

From lab to field. Precision fertilization of biobased fertilizers (The use of digestate in agriculture)

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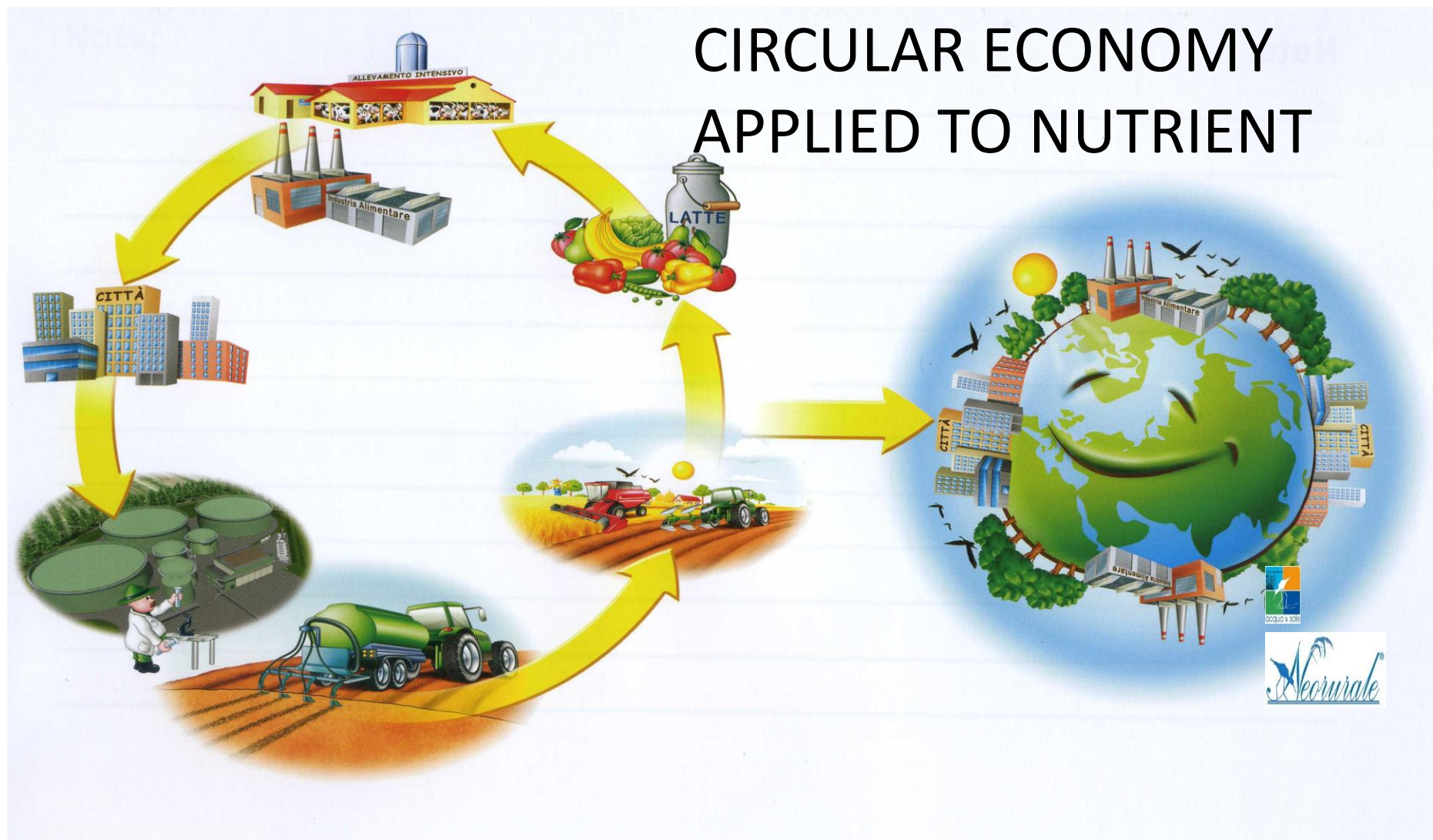
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THE CIRCULAR ECONOMY CAN HELP IN RE-THINK
COMPLETELY FERTILIZER PRODUCTION AND USE



CIRCULAR ECONOMY APPLIED TO NUTRIENT





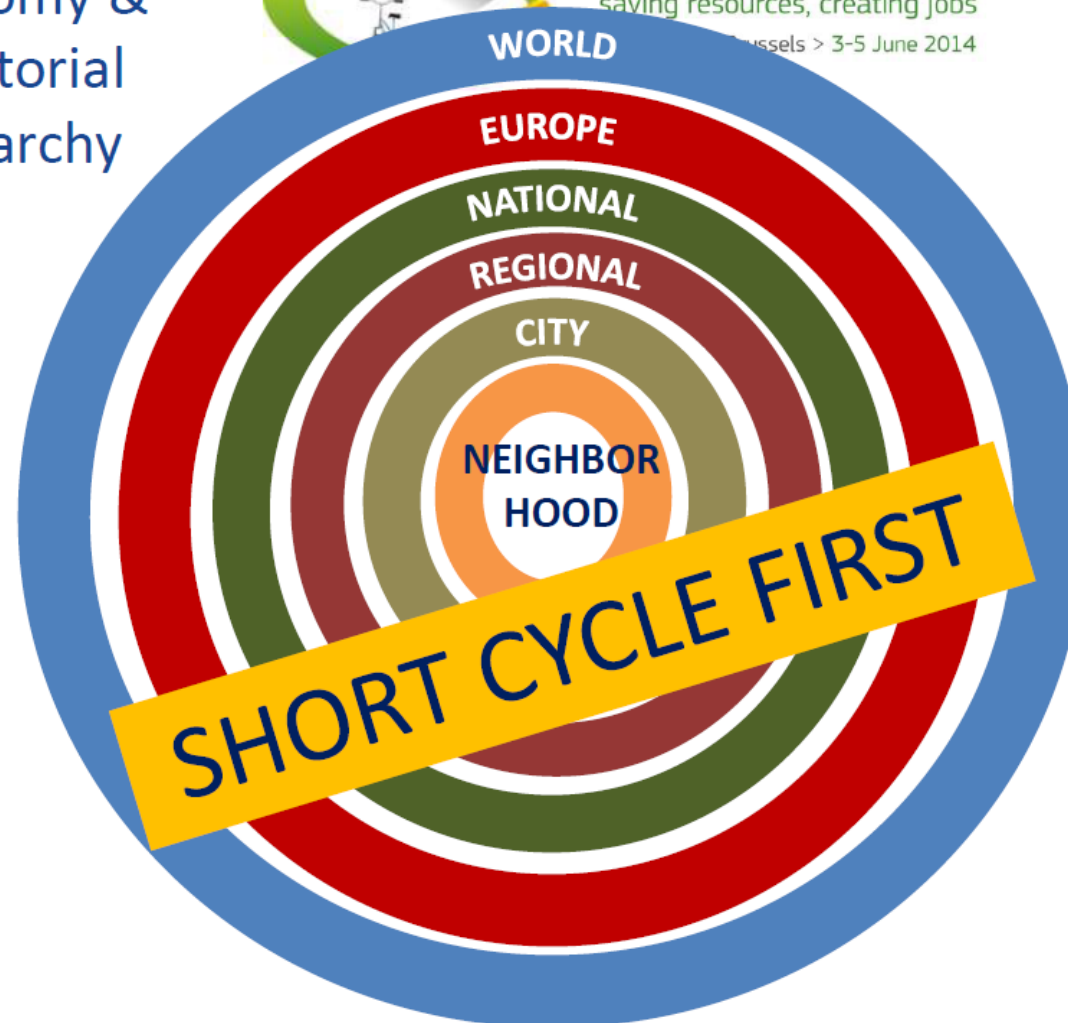
Nutrient: SHORT
CYCLE FIRST.....

.....that is not a
simple local waste
recycling and
disposal

Circular
economy &
territorial
hierarchy

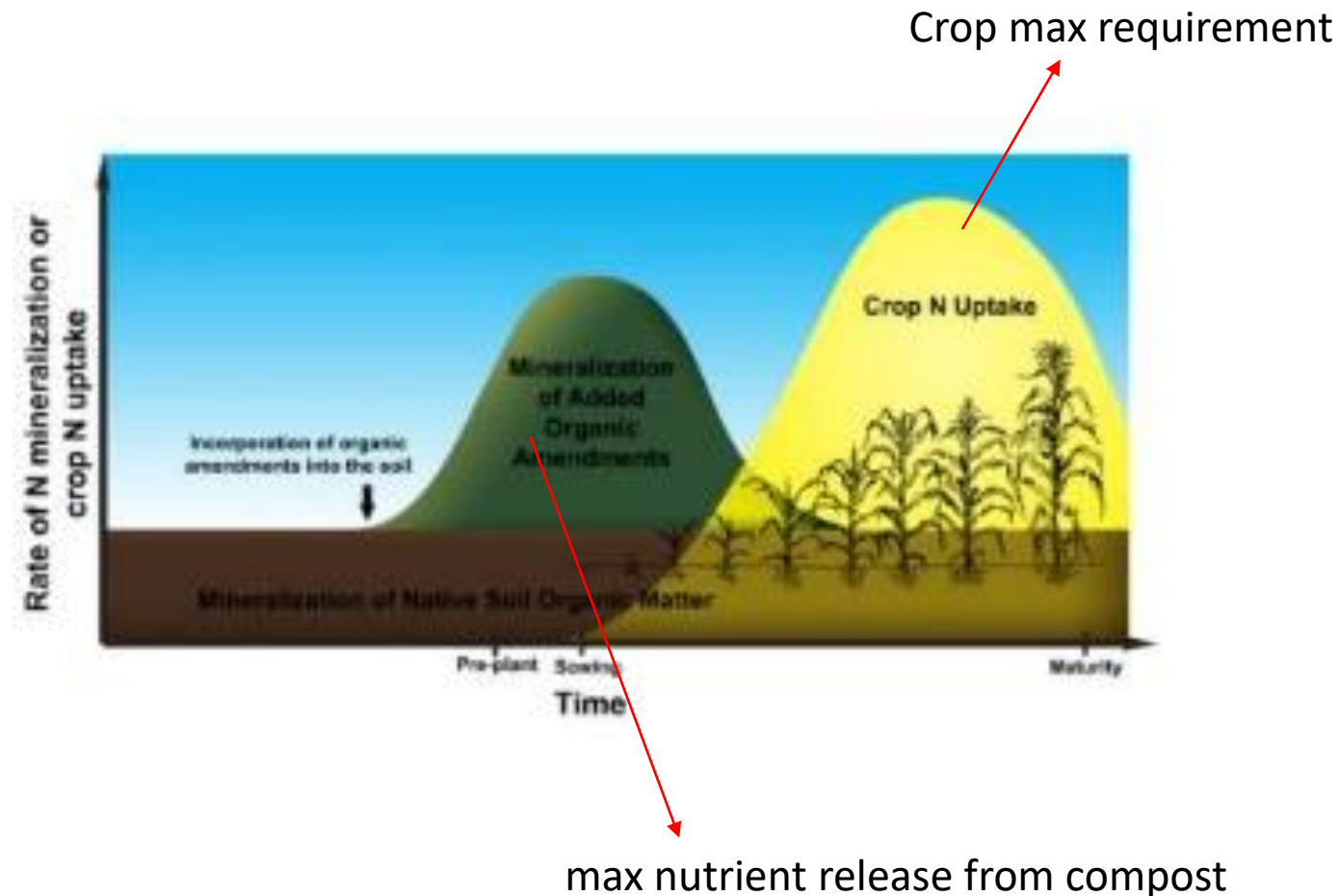


CIRCULAR ECONOMY
saving resources, creating jobs
Brussels > 3-5 June 2014





e.g. from waste to compost, that is not a fertilizers but an organic amendment, not able replacing synthetic fertilizers.





So we need technology and biotechnologies able to transform secondary material into fertilizers.



e.g. : ANAEROBIC DIGESTION
transforms biomass into



BIOFUELS

.....and more.....



Chemosphere 81 (2010) 577–583



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Chemosphere

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Assessing amendment and fertilizing properties of digestates from anaerobic digestion through a comparative study with digested sludge and compost

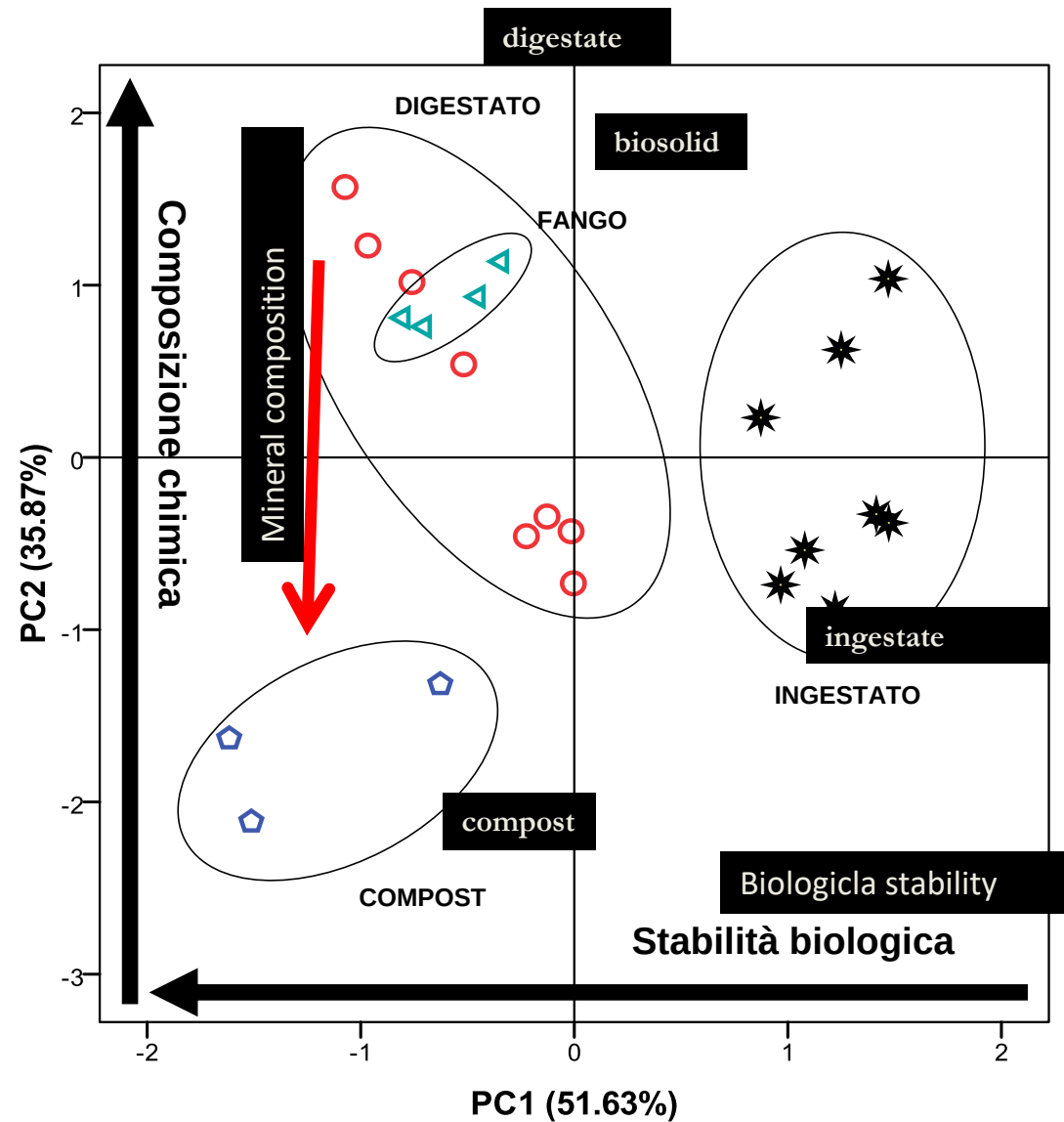
Fulvia Tambone^{*}, Barbara Scaglia, Giuliana D'Imporzano, Andrea Schievano, Valentina Orzi, Silvia Salati, Fabrizio Adani^{**}

Gruppo RICICLA, Dipartimento di Produzione Vegetale, Università degli Studi di Milano, Via Celoria 2, 20133 Milano, Italy

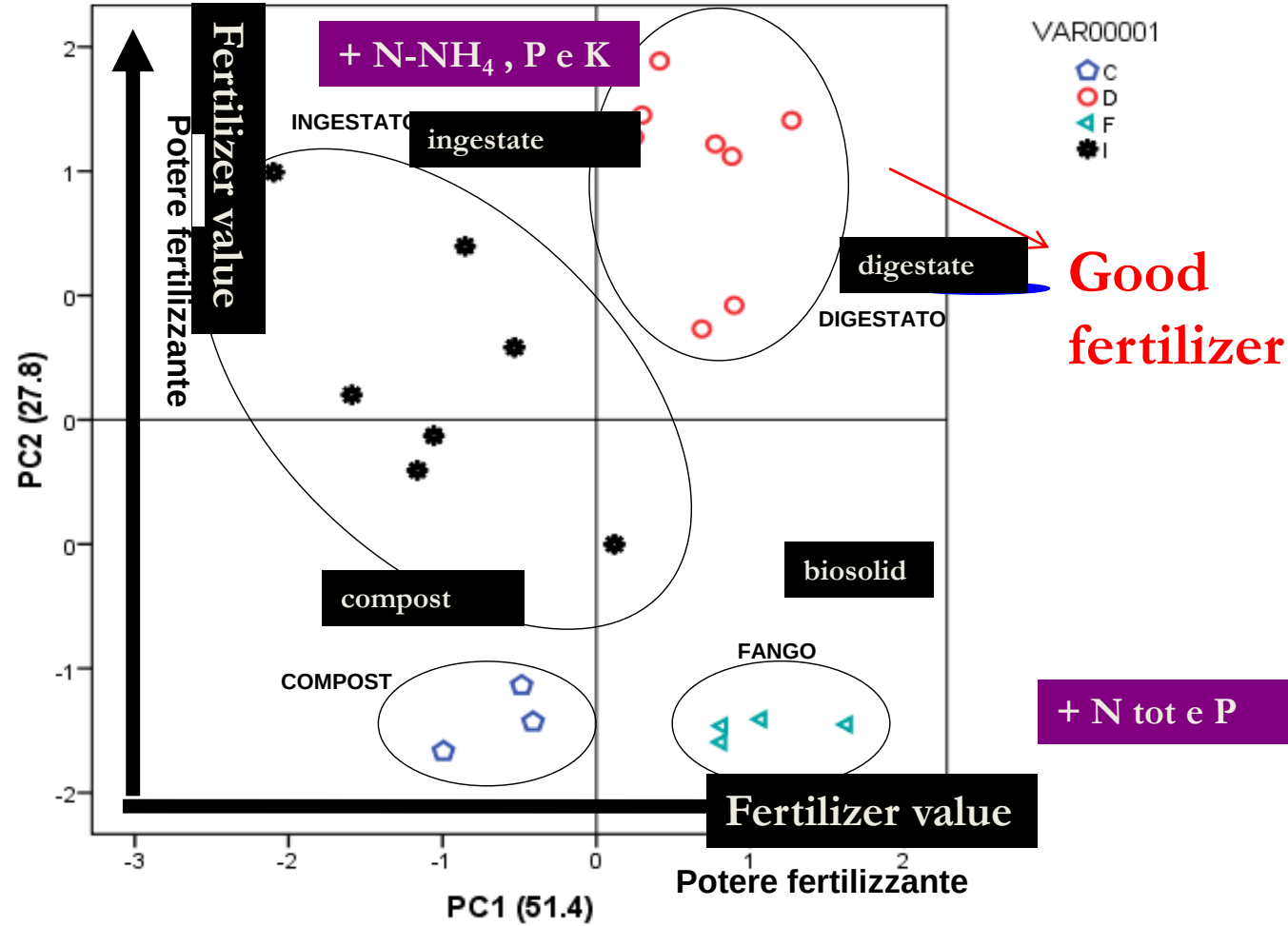
**Anaerobic digestion: modification of
both elements and organic matter
contained**

VAR00001

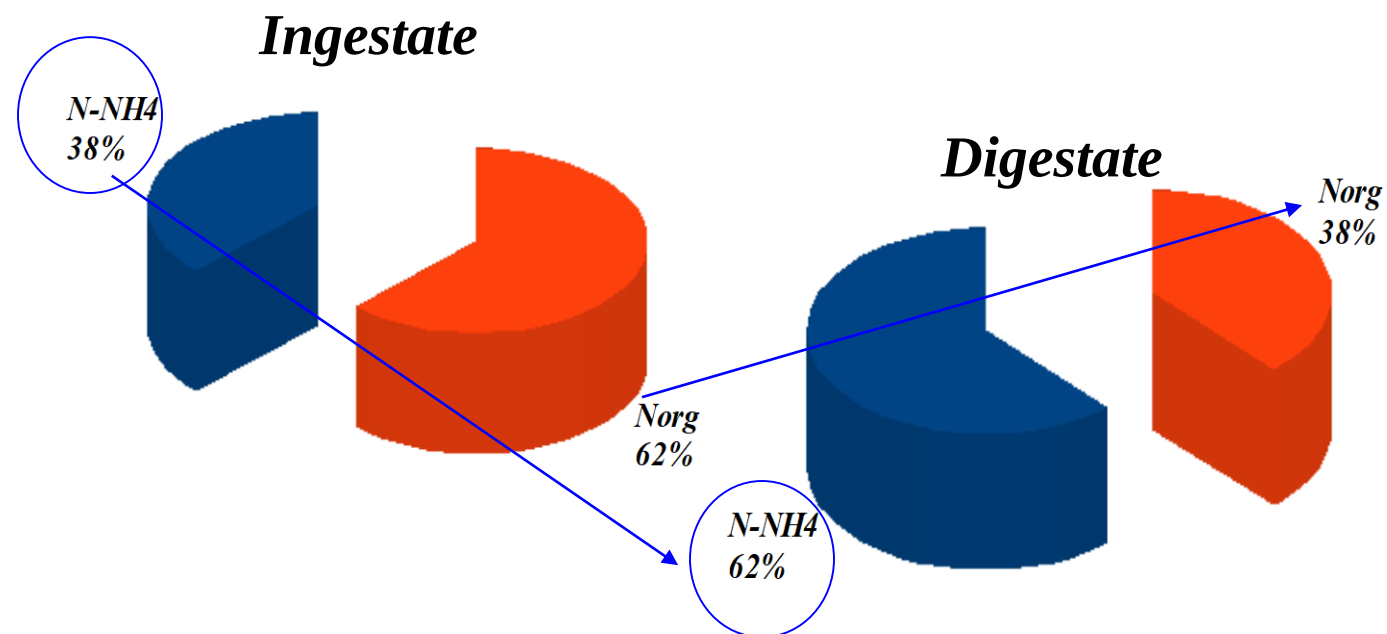
◻ C
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★ I



What about mineral fraction.....?



