Blending controlled-release and urease-inhibitor technologies as innovative solutions to reduce ammonia emissions in coffee environments

Tainah Freitas [1], Damiany Pádua Oliveira [2], Mateus Portes Dutra [2], Pauliana Cristina Zito [1], Estevam Antônio Chagas Reis [1], Tales Jesus Fernandes [3], Ana Paula Pereira Nunes [2], Rubens José Guimarães[1], Flávio Henrique Silveira Rabêlo [2], Douglas Guelfi [2,*]

Supporting information

Table S1

Chemical and physical characterization of the soil of the experimental area before setting up the experiments, in October 2017.

[1]Characteristic	Unit	Soil depth layers (cm)			
		0 - 10	10 - 20	20 - 40	40 - 60
pH	-	5.5	5.7	5.6	5.6
P	mg dm^{-3}	46.67	10.72	5.25	2.30
K	mg dm^{-3}	361.39	270.12	236.30	219.93
Ca^{2+}	cmol$_c$ dm^{-3}	2.59	1.90	1.38	1.10
Mg^{2+}	cmol$_c$ dm^{-3}	2.31	1.05	0.59	0.36
S	mg dm^{-3}	27.32	26.44	30.42	48.61
Cu	mg dm^{-3}	5.21	4.97	3.31	2.22
B	mg dm^{-3}	0.06	0.49	0.46	0.38
Zn	mg dm^{-3}	12.41	5.80	2.22	1.32
Fe	mg dm^{-3}	39.43	57.45	65.69	50.52
Mn	mg dm^{-3}	38.07	34.73	20.93	13.83
Al^{3+}	cmol$_c$ dm^{-3}	0.04	0.09	0.08	0.08
H+Al	cmol$_c$ dm^{-3}	3.95	3.54	3.70	3.00
Sum of bases (SB)	cmol$_c$ dm^{-3}	5.83	3.64	2.57	2.02
Effective CEC (t)	cmol$_c$ dm^{-3}	5.87	3.73	2.65	2.10
Potential CEC (T)	cmol$_c$ dm^{-3}	9.78	7.18	6.27	5.02
Aluminum saturation (m)	%	0.68	2.41	3.01	3.81
Base saturation (V)	%	59.58	50.70	41.03	40.27
Organic matter	dag kg^{-1}	2.47	1.89	1.50	1.69
Remaining P	mg L^{-1}	30.20	28.15	18.60	15.92
Sand	dag kg^{-1}	480	470	460	460
Silt	dag kg^{-1}	90	100	110	100
Clay	dag kg^{-1}	430	430	430	440

Characteristic	Unit	Soil depth layers (cm)				
		0 - 5	5 - 10	10 - 20	20 - 40	40 - 60
Soil bulk density	kg dm^{-3}	1.20	1.29	1.26	1.20	1.19
Total nitrogen	g dm^{-3}	3.33	2.95	2.15	1.75	1.45
Available mineral nitrogen	mg dm^{-3}	65.87	61.07	56.12	49.70	47.18
N-NH$_4^+$	mg dm^{-3}	27.61	27.09	25.44	22.32	21.16
N-NO$_3^-$	mg dm^{-3}	38.26	33.98	30.68	27.38	26.02

12   [1]pH: in KCl ratio 1:2.5. P, K, Fe, Zn, Mn, and Cu: Mehlich 1 extraction solution. Ca, Mg, and Al: KCl (1 mol l^{-1}) extraction solution.
13   S: monocalcium phosphate in acetic acid extraction solution. H + Al: SMP extraction solution. Organic matter: oxidation with
14    $Na_2Cr_2O_7$ 4N + H_2SO_4 10N. B: hot water extraction. Soil bulk density: volumetric ring method. $N-NH_4^+$ and $N-NO_3^-$: nitrogen in the
15   ammonium and nitrate forms, respectively.

