Supplementary Information

Addressing Nitrogenous Gases from Croplands Toward Low-Emission Agriculture

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Supplementary Methods

We searched recent five-year publications from ScienceDirect, Web of Science, PubMed, Agricultural & Environmental Science Database, and Government Reports up to August 20th, 2021. The Government Reports include legislation, executive orders, climate change mitigation plans, GHG inventories, and their associated appendices. The Subject Heading terms of 'Ammonia', 'Nitrogen Oxide', 'Nitrous Oxide', 'Crop', 'Emission', 'Fertilization', and their synonyms were used during the searching process. Types of article included peer-reviewed research, letter, and review studies. Three researchers (SYP, CF, CTC) screened the titles and abstracts independently, reviewed thoroughly for their eligibilities, and then determined about 170 full-text articles with up-to-date information and/or available inventory data (of which ~65 contained inventory/experimental data used to compile the figures/tables/inferences here in this paper). Original studies with the following information were included: (a) effect of agricultural management practices on nitrogen use efficiency; (b) effect of management practices and fertilization on nitrogenous gas emissions; (c) agricultural nitrogen cycle. For the inventory data of reactive nitrogen emissions, **Supplementary Table 1** compiles the background information of the field experiments from the reviewed papers.

Supplementary Table 1. Background Information of the reviewed literature with respect to site and fertilization scheme.

Location	Type of Crop	Year	Fertilization Scheme [a]	Indicators	Field Observations	Improved Management Practices	Ref.
China	Rice		-	NUE	Yes	-	1
China	Rice		-	NUE	Yes	-	2
China	Rice		U	NUE	Yes	-	3
China	Rice		U	NUE	Yes	SRF	4
China	Rice		U	NUE	Yes	SRF	5
China	Rice	2010	U or ADS	NH_3, N_2O	Yes	-	6
China	Rice	2018–2019	U	NH_3	Yes	UI	7
China	Rice	2020	U	NH_3	Yes	BCL	8
China	Rice	2012	U	NO, N_2O	Yes	BC	9
China	Rice [c]	2012–2014	U	NO, N_2O	Yes	MN	10
China	Rice	2014	U	N_2O	Yes	-	11
China	Wheat		-	NUE	Yes	-	12
China	Wheat		U	NUE	Yes	MB	13
China	Corn/Lettuce/Cabbage	2015–2016	U	N_2O	Yes	NI and/or BC	14
China	Corn		U	NUE	Yes	SRF	15
China	Onion	2009–2010	SF	NUE, NO, N_2O	Yes	MN	16
China	Vegetables	2019	SF	NH_3	Yes	-	17
China [d]	Vegetable		SF	N_2O	Yes	MN	18
China	Cabbage	2010–2012	U	NH_3	Yes	OF	19
China	Cabbage	2005	U + CF (NPK)	NO	Yes	MN	20
China	Cabbage/Tomato/Soybean	2014	CF (NPK)	NO, N_2O	Yes	-	21
China	Cabbage/Radish/Garlic	2006	U + CF (NPK)	NO, N_2O	Yes	MN	22
China	Cucumber	2015–2016	U	NO, N_2O	Yes	MN	23
China	Peach	2012–2016	CF (NPK)	NH_3, N_2O	Yes	SRF	24
China	Banana	2010	U	N_2O	Yes	NI	25
China	Tea	2015–2016	U	NO, N_2O	Yes	MN and/or BC	26
Korea	Cabbage		U	NUE	Yes	Agrotain	27
Korea	Cabbage	Sep. 2006	CF (NPK)	NH_3, NO	Yes	-	28
Korea	Rice	Apr. 2020	-	NH_3	Yes	-	29
Korea	Cabbage	2009–2012	-	N_2O	Yes	-	30

Korea	Potato	2009–2012	-	N_2O	Yes	-	30
Japan	Cabbage	2003	U	NO	Yes	-	31
Japan	Cabbage	2000	U	NO	Yes	CRF	32
Japan	Cabbage	2012	SF	NO, N_2O	Yes	MN	33
Japan	Potato	2013	SF	NO, N_2O	Yes	MN	33
Japan	Rice	2013	ADS or AS	N_2O	Yes	-	34
Japan	Vegetable [e]	2007-2010	SF	N_2O	Yes	MN	35
Japan	Sugarcane	2017	AS	N_2O	Yes	-	36
Japan	Soybean	2012	U	N_2O	Yes	LN	37
Japan	Soybean	2017–2018	OC	N_2O	Yes	Cover crop	38
USA	Potato		U	NUE	Yes	-	39
USA	Sugarcane		U	NUE	Yes	HS	40
USA	Sugarcane	2012–2013	U or UAN	NH_3	Yes	-	41
USA	Sugarcane	2012–2013	U or UAN	N_2O	Yes	-	42
USA	Soybean-Corn	2004–2010	-	N_2O	Yes	Cover crop	43
Canada	Soybean-Corn	2012–2015	AN or MN	N_2O	Yes	Irrigation management	44
Canada	Soybean-Maize	2000–2006	CF	N_2O	Yes	Climate change effect	45
Canada	Soybean-Corn	2012–2013	-	2O	Yes	Drainage management	46
Brazil	Sugarcane		U [b]	NUE	Yes	HS	40
Brazil	Sugarcane	2013–2017	U / CAN	NH_3, N_2O	Yes	-	47
Brazil	Sugarcane	2015–2016	U	N_2O	Yes	-	48
Brazil	Sugarcane	2014–2015	U	N_2O	Yes	-	49
Brazil	Pineapple	2012–2014	U	NH_3	Yes	UI	50
Brazil	Corn	2017	-	NH_3	Yes	POF	51
Brazil	Corn	2017–2018	U or AN	N_2O	Yes	-	52
Brazil	Common Bean	2015	U	NH_3	Yes	-	53
Brazil	Soybean	2011–2013	AS / U	N_2O	Yes	Fallow management	54
Australia	Wheat	2008	U	NH_3	Yes	-	55
Australia	Barley	2008	U	NH_3	Yes	-	55
Australia	Sugarcane	2006–2007	U	NH_3, NO, N_2O	Yes	-	56
Australia	Banana	2014–2015	U	N_2O	Yes	-	57
Egypt	Banana	2017–2018	U	NH_3	Yes	SRF and/or OF	58
Iran	Soybean-Wheat	2014–2015	U	N_2O, CO_2	Yes	Rotation cropping	59
Argentina	Soybean	2011–2013	U	N_2O	Yes	Rotation cropping	60