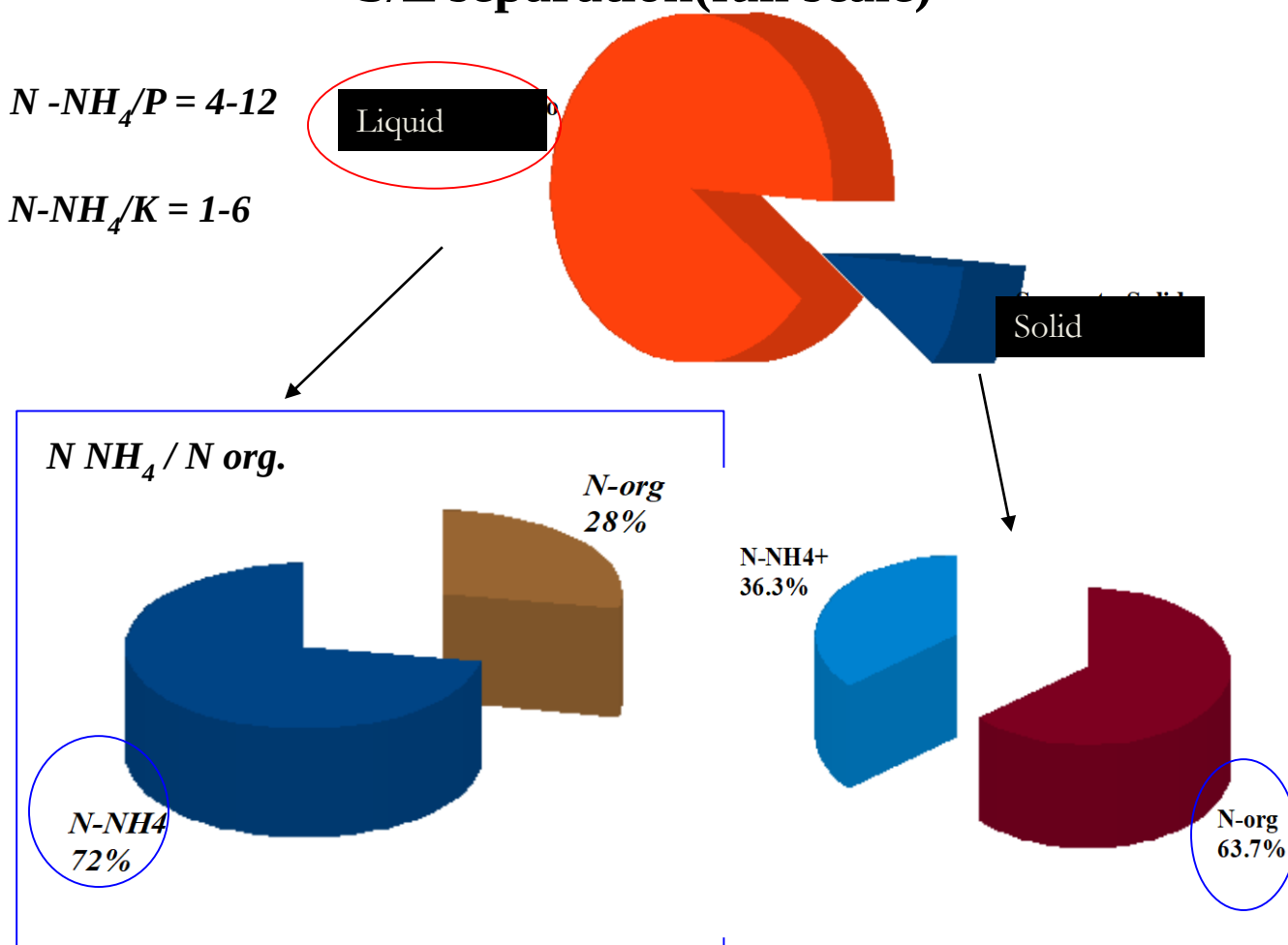
Anaerobic digestion



S/L separation(full scale)

$$N-NH_4/P = 4-12$$

$$N-NH_4/K = 1-6$$



Bioresource Technology 243 (2017) 1251–1256



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech



Short Communication

Solid and liquid fractionation of digestate: Mass balance, chemical characterization, and agronomic and environmental value

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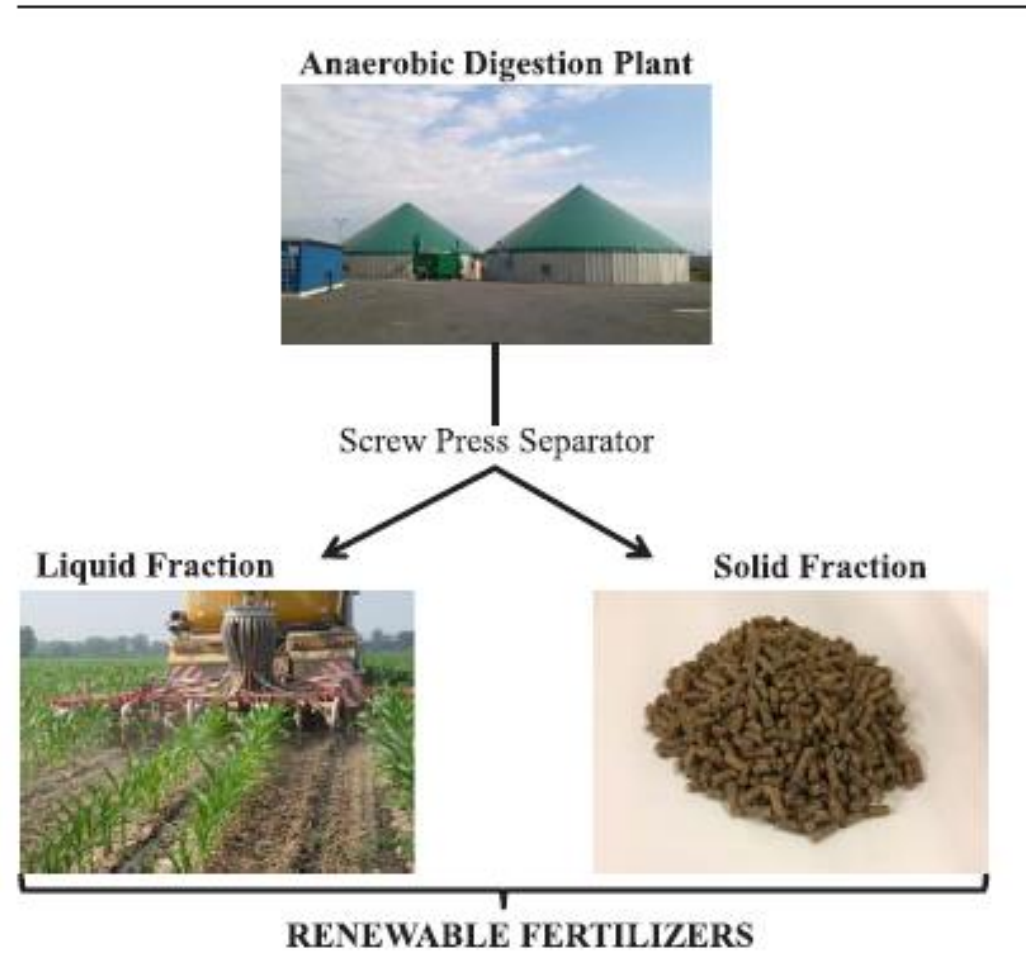


Table 1
Characteristics of the anaerobic digestion plants that originated the digestates.

Plants	Infeed biomasses	Rated power kWh
1	Pig slurry + energetic crops	999
2	Pig slurry + energetic crops	999
3	Pig slurry + energetic crops + cornmeal + milk whey	999
4	Pig slurry + agro-industrial residues	999
5	Pig slurry + energetic crops	999
6	Cow slurry + energetic crops	999
7	Energetic crops + milk whey	340
8	Energetic crops	650
9	Cow slurry + energetic crops	999
10	Cow slurry + cow manure + energetic crops + molasses	999
11	Cow slurry + energetic crops	999
12	Cow slurry + energetic crops + poultry manure	380
13	Cow slurry + energetic crops	999

Separation efficiency (% SF and % LF, fresh weight – FW) was calculated by using the equation previously used by other researchers studying digestate, digestate fractions, and slurries from both cows and pigs collected in Northern Italy, for a total of 130 samples:

$$y = (5E^{-6}x^{2.3878}) \times 100 (R^2 = 0.8262; p < 0.01; n = 130) \quad (1)$$

Table 2

Chemical characteristics of the samples: average values for each plants monitored.

Plants	Samples	DM g kg ⁻¹ FM	TKN g kg ⁻¹ DM	TAN	TAN/TKN %	P ₂ O ₅ tot g kg ⁻¹ DM	TKN/P ₂ O ₅ tot
	D average	61.1 ± 12.5 a	80.6 ± 13.3b	48.9 ± 26.1b	54.9 ± 8.2b	35.6 ± 11.1 a	2.37 ± 0.64b
	LF average	44.8 ± 9.3 a	97.5 ± 19.4b	59.9 ± 20.3b	59.8 ± 9.8b	37.3 ± 12.8 a	2.78 ± 0.87b
	SF average	212 ± 34b	28.7 ± 5.9 a	10.1 ± 3.5 a	35.1 ± 9.1 a	29.9 ± 10.6 a	1.05 ± 0.36 a

D: Digestate; LF: Liquid Fraction; SF: Solid Fraction; DM: Dry Matter; TAN: Total Ammonia Nitrogen; TKN: Total Kjeldhal Nitrogen.

Means followed in the same column by the same letter are not statistically different ($p < 0.05$) according to Tukey's test.

Table 3
Breakdown of Dry Matter, TKN and total P₂O₅ in the SF and LF by separation.

Plants	DM ¹		TKN ²		P ₂ O ₅ ³	
	SF (% DM)	LF (% DM)	SF (% TKN)	LF (% TKN)	SF (% P ₂ O ₅)	LF (% P ₂ O ₅)
1	17.19	82.81	5.54	94.46	17.14	82.86
2	25.24	74.76	9.69	90.31	30.86	69.14
3	35.74	64.26	9.28	90.72	16.58	83.42
4	28.16	71.84	7.65	92.35	15.45	84.55
5	25.07	74.93	8.11	91.89	26.04	73.96
6	31.29	68.71	10.70	89.30	33.90	66.10
7	42.15	57.85	19.06	80.94	38.64	61.36
8	41.78	58.22	23.94	76.06	53.96	46.04
9	21.37	78.63	8.10	91.90	10.03	89.97
10	41.04	58.96	15.06	84.94	22.76	77.24
11	34.44	65.56	18.12	81.88	38.12	61.88
12	49.20	50.80	23.59	76.41	33.28	66.72
13	29.37	70.63	11.85	88.15	31.96	68.04
Average	32.46 ± 9.32	67.54 ± 9.32	13.13 ± 6.21	86.87 ± 6.21	28.36 ± 12.02	71.64 ± 12.02

DM: Dry Matter; SF: Solid Fraction; LF: Liquid Fraction.

¹ Distribution (%) of DM that from digestates flows into SF and LF.

² Distribution (%) of TKN that from digestates flows into SF and LF.

³ Distribution (%) of P₂O₅ that from digestates flows into SF and LF.

Table 4

Comparison between liquid and solid fraction and other organic fertilizers.

		Liquid Fraction (this work)	Solid Fraction (this work)	Poultry Manure ¹	Sewage Sludge ²	Compost ³
TKN	g kg ⁻¹ DM	97.5 ± 19.4	28.7 ± 5.9	37.9 ± 20.2	49.54 ± 16.44	14.8 ± 1.7
N-NH ₄		59.9 ± 20.3	10.1 ± 3.5	17.8 ± 7.7	9.42 ± 3.39	0.18 ± 0.21
P ₂ O ₅ tot		37.3 ± 12.8	29.9 ± 10.6	22.9 ± 13.27	51.34 ± 19.9	5.50 ± 0.92
N-NH ₄ /TKN		59.8 ± 9.8	35.1 ± 9.1	46.9	18.3	1.21

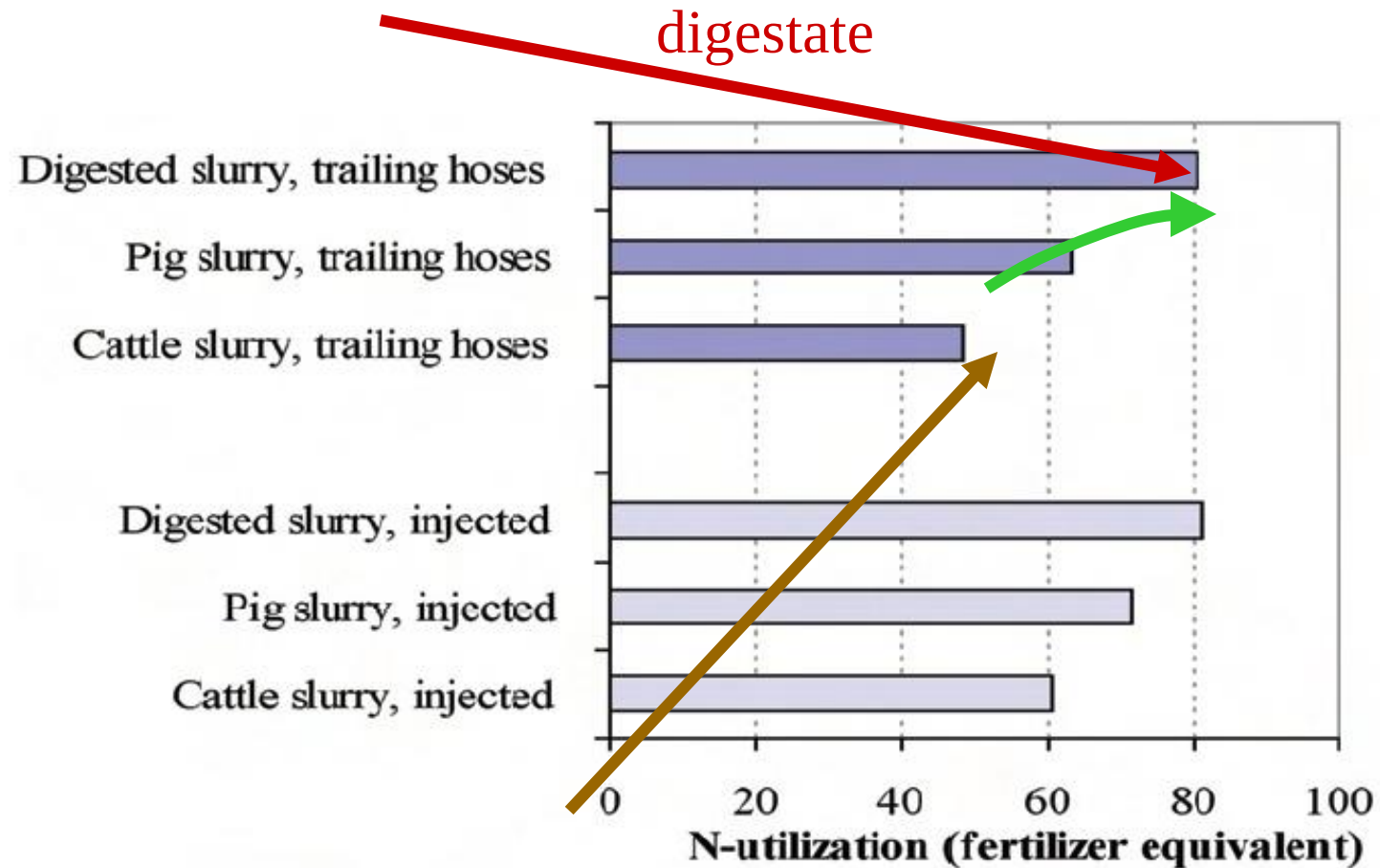
¹ Nicholson et al. (1999), Guerra-Rodriguez et al. (2001), Amanullah et al. (2007), Hirzel and Walter (2008), Dorivar et al. (2008), Malik et al. (2013), Delgado Arroyo et al. (2014).

² Benerjee et al. (1997), Navas et al. (1998), Debosz et al. (2002), Pavan Fernandes et al. (2005), Tambone et al. (2010).

³ Hartz and Giannini (1998).



Fertilizers properties of digestate



Source: Pedersen 2003

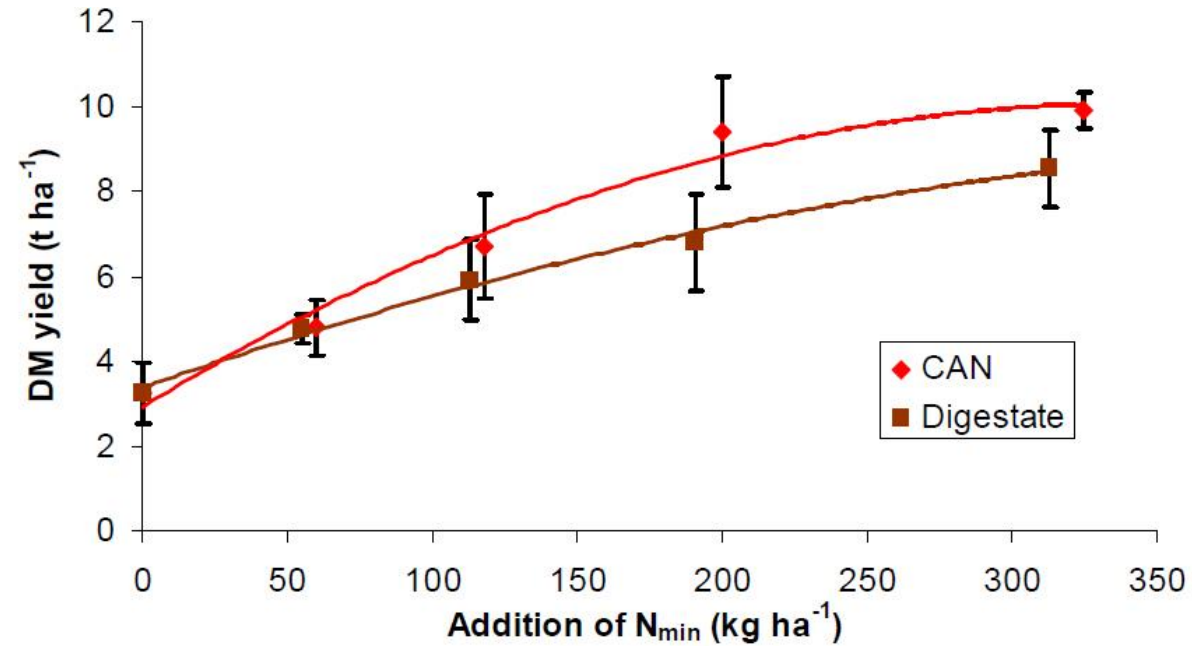


Fig. 2. N response for CAN and digestate (2nd order polynomial)

CAN: Calcium ammonia nitrate nitrate

Dieterich et al, 2008

Waste Management 88 (2019) 21–27



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Measuring the organic amendment properties of the liquid fraction of digestate



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Table 2

Chemical characteristics and biological stability for the liquid fractions of digestate.

Samples	DM ^a g kg ⁻¹ FM (% DM digestate)	TOC g kg ⁻¹ DM	TKN ^a	N-NH ₄ /TKN ^a %	C/N	P ₂ O ₅ tot ^a g kg ⁻¹ DM	OD ₂₀ mg O ₂ g DM ⁻¹ 20 h ⁻¹	GI %
LF1	33.8 ± 9.2(74.93)	352 ± 11	121 ± 29	70.7 ± 9.5	2.90	49.5 ± 1.7	52.4 ± 3.3	31 ± 5
LF2	42.9 ± 0.6(68.71)	358 ± 17	85.1 ± 2.6	58.4 ± 3.8	4.20	34.8 ± 1.2	38.0 ± 1.2	22 ± 3
LF3	62.3 ± 2.2(58.22)	344 ± 13	82.3 ± 0.5	52.2 ± 1.8	4.18	24.8 ± 2.6	13.5 ± 0.5	44 ± 3
LF4	58.4 ± 9.4(50.80)	377 ± 22	82.8 ± 4.9	62.6 ± 10.9	4.55	40.0 ± 7.4	38.9 ± 4.2	21 ± 3
LF5	56.3 ± 4.3(57.85)	359 ± 17	73.0 ± 7.9	39.2 ± 8.7	4.93	30.2 ± 0.5	30.4 ± 3.2	21 ± 5
LF6	36.5 ± 2.2(64.26)	369 ± 12	112 ± 23	55.6 ± 3.7	3.29	56.8 ± 2.9	44.6 ± 1.4	28 ± 4
LF7	48.6 ± 2.7(65.56)	330 ± 15	81.4 ± 3.8	56.9 ± 1.2	4.06	29.5 ± 1.1	23.8 ± 4.1	36 ± 9
LF8	35.9 ± 8.3(82.81)	324 ± 18	119 ± 31	68.6 ± 4.9	2.70	26.1 ± 0.1	32.6 ± 3.5	40 ± 8
LF9	37.9 ± 2.9(71.84)	349 ± 24	105 ± 5	68.6 ± 1.8	3.30	57.9 ± 0.5	60.6 ± 13.6	17 ± 2
LF10	44.9 ± 10.5(58.96)	366 ± 10	119 ± 27	72.1 ± 1.3	3.08	56.0 ± 1.4	41.2 ± 2.3	50 ± 8
LF11	46.6 ± 5.2(74.76)	415 ± 15	124 ± 12	68.0 ± 1.3	3.35	28.9 ± 1.6	64.0 ± 10.5	28 ± 4
Averages	44.8 ± 9.3 (66.25 ± 9.44)	358 ± 25	97.5 ± 19.5	61.2 ± 9.9	3.69 ± 0.73	39.5 ± 13.1	40.1 ± 15.1	31 ± 11

^a Tambone et al., 2017; LF: Liquid Fraction; DM: Dry Matter; TOC: Total Organic Carbon; TKN: Total Kjeldahl Nitrogen; OD: Oxygen Demand; GI = Germination Index; FM: Fresh Matter.

