

Table S1. Basic physical and chemical properties (0–20cm) of soil in 2018.

Site	Total N (g kg ⁻¹)	Olsen-P (mg kg ⁻¹)	NH ₄ OAcK ⁺ (mg kg ⁻¹)	Organic matter (g kg ⁻¹)	pH	N min (kg ha ⁻¹)
N0	0.60	36.3	113.3	13.1	7.7	19.6
N60	0.60	29.5	109.7	12.0	7.8	25.4
N120	0.48	26.2	95.4	10.0	8.0	47.2
N180	0.61	30.1	109.7	13.6	7.9	108.5
N240	0.51	27.0	99.0	13.3	7.6	87.0
N300	0.45	27.4	84.7	15.0	7.6	128.0

Table S2. The hybrids information

Type	Hybrid	Breeding time	RM day	Grain type
National Judged Variety	JQ202	2008	126 ^a	Yellow, Semi-dent ^a
	KY188	2018	128 ^a	Yellow, Semi-dent ^a
	ZD958	1996	130 ^a	Yellow, Semi-dent ^a
	XY335	2000	127 ^a	Yellow, Semi-dent ^a
Crossing combination	NE30	2015	128 ^b	Yellow, Semi-dent ^b
	NE31	2016	127 ^b	Yellow, Semi-dent ^b

a: Data from (<http://202.127.42.47:6006/Home/BigDataIndex>)

b: Data from breeding group of China Agricultural University

Table S3. Definitions of the features extracted from different sensors.

Sensor/info.	No. of features	Features	Formula	References
MS	25	Green (G), Red (R), Red-edge (RE), Near-infrared (NIR)	/	/
		Green Difference Vegetation Index (GDVI)	$NIR - G$	[37]
		Green Normalized Difference Vegetation Index (GNDVI)	$(NIR - G)/(NIR + G)$	[38]
		Normalized Red Edge Index (NREI)	$RE/(NIR + RE + G)$	[39]
		Normalized Red Index (NRI)	$R/(NIR + RE + R)$	[40]
		Modified Enhanced Vegetation Index (MEVI)	$2.5 * (NIR - RE)/(NIR + 6 * RE - 7.5 * G + 1)$	[39]
		Modified Normalized Difference Red Edge (MNDRE)	$[NIR - (RE - 2 * G)]/[NIR + (RE - 2 * G)]$	[39]
		Normalized Difference Vegetation Index (NDVI)	$(NIR - R)/(NIR + R)$	[41]
		Renormalized Difference Vegetation Index (RDVI)	$(NIR - R)/SQRT(NIR + R)$	[42]
		Normalized Difference Red Edge (NDRE)	$(NIR - RE)/(NIR + RE)$	[43]
		Red Edge Point Reflectance (REPR)	$(R + NIR)/2$	[44]
		Red Edge Difference Vegetation Index (REDVI)	$NIR - RE$	[39]
		Red Edge Re normalized Different Vegetation Index (RERDVI)	$(NIR - RE)/SQRT(NIR + RE)$	[39]
		Red Edge Soil Adjusted Vegetation Index (RESAVI)	$1.5 * [(NIR - RE)/(NIR + RE + 0.5)]$	[39]
		Red Edge Simple Ratio (RESR)	RE/R	[45]
		Modified Red Edge Difference Vegetation Index (MREDVI)	$RE - R$	[39]
		MERIS Terrestrial Chlorophyll Index (MTCI)	$(NIR - RE)/(RE - R)$	[44]
		Modified Red Edge Simple Ratio (MRESR)	$(NIR - R)/(RE - R)$	[40]
		Modified Normalized Difference Red Edge (MNDRE2)	$(NIR - RE + 2 * R)/(NIR + RE - 2 * R)$	[40]
		Red Edge Transformed Vegetation Index (RETVI)	$0.5 * [120 * (NIR - R) - 200 * (RE - R)]$	[40]

