FertiCovery

Online workshop:

Fertilising Products from Secondary Raw Materials: From Evidence to Practice

FROM LAB RESULT TO TRUSTED FERTILISER

A Digital Evidence Pathway for Recovered Fertilising Products

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Product concept

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

Variable feedstocks need acceptance rules

At home, we adjust the recipe

In production, we control the ingredients and process

Each delivery follows the agreed acceptance rules



Photo: Annie Spratt (CC0)

Our rapeseed fertiliser case

EKOPLON: fertilisers and animal feed
Carrier: rapeseed material from feed production

Spray impregnation: spraying a micronutrient solution onto biomass
Biosorption: binding metal ions to biomass

Intended application: organic farming

Before market launch: legal route, production control and trials



Illustrative field photo · Gerda Arendt (CC0)



Process concept

Case: TANGO V. Technology: EP4335835A1. Company: EKOPLON. Organic-farming suitability requires separate assessment.

Research evidence and product decisions



Evidence	What it describes	Product decision needs
Composition	The tested sample	Sampling and batch variation
Microbiology	The tested organisms and sample	Applicable criteria and control plan
Plant response	The tested dose and conditions	Evidence covering the intended crops, soils and use conditions

Assess crop benefit, crop tolerance and environmental effects separately

Product conformity requires assessment under the chosen legal route.
Illustrative photo: Polina Tankilevitch / Pexels

Who needs which product information?

Digital Fertiliser Product Passport

A digital file linking the product and batch to test reports and decisions



User	Information needed	Where to look
Regulator	Conformity with applicable requirements	Technical documentation
Farmer	Declared content, use and precautions	Product label
Quality manager	Evidence for this batch and claim	DFPP linked to study records

Our voluntary proposal for research and product development

Regulations (EU) 2019/1009 and 2024/2516. DFPP denotes the approach proposed in this talk.
Illustrative photo: Kampus Production / Pexels

Product rules, digital labelling and passports



Instrument	Status	Consequence
EU fertilising product	FPR requirements apply	Component eligibility, product category and conformity
Digital label	Voluntary option from 1 May 2027	Digital access and physical information follow legal conditions
ESPR passport	Product-specific rules	Work-plan priorities: steel, textiles, tyres

The legal route determines the mandatory evidence

Prepare traceable records now as product information becomes more digital.

Regulations (EU) 2019/1009 and 2024/2516; COM(2025) 187; European Commission DPP FAQ.
Photo: Håkan Dahlström / Wikimedia Commons | CC BY 2.0 | cropped

The evidence chain

Source lot and process batch

Which incoming material and manufacturing run?

↓

Sample and method version

Which portion and controlled procedure?

↓

Result and reporting basis

Units, wet or dry basis, uncertainty and interpretation limits

↓

Decision, responsible person and record version

What does the evidence support? Who decided? What changed?



Illustrative photo: USGS | public domain

Traceability explains where a result applies. Testing establishes performance.

Moisture changes the nutrient load

1 TONNE OF PRODUCT	Calculation example: 10% nutrient in dry matter
50% dry matter	500 kg dry matter contains 50 kg nutrient
25% dry matter	250 kg dry matter contains 25 kg nutrient



Illustrative photo: Kathleen M. Rowland / USGS | public domain

A process balance follows the mass into every output stream

Plant availability requires separate evidence.

Drying changes: a decision example

Illustrative DFPP scenario using batches A and B



Record	Evidence link	Assessment or decision
Source lot	LOT-01: same source for A and B	One source lot, 2 process batches
Batch A	A-01 / report Cu-A / M-01 v1	Cu-A: dry-mass basis, applies to A
Batch B	B-01 / changed drying	Review moisture and method scope
Decision for B	Release evidence awaiting review	ON HOLD / quality manager / v2
Next step	Mass balance, moisture, biological properties	Obtain evidence required by control plan

The quality manager records the release decision and its supporting evidence.

Illustrative photo: Corey Lawrence / USGS | public domain

Study records needed for reuse



Record	Information needed for reuse
Material	Source lot, process batch and sampling
Analytical result	Method version, units, wet or dry basis and uncertainty
Plant response	Crop, dose basis, comparator, endpoint and experimental unit
Statistics	Independent replication, variability measure and analysis

Link each reported value to raw data and study records

Illustrative photo: Christopher J. Kanagy / USGS | public domain

The paper and its supporting records



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Protection and access agreed before publication

IN THE PAPER

Material and methods

Results and statistics

Interpretation and claim limits

IN THE CONTROLLED ARCHIVE

Raw data and sample records

Method versions and quality-control records

Deviations, changes and decisions

Technology-transfer and legal specialists support these agreements

Choosing the next study

Continuation of the illustrative DFPP scenario

Available: composition data for a defined material

Next decision: can the process make a consistent product?