Table 3

Chemical characteristics and biological stability for the liquid fractions of digestate and for other biomasses (literature data).

Samples	DM g kg ⁻¹ FM	TOC g kg ⁻¹ DM	TKN	N-NH ₄ /TKN %	C/N	P ₂ O ₅ tot g kg ⁻¹ DM	OD ₂₀ mg O ₂ g DM ⁻¹ 20 h ⁻¹
LFs of Digestate (n = 11) ^a	44.8 ± 9.3 b	358 ± 25 ab	97 ± 19 d	61.2 ± 9.9 b	3.69 ± 0.73 b	39 ± 13 c	40.1 ± 15.1 a
Ingestates (n = 34) ^{b,c}	143 ± 19 c	456 ± 29 b	35 ± 3 c	22.2 ± 20.7 a	–	22 ± 9 c	243 ± 8 d
Digestates (n = 43) ^{b,c,d}	43 ± 5 b	378 ± 11 ab	108 ± 3 d	62.7 ± 0.5 b	–	43 ± 0 d	125 ± 46 b
Sewage Sludge (n = 4)	120 ± 0 ^e c	288 ± 127 ^f a	28 ± 5 ^f c	–	10.1 c	12 ± 2 ^f b	91 ± 8 ^e b
Household organic waste (n = 3) ^g	495 ± 51 d	558 ± 10 c	27 ± 6 c	–	37.6 ± 10.2 e	–	233 ± 39 d
Cattle manure (n = 1) ^g	18 ± 1 a	463 ± 3 b	10 ± 1 a	–	46.3 ± 1.3 e	–	36 ± 7 a
Swine manure (n = 1) ^g	30 ± 1 b	349 ± 1 ab	164 ± 3 e	–	2.12 ± 0.7 a	–	125 ± 1 c
Compost (n = 7) ^{c,h,i}	737 ± 30 e	247 ± 36 a	16 ± 1 b	10 ± 0 a	16 ± 3 d	29 ± 10 c	41 ± 5 a

Values of the same column followed by different letters are statistically different (P < 0.05 Tukey test).



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Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv



The role of biological processes in reducing both odor impact and pathogen content during mesophilic anaerobic digestion



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Table 1
Technical data of anaerobic digestion plants.

Plant	CSTR type digesters	Electrical power (kWe)	Feed mixture	HRT Ing ^a -Dig ^b (days)	Process temperature (°C)	Separator	HRT Dig-Pre sep ^c (days)
P1	Single digester	180	Slurry and manure pig	28	39 ± 1		
P2	Primary and secondary digesters	350	Pig slurry, agricultural biomass (corn silage, triticales)	40-45	42 ± 1		
P3	Primary and secondary digesters	400	Pig slurry, agro-products (bran, middlings, food industry waste)	30-35	40 ± 2		
P4	Single digester	999	Pig slurry, maize silage, corn middlings, agri-food products	35-40	39 ± 1		
P5	3 primary, 1 post-digesters	999	Pig slurry, silage (maize, sorghum, triticales), concentrated waste olive oil	40	39 ± 1		
P6	2 primary, 1 secondary, 1 post-digesters	999	Pig slurry, maize silage, triticales	70	39 ± 1	Helical	27
P7	Primary and secondary digesters	999	Cattle slurry, maize silage	35-40	39 ± 1	Helical	-
P8	Primary and secondary digesters	340	Maize silage, whey permeate	24	39 ± 1	Helical	-
P9	1 primary, 1 secondary, 1 post-digesters	650	Maize silage, triticales	20	39 ± 1	Helical	20
P10	Primary and secondary digesters	999	Cattle slurry, maize silage	20	39 ± 1	Helical	20

^a Ing = ingestate tank.

^b Dig = digestate tank.

^c Pre sep = pre separation tank.

V. Orzi et al. / Science of the Total Environment 526 (2015) 116-126

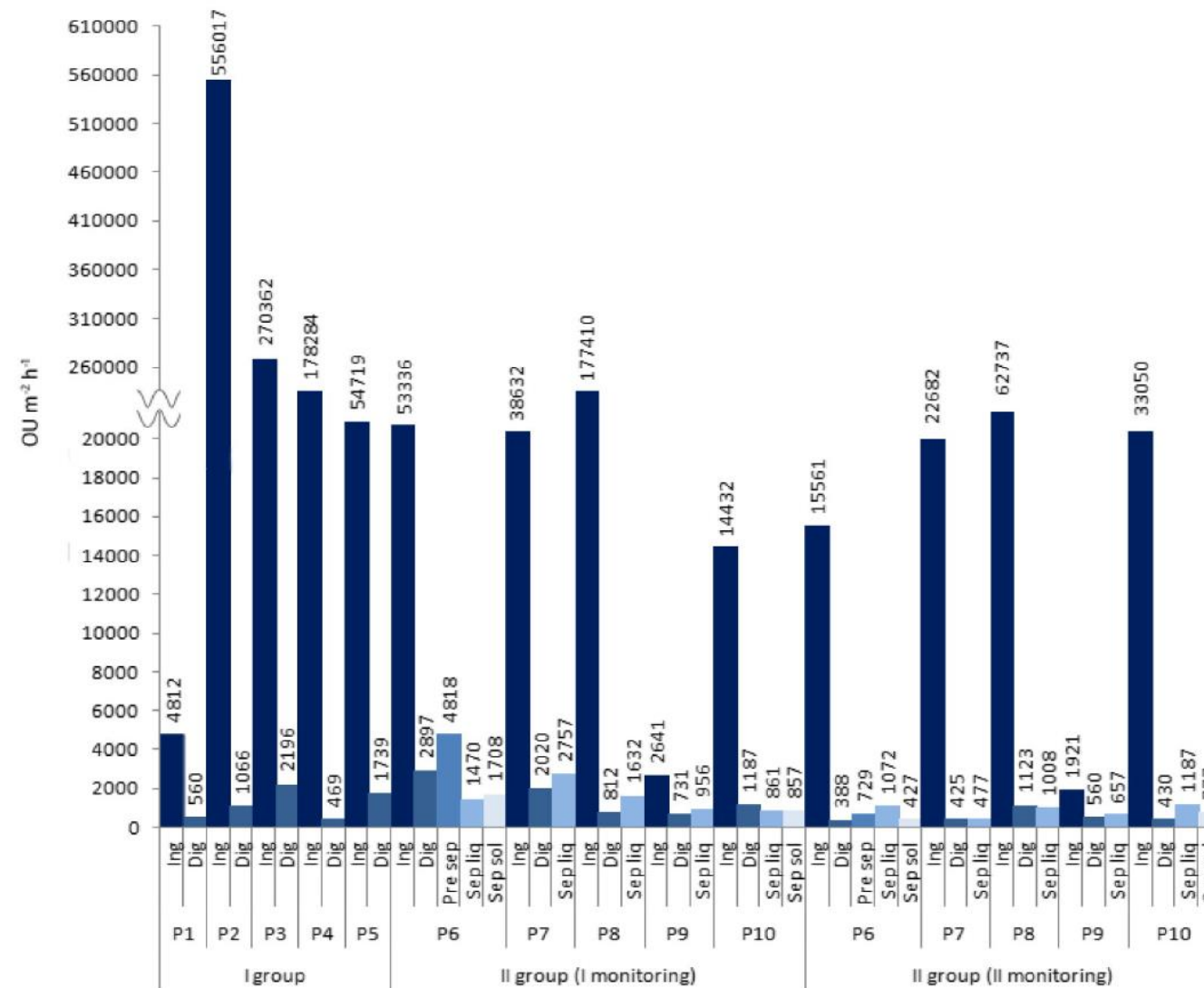


Fig. 1. Odor emission rate of the matrices sampled in the full scale plants.



Systemic
Circular solutions for biowaste



results indicat-

ed, as average for the plants studied, that a reduction of 1–3 orders of magnitude occurred after the MAD process, i.e. Enterobacteriaceae from $6.85 * 10^3 \pm 1.8 * 10^1$ to $1.82 * 10^1 \pm 3.82 * 10^1$; Fecal Coliform from $1.82 * 10^4 \pm 9.09$ to $2.45 * 10^1 \pm 3.8 * 10^1$; *Escherichia coli* from $8.72 * 10^3 \pm 2.4 * 10^1$ to $1.8 * 10^1 \pm 2.94 * 10^1$; *C. perfringens* from $6.4 * 10^4 \pm 7.7$ to $5.2 * 10^3 \pm 8.1$ (all data are expressed as CFU g⁻¹ ww).

Table 4

Correlation matrix for pH, biological stability parameters and toxic ammonia content vs. starting and end pathogen content, for full scale plants studied.

	pH	OD ₂₀ Log (mg O ₂ g ⁻¹ TS)	ABP (NI kg ⁻¹ TS) ^{1/2}	N-NH ₃ toxic (g/kg ww) ^{1/2}
Fecal Coliform Log (CFU g ⁻¹ ww) n = 18	r = -0.56 ^a	r = 0.69 ^b	r = 0.62 ^b	r = -0.85 ^b
<i>Escherichia coli</i> Log (CFU g ⁻¹ ww) n = 22	r = -0.45 ^a	r = 0.45 ^a	r = 0.54 ^b	r = -0.75 ^b
Fecal Streptococci Log (CFU g ⁻¹ ww) n = 26	r = -0.56 ^b	r = 0.42 ^a	r = 0.69 ^b	r = -0.69 ^b
<i>Clostridium perfringens</i> Log (CFU g ⁻¹ ww) n = 30	r = -0.37 ^a	r = 0.41 ^a	-	r = -0.39 ^a
Enterobacteriaceae Log (CFU g ⁻¹ ww) n = 24	r = -0.49 ^a	r = 0.42 ^a	r = 0.56 ^b	r = -0.78 ^b

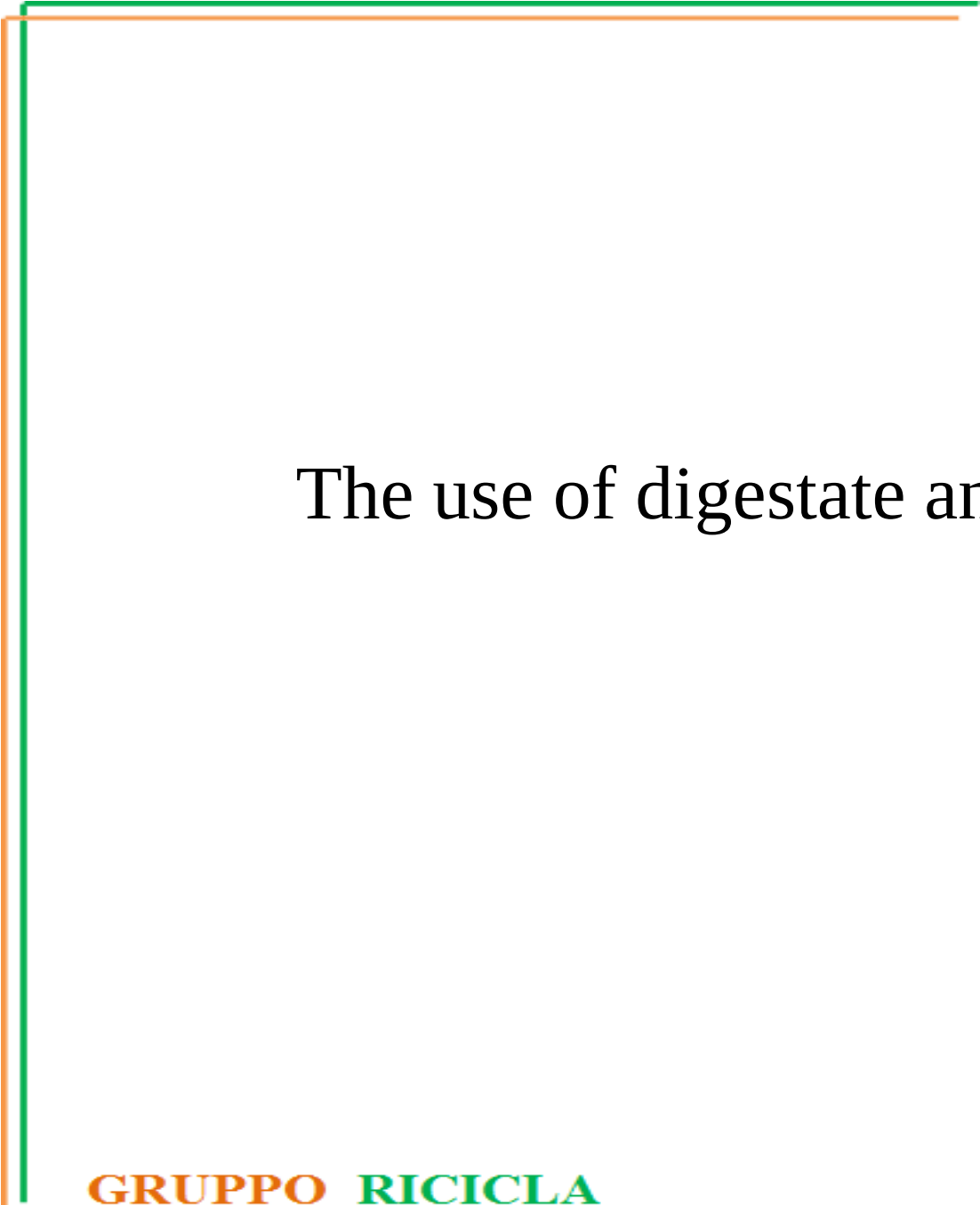
^a Person's correlation significant with p > 0.05.

^b Person's correlation significant with p < 0.01.

4. Conclusion

Mesophilic anaerobic digestion reduced the potential odor impact of biomasses because of the degradation of organic matter and the acquirement of a high degree of biological stability. Potential odor impact can be reduced, on average by 98%. Pathogens, as well, were reduced during MAD because of both ammonia production during the process (toxic form) and competition for substrate between pathogens and indigenous microflora. Plants showed different abilities in reducing pathogen indicators, i.e. anaerobic digestion characterized by a higher pH and toxic ammonia contests showed very good performance in reducing all pathogen indicators including *C. perfringens*.

V. Orzi et al. / Science of the Total Environment 526 (2015) 116–126



The use of digestate and its fraction in full field scale

Science of the Total Environment 547 (2016) 206–214



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journal homepage: www.elsevier.com/locate/scitotenv



Short-term experiments in using digestate products as substitutes for mineral (N) fertilizer: Agronomic performance, odours, and ammonia emission impacts



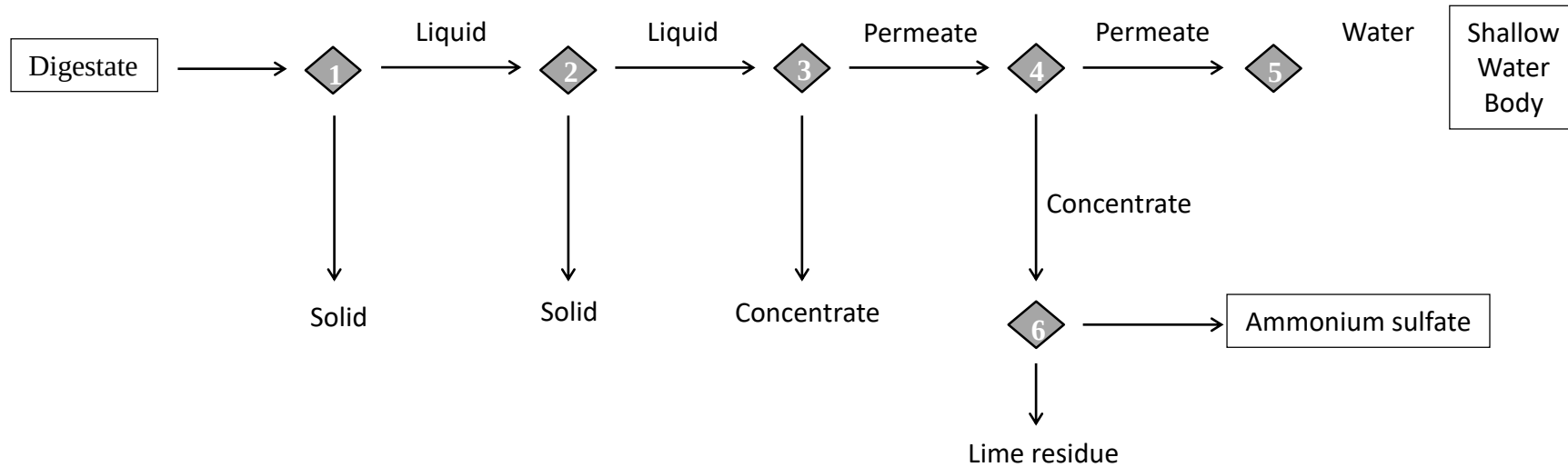
C. Riva^a, V. Orzi^a, M. Carozzi^b, M. Acutis^b, G. Boccasile^c, S. Lonati^a, F. Tambone^a, G. D'Imporzano^a, F. Adani^{a,*}

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Chemical physical treatment



Simplified scheme of the plant (1: Screw press separation, 2: Centrifugation, 3: Ultrafiltration - UF, 4: Reverse Osmosis - RO, 5: Zeolites refining, 6: Cold ammonia stripping)

a

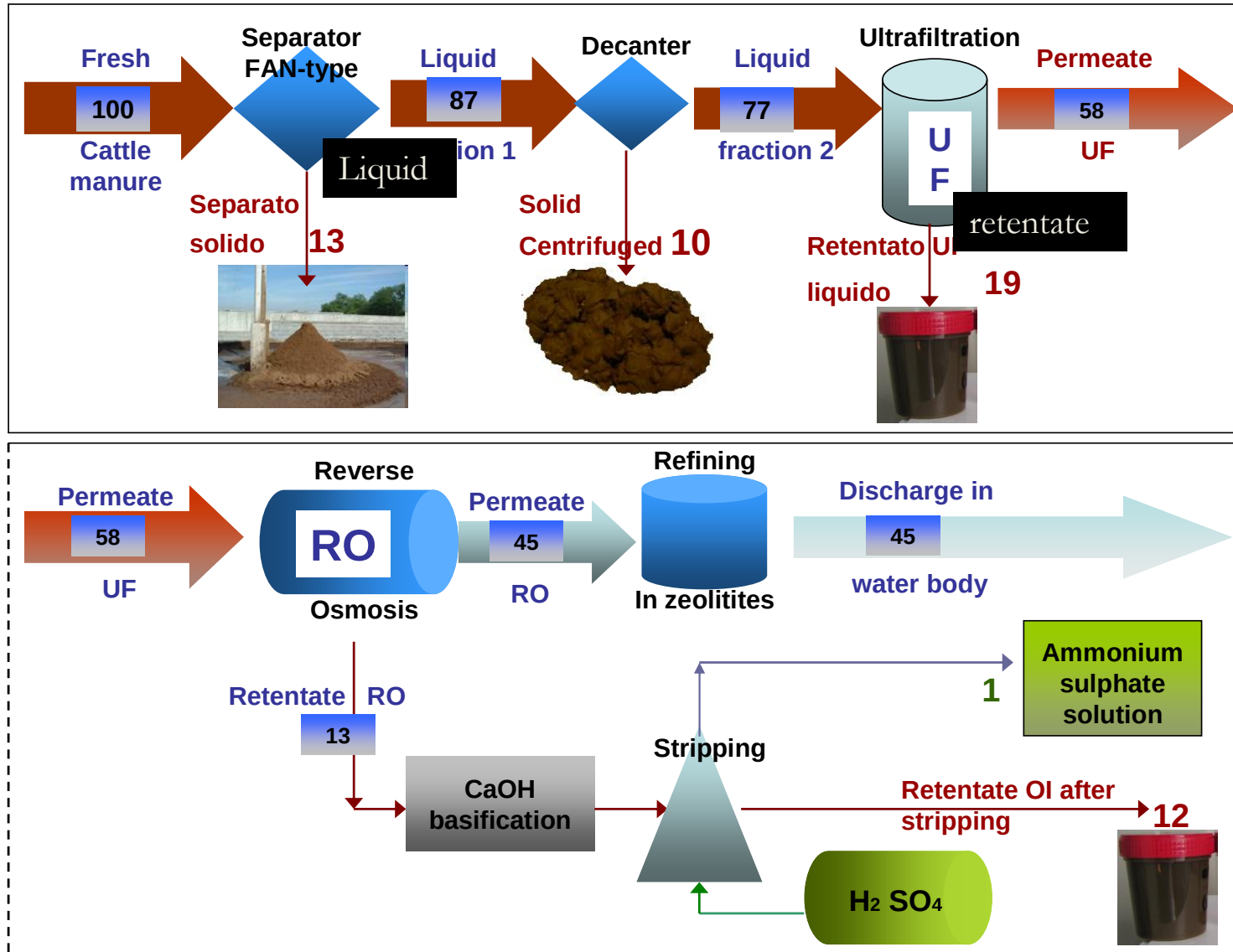


Figure 10 – N-Free® System. Mass flow scheme (a) (per 100 kg wet weight) and total nitrogen balance (b) (per 100 kg of total N)