Table S3. content

Sensor/info.	No. of features	Features	Formula	References
GC	1	Modified Chlorophyll Absorption in Reflectance Index 3 (MCARI3)	$[(\text{NIR} - \text{RE}) - 0.2 * (\text{NIR} - \text{R})] * (\text{NIR} / \text{RE})$	[40]
		Modified Transformed Chlorophyll Absorption in Reflectance Index (MTCARI)	$3 * [(\text{NIR} - \text{RE}) - 0.2 * (\text{NIR} - \text{R}) * (\text{NIR} / \text{RE})]$	[40]
		MCARI2/OSAVI	MCARI2/OSAVI	[40]
		Vegetation fraction (%)	(Number of crop pixels in the plot)/(Total number of the plot pixels)*100	[46]
Texture Info. (G, R, RE, NIR)	6	Gray-level co-occurrence matrix (GLCM)	VA, HO, CO	[47]

Table S4. ANOVA of aboveground measured traits.

Source	V6 stage				V9 stage				V12 stage				R3 stage
	AGB (t ha ⁻¹)	PNC (g kg ⁻¹)	PNU (g kg ⁻¹)	NNI	AGB (t ha ⁻¹)	PNC (g kg ⁻¹)	PNU (g kg ⁻¹)	NNI	AGB (t ha ⁻¹)	PNC (g kg ⁻¹)	PNU (g kg ⁻¹)	NNI	Yield (t ha ⁻¹)
Y	***	***	***	***	***	***	***	***	***	***	***	***	***
N	***	***	***	***	***	***	***	***	***	***	***	***	***
G	***	***	***	**	***	***	***	*	**	**	ns	ns	***
Y*N	***	***	***	***	***	***	***	***	***	***	***	***	***
Y*G	*	ns	ns	ns	*	ns	**	*	ns	ns	ns	ns	*
N*G	ns	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
Y*N*G	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns

Y is year, N is nitrogen rate, G is different varieties. Aboveground biomass (AGB), plant N concentration (PNC), plant N uptake (PNU), N nutrition index (NNI) and Yield across two years (Y), six N rates (N), and six genotypes (G). *, **, and *** indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$ probability levels, respectively. ns was non-significant difference ($P > 0.05$).

Table S5. The ANOVA analysis of linear and linear plus plateau model.

		2018		2019	
	Hybrid	Linear	Linear plus plateau	Linear	Linear plus plateau
		R ²	R ²	R ²	R ²
RY_N	NE30	0.44**	0.90***	0.57***	0.92***
	JQ202	0.49**	0.93***	0.51**	0.90***
	KY188	0.41**	0.92***	0.57***	0.93***
	ZD958	0.50**	0.75***	0.51**	0.92***
	NE31	0.56***	0.79***	0.65***	0.91***
	XY335	0.65***	0.91***	0.74***	0.83***
NNI_N	NE30	0.39**	0.62**	0.82***	0.80***
	JQ202	0.35*	0.70**	0.71***	0.87***
	KY188	0.52**	0.86***	0.88***	0.84***
	ZD958	0.33*	0.84***	0.84***	0.87***
	NE31	0.46**	0.83***	0.88***	0.89***
	XY335	0.63**	0.89***	0.84***	0.84***
RY_NNI	NE30	0.39**	0.77***	0.84***	0.95***
	JQ202	0.32*	0.75***	0.60**	0.76**
	KY188	0.52**	0.87***	0.87***	0.86***
	ZD958	0.41*	0.57*	0.81***	0.87***
	NE31	0.46**	0.69***	0.86***	0.84***
	XY335	0.72***	0.96***	0.84***	0.61**

RY_N, NNI_N and RY_NNI represents the relationship between RY and N, NNI and N, RY and NNI, respectively. *, **, and *** indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$ probability levels, respectively. ns was non-significant difference ($P > 0.05$).

Table S6. The AONR calculated by yield and NNI for 2018 and 2019.