Argentina	Soybean	2010–2012	-	N_2O	Yes	Fallow management	[61]
Mediterranean [d]	Rice		-	N_2O	Yes	-	[62]
Europe	Crops		-	NUE	Yes	-	[63]
Germany	Faba bean	2016–2018	CAN	N_2O	Yes	-	[64]
Italy	Faba bean	2013–2014	-	NH_3, N_2O	Yes	-	[65]
Italy	Corn	2018–2020	U	NH_3	Yes	ADS	[66]
Italy	Soybean	2015	-	N_2O	Yes	Tillage or Cover Crop	[67]

[a] U: urea; SF: synthesized fertilizers; HS: humic substances; MB: bentonite modified with humic substances; ADS: Anaerobic digestion slurry; MN: manure; AN: ammonium nitrate; UAN: urea ammonium nitrate; CAN: calcium ammonium nitrate; AS: ammonium sulphate; CF: composite fertilizer (NPK); SRF: slow release fertilizer; POF: pelleted organomineral fertilizer consisting of the combination of microalgae biomass and urea; UI: urea inhibitor; NI: nitrification inhibitor; BCL: the co-application of biogas slurry and low hydrothermal carbonization aqueous phase; OF: commercial organic fertilizer with poultry litter as the main component; BC: biochar; OC: Organic cultivation; LN: lime nitrogen. [b] 720 hr after foliar application of urea with humic substances. [c] ground cover rice production system under nearly saturated soil water content conditions. [d] Through a meta-analysis study. [e] crop rotation included potato, sweet corn, winter wheat, sugar beet and soybean for consecutive four years.

Supplementary Table 2. Characteristics of different crops with yields, the N uptake, the N surplus, and the nitrogen utilization efficiency from the reviewed literature.

Types	Region	Soil type / texture	Soil pH	OM (g kg^{-1})	P_2O_5 (mg kg^{-1})	TN (g kg^{-1})	Applied-N rate (kg-N ha^{-1})	Type of fertilizer [b]	Yield (t ha^{-1})	N uptake (kg-N ha^{-1})	NUE (%)	N surplus (kg-N ha^{-1})	Ref.
Crops	Europe	-	-	-	-		-	-	-		45–75 (61)	68	[63]
Rice	China	Clay loam	-	25.6	12.8[a]	1.65	300	-	11.18 – 11.75	-	~38.8	-	[1]
Rice	China	-	-	21.3	75.4	1.06	150	-	-	-	16.5–30.0	-	[2]
Rice	China	Loam	-	25.46	63.5	2.46	90–180	U	8.82–9.69	-	21.5–37.4	-	[3]
Rice	China	Calcareous	-	-	-	-	326	U	8.47	-	14.7 [d]	-	[4]
Rice	China	Calcareous	-	-	-	-	341	SRF	9.44	-	21.1 [d]	-	[4]
Rice	China	Calcareous	-	-	-	-	205+130	U+SRF	9.15	-	19.1 [d]	-	[4]
Rice	China	Sandy loam	5.82	20.63	11.8	1.65	180	U	7.9–9.3	-	27.0–36.5	-	[5]
Rice	China	Sandy loam	5.82	20.63	11.8	1.65	120–180	U+SRF	8.0–9.9	-	44.6–46.5	-	[5]
Wheat	China	-	7.1 – 7.2	19.27 – 20.62	16.4–19.2[a]	1.12 – 1.53	135	-	4.58	170.3	66.6	59.1	[12]
Wheat	China	-	-	-	-	-	240	U	~2.10	~104	-	-	[13]
Wheat	China	-	-	-	-	-	240	U+MB	~2.32	~135	-	-	[13]
Sugarcane	Brazil	-	-	-	-	-	-	U+HS [c]	-	-	67.3±2.7	-	[40]
Sugarcane	USA	-	-	-	-	-	-	U+HS [c]	-	-	31.0±1.3	-	[40]
Onion	China	Calcaric Cambisol	-	-	-		466–487	PM+CF	5.90–6.02	104–116	5–7	350–383	[16]