b

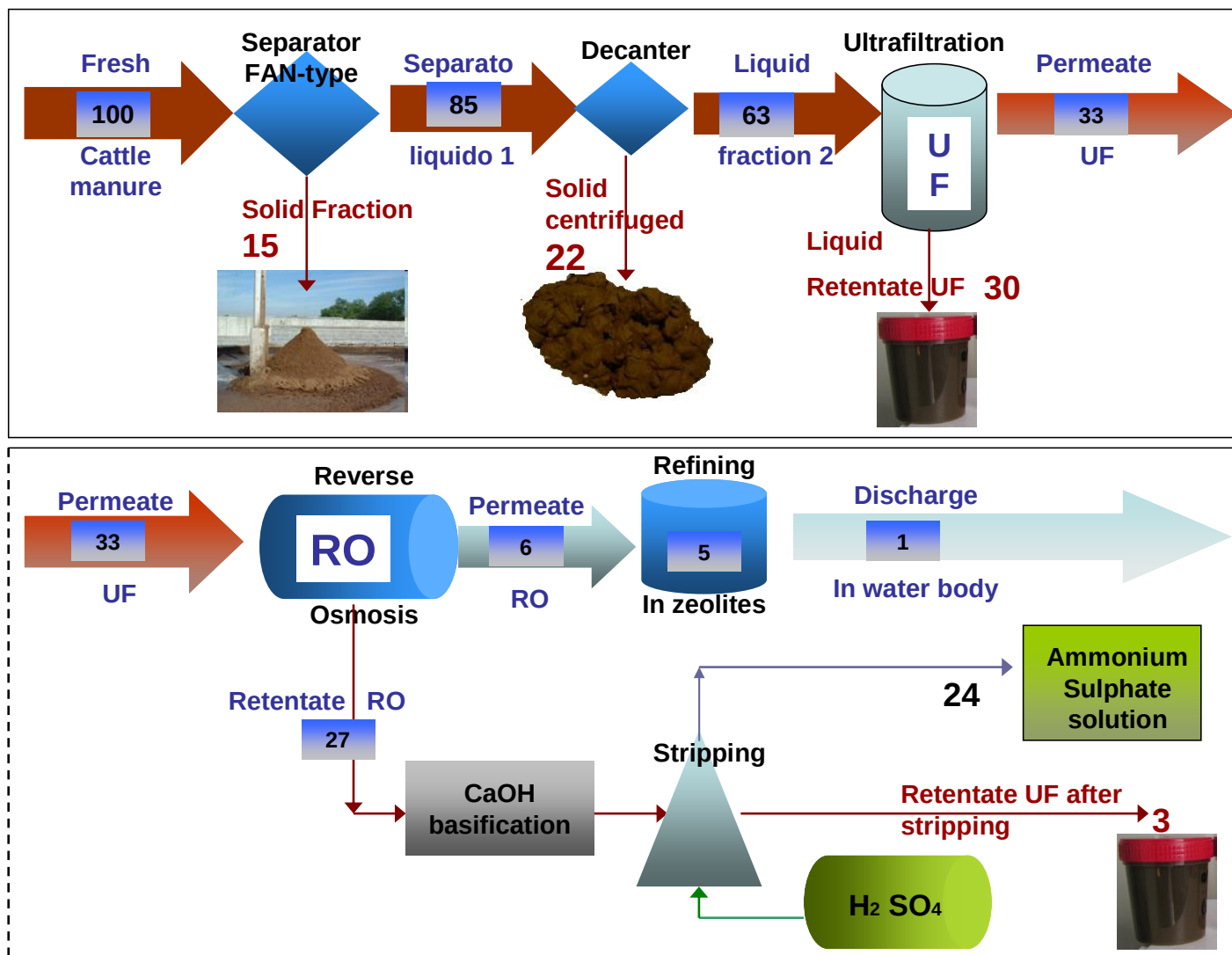


Figure 10 – N-Free® System. Mass flow scheme (a) (per 100 kg wet weight) and total nitrogen balance (b) (per 100 kg of total N)

UF + OI + cold stripping plus zeolite refining.



Zeolite





Untreated

After ultrafiltration

After reverse osmosis

Ammonia sulfate production



Membrane (MF) and ultrafiltration (UF) techniques consist in physical separation by forcing stream input (i.e. liquid fraction of digestate after decanter digestate centrifugation, through membrane by means of pressure. Membranes used to process digestate can be classified as in the following according to pore size: MF- (pores $> 0.1 \mu\text{m}$, 0.1-3 bar), UF- (pores $> \text{nm}$, 2-10 bar) and RO-membranes (no pores, 10-100 bar). Membranes used can be both organo-polymeric or ceramic. The first one are less expensive but they are difficult to be cleaned and they do not support high pressure. Ceramic membrane, used above all for ultrafiltration, are easier to be cleaned (they have resistance to chemicals) and they allow higher performance because of high pressure used. Nevertheless, the higher the separation performance, the higher the energy consumption what might be the main limitation for the implementation of such technique.

Membranes operate a separation of the suspended solid fraction. This process is generally used as pretreatment of the reverse osmosis in a cascade modality. Reverse osmosis applied to the digestate consist in the MF or UF refining.

Slurry = 100 %:

- N-NH_4 reduction (from digestate) = 65 % N-NH_4
- N-NH_4 cutting (from liquid fraction) = 78% N-NH_4
- N tot riduction f(x) N-NH_4 = 36-65 % N_{tot}
- Liquid to shallow water= 47.7 % v/v
- Total solid= 23 % v/v
- Total concentrate = 10 % v/v
- $(\text{NH}_4)_2\text{SO}_4$ produced = 1.2 % v/v

Cost

- 2 €/m^3 = plant management (electricity, reagents etc.).
- $0,6 \text{ €/m}^3$ = no service
- $1,2 \text{ €/m}^3$ = full service
- 1 €/m^3 = pay back(10 a).
- Tot. = €/m^3 4.2 (full service)
- Tot. = 3 €/m^3 no service.

In addition:

- - 1 €/m^3 avoided transportation.
- - 0.5 €/m^3 trade $(\text{NH}_4)_2\text{SO}_4$.
- - $x \text{ €/m}^3$ land rented for slurry disposal

Tot. = €/m^3 2.5-3 (full service)

Agronomic use of liquid separated fraction of digestate





Regione Lombardia SATA –Unimi-DiPrVe
Full scale trials

Table 2

Chemical characterization of the input and output biomasses from the anaerobic digestion plant.

	pH	TS (% ww)	VS (% TS)	TKN (g N kg ⁻¹ ww)	TAN (g NH ₄ ⁺ kg ⁻¹ ww)	VFA (mg l ⁻¹ acetic acid)	ALK (mg l ⁻¹ CaCO ₂)	OD ₂₀ (mg O ₂ g ⁻¹ TS)	ABP (NI kg ⁻¹ TS)
Ingestate	5.14 ± 0.93 ^a	18.1 ± 6.4 ^b	91.8 ± 2.3 ^b	3.75 ± 0.80 ^a (20.7) ^b	1.14 ± 0.11 ^a (6.29) ^a	7909 ± 3336 ^a	9023 ± 1010 ^a	147 ± 27 ^c	554 ± 131 ^b
Digestate	8.10 ± 0.14 ^b	5.66 ± 0.24 ^a	75.9 ± 2.4 ^a	3.56 ± 0.39 ^a (62.9) ^a	1.80 ± 0.39 ^{ab} (31.8) ^a	401 ± 97 ^a	10,483 ± 3678 ^a	27.8 ± 5.4 ^b	224 ± 137 ^c
Separated liquid fraction of digestate	8.38 ± 0.16 ^b	4.36 ± 0.17 ^a	71.8 ± 4.7 ^a	3.44 ± 0.22 ^a (78.8) ^a	2.08 ± 0.13 ^b (47.7) ^a	1068 ± 781 ^a	11,521 ± 5172 ^a	33.2 ± 3.8 ^b	251 ± 103 ^a
Separated solid fraction of digestate	9.73 ± 0.31 ^c	25.6 ± 2.7 ^c	93.3 ± 2.9 ^b	5.54 ± 0.43 ^b (21.6) ^a	1.59 ± 0.68 ^a (6.1) ^a	215 ± 155 ^a	5010 ± 986 ^a	14.3 ± 2.7 ^a	179 ± 87 ^a

^a Values of the same column followed by the same letter are not statistically different (ANOVA bootstrap and Tukey test, $p < 0.05$).

^b Data reported as g N kg⁻¹ TS.

Table 3

Chemical characterization of digestate and liquid fraction of digestate used in field trials.

			TS (% ww)	VS (% ww)	pH	TKN (g N kg ⁻¹ ww)	TAN (g NH ₄ ⁺ kg ⁻¹ ww)	TAN/TKN (%)	P ₂ O ₅ (g kg ⁻¹ ww)	K ₂ O (g kg ⁻¹ ww)	OD ₂₀ (mg O ₂ g ⁻¹ TS)
First campaign	Pre-sowing	Digestate	7.4 ± 0.1 ^e ^a	5.7 ± 0.1 ^e (76.8) ^b	8.1 ± 0.4 ^a	3.4 ± 0.1 ^c (45.9) ^a	2 ± 0 ^b (27) ^a	59	1.88 ± 0.02 ^d (25.46) ^a	4.66 ± 0.04 ^c (62.93) ^a	24.7 ± 4.4 ^a
	Topdressing	Digestate	6.3 ± 0.1 ^d	4.7 ± 0.1 ^d (76.2) ^a	7.8 ± 0.1 ^a	4.1 ± 0.1 ^d (65.1) ^a	2.4 ± 0.1 ^c (38.1) ^a	59	1.58 ± 0.02 ^c (25.45) ^a	4.36 ± 0.02 ^c (70.42) ^a	25.7 ± 0.7 ^a
		Separated liquid fraction of digestate	2.2 ± 0.1 ^a	1.6 ± 0.1 ^a (72.4) ^a	8.0 ± 0.2 ^a	2.7 ± 0.1 ^a (122.7) ^a	2.1 ± 0.1 ^b (95.4) ^a	78	0.54 ± 0.02 ^a (24.72) ^a	1.84 ± 0.04 ^a (83.56) ^a	64.1 ± 7.3 ^c
Second campaign	Pre-sowing	Separated liquid fraction of digestate	3.5 ± 0.1 ^b	2.3 ± 0.1 ^b (71.0)	7.9 ± 0.3 ^a	3 ± 0 ^b (85.7) ^a	1.9 ± 0.1 ^a (54.8) ^a	63 (51) ^c	0.72 ± 0.02 ^b (22.64)	3.51 ± 0.08 ^b (109.58)	37.2 ± 3.7 ^b
	Topdressing	Separated liquid fraction of digestate	3.9 ± 0.1 ^c	2.7 ± 0.1 ^c (69.9) ^a	7.8 ± 0.2 ^a	3 ± 0 ^b (76.9) ^a	1.7 ± 0.1 ^a (17.9) ^a	59 (50) ^c	0.54 ± 0.01 ^a (14.1) ^a	6.86 ± 0.07 ^d (176) ^a	26.5 ± 3.3 ^a

^a Values of the same column followed by the same letter are not statistically different (ANOVA bootstrap and Tukey test, $p < 0.05$).

^b Data reported on TS basis.

^c TAN/TKN (%) of digestate from which liquid fraction was derived.

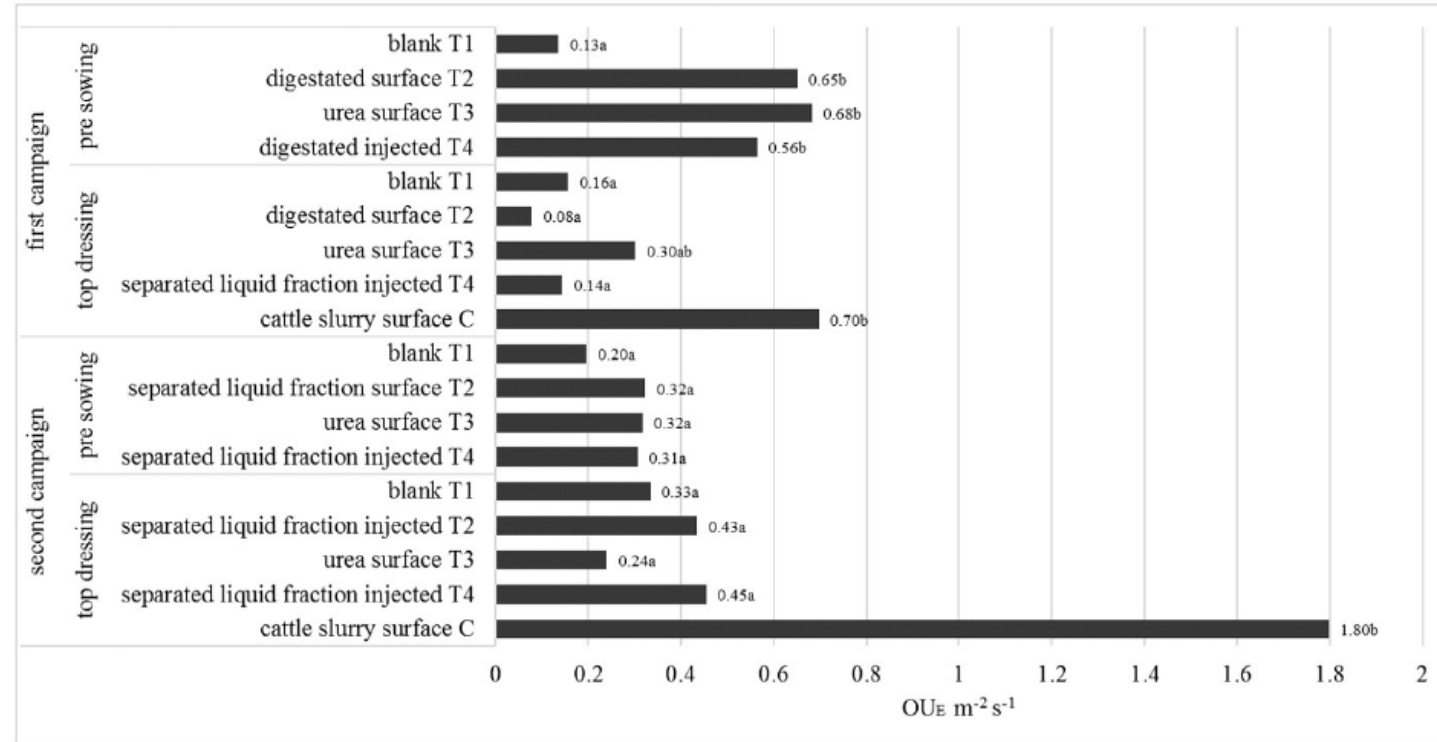


Fig. 1. Odour emission from soils after fertilization (values followed by the same letter are not statistically different within fertilization made (ANOVA bootstrap and Tukey test, $p < 0.05$).

Table 5

Odour reduction during slurry/digestate application as consequence of different management.

Treatment compared	Odours variation	References
Pig slurry injected vs. pig slurry superficial	– 38%	Lau et al. (2003)
Digestate from pig slurry vs. pig slurry	– 17%	Hansen et al. (2003)
Digestate liquid fraction from pig slurry vs. digestate from pig slurry	– 40%	Hansen et al. (2003)
Digestate superficial Vs. slurry superficial	– 75%	Nicolas et al. (2013)
Digestate superficial from pig slurry vs. pig slurry superficial	– 70/80%	Pain et al. (1990)
Digestate injected (cattle manure + energy crops) vs. digestate superficial (cattle manure + energy crops)	– 13.4%	This work (Fig. 2)
Liquid fraction of digestate superficial (cattle manure + energy crops) vs. cattle slurries superficial	– 88%	This work (Fig. 2)
Liquid fraction of digestate injected (cattle manure + energy crops) vs. Liquid fraction of digestate superficial (cattle manure + energy crops)	+ 4%	This work (Fig. 2)
Liquid fraction of digestate injected (cattle manure + energy crops) vs. cattle slurries superficial	– 82%	This work (Fig. 2)

Table 6

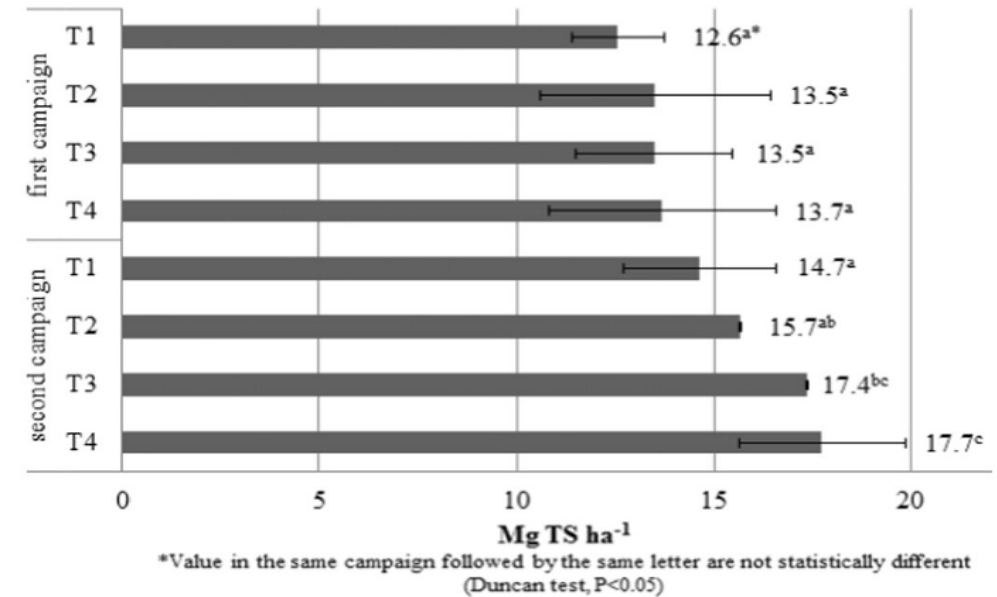
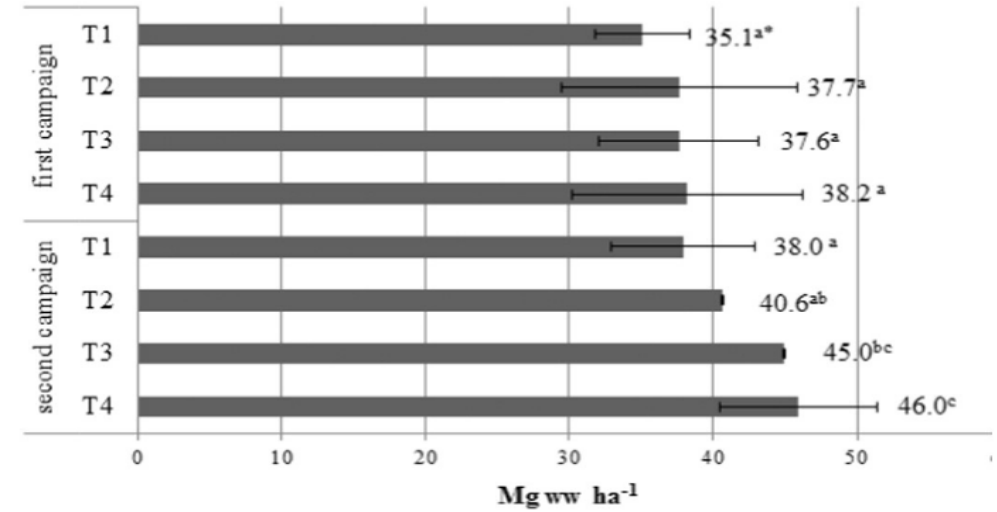
NH₃ emission after fertilizers spreading and emission factors (EF) expressed as the ratio between the N-NH₃ emitted and the TAN applied.

			kg N ha ⁻¹	NH ₃ losses EF (% TAN)	Std ^a
First campaign	Pre-sowing (130 kg N ha ⁻¹)	T2 Digested surface	23.3b ^b	30.4	3.3
		T3 Urea surface	17.8ab	13.7	7.7
		T4 Digested injected	7.1a	9.3	5.3
		T2 Digested injected	2.5a	1.6	0.30
	Toppdressing (200 kg N ha ⁻¹)	T3 Urea surface	2.5a	1.3	0.18
		T4 Separate liquid fraction injected	6.9b	4.5	0.46
		T2 Separate liquid fraction surface	52.6b	46.3	7.4
		T3 Urea surface	17.6a	9.7	1.6
Second campaign	Pre-sowing (180 kg N ha ⁻¹)	T4 Separate liquid fraction injected	12.0a	10.6	0.6
		T2 Separate liquid fraction injected	16.9 a	14.7	9.75
	Toppdressing (160 kg N ha ⁻¹)	T3 Urea surface	13.7 a	6.8	1.8
		T4 Separate liquid fraction injected	13.2 a	8.5	0.2

^a The standard deviation (Std) is calculated between the EF of the same treatment.

^b Values of the same column followed by the same letter are not statistically different within each fertilization (ANOVA bootstrap and Tukey test, $p < 0.05$).

Fig. 2. Maize silage production of for each treatment studied (wet weight: top; dry weight: bottom).