To establish: process balance, scale and storage stability

Application trials use a representative batch of the final formulation



Illustrative cockpit photo
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Agree the next decision and the criteria for success

Industrial symbiosis and responsibility



Illustrative photo · Leeroy (CC0)

Researchers connect material holders and fertiliser manufacturers

SECONDARY MATERIAL HOLDER

Agrees supply quality and continuity

Provides lot and process information

Retains duties for the supplied material

EU ROUTE: LEGAL MANUFACTURER

Ensures conformity and production control

After demonstrated conformity: declaration and CE marking

Keeps the technical documentation

Harmonised EU route: Regulation (EU) 2019/1009, Art. 2(11) and Art. 6; Blue Guide 2022, §3.1.

Evidence handover and product testing

Can another laboratory implement the documented method?

Can the manufacturer repeat the process and maintain product quality?

Does the product work for the intended user under real conditions?



Illustrative laboratory photo
Rhoda Baer / NCI · public domain

Usable records and performance in practice

Evidence for practical use

- Researchers provide evidence that others can assess and use
- Each result stays linked to its material
- Manufacturers remain responsible for the product



Illustrative field photo
Hanna Bergblau (CC0)

What evidence do you need before using a recovered fertiliser?

TANGO V example: co-financed by NCBR

FertiCovery

Online workshop:

Fertilising Products from Secondary Raw Materials: From Evidence to Practice

TESTING RECOVERED FERTILISERS: WHAT DOES THE EVIDENCE TELL US?

What Is in the Product? Composition and Quality

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FertiCovery

Chemical analysis of fertilising products

16 physically received samples representing **16 technologies**: **4** anaerobic digestion products, **3** composting products, **3** hydrolysis products, **3** physical-process products, **2** physicochemical-process products, and **1** thermochemical-process product.

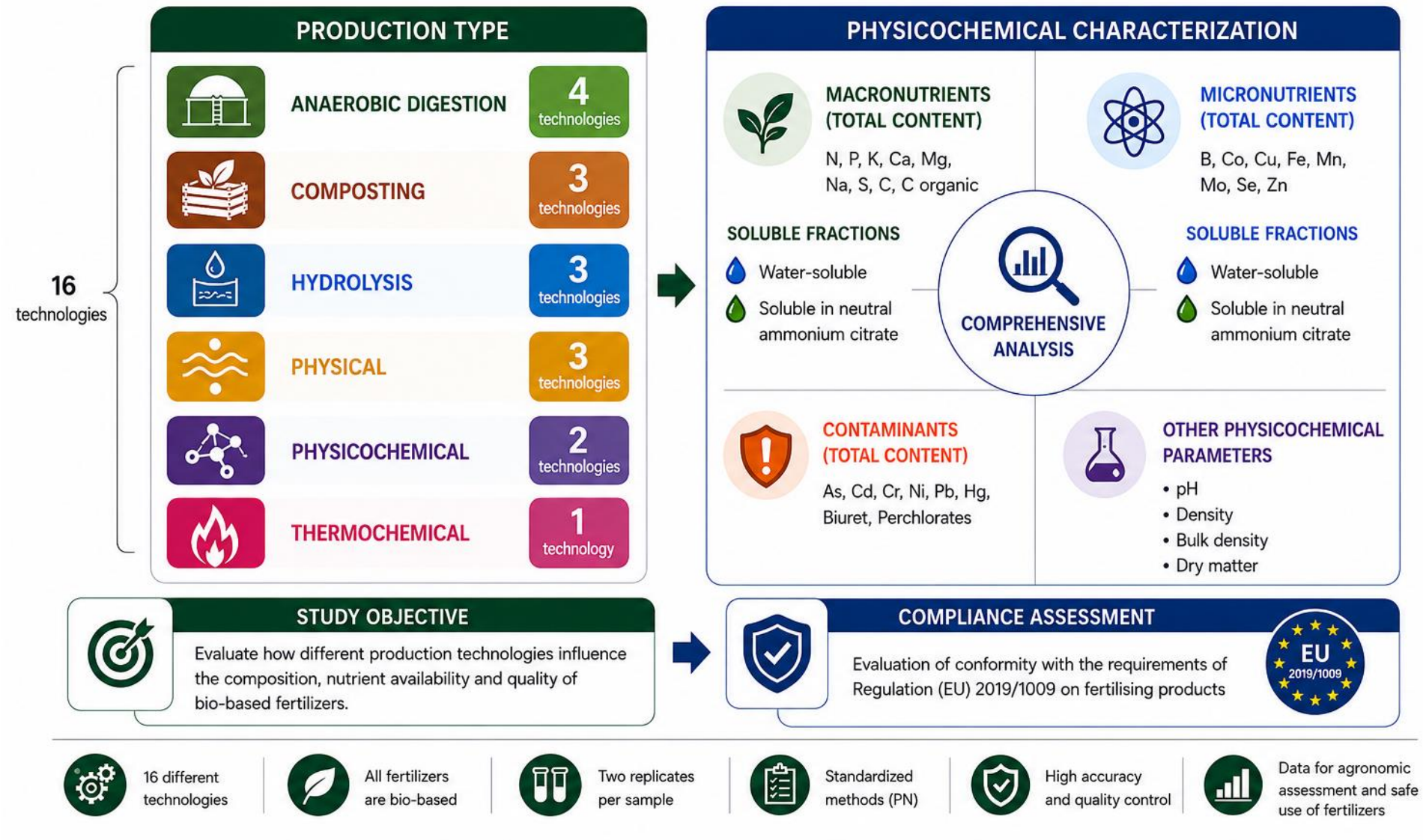
1	2	3	4	5	6	7
Physico-chemical	**Composition**	**Safety**	**Leaching**	**Germination**	**Pot trial**	**Comparison**
pH · dry matter · bulk density	macro- and micronutrients	toxic elements, *E. coli*, *Salmonella* spp.	PN-EN extraction, 24-h column (solids)	cucumber and wheat, 14 days	4 soils: standard, saline, alkaline, drought	Efficiency, plant response, environment
Done	Done	Done	In progress	Done	In progress	In progress