16 Table S2

17 Date of removal of sponges for evaluation of volatilized N-NH$_3$.

[1]Fertilizers	[2]Parceled application	Date of removal of sponges for evaluation of volatilized N-NH$_3$	
		Day(s) after nitrogen fertilization	
		2017-18 Crop Year	2018-19 Crop Year
U*Con* and U*NBPT*	1	1, 2, 3, 4, 5, 6, 8, 10, 11, 13, 17, 21	1, 2, 3, 4, 5, 6, 8, 11, 15, 20, 25
	2	1, 2, 3, 4, 5, 6, 8, 11, 15, 20, 27	1, 2, 3, 4, 5, 6, 8, 11, 15, 19, 25
	3	1, 2, 3, 4, 5, 6, 8, 11, 14, 18, 23, 29, 36	1, 2, 3, 4, 5, 6, 8, 11, 15, 20, 25
	Equivalence in days after the first fertilization	1, 2, 3, 4, 5, 6, 8, 10, 13, 17, 21, 29, 30, 31, 32, 33, 34, 36, 39, 43, 48, 55, 57, 58, 59, 60, 61, 62, 64, 67, 70, 74, 79, 85, 92	1, 2, 3, 4, 5, 6, 8, 11, 15, 20, 25, 29, 30, 31, 32, 33, 34, 36, 39, 43, 47, 53, 57, 58, 59, 60, 61, 62, 64, 67, 71, 76, 81
EMax*41*, EMax*43*, Blend*41*, and Blend*43*	[§]Single application	1, 2, 3, 4, 5, 6, 7, 8, 10, 13, 17, 21, 29, 36, 43, 49, 55, 64, 67, 74, 81, 85, 92, 99, 107, 113, 120, 128, 134, 140, 148, 156, 162, 169, 176, 186, 195	1, 2, 3, 4, 5, 6, 8, 11, 15, 20, 25, 32, 39, 46, 53, 60, 67, 74, 81, 88, 95, 102, 109, 116, 123, 130, 137, 145, 151, 158, 165, 172, 179, 186, 193, 200

18 [1]Fertilizers – U*Con*: conventional urea. U*NBPT*: urea with N-(n-butyl) thiophosphoric triamide (NBPT). EMax*41*: urea E-Max 41%.
19 EMax*43*: urea E-Max 43%. Blend*41:* mixture of U*NBPT* with EMax*41*. Blend*43*: mixture of U*NBPT* with EMax*43*.

20 [2]Parceled application: fractionation of nitrogen fertilization in ⅓ of the 300 kg N ha^{-1} application rate. [§]Application rate: 300 kg
21 N ha^{-1}.

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24 Table S3

25 Rainfall and soil moisture and temperature in the first 6 days after single application of the fertilizer or after parceled
26 applications of the fertilizer.

Characteristic	Parceled application[1]	2017-18 crop year						
		Day(s) after fertilization						
		1	2	3	4	5	6	∑
Rainfall (mm)	1[2]	23.5	10	0	0	0	0	33.5
	2	52	0	0	0	0	0	52
	3	15	37	21	5	6	0	84
Soil moisture (%)	1	14.50	20.70	20.40	19.60	19.80	17.70	-
	2	25.90	24.10	17.60	21.10	18.80	19.40	-
	3	25.40	24.50	23.70	21.60	24.80	23.40	-
Soil temperature (ºC)	1	20.3	20.2	19.4	20.2	20.4	20.9	-
	2	21.6	21.7	21.3	20.5	20.7	21.3	-
	3	20.6	20.2	20.4	21.1	21.2	20.8	-
Characteristic	Parceled application[1]	2018-19 crop year						
		Day(s) after fertilization						
		1	2	3	4	5	6	∑
Rainfall (mm)	1[2]	10	0	0	0	0	3	13
	2	0	0	0	0	0	0	0
	3	7	10	0	0	0	0	17
Soil moisture (%)	1	20.90	22.30	19.30	19.60	16.40	17.90	-
	2	18.40	17.90	17.50	18.70	16.60	16.90	-
	3	23.30	23.30	22.80	19.70	17.10	17.30	-
Soil temperature (ºC)	1	19.7	20.8	21.2	21.8	22.0	22.0	-
	2	18.7	19.3	20.2	21.1	20.7	21.2	-
	3	20.9	21.5	22.0	22.6	22.6	22.0	-

27 [1]Parceled application of the nitrogen fertilizer at ⅓ of the 300 kg N ha^{-1} application rate.