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Anaerobic digestion coupled with digestate injection reduced odour emissions from soil during manure distribution

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odour nuisance



odour mitigation

V. Orzi et al. / Science of the Total Environment 621 (2018) 168–176

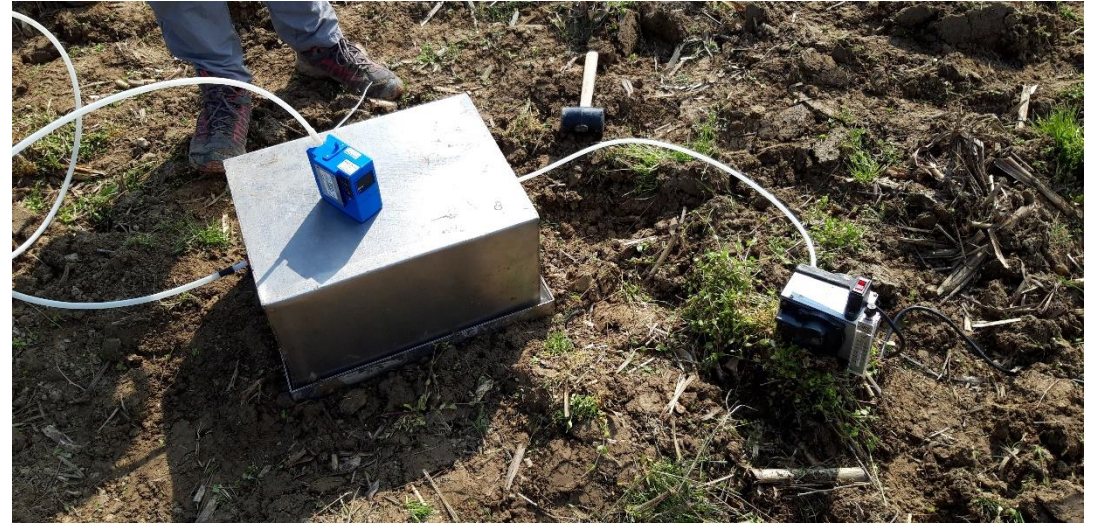
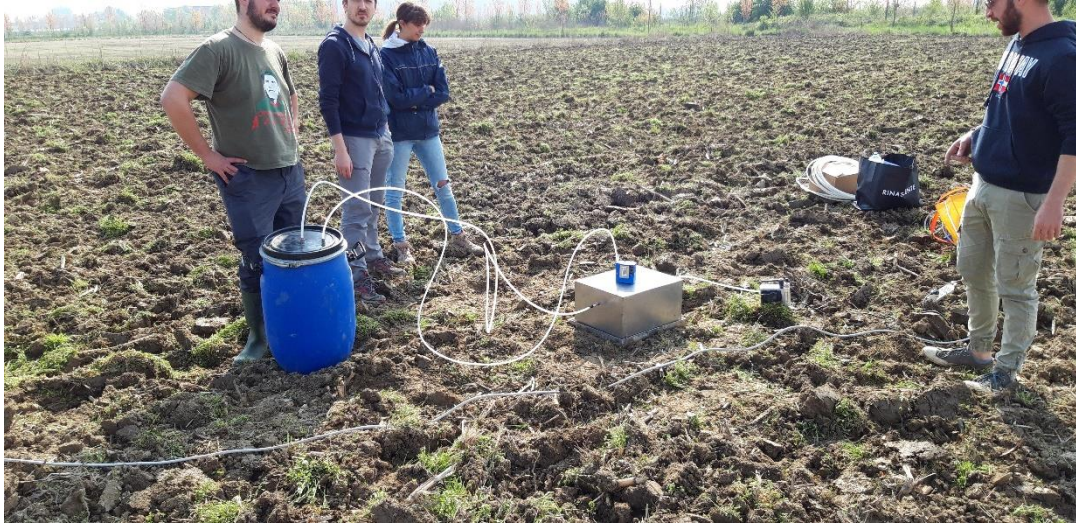
Table 1
Experimental plan design.

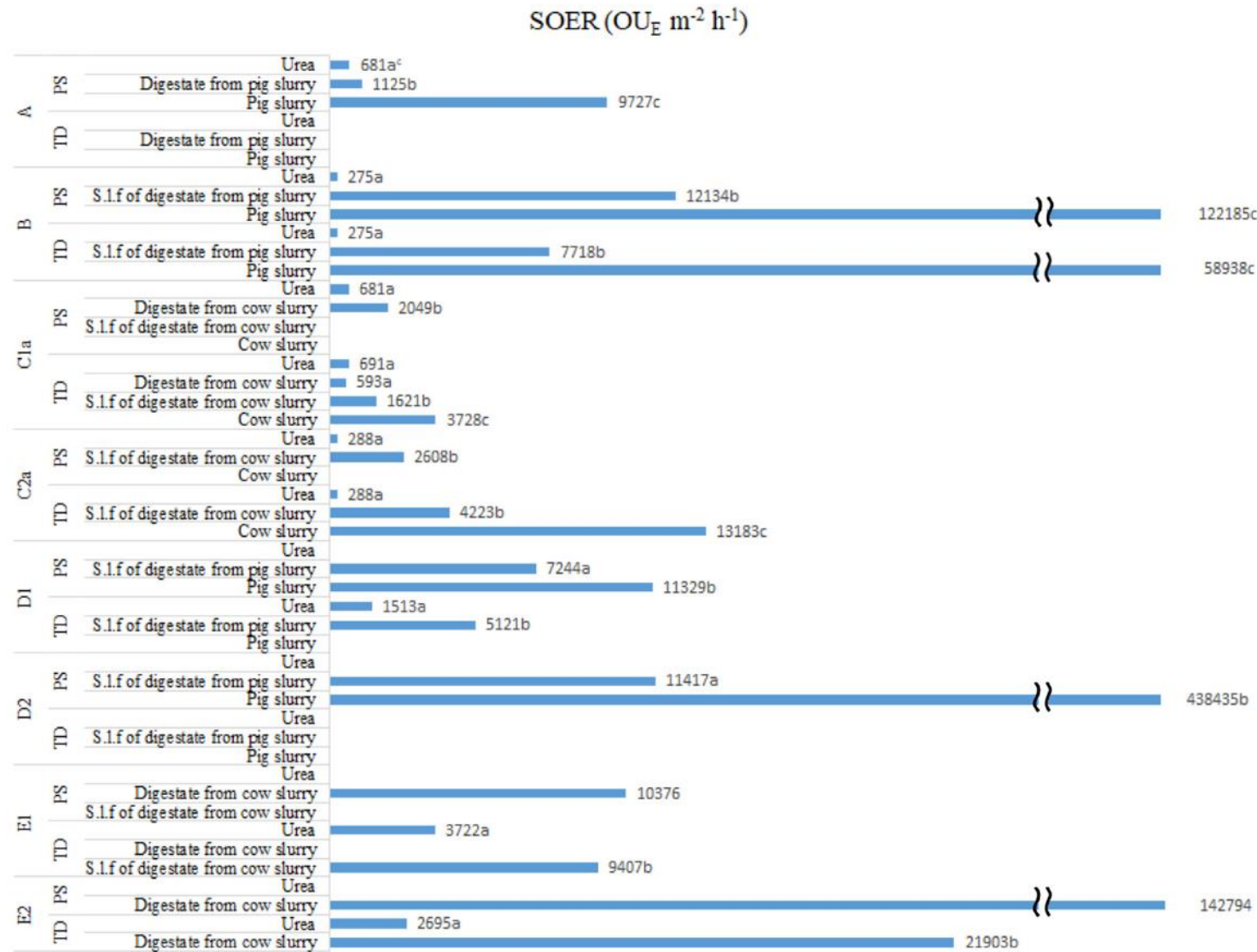
Field A	Treatment	Pre-sowing (120 kg N ha ⁻¹) – PS	Application modality	Topdressing - TD	Application modality
	T1	Blank – no fertilization	n.a. ^a	–	–
	T2	Digestate from pig slurry	Surface	–	–
	T3	Urea	Surface	–	–
	T4	Digestate from pig slurry	Injected	–	–
Field B	T5	Pig slurry	Surface	–	–
	Treatment	Pre-sowing (191 kg N ha ⁻¹)	Application modality	Topdressing (116 kg N ha ⁻¹)	Application modality
	T1	Blank – no fertilization	n.a. ^a	Blank – no fertilization	n.a. ^a
	T2	S.l.f. ^b of digestate from pig slurry	Surface	S.l.f. ^b of digestate from pig slurry	Injected
	T3	Urea	Surface	Urea	Surface
Field C ₁	T4	S.l.f. ^b of digestate from pig slurry	Injected	S.l.f. ^b of digestate from pig slurry	Injected
	T5	Pig slurry	Surface	Pig slurry	Surface
	Treatment	Pre-sowing (130 kg N ha ⁻¹)	Application modality	Topdressing (200 kg N ha ⁻¹)	Application modality
	T1	Blank – no fertilization	n.a. ^a	Blank – no fertilization	n.a. ^a
	T2	Digestate from cow slurry	Surface	Digestate from cow slurry	Injected
Field C ₂	T3	Urea	Surface	Urea	Surface
	T4	Digestate from cow slurry	Injected	S.l.f. ^b of digestate from cow slurry	Injected
	T5	–	–	Cow slurry	Surface
	Treatment	Pre-sowing (180 kg N ha ⁻¹)	Application modality	Topdressing (160 kg N ha ⁻¹)	Application modality
	T1	Blank –no fertilization	n.a. ^a	Blank – no fertilization	n.a. ^a
Field D ₁	T2	S.l.f. ^b of digestate from cow slurry	Surface	S.l.f. ^b of digestate from cow slurry	Injected
	T3	Urea	Surface	Urea	Surface
	T4	S.l.f. ^b of digestate from cow slurry	Injected	S.l.f. ^b of digestate from cow slurry	Injected
	T5	–	–	Cow slurry	Surface
	Treatment	Pre-sowing (239 kg N ha ⁻¹)	Application modality	Topdressing 143 kg N ha ⁻¹)	Application modality
Field D ₂	T1	Blank –no fertilization	n.a. ^a	Blank – no fertilization	n.a. ^a
	T2	Pig slurry	Surface	Urea	Surface
	T3	S.l.f. ^b of digestate from pig slurry	Injected	S.l.f. ^b of digestate from pig slurry	Injected
	Treatment	Pre-sowing (205 kg N ha ⁻¹)	Application modality	Topdressing	Application modality
	T1	Blank –no fertilization	n.a. ^a	–	–
Field E ₁	T2	Pig slurry	Surface	–	–
	T3	S.l.f. ^b of digestate from pig slurry	Injected	–	–
	Treatment	Pre-sowing (175 kg N ha ⁻¹)	Application modality	Topdressing (145 kg N ha ⁻¹)	Application modality
	T1	Blank –no fertilization	n.a. ^a	Blank –no fertilization	n.a. ^a
	T2	Digestate from cow slurry	Surface	Urea	Surface
Field E ₂	T3	Digestate from cow slurry	Injection	S.l.f. ^b of digestate from cow slurry	Injected
	Treatment	Pre-sowing (269 kg N ha ⁻¹)	Application modality	Topdressing (144 kg N ha ⁻¹)	Application modality
	T1	Blank –no fertilization	n.a. ^a	Blank –no fertilization	n.a. ^a
	T2	Digestate from cow slurry	Surface	Urea	Surface
	T3	Digestate from cow slurry	Injection	Digestate from cow slurry	Injection

^a No application.

^b Separate liquid fraction.

Experimental plan





Results matrices

Fig. 1. Odour impact of the fertilizers matrices. ^aData previously reported in Riva et al. (2016); ^bseparate liquid fraction; ^cvalues followed by the same letter are not statistically different within fertilization made (ANOVA bootstrap and Tukey test, $p < 0.05$).

Table 3

Odour impact of the organic matrices and synthetic fertilizers on soils.

Field	Treatment	Experimental plan design	Pre-sowing (PS)	Experimental plan design	Topdressing (TD)
			SOER (OU _E m ⁻² h ⁻¹)		SOER (OU _E m ⁻² h ⁻¹)
A	T1	Blank – no fertilization	310a ^b	n.p. ^c	
	T2	Digestate from pig slurry-surface	3318c	n.p.	
	T3	Urea-surface	2893bc	n.p.	
	T4	Digestate from pig slurry- injected	1645b	n.p.	
	T5	Pig slurry-surface	3914c	n.p.	
B	T1	Blank – no fertilization	1452ab	Blank – no fertilization	310a
	T2	S.l.f. ^b of digestate from pig slurry-surface	5221c	S.l.f. ^b of digestate from pig slurry-injected	266a
	T3	Urea-surface	3024b	Urea-surface	262a
	T4	S.l.f. ^b of digestate from pig slurry-injected	840a	S.l.f. ^b of digestate from pig slurry-injected	268a
	T5	Pig slurry-surface	5556c	Pig slurry-surface	636b
C ₁ ^a	T1	Blank – no fertilization	483a	Blank – no fertilization	560b
	T2	Digestate from cow slurry-surface	2340b	Digestate from cow slurry-injected	279a
	T3	Urea-surface	2458b	Urea-surface	1084c
	T4	Digestate from cow slurry-injected	2030b	S.l.f. ^b of digestate from cow slurry-injected	517b
	T5			Cow slurry-surface	2513d
C ₂ ^a	T1	Blank –no fertilization	706a	Blank – no fertilization	1202b
	T2	S.l.f. ^b of digestate from cow slurry-surface	1158b	S.l.f. ^b of digestate from cow slurry-injected	1575b
	T3	Urea-surface	1141b	Urea-surface	862a
	T4	S.l.f. ^b of digestate from cow slurry-injected	1102b	S.l.f. ^b of digestate from cow slurry-injected	1563b
	T5			Cow slurry-surface	6474c
D ₁	T1	Blank –no fertilization	323a	Blank – no fertilization	612a
	T2	Pig slurry-surface	2724b	Urea-surface	599a
	T3	S.l.f. ^b of digestate from pig slurry-injected	218a	S.l.f. ^b of digestate from pig slurry-injected	704a
D ₂	T1	Blank –no fertilization	587a	n.p.	
	T2	Pig slurry-surface	3715c	n.p.	
	T3	S.l.f. ^b of digestate from pig slurry-injected	896b	n.p.	
E ₁	T1	Blank –no fertilization	500b	Blank –no fertilization	407a
	T2	Digestate from cow slurry-surface	1185c	Urea-surface	2186b
	T3	Digestate from cow slurry-injected	394a	S.l.f. ^b of digestate from cow slurry-injected	1189b
E ₂	T1	Blank –no fertilization	412a	Blank –no fertilization	512a
	T2	Digestate from cow slurry-surface	2848b	Urea-surface	2941c
	T3	Digestate from cow slurry-injected	1846b	Digestate from cow slurry-injected	997b

^a Data previously reported in Riva et al. (2016).^b Values followed by the same letter are not statistically different within fertilization made (ANOVA bootstrap and Tukey test, $p < 0.05$).^c Not performed.

Result Soils

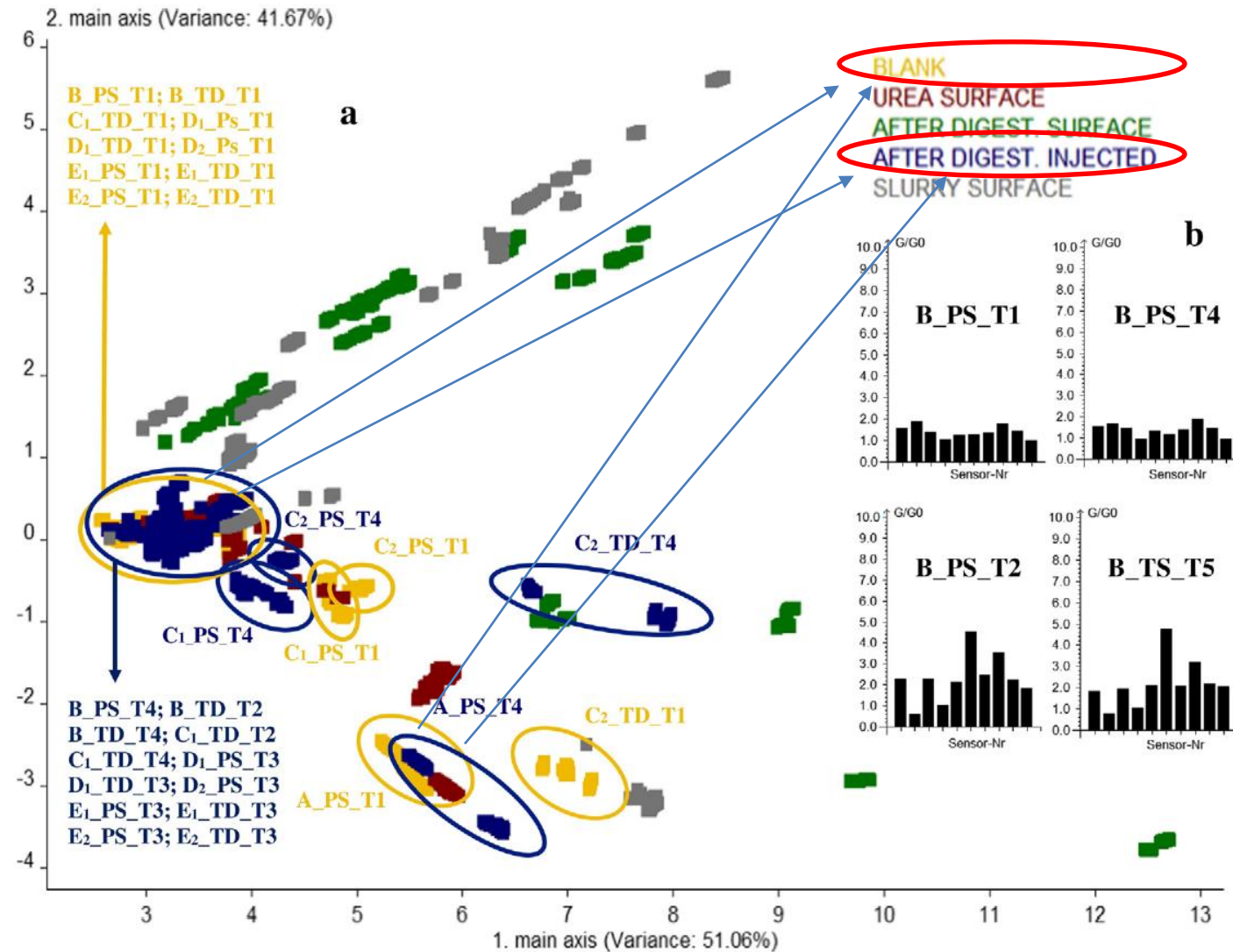


Fig. 3. PCA bi-plot of the odour EN-footprints for soil treated with fertilizers grouped for treatment - Blank vs. Digestate injection for each treatment are highlighted by circles (a), and an example of EN sensors signal patterns (b): Blank (B_PS_T1), Digestate Injected (B_PS_T2), Digestate surface (B_PS_T2) and Pig slurry surface (B_TS_T5).

Sustainable Development Foundation price on 2013



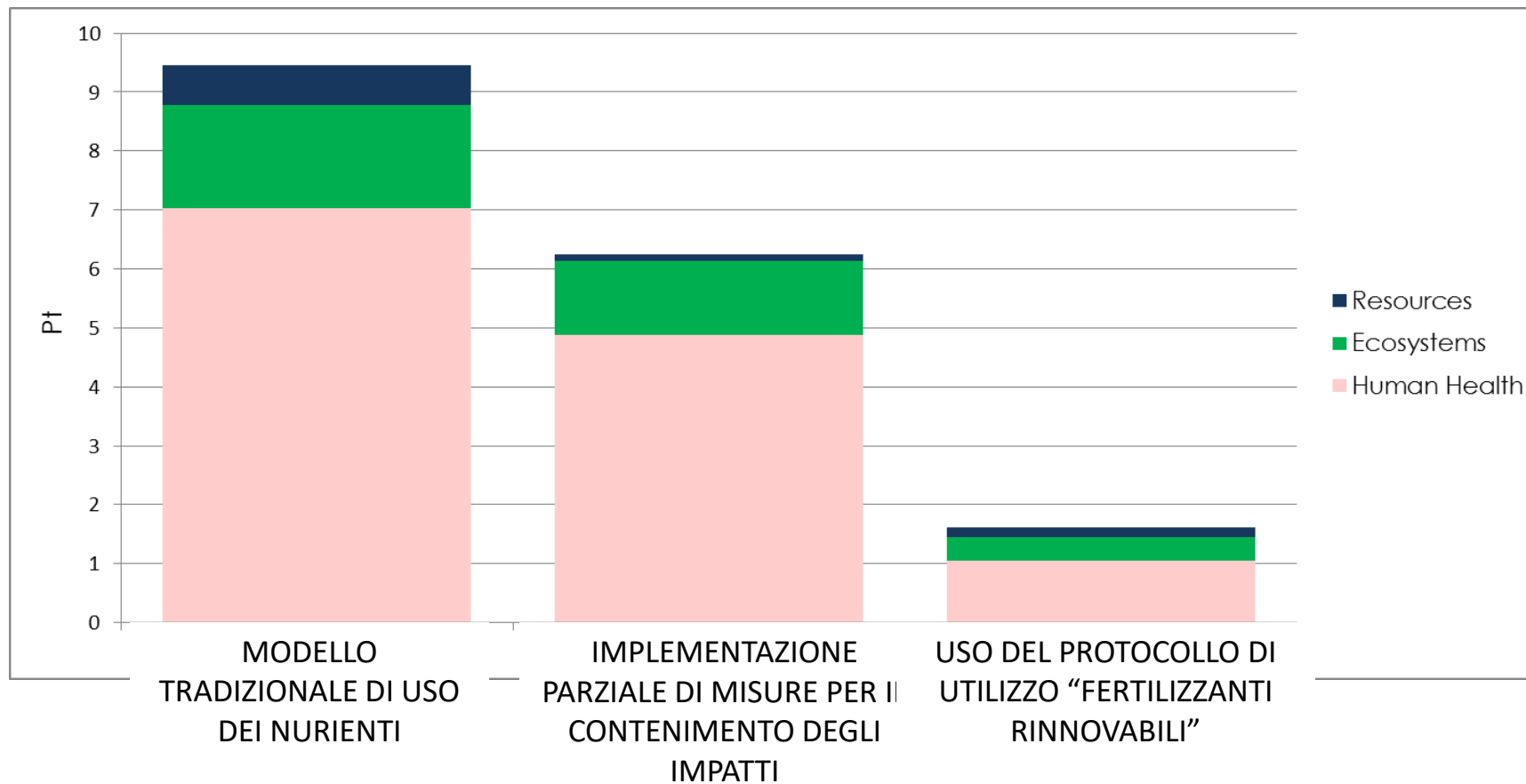
**Integrated system to produce renewable energy and
renewable fertilizers from farms**