ANALYSED FERTILISER PRODUCTS

Products and technology type

Name	Technology type	Name of value chain
FERT 1	**Anaerobic digestion**	*Dry anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 2		*Semi-dry anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 3		*Wet anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 4		*Anaerobic digestion of manure and digestate upgrading by membrane filtration, evaporation, stripping and scrubbing*
FERT 7	**Composting**	*Tunnel composting of biowaste*
FERT 8		*Open windrow composting of green waste*
FERT 9		*Semi-permeable membrane windrow composting of green waste and biowaste*
FERT 12	**Hydrolysis**	*Hydrolysis of sewage sludge for biostimulant production*
FERT 14		*Hydrolysis of keratin waste for liquid organo-mineral fertiliser production*
FERT 15		*Hydrolysis of digestate for organo-mineral fertiliser production*
FERT 17	**Physical**	*Struvite precipitation of wastewater with stirred tank reactor*
FERT 18		*Struvite precipitation of wastewater with fluidised bed reactor*
FERT 20		*Liquid digestate valorisation through biological treatment and membrane filtration*
FERT 21	**Physicochemical**	*Stripping and scrubbing of wastewater for ammonium nitrate/sulphate production*
FERT 22		*Membrane filtration, stripping and scrubbing of manure and digestate for ammonium sulphate production*
FERT 24	**Thermochemical**	*Pyrolysis of wood chips for biochar production*