28 [2]First parceled application of the conventional urea and of urea with N-(n-butyl) thiophosphoric triamide (NBPT) or single
29 application of the controlled-release fertilizers (EMAx41; EMax43) or of their corresponding blends (Blend41 and Blend43) in
30 the crop year. EMax41: urea E-Max 41%. EMax43: urea E-Max 43%. Blend41: mixture of U$NBPT$ with EMax41. Blend43: mixture of U$NBPT$
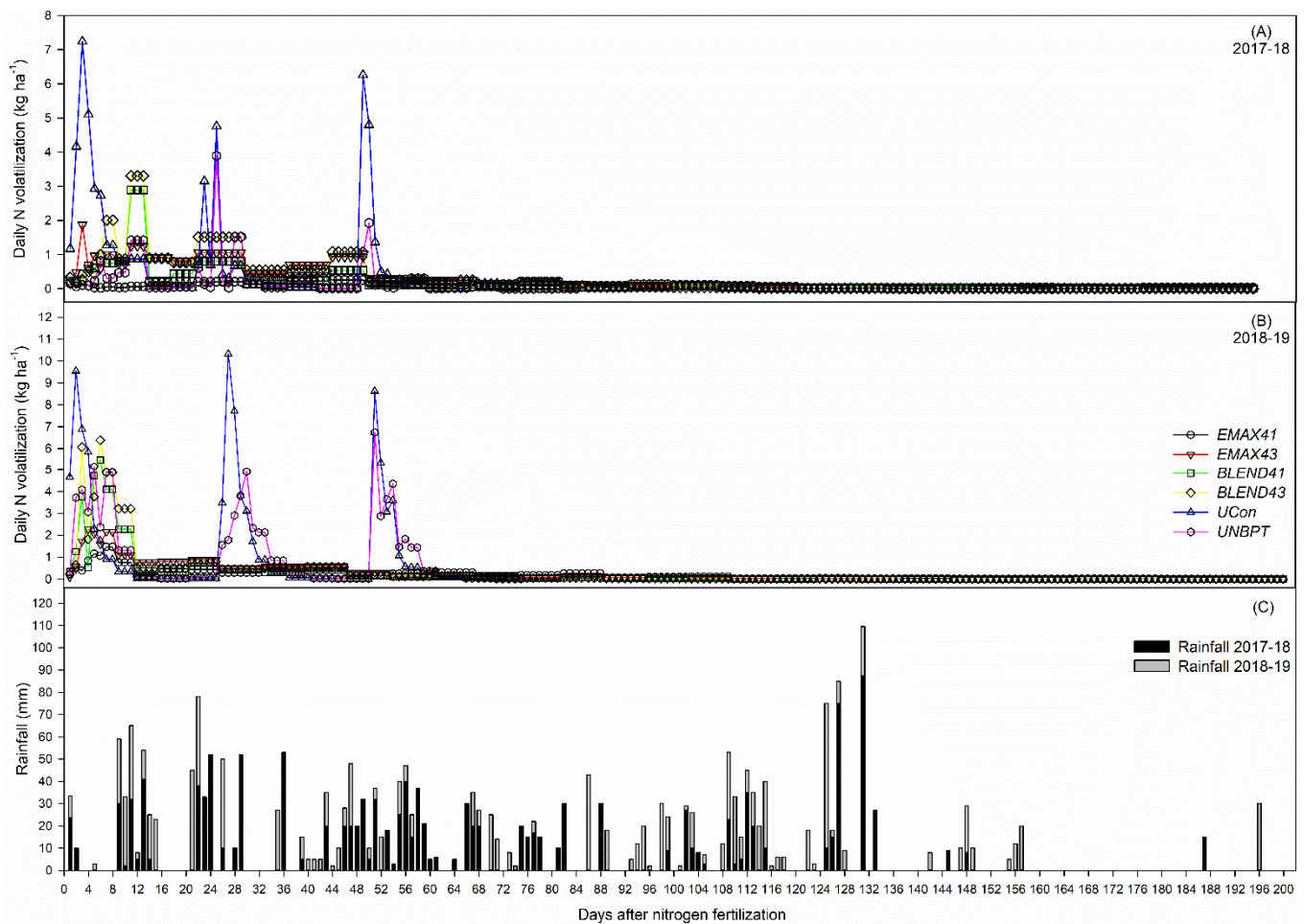31 with EMax43.

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33 Table S4

34 Regression of the logistic model for data on N release in the laboratory and field in two consecutive crop years (2017-

35 18 and 2018-19) and for data on N-NH$_3$ volatilization in the field in the same crop years.