Cabbage	S Korea	Clay loam	6.9	14.9	114	-	320	U+Agrotain	-	69	17.8	-	[27]
Potato	USA	Loamy sand	5.9–6.1	18–19	-	-	180–270	U	-	-	50.5–60.2	-	[39]
Corn	China	Sandy loam	-	9.16–11.8	5.95–7.36	0.97–1.12	450	U	11.4–11.9	-	33.8–39.9	-	[15]
Corn	China	Sandy loam	-	9.16–11.8	5.95–7.36	0.97–1.12	450	U/SRF	12.0–12.9	-	39.2–43.8	-	[15]

[a] measured as “Olsen P (mg kg^{-1})”. [b] U: urea; PM: Poultry manure; CF: chemical fertilizers; SRF: slow release fertilizer; HS: humic substances; MB: bentonite modified with humic substances. [c] 720 hr after foliar application of urea with humic substances. [d] determined as “crop yield (kg) / fertilization dose (kg)”, i.e., N agronomic efficiency.

Supplementary Table 3. Examples of NH_3 emission intensity and emission factor for different crops from the reviewed literature.

Crop	Soil type / texture	Soil pH	CEC (cmol kg^{-1})	Soil N content	Fertilizer types [c]	N-applied Ratio (kg-N ha^{-1})	Mean Temp (°C)	Emission intensity (kg-N ha^{-1})	N volatilized (%)	Location/year	Ref.
Rice	Clay loam	-	-	0.30–0.31[a]	ADS	270	16.4	44.3±3.7	16.4±3.7	China/Mar. 2010	6
Rice	Clay loam	-	-	0.30–0.31[a]	Urea	270	16.4	19.9±4.3	7.4±1.8	China/Mar. 2010	6
Rice	Anthrosolos	-	-	0.09[a]	Urea	270	-	34.1–40.2	11.9–13.7	China/2018–2019	7
Rice	Anthrosolos	-	-	0.09[a]	Urea/UI	270	-	20.4–22.4	6.9–7.1	China/2018–2019	7
Rice	-	7.70	-	0.11[a]	Urea	240	-	58.1±7.5	24.20±0.03	China/Jul. 2020	8
Rice	-	7.70	-	0.11[a]	BCL	240		20.0±1.6	8.33±0.01	China/Jul. 2020	8
Rice	-	-	-	-	-	85	17.2	28.4	33.4	S. Korea/Apr. 2020	29
Wheat	Grey clay	7.5–7.8	24.2–29.7	0.16–0.20[a]	Urea	46	7.8–21.4	5.8–10.6	13–23	Australia/Sep. 2008	55
Wheat	Sodosol	7.3	6.5	0.06[a]	Urea	46	9.8–23.1	2.5±0.5	5.4	Australia/Aug. 2008	55
Barley	Grey clay	7.5–7.8	24.2–29.7	0.16–0.20[a]	Urea	92	7.8–21.4	14.8–17.5	16–19	Australia/Sep. 2008	55
Vegetables	-	8.42	-	0.09[a]/16.3[b]	IF	450	29	58.2±1.3	12.9±0.3	China/Jun. 2019	17
Cabbage	-	5.9±0.6	-	-	CF	526	22.7	0.74±0.53[d]	-	S. Korea/Sep. 2006	28
Cabbage		5.45	-	0.17[a]	Urea	300	15.8	~42–48	13.3–16.0	China/2010–2012	19
Cabbage		5.45	-	0.17[a]	OF	300	15.8	~48–54	15.4–15.9	China/2010–2012	19

Sugarcane	Silt loam	6.1±0.5	15.1±2.9	0.09±0.92[a]	Urea	135	-	5.7–8.1	2.4±0.3	USA/2012–2013	[41]
Sugarcane	Silt loam	6.1±0.5	15.1±2.9	0.09±0.92[a]	UAN	135	-	3.8–4.4	1.2±0.2	USA/2012–2013	[41]
Sugarcane	Clay	4.9–5.0	58–74	-	Urea	60–180	22.5	6.4–28.8	10.8–16.0	Brazil/2013–2017	[47]
Sugarcane	Clay	4.9–5.0	58–74	-	CAN	180	22.5	0.54–1.26	0.3–0.7	Brazil/2013–2017	[47]
Sugarcane	-	-	-	-	Urea	150	22.3	~0.5	~0.3	Australia/2006–2007	[56]
Pineapple	Sandy clay loam	5.7	-	-	Urea/UI	-	35	83.2	8.45	Brazil/2012–2014	[50]
Banana	Silty loam	8.36	16±0	0.03[a]	Urea	500	7–30	172	34	Egypt/2017–2018	[58]
Banana	Silty loam	8.36	16±0	0.03[a]	SRF	500	7–30	132	26	Egypt/2017–2018	[58]
Banana	Silty loam	8.36	16±0	0.03[a]	OF	500	7–30	100	20	Egypt/2017–2018	[58]
Corn	Clay	4.52	-	0.014[a]	POF	200	17.4–20.3	15.0–16.3	7.5–8.2	Brazil/2017	[51]
Corn	Loam	7.0±0.4	21.5±2.6	0.18±0.04[a]	Urea	275–285	15.0–19.9	24.8±8.3	13.4±4.5	Italy/2018–2020	[66]
Corn	Loam				ADD	290–329		25.6±9.4	7.0±2.5	Italy/2018–2020	[66]
Peach	-	-	-	-	CF	436.4	-	77.2	17.7	China/2012–2016	[24]
Peach	-	-	-	-	SRF	436.4	-	36.9	8.5	China/2012–2016	[24]
Common Bean	Sandy loam	4.9–5.1	4.0–4.5	-	Urea	100	-	11.0	11.0	Brazil/June 2015	[53]
Common Bean	Sandy clay loam	4.3–4.5	7.0–7.3	-	Urea	100	-	15.3	15.3	Brazil/June 2015	[53]