SCOPE OF DETERMINED PARAMETERS



METODOLOGY

Chemical analysis of fertilising products

PARAMETERS	PRINCIPLE / TECHNIQUE	SAMPLE PREPARATION
MACRONUTRIENTS (TOTAL CONTENT) C, C organic, N, P, K, Ca, Mg, Na, S	• **Total N, C and C organic:** Thermoconductometric (TCD) method with CN elemental analyzer (Vario MACRO Cube, ELEMENTAR) • **Other elements:** ICP-OES (Agilent 5900) after prior calibration with matrix effect correction	• Homogenization • For total contents: microwave-assisted acid digestion (START D, Milestone) under appropriately selected time–temperature conditions • Analysis performed in two parallel replicates
MICRONUTRIENTS (TOTAL CONTENT) B, Co, Cu, Fe, Mn, Mo, Se, Zn	• ICP-OES (Agilent 5900) after prior calibration with matrix effect correction	• Homogenization • For total contents: microwave-assisted acid digestion (START D, Milestone) under appropriately selected time–temperature conditions • Analysis performed in two parallel replicates
SOLUBLE FRACTIONS Water-soluble (WS) Soluble in neutral ammonium citrate (NAC)	• Standardized methods for extraction • Analysis by ICP-OES (Agilent 5900) after prior calibration with matrix effect correction	• Homogenization • Extraction according to standardized methods • Analysis performed in two parallel replicates
CONTAMINANTS (TOTAL CONTENT) As, Cd, Cr, Ni, Pb, Hg, Biuret, Perchlorates	• **As, Cd, Cr, Ni, Pb:** ICP-OES (Agilent 5900) after prior calibration with matrix effect correction • **Total Hg:** Direct mercury analyzer (DMA-80, Milestone) • **Biuret and perchlorates:** Spectrophotometric methods	• Homogenization • For total contents (elements): microwave-assisted acid digestion (START D, Milestone) under appropriately selected time–temperature conditions • Analysis performed in two parallel replicates (elements) • Analysis performed in two parallel replicates (biuret and perchlorates)
OTHER PHYSICOCHEMICAL PARAMETERS pH, Density, Bulk density, Dry matter	• **pH:** Potentiometric method • **Density** (liquids) and bulk density (solids): Gravimetric-volumetric method • **Dry matter:** Gravimetric method	• Homogenization • Measurement according to the appropriate method • Analysis performed in two parallel replicates

QUALITY ASSURANCE

- Two replicates per sample
- Use of reference materials
- Method blanks and control samples
- Instrument calibration and matrix effect correction
- Data quality control

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ilac-MRA

- Standardized methods
- High accuracy and reliability
- Modern analytical techniques
- Quality control at every step
- Comprehensive characterization of bio-based fertilizers

RESULTS: Anaerobic digestion
(FERT 1–4)

TOTAL MACRONUTRIENTS, %	
N	0.83 – 1.20
C	1.91 – 16.95
C_{org}	1.91 – 15.66

TOTAL MACRONUTRIENTS, %	
P_2O_5	0.40 – 0.63
K_2O	0.46 – 0.76
CaO	0.055 – 2.67
MgO	0.016 – 0.37
Na_2O	0.14 – 0.39
SO_3	0.039 – 0.73

WATER-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	0.027 – 0.038
K_2O	0.35 – 0.74
CaO	0.055 – 0.16
MgO	0.013 – 0.039
Na_2O	0.12 – 0.37
SO_3	0.037 – 0.34

NAC-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	0.15 – 0.51
K_2O	0.39 – 0.93
CaO	0.055 – 3.05
MgO	0.024 – 0.22
Na_2O	0.19 – 0.53
SO_3	0.037 – 0.38

TOTAL MICRONUTRIENTS, mg/kg	
B	2.4 – 23
Co	<0.10 – 9
Cu	2.9 – 23
Fe	85 – 4,984
Mn	7.2 – 149
Mo	0.64 – 1.20
Se	≤ 3.0
Zn	6.9 – 105

WATER-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0 – 5.0
Co	0.13 – 0.50
Cu	1.7 – 4.4
Fe	120 – 1,807
Mn	4.7 – 105
Mo	<0.10 – 0.47
Se	≤ 3.0
Zn	19 – 74

NAC-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0 – 5.0
Co	0.13 – 0.50
Cu	1.7 – 4.4
Fe	120 – 1,807
Mn	4.7 – 105
Mo	<0.10 – 0.47
Se	≤ 3.0
Zn	19 – 74

RESULTS: Composting

(FERT 7–9)

TOTAL MACRONUTRIENTS, %

N	0.74 – 2.25
C	10.54 – 25.69
C_{org}	4.87 – 25.46

TOTAL MACRONUTRIENTS, %

N_{total}	0.74 – 2.25
C_{total}	10.54 – 25.69
P_2O_5	0.26 – 1.47
K_2O	0.46 – 1.75
CaO	1.72 – 4.07
MgO	0.31 – 0.58
Na_2O	0.07 – 1.01
SO_3	0.26 – 0.84

WATER-SOLUBLE MACRONUTRIENTS, %

P_2O_5	0.032 – 0.14
K_2O	0.26 – 1.38
CaO	0.083 – 0.21
MgO	0.19 – 0.42
Na_2O	0.13 – 1.50
SO_3	0.045 – 0.25