AONR	2018 (kg ha ⁻¹)				2019 (kg ha ⁻¹)				Average (kg ha ⁻¹)			
	Yield_M	Yield_S	NNI_M	NNI_S	Yield_M	Yield_S	NNI_M	NNI_S	Yield_M	Yield_S	NNI_M	NNI_S
NE30	63.1	65.2	71.8	77.7	79.2	76.5	84.5	66.8	71.2	70.9	78.1	72.3
JQ202	65.4	65.0	76.2	70.9	73.1	83.8	79.9	61.9	69.3	74.4	78.0	66.4
KY188	62.4	57.9	51	53.9	76.4	87.5	76.1	64.7	69.4	72.7	63.5	59.3
ZD958	68.0	69.6	63.7	56.8	86.8	88.4	95.9	101.3	77.4	79	79.8	79.0
NE31	93.5	72.0	102.6	90.0	86.3	74.9	99.6	91.4	89.9	73.4	101.1	90.7
XY335	91.6	81.7	79.3	93.2	109.2	104.9	111.5	92.2	100.4	93.3	95.4	92.7
R ²	0.68		0.70		0.54		0.71		0.62		0.90	

Yield_M, Yield_S, NNI_M and NNI_S represents AONR calculated by measured yield, simulated yield, measured NNI, simulated NNI separately.

AONR is optimal nitrogen application rate.

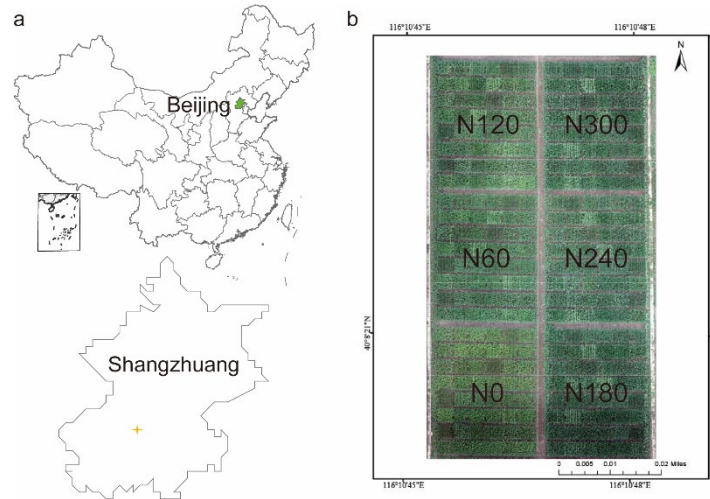


Figure S1. Information of experiment location

(a) The location of the experiment sites. **(b)** The experimental plot layout of different nitrogen rates.

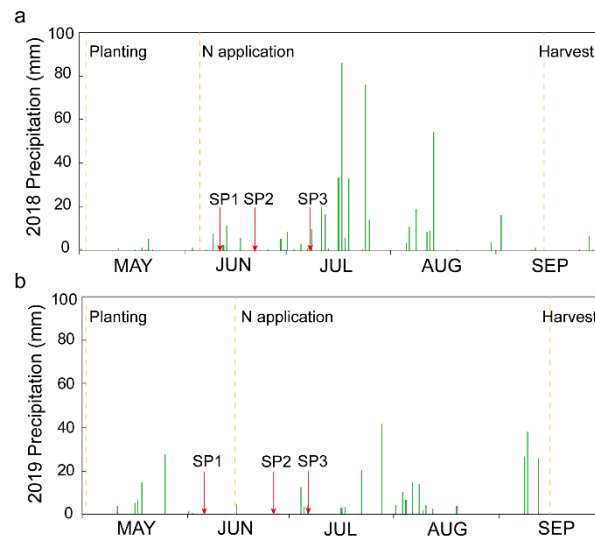


Figure S2. Daily precipitation information during the growing season.

2018 (a) and 2019 (b). SP represents sampling time of phenotype measurement, and the following numbers represent the sampling order