RELEASE OF NITROGEN		
FIELD EXPERIMENTS		
2017 – 18 crop year		
[1]Fertilizer	Equations	Coefficient of determination (R^2)
EMax*41*	[2]%N = 69.34/ (1 +$e^{(0.04(67.83 \text{ -DAF}))}$)	0.98
EMax*43*	%N = 91.87/ (1 +$e^{(0.05(42.64 \text{ -DAF}))}$)	0.99
Blend*41*	%N = 88.54/ (1 +$e^{(1.64(17.52 \text{ -DAF}))}$)	1.00
Blend*43*	%N = 97.08/ (1 +$e^{(0.03(13.11 \text{ -DAF}))}$)	0.99
2018 – 19 crop year		
EMax*41*	% N = 77.51 / (1 +$e^{(0.03(75.86 \text{ -DAF}))}$)	0.97
EMax*43*	% N = 78.29/ (1 +$e^{(0.04(49.80 \text{ -DAF}))}$)	0.98
Blend*41*	% N = 87.12/ (1 +$e^{(0.02(14.62 \text{ -DAF}))}$)	0.99
Blend*43*	% N = 90.80/ (1 +$e^{(0.02(6.31 \text{ -DAF}))}$)	0.99
LABORATORY EXPERIMENT		
EMax*41*	% N = 86.87/ (1 +$e^{(0.04(45.21 \text{ -DAF}))}$)	0.98
EMax*43*	% N = 90.64/ (1 +$e^{(0.04(36.71 \text{ -DAF}))}$)	0.98
Blend*41*	% N = 96.19/ (1 +$e^{(0.02(1.60 \text{ -DAF}))}$)	1.00
Blend*43*	% N = 97.68/ (1 +$e^{(0.03(-2.27 \text{ -DAF}))}$)	0.99
N-NNH$_3$ VOLATILIZATION		
FIELD EXPERIMENTS		
2017 – 18 crop year		
[1]Fertilizer	Equations	Coefficient of determination (R^2)
UCon	(1) N volatilization (kg ha^{-1}) = 33.66/ (1 +$e^{(0.90(2.53 \text{ - DAF}))}$)	0.99
	(2) N volatilization (kg ha^{-1}) = 32.82/ (1 +$e^{(0.92(2.55 \text{ - DAF}))}$)	0.98
	(3) N volatilization (kg ha^{-1}) = 24.44/ (1 +$e^{(0.64(1.72 \text{ - DAF}))}$)	0.99
UNBPT	(1) N volatilization (kg ha^{-1}) = 33.05/ (1 +$e^{(0.59(5.27 \text{ - DAF}))}$)	0.99
	(2) N volatilization (kg ha^{-1}) = 25.06/ (1 +$e^{(0.60(4.73 \text{ - DAF}))}$)	0.99
	(3) N volatilization (kg ha^{-1}) = 25.50/ (1 +$e^{(0.51(2.86 \text{ - DAF}))}$)	1.00
EMax*41*	N volatilization (kg ha^{-1}) = 18.90/ (1 +$e^{(0.05(54.14 \text{ - DAF}))}$)	0.99
EMax*43*	N volatilization (kg ha^{-1}) = 50.97/ (1 +$e^{(0.07(30.20 \text{ - DAF}))}$)	0.99
Blend*41*	N volatilization (kg ha^{-1}) = 34.75/ (1 +$e^{(0.07(23.55 \text{ - DAF}))}$)	0.96
Blend*43*	N volatilization (kg ha^{-1}) = 57.52/ (1 +$e^{(0.09(25.05 \text{ - DAF}))}$)	0.99
2018 – 19 crop year		
UCon	(1) N volatilization (kg ha^{-1}) = 29.56/ (1 +$e^{(0.63(3.84 \text{ - DAF}))}$)	0.98
	(2) N volatilization (kg ha^{-1}) = 11.93/ (1 +$e^{(0.84(3.21 \text{ - DAF}))}$)	0.97
	(3) N volatilization (kg ha^{-1}) = 14.64/ (1 +$e^{(0.74(1.02 \text{ - DAF}))}$)	0.89
UNBPT	(1) N volatilization (kg ha^{-1}) = 8.09/ (1 +$e^{(0.47(9.90 \text{ - DAF}))}$)	0.98
	(2) N volatilization (kg ha^{-1}) = 9.21/ (1 +$e^{(0.54(5.24 \text{ - DAF}))}$)	0.96
	(3) N volatilization (kg ha^{-1}) = 5.26/ (1 +$e^{(0.24(2.93 \text{ - DAF}))}$)	0.94
EMax*41*	N volatilization (kg ha^{-1}) = 35.59/ (1 +$e^{(0.05(35.36 \text{ - DAF}))}$)	0.99
EMax*43*	N volatilization (kg ha^{-1}) = 48.84/ (1 +$e^{(0.06(24.30 \text{ - DAF}))}$)	0.98
Blend*41*	N volatilization (kg ha^{-1}) = 49.57/ (1 +$e^{(0.08(12.39 \text{ - DAF}))}$)	0.93
Blend*43*	N volatilization (kg ha^{-1}) = 62.02/ (1 +$e^{(0.09(12.72 \text{ - DAF}))}$)	0.94