Common Bean	Clay	4.5	8.1–8.8	-	Urea	100	-	15.5	15.5	Brazil/June 2015	[53]
Faba bean	Silt	8.1	-	0.13[a]	-	0	9.7–16.5	0.49	-	Italy/2013–2014	[65]

[a] total nitrogen (%). [b] NH_4^+ concentration (mg kg^{-1}). [c] ADS: Anaerobic digestion slurry; UAN: urea ammonium nitrate; CAN: calcium ammonium nitrate; IF: inorganic compound fertilizer; CF: composite fertilizer, SRF: slow release fertilizer; ADD: anaerobic digestion digestate; POF: pelleted organomineral fertilizer consisting of the combination of microalgae biomass and urea; UI: urea inhibitor; BCL: the co-application of biogas slurry and low hydrothermal carbonization aqueous phase; OF: commercial organic fertilizer with poultry litter as the main component. [d] presented in the flux unit of mg m^{-2} hr^{-1}.

Supplementary Table 4. Examples of NO emission intensity and emission factor for different crops from the reviewed literature.

Crop	Soil texture / type	Soil pH (H_2O)	Soil N content	Soil C content	Fertilizer types [e]	N-applied Ratio (kg-N ha^{-1})	Mean Temp (°C)	Emission intensity (kg-N ha^{-1})	Emission factor (%)	Location/year	Ref.
Rice	-	5.95	0.05[a]	1.14[c]	U	262.5	16.0	0.24±0.01	0.080	China/2012	9
Rice	-	5.95	0.05[a]	1.14[c]	U	225	16.0	0.21±0.01	0.078	China/2012	9
Rice	-	5.95	0.05[a]	1.14[c]	U+BC	225	16.0	0.21±0.02	0.076	China/2012	9
Rice	Silt loam	6.00	0.13[a]	1.19[c]	U	150	14.2	0.06±0.01	0.021	China/2012–2014	10
Rice	Silt loam	6.00	0.13[a]	1.19[c]	U+MN	150	14.2 [h]	0.07±0.01	0.018	China/2012–2014	10
Cabbage	-	5.91±0.64	-	-	CF	526	22.7	81.3±104[g]	-	S. Korea/Sep. 2006	28
Cabbage	Loam	5.9	0.32[a]	33.1[d]	SF+MN	250+272	13.8	1.29–2.97	0.25–0.57	Japan/2012	33
Cabbage	Clay loam	5.7	0.15[a]	17.7[d]	SF+MN	120+136	13.8	0.23–0.56	0.09–0.22	Japan/2012	33
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	100	17.8	1.25±0.43		China/Mar. 2014	21
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	150	17.8	1.55±0.71		China/Mar. 2014	21
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	200	17.8	1.89±0.34		China/Mar. 2014	21
Cabbage	-	-	32[b]	-	CF+MN+U	271	15.9	2.83		China/Sep. 2006	22
Cabbage	Sandy clay loam	6.22±0.11	0.13[a]	16.4[d]	CF+MN+U	63.5	22.5	2.05	2.4	China/Sep. 2005	20
Cabbage	Andisol	5.6	0.38[a]	-	Urea	250	-	0.09–1.95		Japan/2003	31
Cabbage	Andosol	5.6	0.38[a]	4.6[c]	U	200	-	39.8	0.20	Japan/2000	32
Cabbage	Andosol	5.6	0.38[a]	4.6[c]	CRF	200–250	-	6.9–10.7	0.03–0.04	Japan/2000	32
Potato	Loam	5.9	0.32[a]	33.1[d]	SF+MN	250+272	13.8	1.67–1.96	0.32–0.38	Japan/2013	33
Potato	Clay loam	5.7	0.15[a]	17.7[d]	SF+MN	120+136	13.8	0.84–0.98	0.33–0.38	Japan/2013	33
Sugarcane	-	-	-	-	U	150	22.3	~0.95[f]	0.63	Australia/2006–2007	56
Onion	Cambisol	8.10	0.09[a]	0.96[c]	MN	46–67	12.8	0.42±0.02	0.39	China/2009–2010	16

Onion	Cambisol	8.10	0.09[a]	0.96[c]	MN+DP+U	466–487	12.8	0.76–1.38	0.11–0.22	China/2009–2010	[16]
Cucumber	Planosol	5.63	0.17[a]	1.3[c]	U	180	16.5	5.01±0.34	0.54±0.06	China/2015–2016	[23]
Cucumber	Planosol	5.63	0.17[a]	1.3[c]	MN	180	16.5	1.64±0.12	0.03±0.01	China/2015–2016	[23]
Tomato	Clay	5.5	0.19[a]	1.47[c]	CF	260	17.8	3.69±0.28	-	China/2013–2014	[21]
Tomato	Clay	5.5	0.19[a]	1.47[c]	CF	400	17.8	5.08±0.40	-	China/2013–2014	[21]
Tomato	Clay	5.5	0.19[a]	1.47[c]	CF	520	17.8	5.95±0.26	-	China/2013–2014	[21]
Radish	-	-	65[b]	-	CF+MN+U	264	15.9	6.4	-	China/Sep. 2006	[22]
Garlic	-	-	65[b]	-	CF+MN+U	267	15.9	30.2	-	China/Sep. 2006	[22]
Tea	Sandy loam	4.4	0.25[a]	2.41[c]	U	150	15.5	3.7±0.3	-	China/2015–2016	[26]
Green soybean	Clay	5.5	0.19[a]	1.47[c]	CF	60	17.8	2.00±0.57	-	China/May 2014	[21]
Green soybean	Clay	5.5	0.19[a]	1.47[c]	CF	90	17.8	2.62±0.91	-	China/May 2014	[21]
Green soybean	Clay	5.5	0.19[a]	1.47[c]	CF	120	17.8	2.97±0.61	-	China/May 2014	[21]