AZIENDA AGRICOLA BIZZONI F.lli S.s. – SOCIETA' AGRICOLA

GRUPPO RICICLA – DISAA dell'Università degli Studi di Milano



LCA in digestate use



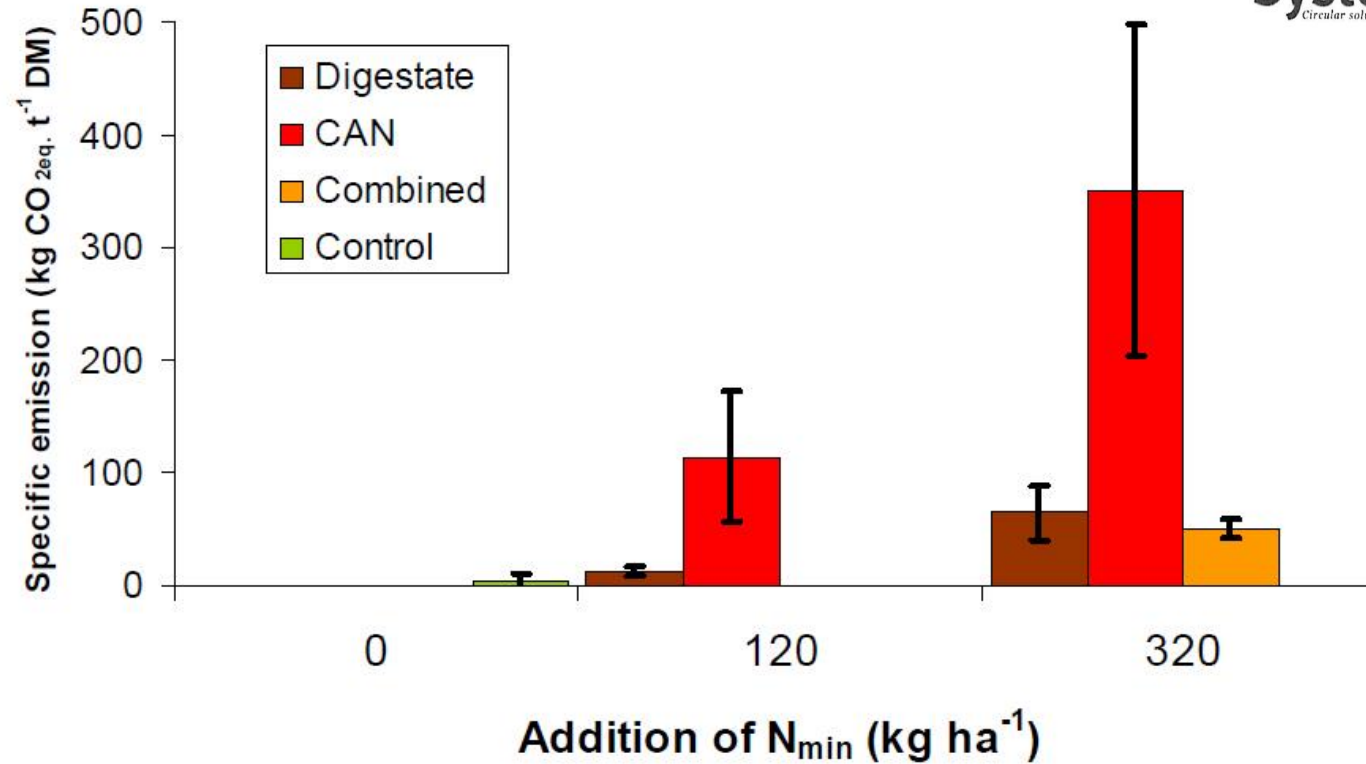
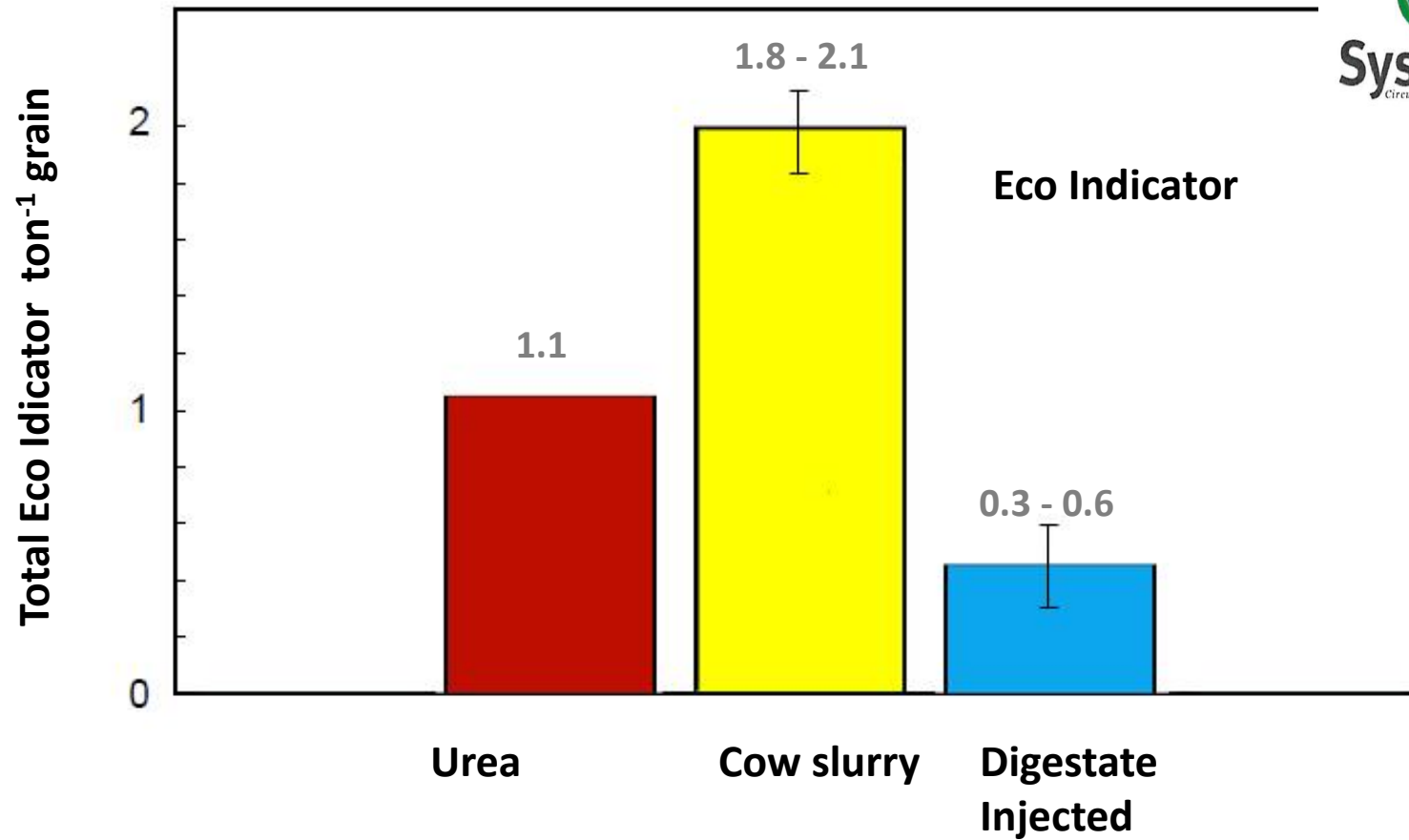


Fig. 3. Specific emissions of CH_4 and N_2O per tonne of biomass ($kg\ CO_{2eq}\ t^{-1}\ DM$)

CAN: ammonia nitrate



- Winter wheat;
- considering: production, packaging, transport, agriculture use;
- Impacts considered: global warming, acidification, smog, heavy metal

Over 90% of impact due to agriculture

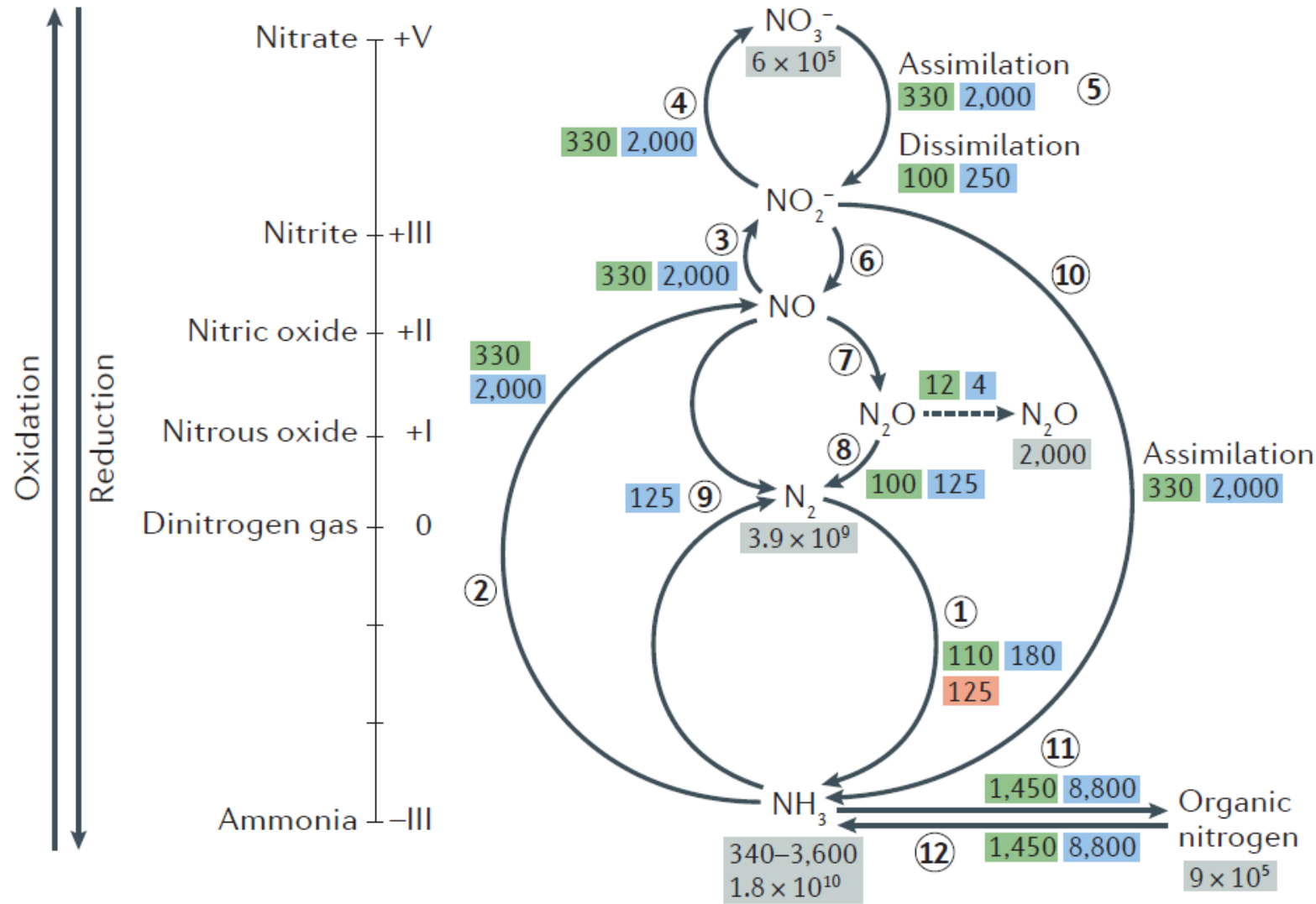
(elaborated from da Kuester and Jenssen, 1998)

To complete the knowledge

The role of soil biological activity in reducing nitrate presence in the deepest layers of agricultural soils.

Massimo Zilio¹, Silvia Motta², Fulvia Tambone¹, Barbara Scaglia¹, Gabriele Boccasile³, Andrea Squartini⁴,

Fabrizio Adani¹



Nitrogen-transforming processes

Nitrogen fixation ①

Nitrification ② ③ ④

Denitrification ⑤ ⑥ ⑦ ⑧

Anammox ⑥ ⑨

Assimilation ⑤ ⑩ and ⑪

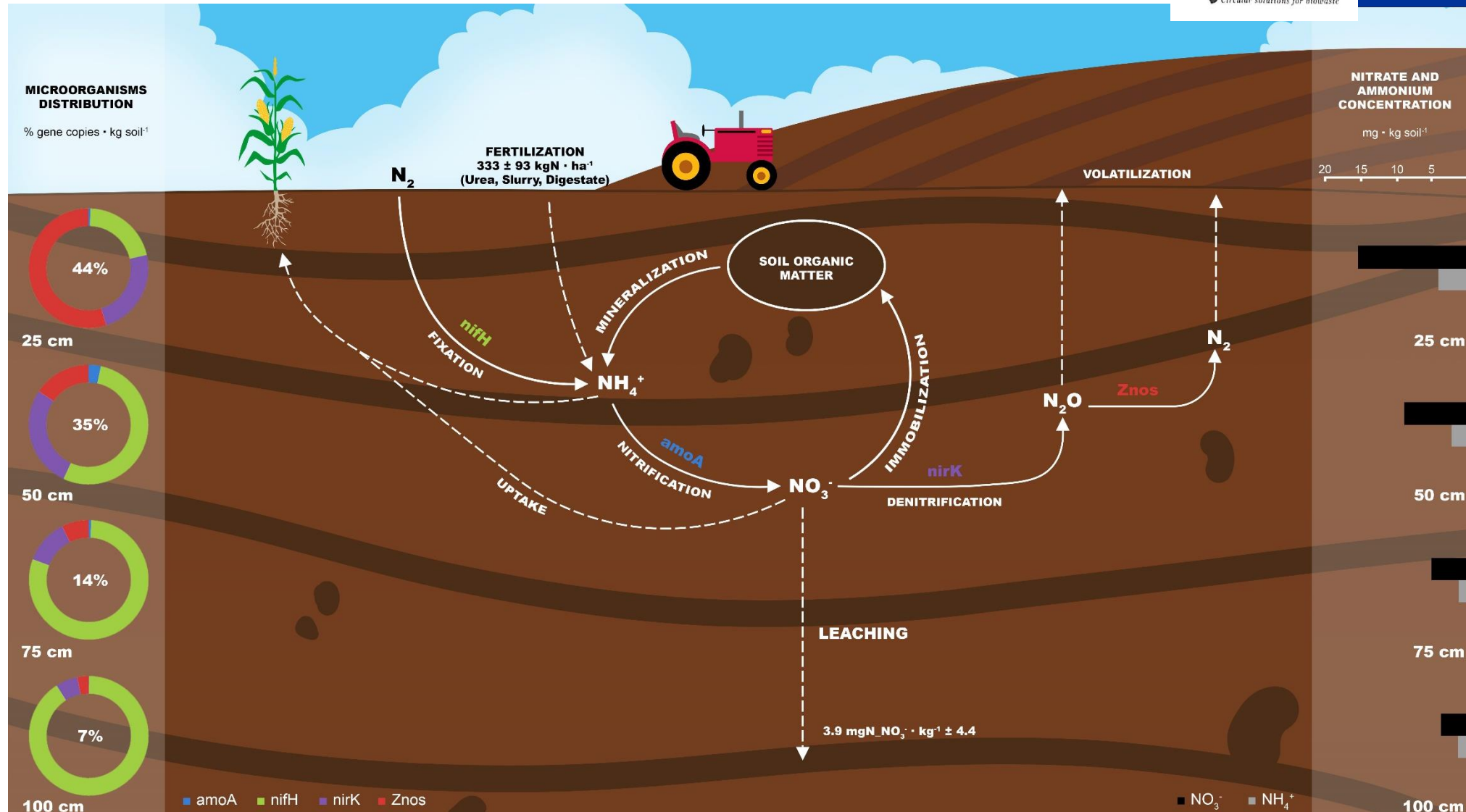
Ammonification ⑫

■ Nitrogen inventory (teragram)

■ Terrestrial nitrogen flux (teragram per year)

■ Marine nitrogen flux (teragram per year)

■ Anthropogenic nitrogen flux (teragram per year)



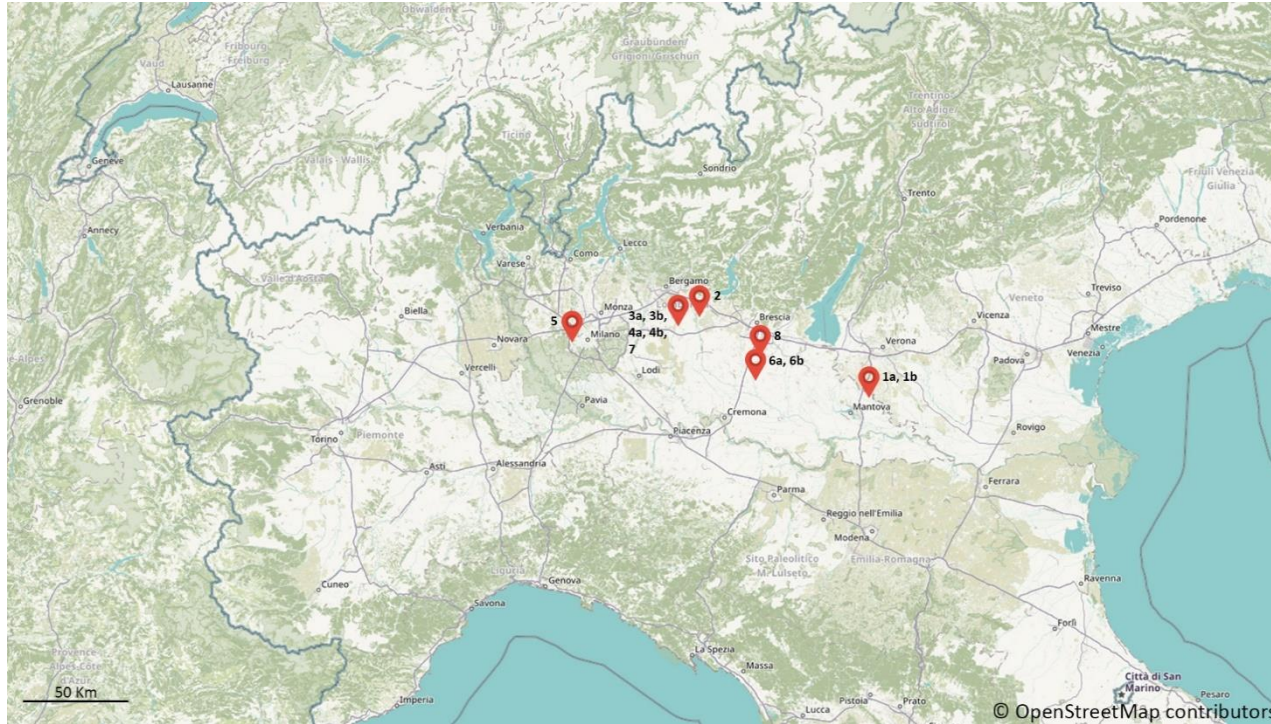


Figure S1. Geographical location of the soils exploited in this work. The reported cartographic table, excluding the points of interest, was obtained from OpenStreetMap.org. The data is available under the Open Database License, and the cartographic table is published with a CC BY-SA license.

Table S1. Soil studied and soil agronomic management. In the Table are reported the agronomic data of all the experiments made.

SOIL CODE	YEAR	CROPS	FERTILIZER	TIME OF FERTILIZATION	TOTAL N SUPPLIED (kg ha ⁻¹)	CROP HARVEST DATE	FIELD AREA (Ha)
1a	2014	Maize	Cattle slurry	16/05/2014 12/06/2014	117 140	07/10/2014	2.95
1b		Maize – Cover crop	Urea	31/03/2014 15/07/2014	116 164	17/10/2014	4.41
2		Barley – Silage maize	Digestate liquid fraction	18/04/2014 13/05/2014	94 59	11/09/2014	4.76
3a	2015	Maize	Digestate liquid fraction	13/05/2015 15/06/2015	178 153	31/08/2015	2.63
3b		Maize	Pig slurry	13/05/2015 15/06/2015	300 104	31/08/2015	1.73
4a	2016	Maize	Digestate liquid fraction + Urea	06/04/2016 07/06/2016	245 138	25/08/2016	2.63
4b		Maize	Pig slurry + Urea	06/04/2016 07/06/2016	287 138	25/08/2016	1.73
5		Maize	Digestate	08/06/2016 13/06/2016	222 47	25/09/2016	3.01
6a		Maize	Digestate	24/06/2016 25/07/2016	269 110	06/10/2016	3.5
6b		Maize	Digestate + Urea	24/06/2016 25/07/2016	269 184	06/10/2016	3.41
7 (4a + extra N)		Maize	Digestate liquid fraction + Urea + Pig Slurry	06/04/2016 07/06/2016 03/10/2016	245 138 860	25/08/2016	2.63
8		Maize	Digestate + Urea + Pig slurry	10/04/2016 28/07/2016 24/10/2016	270 620 580	22/08/2016	4.34