NAC-SOLUBLE MACRONUTRIENTS, %

P_2O_5	0.29 – 1.38
K_2O	0.43 – 1.88
CaO	1.70 – 4.04
MgO	0.19 – 0.42
Na_2O	0.13 – 1.50
SO_3	0.10 – 0.37

TOTAL MICRONUTRIENTS, mg/kg

B	15 – 68
Co	1.8 – 2.6
Cu	16 – 44
Fe	4432 – 6830
Mn	113 – 268
Mo	0.91 – 1.00
Se	≤ 3.0
Zn	88 – 170

WATER-SOLUBLE MICRONUTRIENTS, mg/kg

B	<1.0 – 2.8
Co	<0.10
Cu	2.4 – 4.4
Fe	33 – 82
Mn	0.93 – 2.5
Mo	0.16 – 0.39
Se	≤ 3.0
Zn	5.3 – 68

NAC-SOLUBLE MICRONUTRIENTS, mg/kg

B	3.5 – 11.8
Co	0.26 – 0.84
Cu	3.7 – 11
Fe	1248 – 1759
Mn	95 – 210
Mo	0.15 – 0.66
Se	≤ 3.0
Zn	70 – 95

RESULTS: Hydrolysis

(FERT 12, 14, 15)

TOTAL MACRONUTRIENTS, %	
N_{total}	2.13 – 8.86
C_{total}	2.03 – 35.50
C_{org}	2.03 – 34.76

TOTAL MACRONUTRIENTS, %	
P_2O_5	<0.025 – 1.94
K_2O	0.096 – 3.67
CaO	0.069 – 2.09
MgO	0.022 – 0.26
Na_2O	0.14 – 4.19
SO_3	1.72 – 9.32

WATER-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	<0.025 – 1.64
K_2O	0.10 – 3.03
CaO	0.042 – 1.29
MgO	0.007 – 0.20
Na_2O	0.18 – 1.19
SO_3	1.79 – 9.37

NAC-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	<0.025 – 2.0
K_2O	0.10 – 3.33
CaO	0.35 – 1.64
MgO	0.020 – 0.29
Na_2O	0.23 – 4.01
SO_3	1.74 – 9.02

TOTAL MICRONUTRIENTS, mg/kg	
B	1.4 – 25
Co	<0.10 – 1.4
Cu	2.1 – 3480
Fe	23 – 2692
Mn	1.4 – 297
Mo	<0.10 – 8.1
Se	≤ 3.0
Zn	12 – 12860

WATER-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0 – 15
Co	<0.10 – 0.42
Cu	<0.25 – 159.3
Fe	2.9 – 69
Mn	<0.30 – 127
Mo	<0.10 – 0.16
Se	≤ 3.0
Zn	10 – 7057

NAC-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0 – 19.3
Co	<0.10 – 0.70
Cu	1.9 – 2866
Fe	12 – 1323
Mn	2.5 – 285
Mo	<0.10 – 8.80
Se	≤ 3.0
Zn	12 – 9701

RESULTS: Physical

Struvite Recovery and Digestate Valorisation (FERT 17, 18, 20)

TOTAL MACRONUTRIENTS, %

N_{total}	0.66 – 5.53
C_{total}	0.33 – 1.08
C_{org}	0.22 – 1.08

TOTAL MACRONUTRIENTS, %

P_2O_5	0.16 – 32.78
K_2O	0.061 – 2.95
CaO	0.13 – 0.49
MgO	0.049 – 12.02
Na_2O	0.078 – 0.18
SO_3	0.024 – 0.061

WATER-SOLUBLE MACRONUTRIENTS, %

P_2O_5	0.093 – 0.87
K_2O	0.029 – 2.80
CaO	0.032 – 0.043
MgO	0.0047 – 0.082
Na_2O	0.011 – 0.16
SO_3	0.008 – 0.046

NAC-SOLUBLE MACRONUTRIENTS, %

P_2O_5	0.20 – 24.61
K_2O	0.082 – 3.66
CaO	0.27 – 0.68
MgO	0.025 – 10.77
Na_2O	0.12 – 0.29
SO_3	0.036 – 0.048

TOTAL MICRONUTRIENTS, mg/kg

B	<1.0 – 11
Co	<0.10
Cu	2.0 – 5; Fe 58 – 735
Mn	7.3 – 101
Mo	<0.10 – 0.08
Se	≤ 3.0
Zn	8.1 – 3823