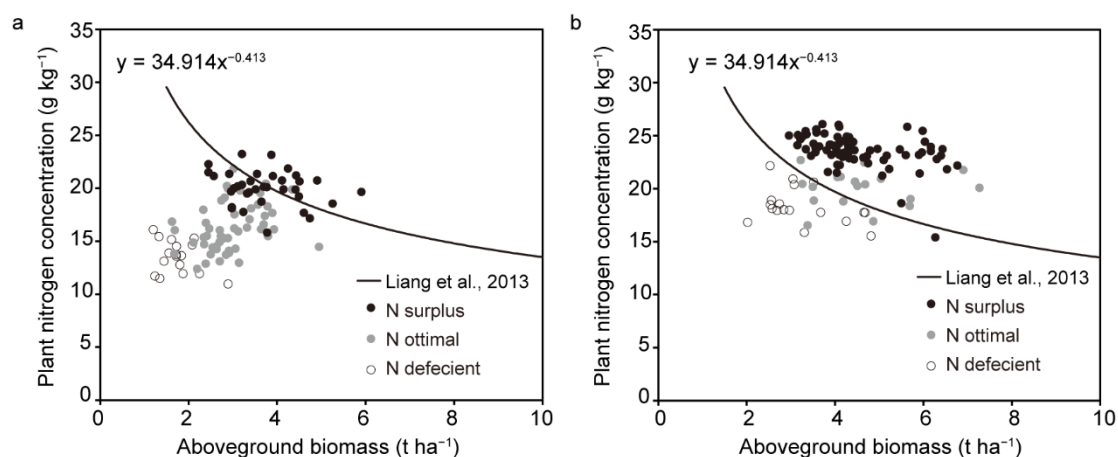


Figure S3. Evaluation of the existing critical N dilution curve for spring maize in North China with measurement phenotype.

(a) in 2018 and (b) 2019. Plant N concentration and biomass data under N0 treat was defined as deficient, N60 was optimal, and N120–N300 was surplus N120–N300 conditions The critical N dilution curve was developed for spring maize by previous study (Liang et al. 2008; $N_c = 36.914W^{-0.413}$

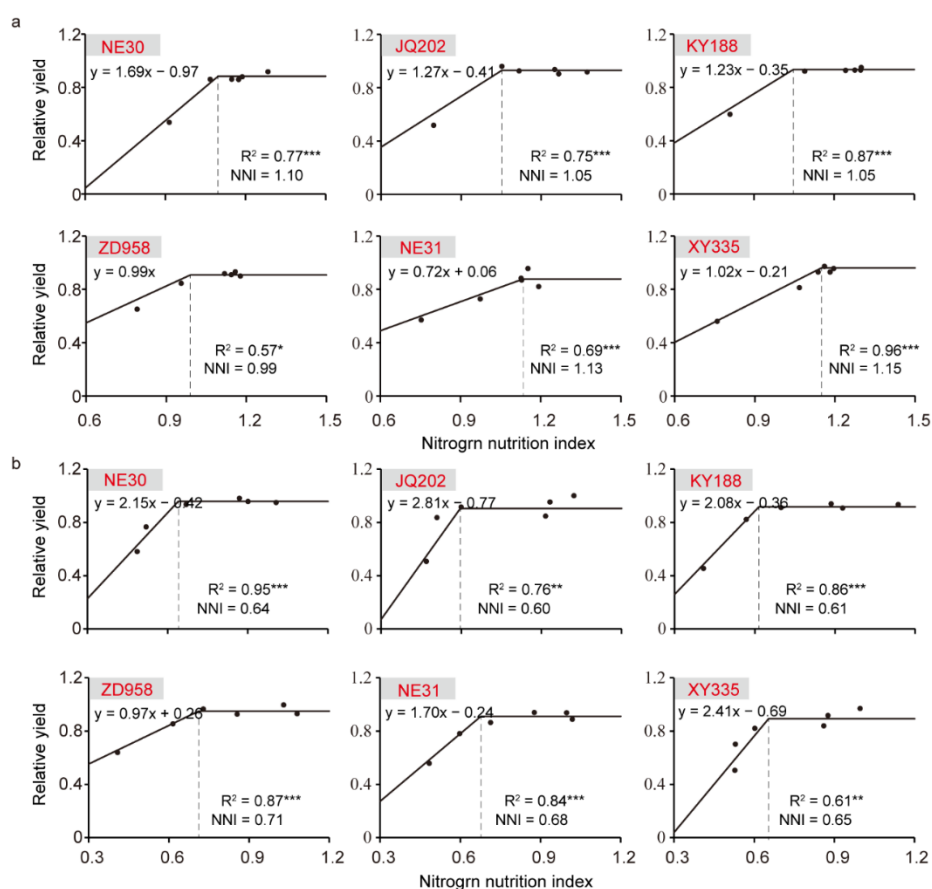


Figure S4. Identification of the threshold of nitrogen nutrition index (NNI).

Relationships between relative yield and NNI for different varieties in 2018 (a) and 2019 (b). The inflection point of the linear plus platform equation is defined as the threshold value of the NNI.