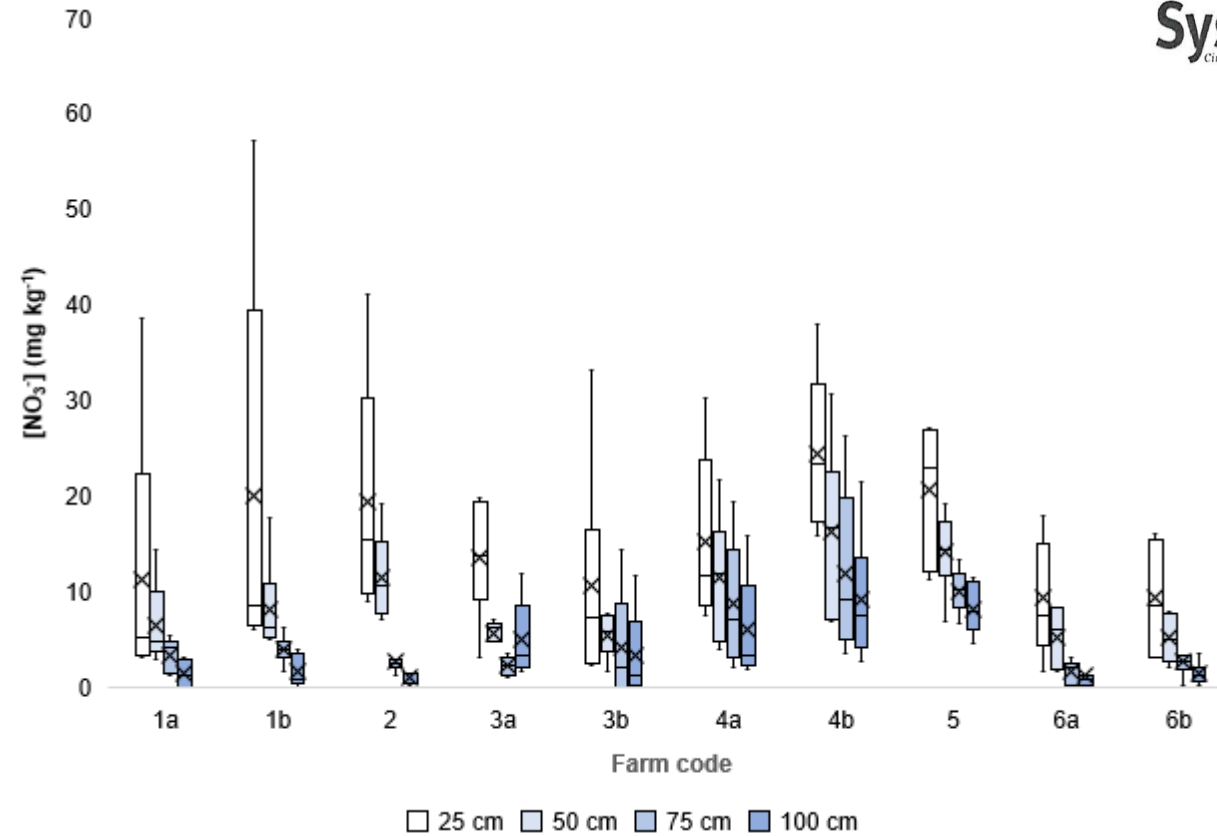
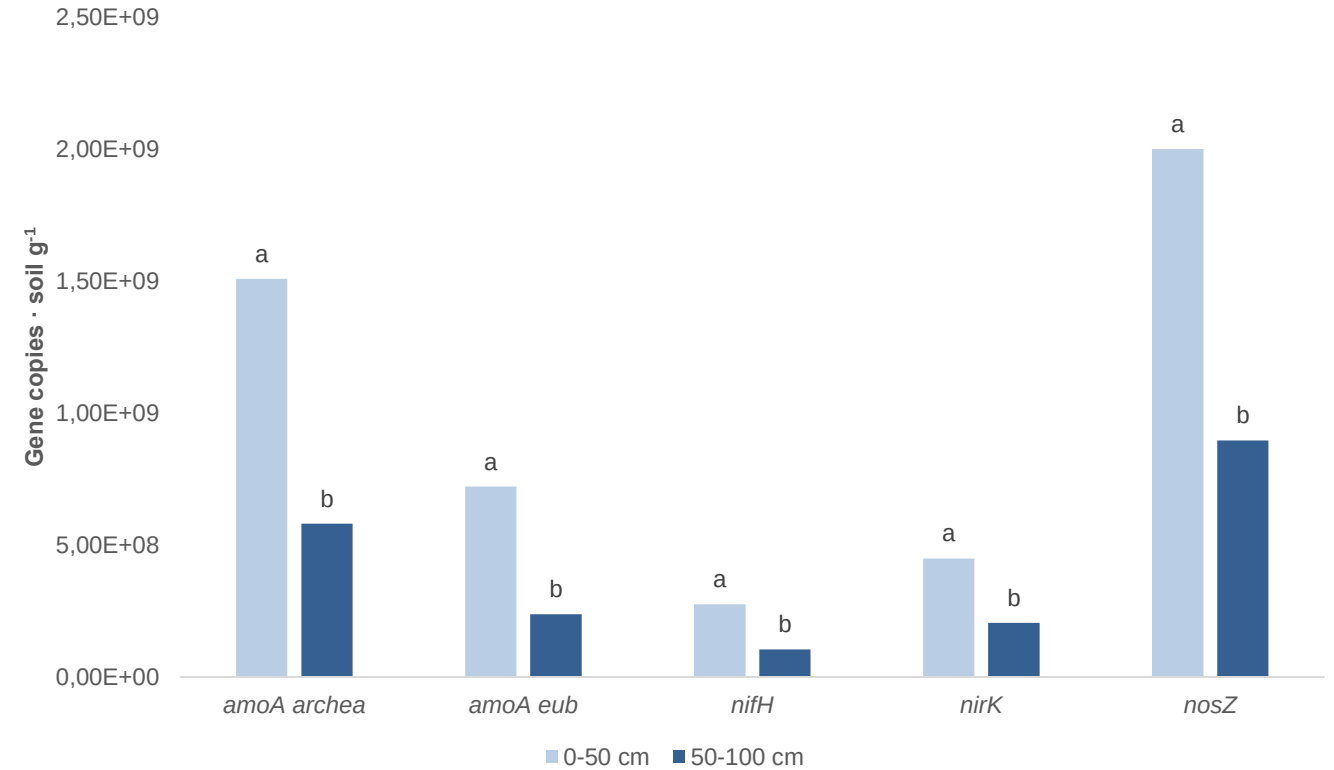
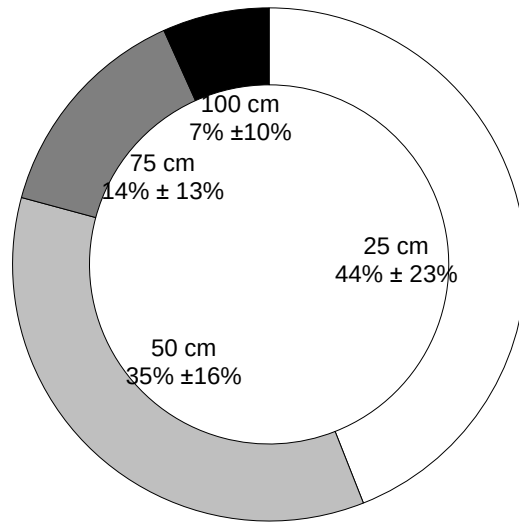


Fig. 1. Nitrate concentration in soil. For each experiment, divided for depth classes, the box plot shows minimum and maximum values sampled (bars), the first and the third quartile (boxes), the median (lines inside boxes) and the average (crosses); $n = 248$.



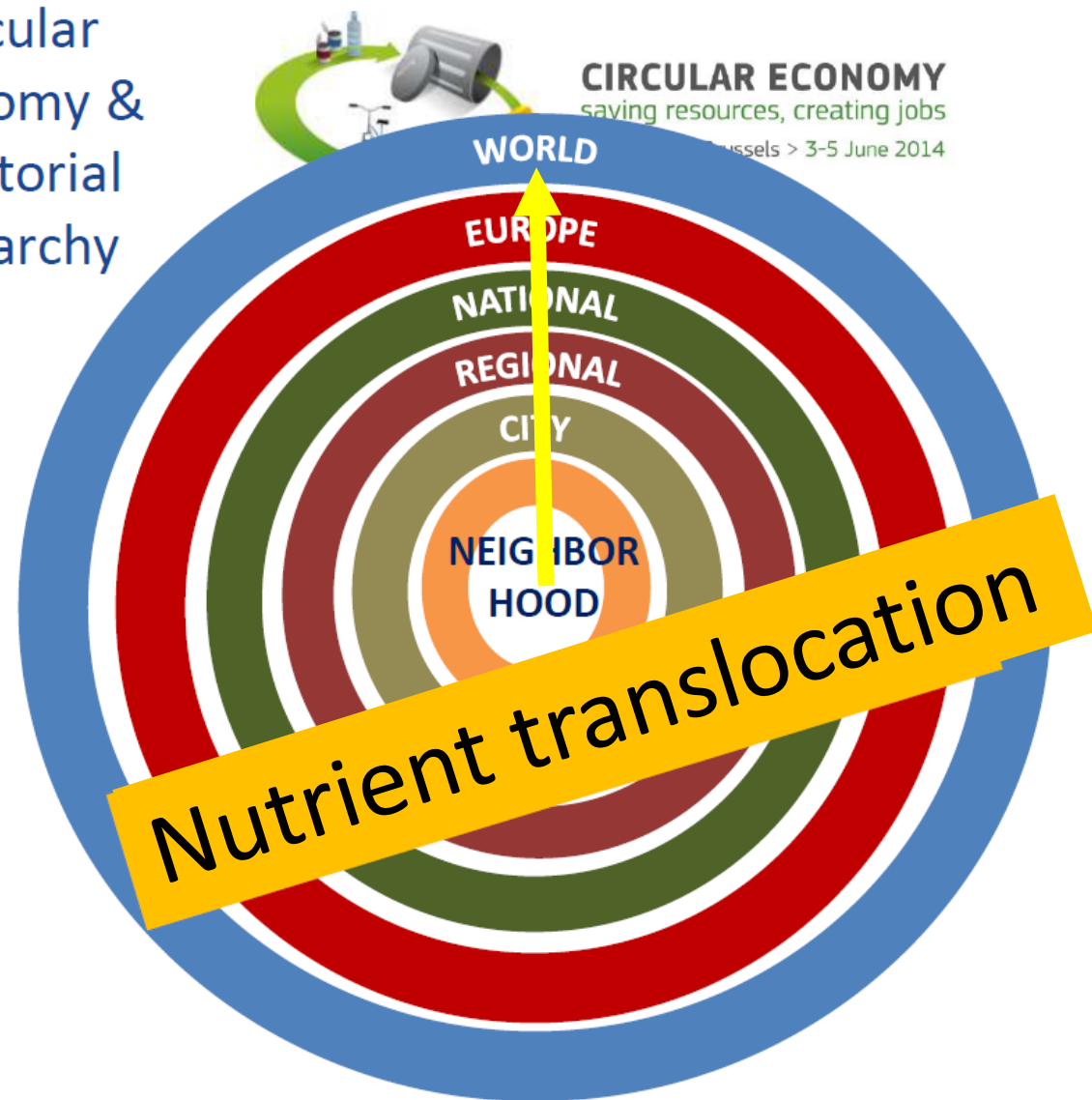
	<i>amoA</i> archaea 0-50 cm	<i>amoA</i> eubacteria 0-50 cm	<i>nifH</i> 0-50 cm	<i>nirK</i> 0-50 cm	<i>nosZ</i> 0-50 cm	N-NO ₃ 0-50 cm
<i>amoA</i> eubacteria 0-50 cm	0.981*					
<i>nifH</i> 0-50 cm	0.962*	0.977*				
<i>nirK</i> 0-50 cm	0.907*	0.939*	0.847*			
<i>nosZ</i> 0-50 cm	0.975*	0.995*	0.992*	0.907*		
N-NO ₃ 0-50 cm	0.580	0.635*	0.521	0.787*	0.599	
N-NH ₄ 0-50 cm	0.742*	0.756*	0.660*	0.809*	0.711*	0.444

Results of this work suggest that with a normal N fertilization, soil biological activity, indirectly quantified by measuring the number of gene copies, is adequate to nitrify-denitrify N, showing in all soils studied a good opposition to nitrate leaching in the deepest soil layers and ensuring low nitrate content at 1-meter depth. However, for higher N fertilization rates, soil biological activities related to the N-cycle are not sufficient, with soil characteristics such as texture and rainfall becoming important variables in determining nitrate leaching.

To conclude a real example of Circular Economy applied to nutrient in Italy

Nutrient recovery
to transfer them
from **rich-nutrient**
region to **poor-**
nutrient region.

Circular
economy &
territorial
hierarchy



INTRODUCTION TO THE CENTER FOR THE RECOVERY OF NUTRIENTS FROM ORGANIC WASTES IN ITALY: AN EXAMPLE



Vellezzo- Bellini (PV)

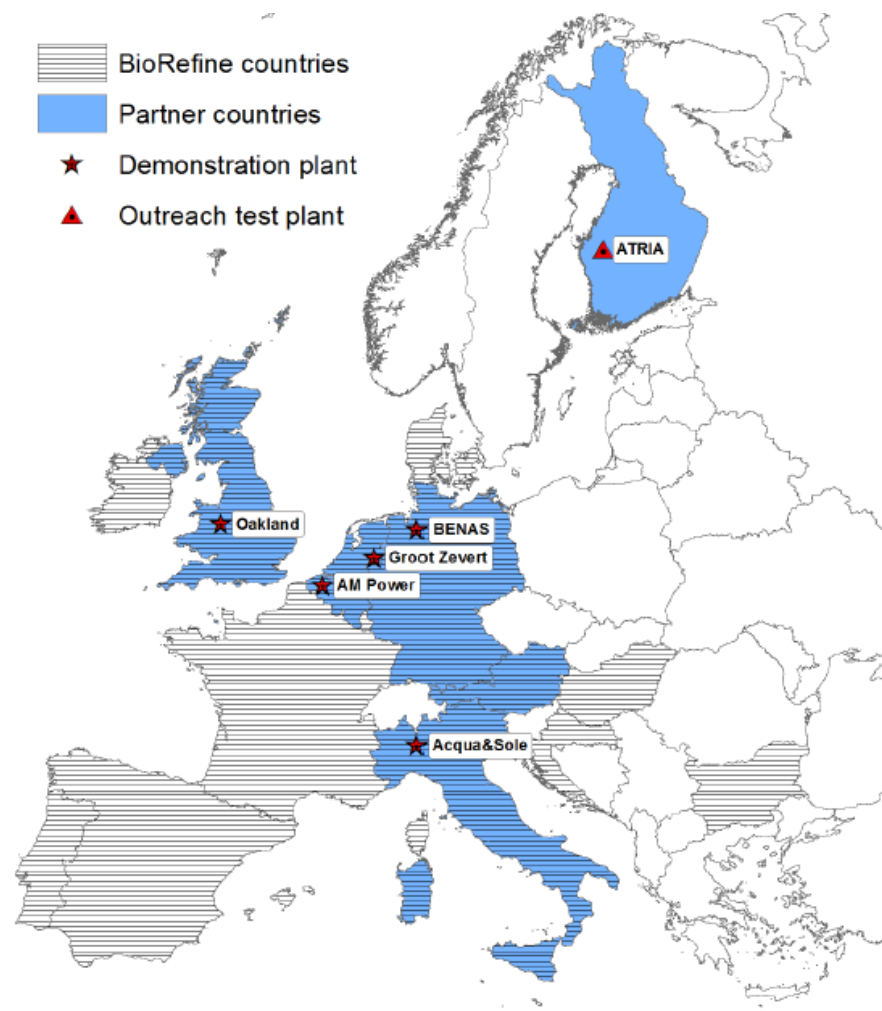
Systemic large scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe

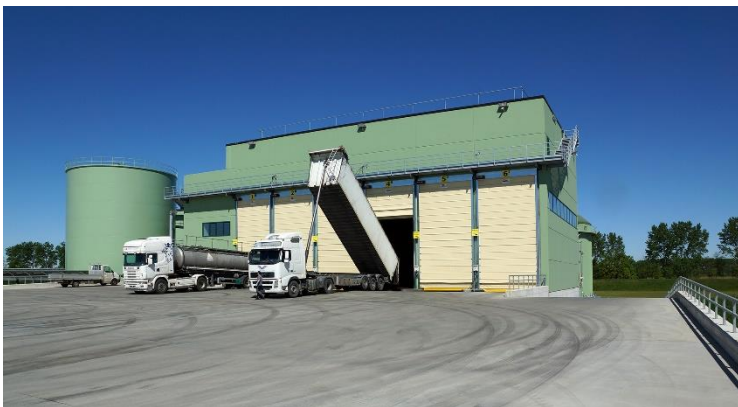
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Type of action: IA
(Innovation action)

Proposal number: 730400-2

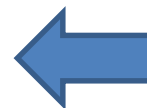
SYSTEMIC aspires to produce fertilizers that are up to standard compared to synthetic products. In order to realize this ambition, product quality will be monitored and optimized in order to meet the criteria of the end users, who are naturally closely involved in the whole process. This iteration process ensures that *demonstration plants* will produce user-specific products that can be applied in the nearby region.





Renewable fertilizers from organic wastes

- 4,000 Ha fertilized
- Minimum Tillage
- Precision Agriculture (GPS)



- 108,000 t/year of organic waste;
- 195,000 tons of organic fertilizer completely sanitized and deodorized through a thermophilic anaerobic treatment;
- 4,000 tons of ammonium sulphate;
- Fertilizers used by injection promoting precision and conservative agriculture.
- 12,000 MWh/y , and to replace the following quantities of mineral fertilizers:

Input organic waste [t/y]	108,000
Output organic waste (To be injectable directly into the soil) [t/y]	195,000
<i>The digestates could replace this amount of fertilizer [t/y]</i>	
nitrogen as urea 46%	2,676
Phosphorus as rock phosphate 34% (P2O5)	3,206
Potassium as Potash 60% (K2O)	437

EXPERIMENTAL DESIGN SYSTEMIC: maize for grain for 3 years

THE SITE



THE FIELD

D1	C1	U1	D2	C2	U2	D3	U3	C3
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Plot	Treatment	Date	N (kg ha ⁻¹)
U	No fertilization		/
C	Urea	23/04/2018	185.35
	Ammonium sulphate	22/06/2018	91.69
D	Digestate	23/04/2018	190*
	Ammonium sulphate	22/06/2018	91.69

**assuming an efficiency coefficient for digestate-N_{tot} of 0.5.*

SAMPLES WERE TAKEN:

- Before fertilization (t_0): superficial soil samples
- During fertilization: digestate sample, odour and GHG emission
- Plant emergence: superficial soil and seedlings samples
- 80 days after fertilization: soil cores at depths 0-25, 25-50, 50-75 and 75-100 cm
- Maize maturity: grain

PLANNED ACTIVITIES

DIGESTATE:

- Periodic analysis of the digestate produced by the plant (Pollutants, N, C, P, metals)
- Extraction of the Dissolved Organic Matter (DOM) from digestate and GC-MS characterization
- Test of the biostimulant auxine-like activity of the DOM extracted from digestate
- Test of the biostimulant activity of the DOM extracted from soil fertilized with digestate: auxine-like activity test, vegetation test in laboratory and open field

ENVIRONMENTAL ANALYSIS:

- Measurement of greenhouse gas emissions (NH_3 , N_2O , CO_2 , CH_4) and odors during fertilization
- Nitrate leaching: coring up to a depth of one meter and analysis of the nitrogen speciation in the soil every 25 cm of depth (before and after fertilization with digestate)
- Quantification and characterization of microorganism populations involved in the nitrogen cycle in soil cores every 25 cm of depth (before and after fertilization with digestate)

SOIL CHEMISTRY:

- Carbon distribution, Organic fraction characterization (^{13}C CPMAS NMR, GC-MS) and radio dating
- Speciation of P and ^{31}P NMR analysis of single fractions

YIELD:

- Evaluation of the production of grains by plants fertilized with digestate
- Analysis of metals, P, N and C content in grains

DIGESTATE ANALYSIS – 1: main characteristics

Parameter	Unit of measure	Value	Lombardy DGR limits 2031/2014 for the use of sewage sludge in agriculture
pH	pH unit	8.6 ± 0.3	5.5-11
Dry residue at 105 °C	%	10.3 ± 0.48	n.e. ^(*)
Dry residue at 600 °C	%	4.26 ± 0.37	n.e.
SSV/STS ratio		57.8 ± 1.04	≤65
Degree of humification	%	43.6 ± 9.8	n.e.
Organic carbon	% d.w.	29.2 ± 4.13	≥20
Total nitrogen	% d.w.	7.7 ± 0.3	≥1.5
N-NH ₄ ⁺ / Total nitrogen	% d.w.	62 ± 3	n.e.
Total phosphorous	% d.w.	3.1 ± 0.04	≥0.4
Potassium	g kg ⁻¹ d.w.	9.9 ± 1.4	n.e.
Arsenic		9.1 ± 2.08	n.e.
Cadmium		1.5 ± 0.4	≤20
Chromium		110 ± 13	≤750
Mercury	mg kg ⁻¹ d.w.	<1.9	≤10
Nickel		73.9 ± 8.9	≤300
Lead		76.8 ± 15	≤750
Copper		444 ± 58	≤1000
Zinc		1369 ± 111	≤2500

The digestate widely respects all the limits included in the Italian legislation that regulates the use of sludge in agriculture

(*) n.e.: not expected from Lombardy DGR limits 2031/2014

SOIL ANALYSIS- 1: t₀ (2018)

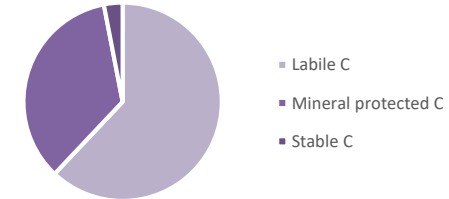
MAIN CHARACTERISTICS

Parameter	Unit of measure	Value	Italian limit D.lgs. 99/92 for the protection of agriculture soils
pH	pH unit	7.0	≥5
CSC	C (mol kg ⁻¹)	19.3	≥8
Oxidizing power for chromium	μmol Cr(VI)	< 0.2	≤1
Total Organic Carbon	g kg ⁻¹ DM	16.07	n.e. ^(*)
Ratio C:N		9.13	n.e. ^(*)
Cadmium	mg kg ⁻¹ DM	< 0.5	≤1.5
Mercury		< 0.5	≤1
Nickel		13.1 ± 2.62	≤75
Lead		17.1 ± 3.42	≤100
Copper		21.2 ± 4.24	≤100
Zinc		51.6 ± 10.32	≤300
Texture	Silt (%)	Clay (%)	Sand (%)
	44.2 ± 2.1	10.4 ± 0.5	45.5 ± 1.6

SOIL ANALYSIS - 2: t₀ (2018)

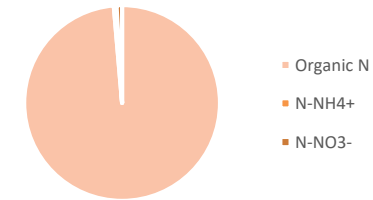
CARBON FRACTIONATION

Labile C (biochemical protected)	Mineral protected C	Stable C (chemical protected)
% TOC		
62 ± 2	34.9 ± 1.6	3.04 ± 0.01



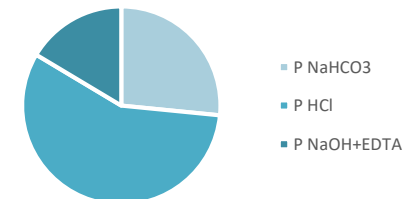
NITROGEN SPECIATION

N tot	N-org	N-NO ₃ ⁻	N-NH ₄ ⁺
mg kg ⁻¹ DM			
1430 ± 82	1411 ± 80	13 ± 2	6.5 ± 0.3



