release nitrogen to urea nitrogen is 1:2, 180 kg N ha^{-1}; N180C2, CRU-N: urea-N=2:1, ratio of controlled release nitrogen to urea nitrogen is 1:2,180 kg N ha^{-1}.

Table S1. Reactive N emission and GHG emission factors for the product and transport of various agricultural inputs in a summer maize production system.

Item	Unit	Reactive N emission (10^{-3} kg N $unit^{-1}$)	GHG emissions (kg CO_2 eq $unit^{-1}$)	References
Urea product and transport	kg N	7.15	8.30	Zhang et al., 2013; Yue, 2013
CRU product and transport	kg N	7.15	9.02	Zhang, 2019
P product and transport	kg P_2O_5	0.184	0.79	Cui et al., 2013; Yue, 2013
K product and transport	kg K_2O	0.146	0.55	Cui et al., 2013; Yue, 2013
Herbicide product and transport	kg	4.69	19.13	Williams et al., 2006; Clark et al., 2016
Electricity for irrigation	kWh	1.97	0.95	Huang et al., 2013; Yue, 2013
Diesel fuel	L	2.86	3.75	Yue, 2013; Pishgar-Komleh et al., 2013

Agricultural materials	P fertilizer (kg P_2O_5 ha^{-1})	K fertilizer (kg K_2O ha^{-1})	Pesticides (kg ha^{-1})	Diesel fuel (L ha^{-1})	Electricity for irrigation (kWh)
Rate	90	90	4.55	70	1330*

Note: *Value is the electricity used for irrigation, which was calculated by the irrigation electricity use quantity (532 kWh per irrigation in the NCP) multiplied by average irrigation time (2.5 time) across the two growing seasons.

Table S2. Two-way analysis of variance of the nitrogen (N) level and N source on grain yield, varieties, N footprint, and C footprint of summer maize in the 2019 and 2020 growing seasons.

Source of variation	Grain yield		N footprint		C footprint	
	2019	2020	2019	2020	2019	2020
N level (L)	***	***	***	***	***	***
Variety (V)	ns	ns	ns	ns	ns	ns
L*V	*	ns	ns	ns	ns	ns

Source of variation	Grain yield		N footprint		C footprint	
	2019	2020	2019	2020	2019	2020
N resource (R)	***	***	***	***	***	***
Variety (V)	ns	ns	ns	ns	ns	ns
L*V	*	*	ns	ns	ns	ns

Note: *and *** indicate significant difference at *P<0. 05* and *<0.001*, respectively; ns indicates no significant difference.

Table S3. Ear numbers, grain numbers, and hundred-grain weight of summer maize in the 2019 and 2020 growing seasons.

Varieties	N treatment	2019			2020		
		Ear numbers (plant·ha^{-1})	Grain numbers per ear	Hundred grains (g)	Ear number (plant·ha^{-1})	Grain number per ear	Hundred grains (g)
ZD958	N0	65740 a	418.74 c	30.86 a	62037 a	424.67 b	30.79 c
	N180U	64814 a	522.93 ab	32.44 a	57407 a	591.07 a	33.24 ab
	N180C1	65740 a	479.44 b	33.76 a	60185 a	606.27 a	33.64 ab
	N180C2	65740 a	534.64 a	34.08 a	63889 a	614.67 a	34.40 a
	N180C	65740 a	519.73 ab	31.98 a	60185 a	598.67 a	32.56 b
YH988	N0	61111 a	384.33 b	30.85 a	60185 a	410.67 c	29.35 d
	N180U	65740 a	491.33 a	32.84 a	62037 a	585.87 b	32.55 bc
	N180C1	67592 a	528.69 a	32.89 a	60185 a	640.80 a	34.19 a
	N180C2	65740 a	515.33 a	32.58 a	59295 a	619.73 ab	33.13 b
	N180C	64815 a	512.73 a	31.84 a	57407 a	605.33 ab	32.05 c
Source of variation							
Nitrogen application (N)		ns	**	ns	ns	***	*
Variety (V)		ns	ns	ns	ns	*	ns
N*V		ns	ns	ns	ns	ns	ns

N0, no N; N180U, urea-N, 180 kg N ha^{-1}, applied twice before seeding and at the 6-leaf stage; N180C1, ratio of controlled release nitrogen to urea nitrogen is 1:2, 180 kg N ha^{-1}; N180C2, ratio of controlled release nitrogen to urea nitrogen is 2:1, 180 kg N ha^{-1}.

*, **, and *** indicate significant difference at *P<0. 05*, *<0.01*, and *<0.001*, respectively; ns indicates no significant difference. Means followed by the same lowercase letter are not significantly.