WATER-SOLUBLE MICRONUTRIENTS, mg/kg

B	<1.0
Co	<0.10
Cu	0.73 – 2.5
Fe	<0.50 – 18.5
Mn	<0.10 – 2.6
Mo	<0.10
Se	≤ 3.0
Zn	0.73 – 13

NAC-SOLUBLE MICRONUTRIENTS, mg/kg

B	<1.0
Co	0.13 – 0.17
Cu	3.4 – 12
Fe	53 – 684
Mn	9.1 – 94
Mo	<0.10
Se	≤ 3.0
Zn	5.5 – 21

RESULTS: Physicochemical

Ammonium Salt Recovery (FERT 21–22)

OTHER TOTAL MACRONUTRIENTS, %

N_{total}	5.75 – 9.02
C_{total}	0.29 – 0.33
C_{org}	0.29 – 0.33

TOTAL MACRONUTRIENTS, %

P_2O_5	<0.025
K_2O	0.0035 – 0.0047
CaO	0.086 – 1.62
MgO	0.028 – 0.034
Na_2O	0.23 – 0.26
SO_3	15.33 – 21.01

WATER-SOLUBLE MACRONUTRIENTS, %

P_2O_5	<0.025
K_2O	<0.0030
CaO	0.052 – 0.51
MgO	0.0063 – 0.011
Na_2O	0.17 – 0.21
SO_3	13.99 – 17.81

NAC-SOLUBLE MACRONUTRIENTS, %

P_2O_5	<0.025
K_2O	0.0064 – 0.011
CaO	0.076 – 0.082
MgO	0.017 – 0.018
Na_2O	0.22 – 0.38
SO_3	15.37 – 20.06

TOTAL MICRONUTRIENTS, mg/kg

B	4.6 – 4.7
Co	<0.10
Cu	4.4 – 8.4
Fe	28 – 32
Mn	2.3 – 3.1
Mo	<0.10 – 0.27
Se	≤ 3.0
Zn	11 – 63

WATER-SOLUBLE MICRONUTRIENTS, mg/kg

B	<1.0
Co	<0.10
Cu	0.63 – 0.98
Fe	<0.50
Mn	0.57 – 1.7
Mo	<0.10 – 0.11
Se	≤ 3.0
Zn	4.3 – 10

NAC-SOLUBLE MICRONUTRIENTS, mg/kg

B	<1.0
Co	<0.10 – 0.16
Cu	3.5 – 7.1
Fe	17 – 25
Mn	2.3 – 2.7
Mo	<0.10
Se	≤ 3.0
Zn	12 – 25

RESULTS: Thermochemical

Biochar (FERT 24)

TOTAL MACRONUTRIENTS, %	
N_{total}	0.20
C_{total}	32.22
C_{org}	30.27

TOTAL MACRONUTRIENTS, %	
P_2O_5	0.11
K_2O	0.15
CaO	2.80
MgO	0.14
Na_2O	0.017
SO_3	0.075

WATER-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	<0.025
K_2O	0.035
CaO	0.12
MgO	0.011
Na_2O	0.011
SO_3	0.020

NAC-SOLUBLE MACRONUTRIENTS, %	
P_2O_5	0.12
K_2O	0.053
CaO	2.47
MgO	0.040
Na_2O	0.016
SO_3	0.086

TOTAL MICRONUTRIENTS, mg/kg	
B	13
Co	1.0
Cu	8.4
Fe	1734
Mn	163
Mo	0.42
Se	≤ 3.0
Zn	28

WATER-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0
Co	<0.10
Cu	0.47
Fe	<0.50
Mn	0.34
Mo	<0.10
Se	≤ 3.0
Zn	1.3

NAC-SOLUBLE MICRONUTRIENTS, mg/kg	
B	<1.0
Co	0.17
Cu	3.6
Fe	206
Mn	159
Mo	<0.10
Se	≤ 3.0
Zn	14

RESULTS: Contaminants

As	Cd	Cr	Cr(VI)	Ni	Pb	Biuret	Cl⁻
Arsenic (As) mg/kg s.m.	Cadmium (Cd) mg/kg s.m.	Chromium (Cr) mg/kg s.m.	Chromium (VI) mg/kg s.m.	Nickel (Ni) mg/kg s.m.	Lead (Pb) mg/kg s.m.	Biuret % (w/w)	Chlorides % (w/w)
<0.30 – 4.8	<0.030 – 1.5	0.40 – 38	<1.5	1.2 – 34	<0.25 – 48	<5.0	<1.0