[a] total nitrogen (%). [b] NH_4^+ concentration (mg kg^{-1}). [c] SOC: soil organic carbon (%). [d] TC: total carbon (g-C kg^{-1}). [e] U: Urea; DP: diammonium phosphate; SF: synthesized fertilizers; MN: manure; CF: composite fertilizer (NPK); CRF: controlled release fertilizer; BC: biochar. [f] Measured in term of NO_x. [g] presented in the flux unit of µg m^{-2} hr^{-1}. [h] ground cover rice production system under nearly saturated soil water content conditions.

Supplementary Table 5. Examples of N_2O emission intensity and emission factor for different crops from the reviewed literature.

Crop	Soil texture /type	Soil pH (H_2O)	Soil N content	Soil C content	Fertilizer types [e]	N-applied Ratio (kg-N ha^{-1})	Mean Temp (°C)	Emission intensity (kg-N ha^{-1})	Emission factor (%)	Location/year	Ref.
Rice	Clay loam	-	0.30–0.31[a]	2.3–2.5[c]	ADS	270	16.4	0.7±0.3	0.26±0.15	China/Mar. 2010	6
Rice	Clay loam	-	0.30–0.31[a]	2.3–2.5[c]	U	270	16.4	0.4±0.2	0.15±0.12	China/Mar. 2010	6
Rice	Sandy loam	5.54	0.11[a]	11.9[d]	ADS	80	-	0.017±0.004	0.02±0.01	Japan/2013	34
Rice	Sandy loam	5.54	0.11[a]	11.9[d]	AS	80	-	0.060±0.025	0.08±0.03	Japan/2013	34
Rice	Alluvial	8.62	0.11[a]/9.81[b]	-	U	240	9.4	1.87±0.21	-	China/May 2014	11
Rice	-	-	-	-	-	161±59	-	0.5±0.8	1.49	Mediterranean [f]	62
Rice	Silt loam	6.00	0.13[a]	1.19[c]	U	150	14.2	1.60±0.20	0.97	China/2012–2014	10
Rice	-	5.95	0.05[a]	1.14[c]	U	262.5	16.0	5.40±0.13	1.80	China/2012	9
Rice	-	5.95	0.05[a]	1.14[c]	U	225	16.0	4.06±0.33	1.50	China/2012	9
Rice	-	5.95	0.05[a]	1.14[c]	U+BC	225	16.0	3.80±0.38	1.38	China/2012	9
Rice[g]	Silt loam	6.00	0.13[a]	1.19[c]	U+MN	150	14.2	0.87±0.12	0.46	China/2012–2014	10
Vegetable[h]	Clay loam	6.4	0.24[a]/10.7[b]	28[d]	SF	24–150	5.8–6.7	1.14	0.26±0.44	Japan/2007-2010	35
Vegetable[h]	Clay loam	6.4	0.24[a]/10.7[b]	28[d]	MN	524–988	5.8–6.7	2.12	0.11±0.16	Japan/2007-2010	35
Vegetable	-	-	-	-	SF	<250	-	0.52–1.43	0.47–0.66	China [f]	18
Vegetable	-	-	-	-	SF	250–500	-	1.33–4.11	0.29–0.99	China [f]	18
Vegetable	-	-	-	-	SF+MN	250–500	-	1.61–6.18	0.36–1.37	China [f]	18
Sugarcane	Silt loam	6.1±0.5	0.09±0.92[a]	9.1±0.9[d]	U	135–157	-	7.3–9.5	3.52±0.32	USA/2012–2013	42
Sugarcane	Silt loam	6.1±0.5	0.09±0.92[a]	9.1±0.9[d]	UAN	135–157	-	5.0–5.6	1.67±0.27	USA/2012–2013	42