36 [*]Equations corresponding to Figures 2 and 4. [1]Fertilizer – U*Con*: conventional urea. U*NBPT*: urea with N-(n-butyl) thiophosphoric triamide (NBPT). EMax*41*: urea

37 E-Max 41%. EMax*43*: urea E-Max 43%. Blend*41*: mixture of U*NBPT* with EMax*41*. Blend*43*: mixture of U*NBPT* with EMax*43*. [2]%N: equals the % of nitrogen

38 released. DAF: days after nitrogen fertilization. (1), (2), and (3): parceled application of nitrogen fertilizer of U*Con* and U*NBPT* at ⅓ of the 300 kg N ha^{-1} application

39 rate carried out in November (1), December (2), and January (3) of the 2017-18 and 2018-19 crop years. Total fertilization (300 kg N ha^{-1}) with EMax*41*, EMax*43*,

40 Blend*41*, and Blend*43* carried out in November of each crop year.

41 Table S5

42 Regressions of coffee bean yield according to type of nitrogen fertilizer and application rates.*

[1]Fertilizer	Equations (coefficients in kg ha^{-1})	R^2
	------------------------------------2017-18 Crop year ------------------------------------	
UCon	Y = 3065.1570 +2.599x if x < 243.01; Y = 3694.70 if x ≥ 243.01 kg N ha^{-1}	-
UNBPT	Y = 2988.2 + 0.7576x	0.97
EMax41	Y = 3121.5867 + 1.6294x if x < 292.40 kg N ha^{-1}; Y = 3597.90 if x ≥ 292.40 kg N ha^{-1}	-
EMax43	Y = 3039.4025 + 2.7363x if x < 236.82 kg N ha^{-1}; Y = 3685.74 if x ≥ 236.82 kg N ha^{-1}	-
Blend41	Y = 2956.10 + 1.452x	0.94
Blend43	Y = 2923.80 + 1.7848x	0.89
Fertilizer	------------------------------------ 2018-19 Crop year ------------------------------------	R^2
UCon	Y = 564.28 + 0.7639x	0.95
UNBPT	Y = 595.16 + 1.1349x	0.99
EMax41	Y = 591.01 + 1.2687x	0.95
EMax43	Y = 628.1106 + 0.9036x if x < 374.84 kg N ha^{-1}; Y = 966.80 if x ≥ 374.84 kg N ha^{-1}	-
Blend41	Y = 607.31 + 3.1012x - 0.0035x^2	0.88
Blend43	Y = 665.3617 + 1.268x if x < 362.55 kg N ha^{-1}; Y = 1125.10 if x ≥ 362.55 kg N ha^{-1}	-

43 *Equations corresponding to Figure 6. [1]Fertilizer – UCon: conventional urea. UNBPT: urea with n-(n-butyl) thiophosphoric triamide (NBPT).
44 EMax41: urea E-Max 41%. EMax43: urea E-Max 43%. Blend41: mixture of urea with n-(n-butyl) thiophosphoric triamide (NBPT) and EMax41.
45 Blend43: mixture of urea with n-(n-butyl) thiophosphoric triamide (NBPT) and EMax43. R^2: Coefficient of determination

Fig. S1 Daily volatilization [per parceled application of U*Con* and U*NBPT* (A) and per single application [for controlled-release fertilizers and blends (B)], with rainfall (C) in two agricultural crop years with arabica coffee.

Parceled applications of nitrogen fertilization of U*Con* and U*NBPT* at ⅓ of the 300 kg N ha^{-1} application rate carried out in November, December, and January of the 2017-18 and 2018-19 crop years. Total fertilization (300 kg N ha^{-1}) with EMax*41*, EMax*43*, Blend*41*, and Blend*43* carried out in November of each crop year.

Fertilizer – U*Con*: conventional urea. U*NBPT*: urea with N-(n-butyl) thiophosphoric triamide (NBPT). EMax*41*: urea E-Max 41%. EMax*43*: urea E-Max 43%. Blend*41:* mixture of U*NBPT* with EMax*41*. Blend*43*: mixture of U*NBPT* with EMax*43*.

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