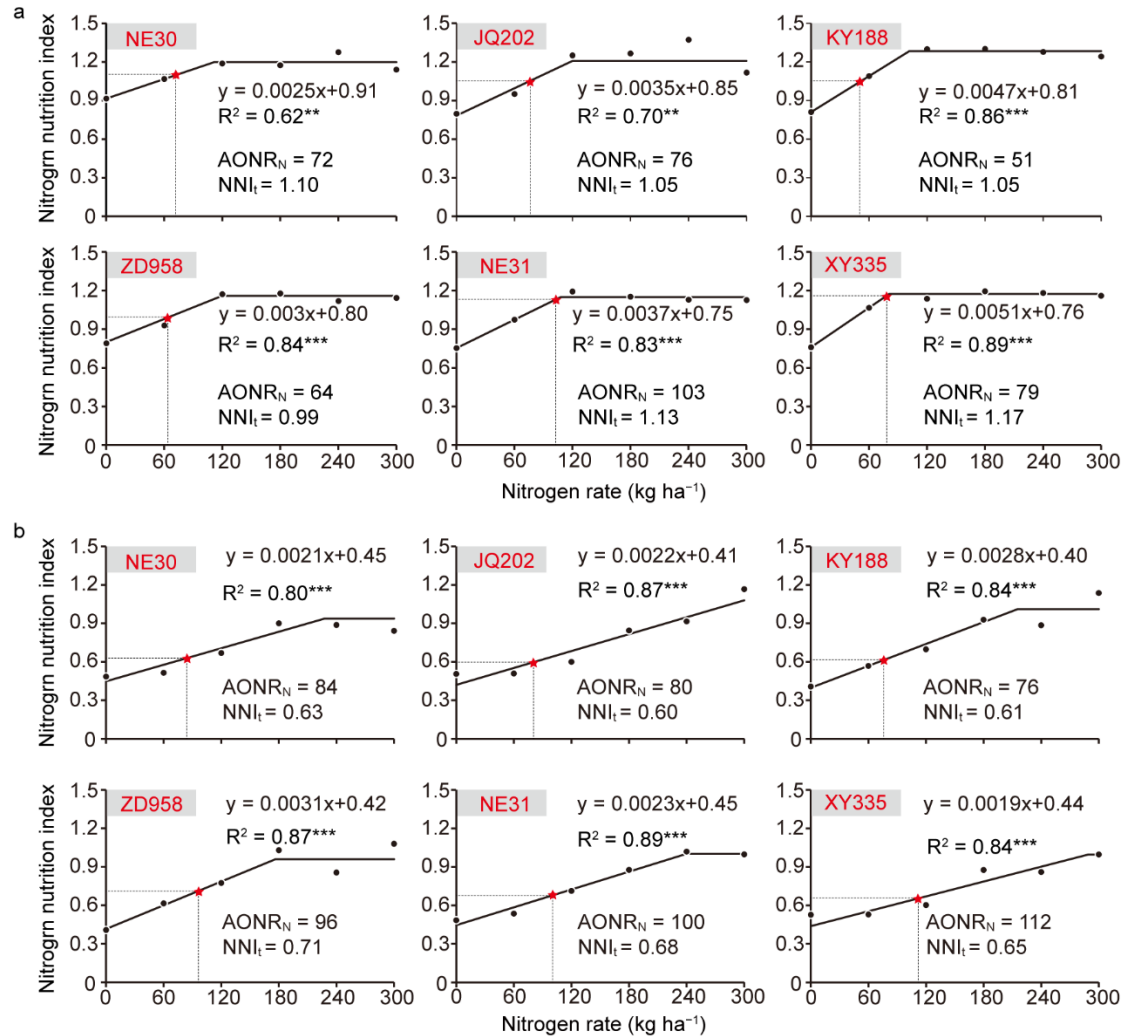


Figure S5. The response of NNI to nitrogen application rate for each variety.

(a) The V9 stage in 2018 and (b) in 2019. The abscissa of the red dot represents the NNI threshold of each species, and the corresponding ordinate represents the optimal fertilization (AONR) based on the NNI threshold. These data were based on three replicates of each hybrid.