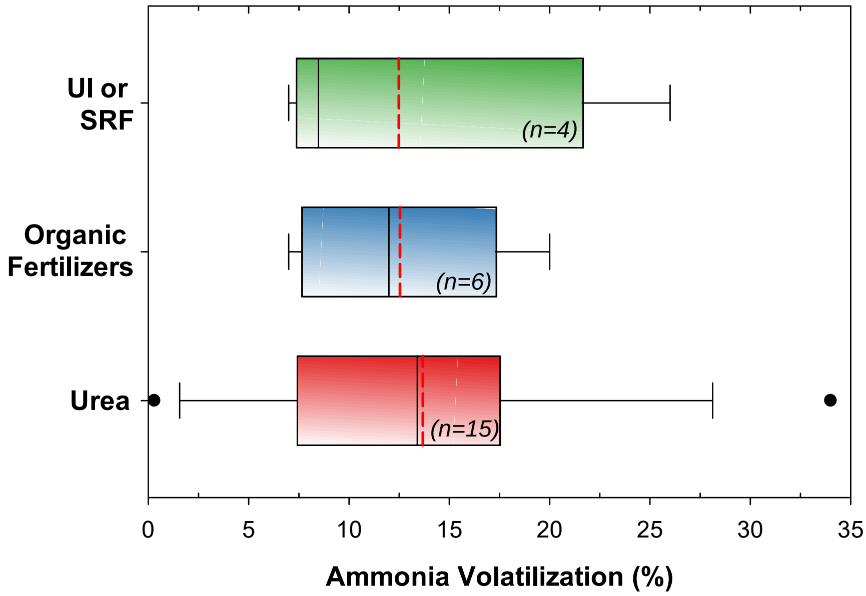
Sugarcane	Clay	4.9–5.0	-	-	U	60–180	22.5	5.28–8.84	0.81–1.13	Brazil/2013–2017	47
Sugarcane	Clay	4.9–5.0	-	-	CAN	60–180	22.5	3.15–6.75	0.38–0.68	Brazil/2013–2017	47
Sugarcane	-	-	-	-	U	150	22.3	~4.65	3.1	Australia/2006–2007	56
Sugarcane	Clay	5.4	0.2[a]	19[d]	AS	100	23.8	0.95	0.41	Japan/Aug. 2017	36
Sugarcane	Sandy loam	5.4	0.03[a]	4.1[d]	U	100	14.0	0.51	0.07	Brazil/2015–2016	48
Sugarcane	Sandy loam	5.76	-	-	U	120–180	28.2	0.23	1.69	Brazil/2014–2015	49
Cabbage	Loam	5.9	0.32[a]	33.1[d]	SF+MN	250+272	13.8	0.79–2.05	0.15–0.39	Japan/2012	33
Cabbage	Clay loam	5.7	0.15[a]	17.7[d]	SF+MN	120+136	13.8	0.80–1.41	0.31–0.55	Japan/2012	33
Cabbage	Red soil	4.88	0.13[a]	2.05[c]	U	180	22.5	4.07±0.26	2.26±0.14	China/2015–2016	14
Cabbage	Red soil	4.88	0.13[a]	2.05[c]	U+NI	180	22.5	1.98±0.34	1.10±0.19	China/2015–2016	14
Cabbage	Red soil	4.88	0.13[a]	2.05[c]	U+BC	180	22.5	1.98±0.33	1.10±0.18	China/2015–2016	14
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	100	17.8	1.78±0.23		China/Mar. 2014	21
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	150	17.8	2.09±0.26		China/Mar. 2014	21
Cabbage	Clay	5.5	0.19[a]	1.47[c]	CF	200	17.8	2.70±0.48		China/Mar. 2014	21
Cabbage	-	-	32[b]	-	CF+MN+U	271	15.9	0.48		China/Sep. 2006	22
Cabbage	Sandy clay loam	6.0	0.11[a]	-	-	320	10.3–10.8	1.49±0.06	0.44±0.03	Korea/Spring 2009–2012	30
Cabbage	Sandy clay loam	6.0	0.11[a]	-	-	320	10.3–10.8	1.14±0.22	0.32±0.07	Korea/Fall 2009–2012	30
Lettuce	Red soil	4.88	0.13[a]	2.05[c]	U	150	22.5	3.03±0.87	2.02±0.58	China/Oct. 2015	14
Lettuce	Red soil	4.88	0.13[a]	2.05[c]	U+NI	150	22.5	1.16±0.09	0.77±0.06	China/Oct. 2015	14
Lettuce	Red soil	4.88	0.13[a]	2.05[c]	U+BC	150	22.5	1.40±0.03	0.93±0.02	China/Oct. 2015	14
Banana	Clay loam	7.2	-	23[d]	U	180–370	23.6	~0.8–0.9	0.20–1.14	Australia/2014–2015	57