TECHNOLOGY	SAMPLES (n)	As (mg/kg s.m.)	Cd (mg/kg s.m.)	Cr (mg/kg s.m.)	Cr(VI) (mg/kg s.m.)	Ni (mg/kg s.m.)	Pb (mg/kg s.m.)	Biuret (% w/w)	Chlorides (% w/w)
ANAEROBIC DIGESTION	4 (1, 2, 3, 4)	1.7 – 4.1	<0.030 – 0.90	4.9 – 38	<1.5	7.5 – 15	6.2 – 48	<5.0	<1.0
COMPOSTING	3 (7, 8, 9)	2.4 – 4.8	0.43 – 0.74	25 – 31	<1.5	7.1 – 12	22 – 46	<5.0	<1.0
HYDROLYSIS	3 (12, 14, 15)	<0.30 – 0.96	<0.030 – 1.5	0.40 – 37	<1.5	5.8 – 8.0	0.77 – 5.8	<5.0	<1.0
PHYSICAL	3 (17, 18, 20)	<0.30 – 9.09	<0.030 – 0.27	4.8 – 6.1	<1.5	1.2 – 4.5	<0.25 – 0.44	<5.0	<1.0
PHYSICOCHEMICAL	2 (21, 22)	<0.30 – 0.30	0.061 – 0.13	1.2 – 1.7	<1.5	3.7 – 34	0.50 – 2.4	<5.0	<1.0
THERMOCHEMICAL	1 (24)	1.3 – 1.3	0.21 – 0.21	36 – 36	<1.5	19 – 19	7.3 – 7.3	<5.0	<1.0
ALL SAMPLES (n = 16)		**<0.30 – 9.09**	**<0.030 – 1.5**	**0.40 – 38**	**<1.5**	**1.2 – 34**	**<0.25 – 48**	**<5.0**	**<1.0**

Ranges are based on measured values (min – max).
< indicates values below the quantification limit.

Units: mg/kg s.m. = milligrams per kilogram of dry matter % (w/w) = percent by weight

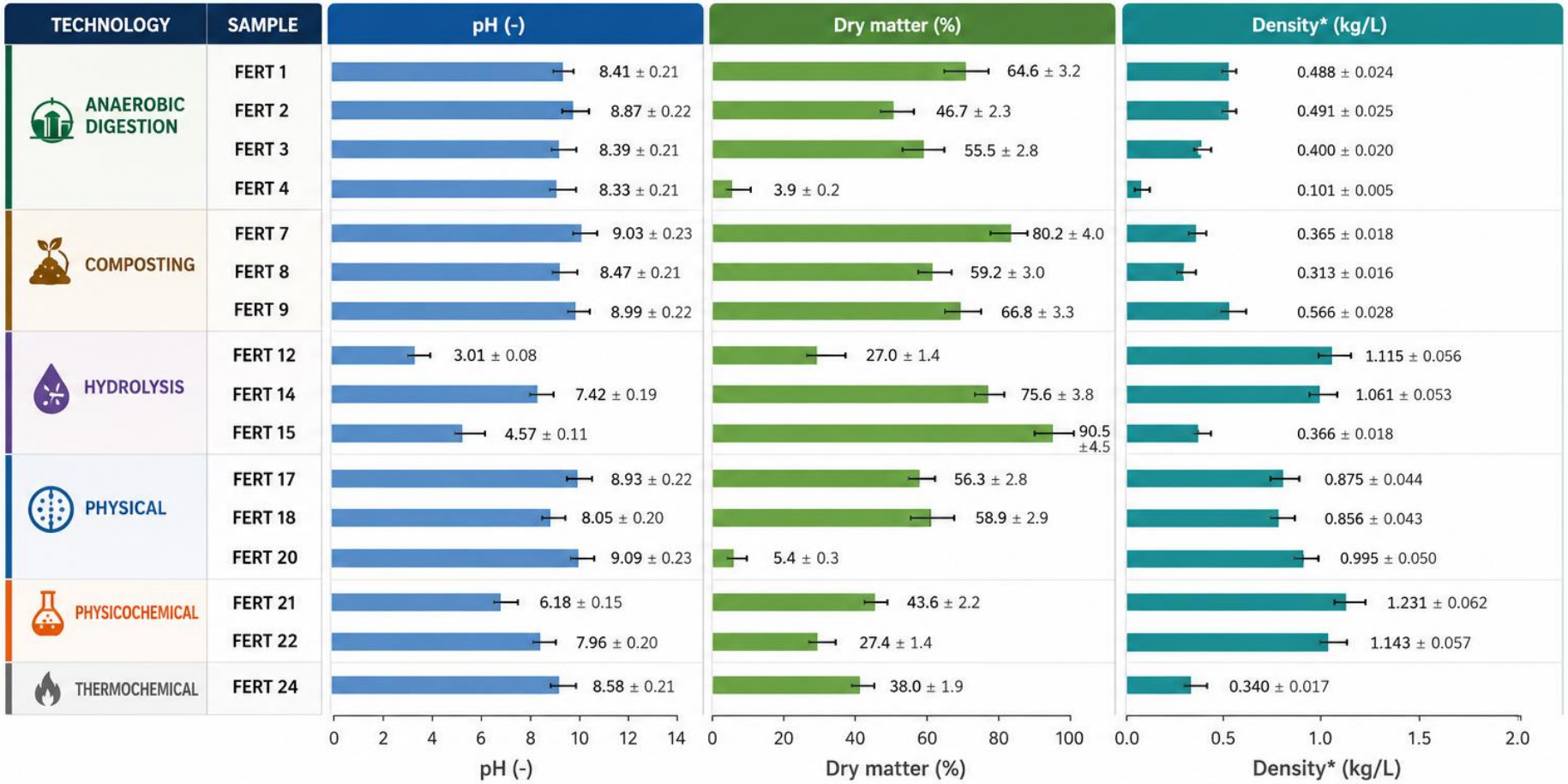
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RESULTS: Physicochemical parameters