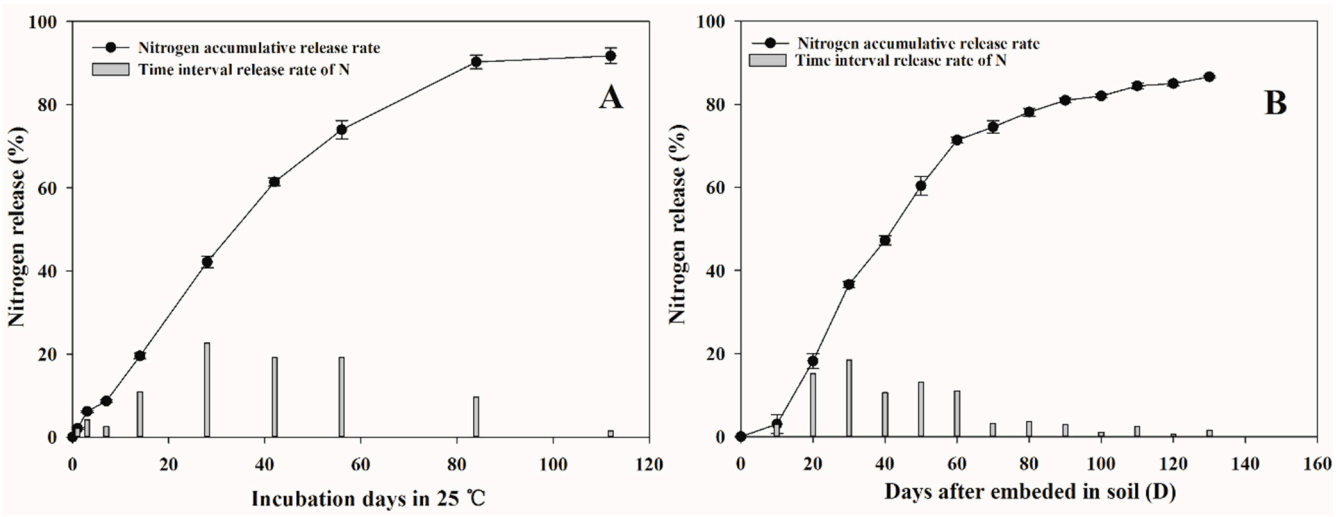

Figure S3. Release of CRU accumulatively and per time interval in 2019 in (A) laboratory water (25°C) and (B) the field.

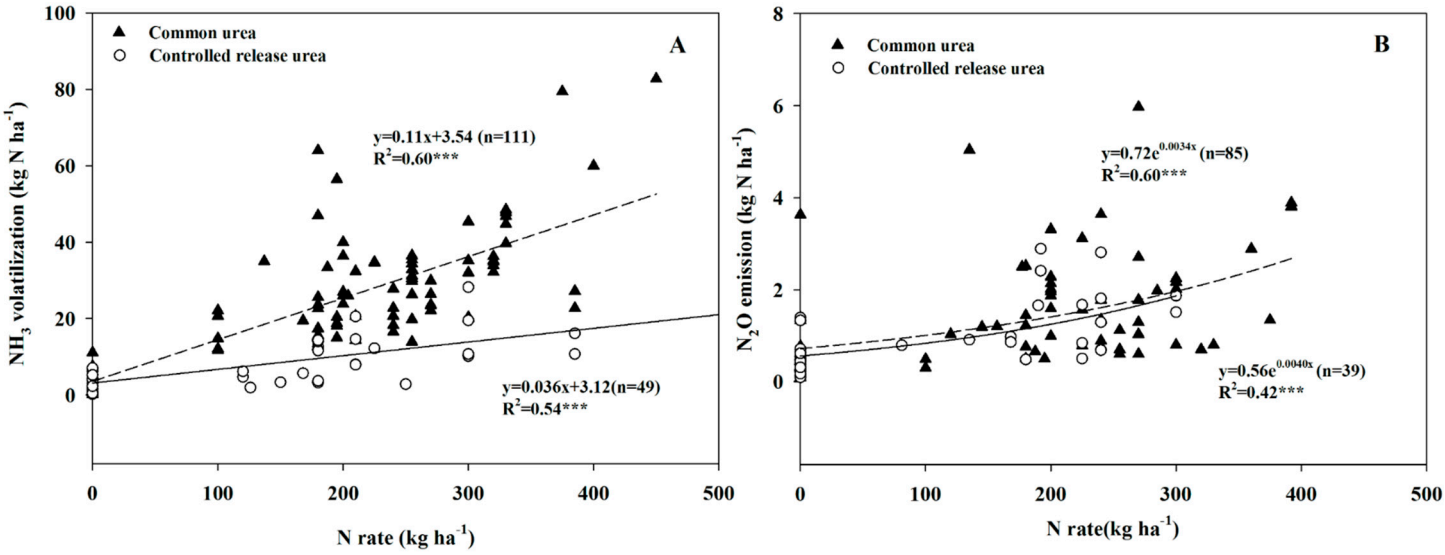

Figure S4. Relationships between N rate and (A) NH_3 volatilization, (B) N_2O emissions with common urea (black solid circles and solid line) and controlled release urea (hollow triangles and circles and dotted line) for summer maize production. *** indicates significance at $P < 0.001$.

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