PHOSPHOROUS SPECIATION

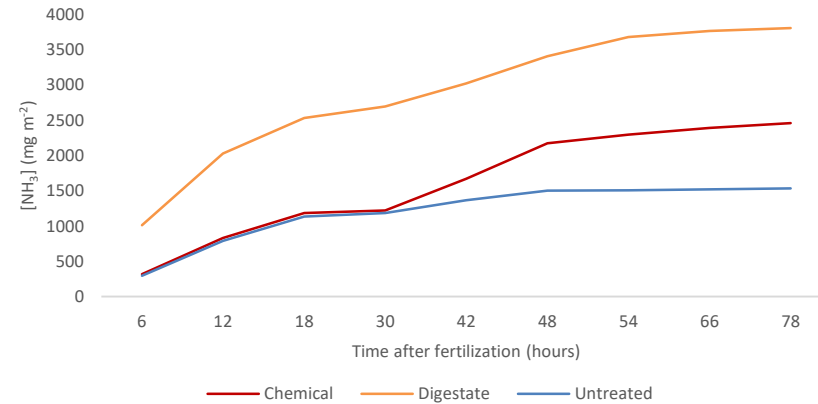
P tot	P NaHCO ₃	P HCl	P NaOH+EDTA	Recovery %
mg kg ⁻¹ DM				
395 ± 21	89 ± 12	191 ± 15	55 ± 18	85 ± 7



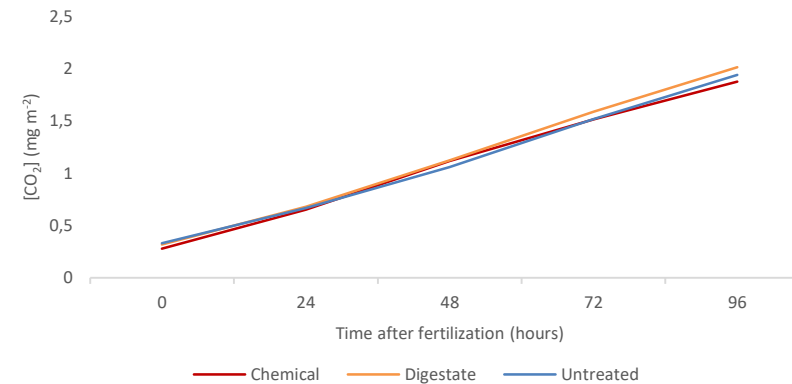
Scheduled for next year: radio dating of the carbon fraction in the soil

DIGESTATE IMPACT - 1: GHG emission during spreading

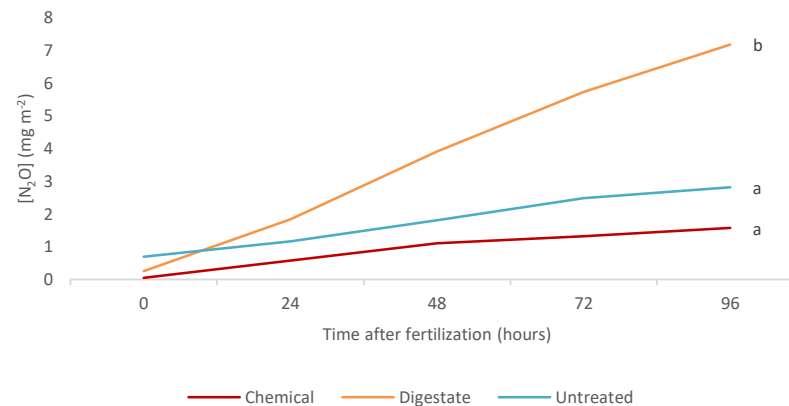
AMMONIA (CUMULATED)



CO₂ (CUMULATED)



N₂O (CUMULATED)

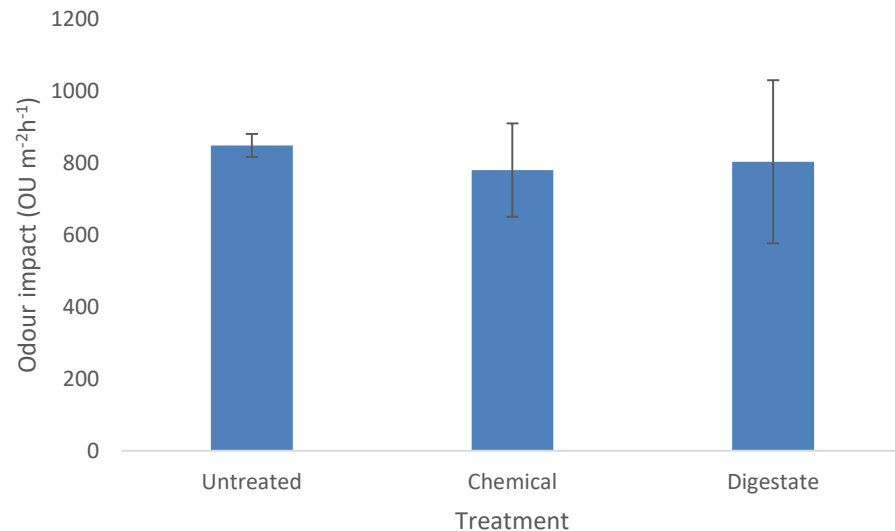


METHANE

No measurable emissions recorded

DIGESTATE IMPACT - 2: odour emission during spreading

ODOUR EMISSION DURING OPEN FIELD FERTILIZATION



Urea spread on soil surface

Digestate injected in soil at 10 cm depth

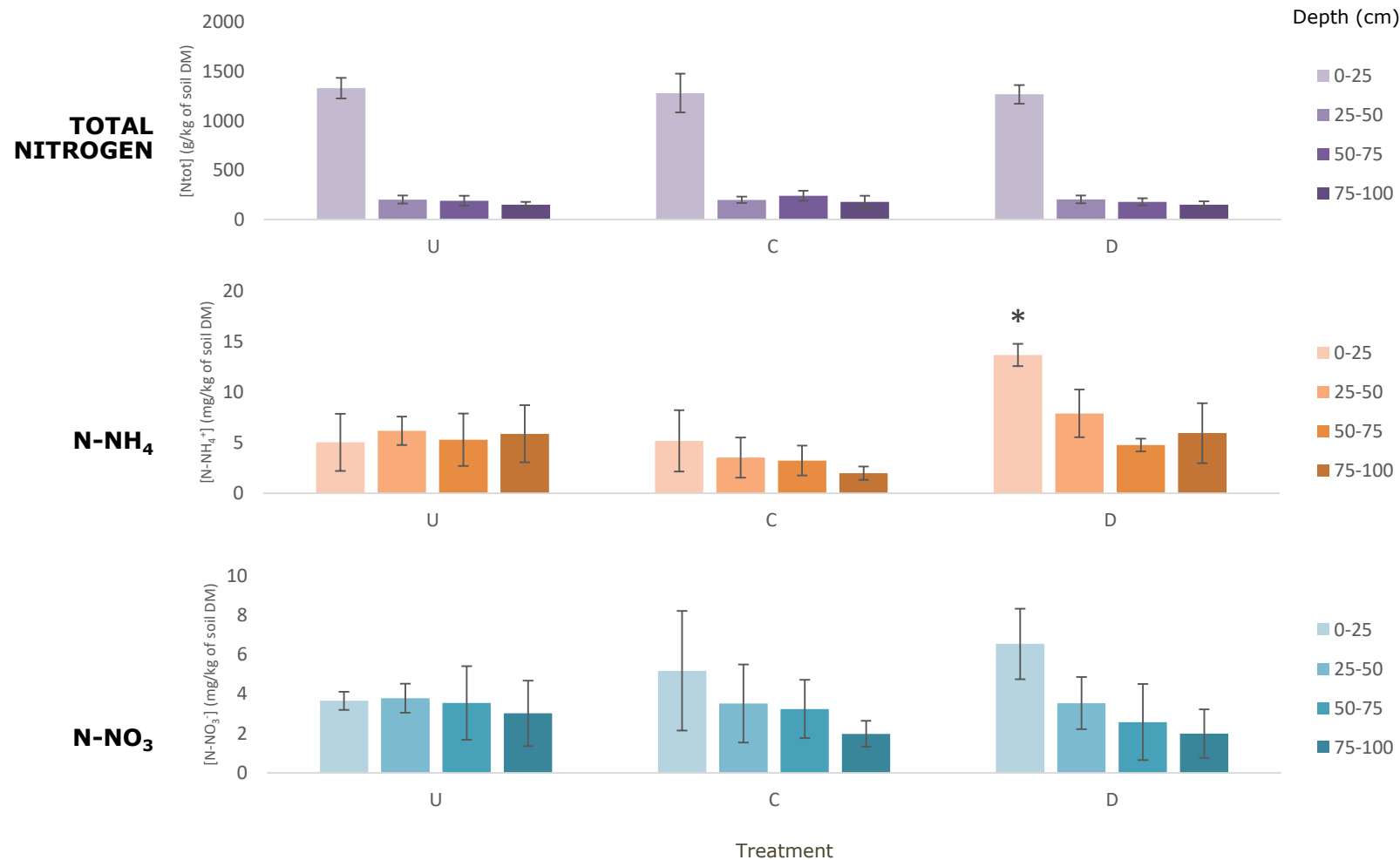
ODOUR POTENTIAL (LAB ANALYSIS)

Treatment	Odour potential (OU m ⁻² h ⁻¹)
Untreated	-
Chemical	827 ± 256
Digestate	3.949 ± 817

Digestate shows an high odour potential, but the injection into the soil significantly reduces odour, to a level comparable with chemical fertilizers

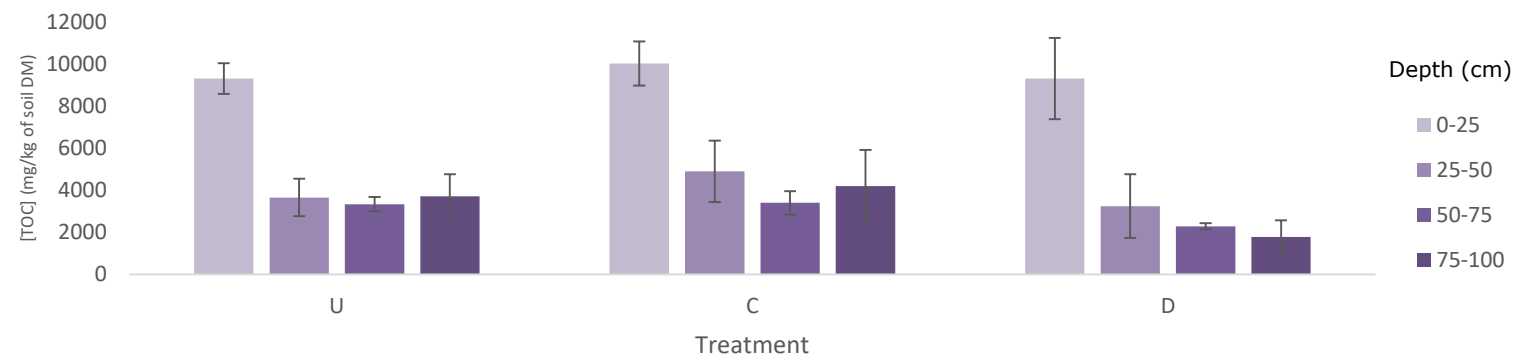
DIGESTATE IMPACT - 3: N leaching 80 days after spreading

NITROGEN SPECIATION

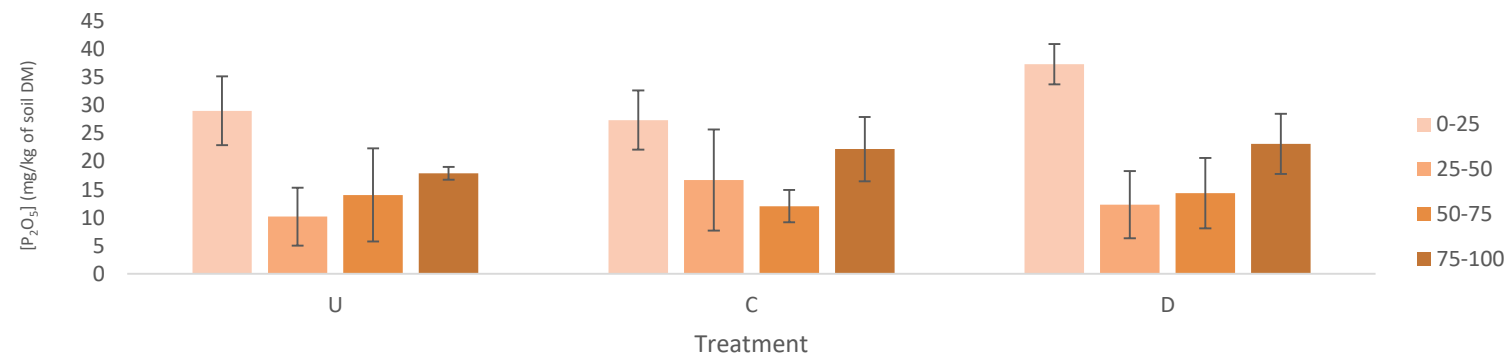


SOIL ANALYSIS 80 days after digestate spreading

TOTAL ORGANIC CARBON

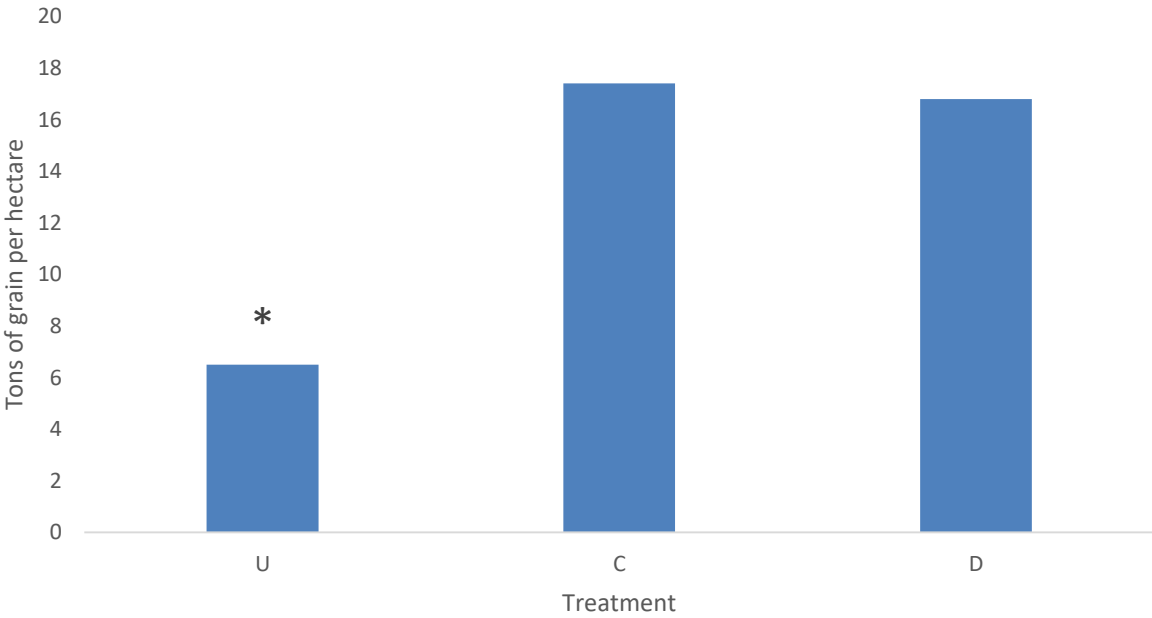


P₂O₅



MAIZE YIELD

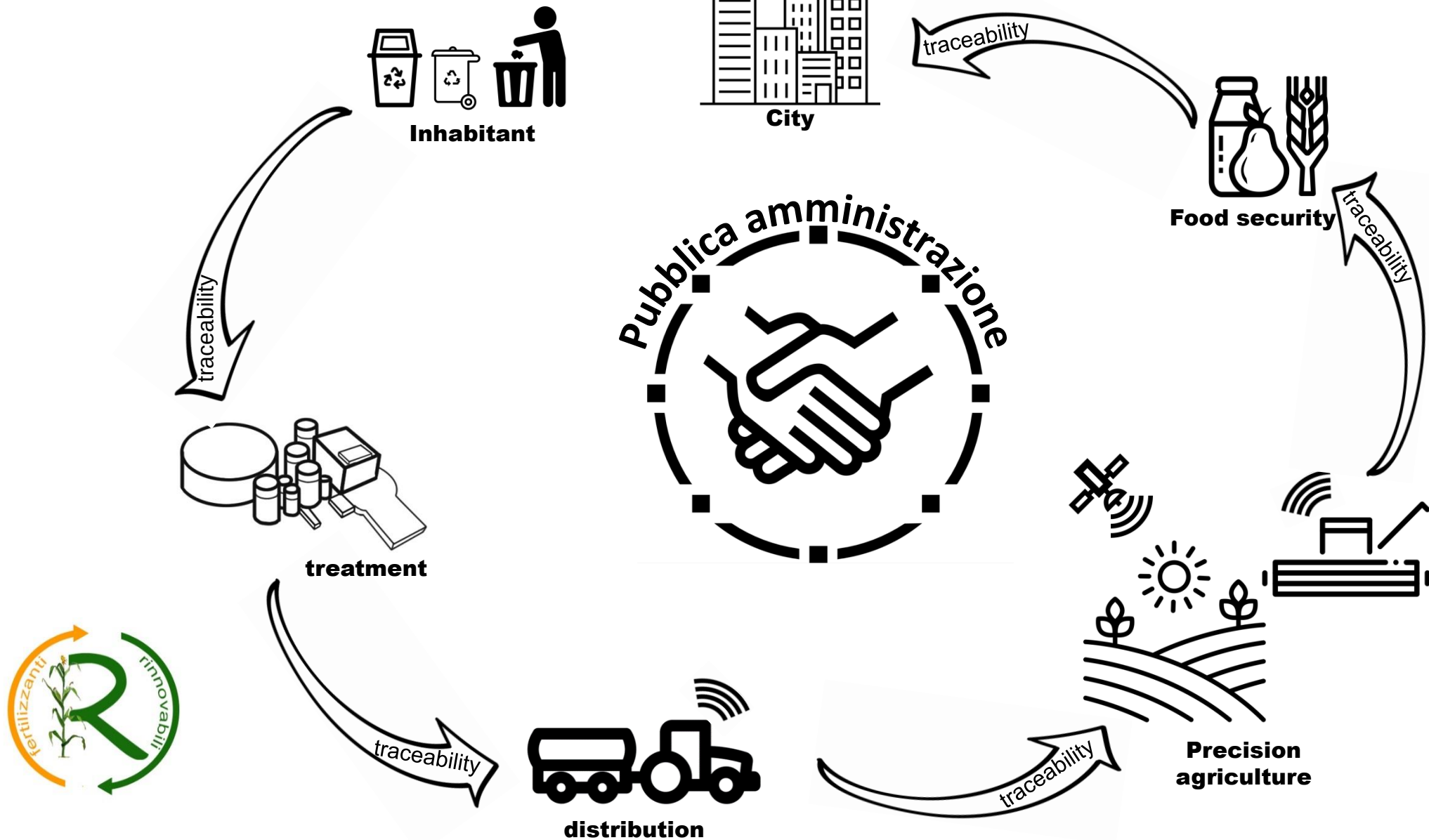
Plot	Treatment	Date	N (kg ha ⁻¹)
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D	Digestate	23/04/2018	190*
	Ammonium sulphate	22/06/2018	91.69



Average moisture 16.1% wet weight

(*) Indicates that the value is significantly different from the values for other treatments (ANOVA, $p < 0.05$).

Circular responsibility



GRUPPO RICICLA





Fabrizio Adani
Full Professor



Min Su
Engineer



Fulvia Tambone
Associate professor

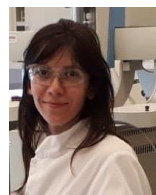


Barbara Scaglia
Associate Professor



Parisa Abbasi Parizad
Biologist

Gabriella Papa
Biobased and Biofuels expert



Pietro Squillace
Agronomist



Marta dell'Orto
Plant and algae physiologist



Axel Herrera
Agronomist



Giuliana D'Imporzano
LCA specialist

GRUPPO RICICLA



Gretha Di Donato
Chemist



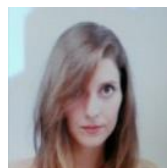
Floriana Bedussi
Agronomist



Tommy Pepè Sciarria
Biologist



Massimo Zilio
Biotechnologist



Sara Zangarini
Environmental Scientist



Bruno Rizzi
Agronomist



Patrizia De Nisi
Plant physiologist and HPLC, GC-MS specialist



Ambrogio Pigoli
Agronomist

GRUPPO RICICLA

DIGESTATE ANALYSIS – 2:

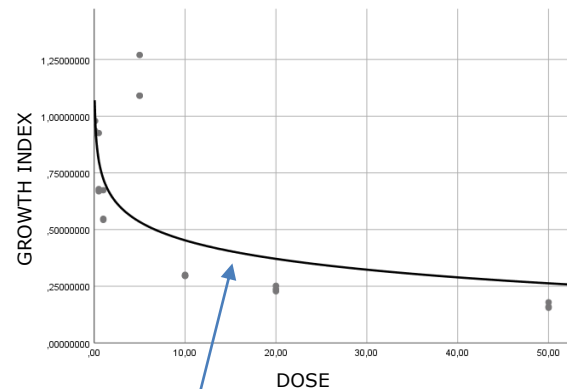
biostimulant effect

BIOSTIMULANT EFFECT OF THE DISSOLVED ORGANIC MATTER



Dissolved organic matter was extracted from the digestate, and tested for its biostimulant auxine-like effect on cucumber seeds.

STANDARD CURVE (AUXINE)



Dose-dependent reduction of root elongation

ROOT ELONGATION CURVE – SEEDS TREATED WITH DIGESTATE