Banana	Sandy loam	5.53	0.12[a]	1.21[c]	U	312–623	23.5	6.39–12.80	1.76–2.31	China/Mar. 2010	25
Banana	Sandy loam	5.53	0.12[a]	1.21[c]	U+NI	549	23.5	4.44±0.71	0.69±0.27	China/Mar. 2010	25
Potato	Loam	5.9	0.32[a]	33.1[d]	SF+MN	250+272	13.8	0.42–1.03	0.08–0.20	Japan/2013	33
Potato	Clay loam	5.7	0.15[a]	17.7[d]	SF+MN	120+136	13.8	0.72–1.27	0.28–0.50	Japan/2013	33
Potato	Sandy clay loam	6.0	0.11[a]	-	-	137	10.3–10.8	1.27±0.27	0.67±0.11	Korea/2009–2012	30
Onion	Cambisol	8.10	0.09[a]	0.96[c]	SF+MN	466–487	12.8	1.32–1.79	0.25–0.67	China/2009–2010	16
Cucumber	Planosol	5.63	0.17[a]	1.3[c]	U	180	16.5	13.1±0.48	1.30±0.05	China/2015–2016	23
Cucumber	Planosol	5.63	0.17[a]	1.3[c]	MN	180	16.5	10.1±0.78	0.76±0.08	China/2015–2016	23
Corn	Red soil	4.88	0.13[a]	2.05[c]	U	360	22.5	36.2±1.1	10.1±0.3	China/Apr. 2016	14
Corn	Red soil	4.88	0.13[a]	2.05[c]	U+NI	360	22.5	26.9±1.7	7.47±0.47	China/Apr. 2016	14
Corn	Red soil	4.88	0.13[a]	2.05[c]	U+BC	360	22.5	20.1±1.8	5.58±0.50	China/Apr. 2016	14
Corn	Clay	4.8	-	-	U	100	-	0.26	0.24	Brazil/2017–2018	52
Corn	Clay	4.8	-	-	AN	100	-	0.15	0.10	Brazil/2017–2018	52
Corn	Clay loam	6.4	-	-	AN	200	-	0.71–2.62	0.87–1.18	Canada/2012,2014	44
Corn	Clay loam	6.4	-	-	MN	~135	-	0.48–2.35	0.52–1.02	Canada/2012,2014	44
Corn	Silt loam	-	-	-	-	170	17.4	23.7–30.9 [k]	-	Canada/2013	46
Peach	-	-	-	-	ECF	436.4	-	0.23	0.05	China/2012–2016	24
Peach	-	-	-	-	BCRF	436.4	-	0.12	0.03	China/2012–2016	24
Tomato	Clay	5.5	0.19[a]	1.47[c]	CF	260	17.8	4.97±0.32	1.91	China/2013–2014	21
Tomato	Clay	5.5	0.19[a]	1.47[c]	CF	400	17.8	5.20±0.34	1.30	China/2013–2014	21
Radish	-	-	65[b]	-	CF+MN+U	264	15.9	0.36	0.14	China/Sep. 2006	22
Garlic	-	-	65[b]	-	CF+MN+U	267	15.9	0.73	0.27	China/Sep. 2006	22
Corn/Soybean	-	-	-	-	-	~160	-	7.8–8.2	-	USA/2004–2010	43

Soybean	Silt clay	6.8	0.17–0.37[b]	1.2–1.8[c]	-	-	15.0	2.19–4.91	-	Italy/2015	67
Soybean	Clay loam	6.4	-	-	AN	0		0.19–0.66	-	Canada/2013,2015	44
Soybean	Clay loam	6.4	-	-	MN	0		0.22–0.76	-	Canada/2013,2015	44
Soybean	Clay loam	6.4	0.12[a]	12[d]	U or LN	100	23.9–26.9	1.8–3.1	1.8–3.1	Japan/2012	37
Soybean	Loam	6.6	-	38[d]	OC	-	14.7–15.8	0.37–0.82	-	Japan/2017–2018	38
Soybean	-	-	-	-	-	-	17.6	0.92	-	Argentina/2011–13	60
Soybean	Sandy Loam	5.9	-	4.7[d]	AS+U	20+40	14–25	0.76–1.24	-	Brazil/2011–2013	54
Soybean [i]	Sandy clay loam	7.1	0.06[a]	0.5[c]	U	0–120	26.2	0.48–1.44	-	Iran/2014–2015	59
Soybean [j]	Clay loam	6.1–6.2	-	0.41–1.85	-	0	9.3	3.56–4.05	-	Canada/2000–2006	45
Soybean	Silt loam	-	-	-	-	10	18	4.1–10.4 [k]	-	Canada/2012–2013	46
Soybean	-	5.7	0.19[a]	2.03[c]	-	-	16.5	0.96–1.45	-	Argentina/2010–12	61
Faba bean	Sandy to Clay loam	6.5±0.2	-	1.3±0.1[c]	CAN	240	-	0.65±0.88	0.27	Germany/2016–2018	64
Faba bean	Silt	8.1	0.13[a]	1.4[c]	-	0	9.7–16.5	1.71–2.59	-	Italy/2013–2014	65

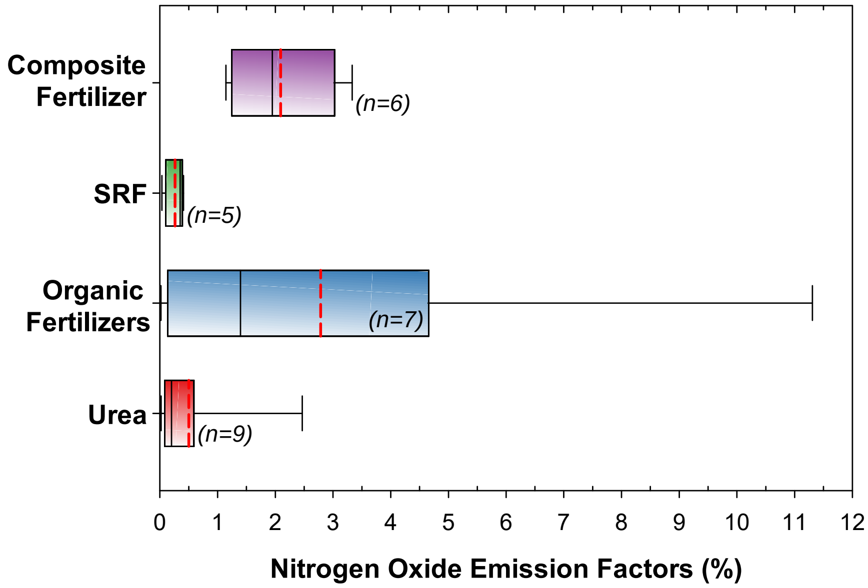
[a] total nitrogen (%). [b] NH_4^+ concentration (mg kg^{-1}). [c] SOC: soil organic carbon (%). [d] TC: total carbon (g-C kg^{-1}). [e] U: urea; ADS: anaerobic digestion slurry; AN: ammonium nitrate; AS: ammonium sulphate; SF: synthesized fertilizers; OC: organic cultivation; MN: manure; CF: composite fertilizer, BCRF: bag-controlled release fertilizer; UAN: urea ammonium nitrate; CAN: calcium ammonium nitrate; NI: nitrification inhibitor; BC: biochar; LN: lime nitrogen. [f] Through a meta-analysis study. [g] ground cover rice production system under nearly saturated soil water content conditions. [h] crop rotation included potato, sweet corn, winter wheat, sugar beet and soybean for consecutive four years. [i] crop rotation include a durum wheat and soybean. [j] crop rotation with maize in the year of 2000-2002. [k] presented in the flux unit of g-N ha^{-1} d^{-1}.

Supplementary Note 1: Ammonia Volatilization

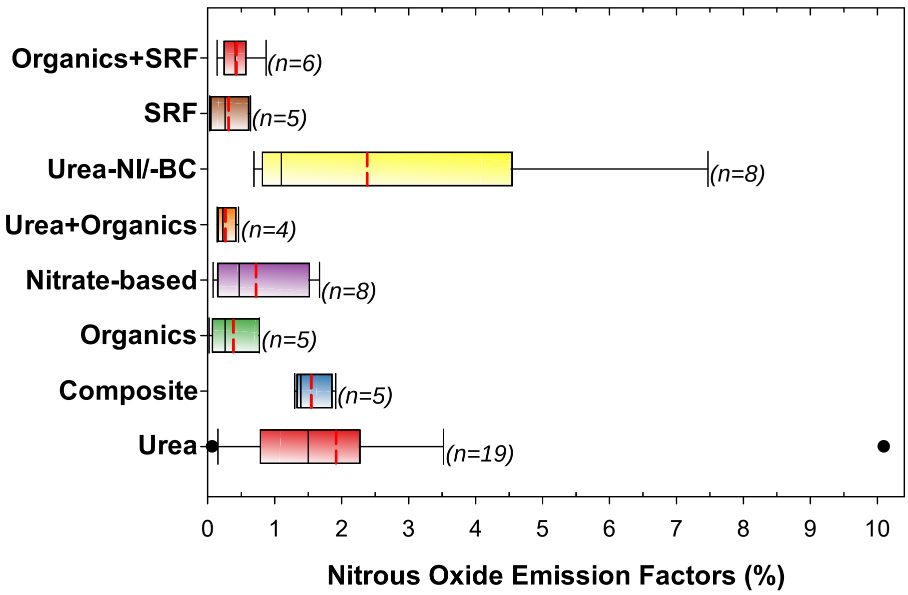


Supplementary Figure 1. NH_3 volatilization for urea, organic fertilizers, and urea with nitrification inhibitors or slow release fertilizers. Red dash lines indicate the group mean. The results indicated the NH_3 volatilization for the urea group was 13.7±2.2% (n = 15, $p < 0.05$; using One-sample t-test); that for the organic fertilizer group was 12.5±2.2% (n = 6, $p < 0.05$; using One-sample t-test), and that for urea with nitrification inhibitors or slow release fertilizers was 12.5±4.5% (n = 4, $p < 0.05$; using One-sample t-test). All error bars are determined at the 0.05 confidence level (Student's t-test).

Supplementary Note 2: Nitrogen Oxide Emission Factor



Supplementary Figure 2. NO emission factors for urea, organic fertilizer, slow-release fertilizer, and composite fertilizer. Red dash lines indicate the group mean. The results indicated the emission factors for the (i), (ii), (iii) and (iv) groups were 0.50±0.26% (n = 9, p < 0.05; using One-sample *t*-test), 2.39±1.54% (n = 7, p < 0.05; using One-sample *t*-test), 0.26±0.07% (n = 5, p < 0.05; using One-sample *t*-test), and 2.09±0.38% (n = 6, p < 0.05; using One-sample *t*-test), respectively. All error bars are determined at the 0.05 confidence level (Student's t-test).



Supplementary Figure 3. N_2O emission factors for different types of fertilizers. Red dash lines indicate the group mean. The emission factors were 1.92±0.50% (n = 19, p < 0.05; using One-sample t-test) for urea, 1.55±0.12% (n = 5, p < 0.05; using One-sample t-test) for composite fertilizers, 0.38±0.16% (n = 5, p < 0.05; using One-sample t-test) for organic fertilizers, 0.72±0.23% (n = 8, p < 0.05; using One-sample t-test) for nitrate-based fertilizers, 0.26±0.07% (n = 4, p < 0.05; using One-sample t-test) for urea with organic (or composite) fertilizers, 2.38±0.93% (n = 8, p < 0.05; using One-sample t-test) for urea with nitrification inhibitor or biochars, 0.31±0.13% (n = 5, p < 0.05; using One-sample t-test) for slow-release fertilizers, and 0.43±0.10% (n = 6, p < 0.05; using One-sample t-test) for manure with slow-release fertilizers. All error bars are determined at the 0.05 confidence level (Student's t-test).

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