pH (-)
- Range: 3.01 – 9.09
- Most samples are alkaline (pH 7–9).
- Lowest pH: FERT 12 (3.01).

Dry matter (%)
- Range: 3.9 – 90.5 %
- Highest: FERT 15 (90.5 %)
- Lowest: FERT 4 (3.9 %)

Density* (kg/L)
- Range: 0.101 – 1.231 kg/L
- Highest: FERT 21 (1.231 kg/L)
- Lowest: FERT 4 (0.101 kg/L)



* *For solid samples, the bulk density was determined.*

RESULTS

Chemical analysis of fertilising products

1. DIVERSE PRODUCTS, COMPLEMENTARY ROLES

- Technologies produce a wide range of fertilising products, from organic soil improvers to mineral concentrates.
- Each product has a specific nutrient profile and agronomic function.

Supports matching the right product to the right agronomic need.

2. VALUABLE NUTRIENT SOURCES

- Many products provide significant amounts of N, P and/or K, including in plant-available forms.
- Recovered nutrients can substitute a meaningful share of mineral fertilisers.

Enables nutrient recovery to close nutrient loops and reduce dependence on primary resources.

3. GENERALLY SAFE AND COMPLIANT

- Contaminant levels in most products are below the limits of Regulation (EU) 2019/1009.
- A few products require further optimisation and monitoring (e.g. specific metals).

Provides confidence for safe use and identifies products needing additional quality control.

4. AGRONOMIC VALUE

- Products differ in nutrient availability, organic matter content and beneficial properties.
- Potential to improve soil fertility, structure and long-term productivity.

Guides agronomic recommendations and supports soil health improvement.

5. BASIS FOR COMPARISON AND PRIORITISATION

- Harmonised dataset allows robust comparison across technologies and products.
- Helps identify high-potential solutions for scale-up and market introduction.

Supports prioritisation of technologies and investment in the most promising solutions.

6. DATA FOR DECISIONS AND POLICY

- Results support compliance with EU regulation and standardisation efforts.
- Provides a scientific basis for policy, certification and market acceptance.

Enables informed decisions for regulators, industry and end-users.

OVERALL IMPACT

The results demonstrate that nutrient recovery technologies can deliver safe, valuable and agronomically effective fertilising products, contributing to a circular and sustainable nutrient system.

- Advance circular economy and resource efficiency
- Reduce environmental impacts and reliance on mineral fertilisers
- Support innovation and market uptake of secondary products
- Contribute to EU goals for sustainability and food security

Funded by the European Union

FertiCovery

Online workshop:

Fertilising Products from Secondary Raw Materials: From Evidence to Practice

TESTING RECOVERED FERTILISERS: WHAT DOES THE EVIDENCE TELL US?

Is It Safe? Microbiological and Environmental Evidence

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Università degli Studi di Torino

27 October 2026

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

WHY THE MICROBIOLOGICAL COMPOSITION OF BIO-BASED FERTILISERS MATTERS?

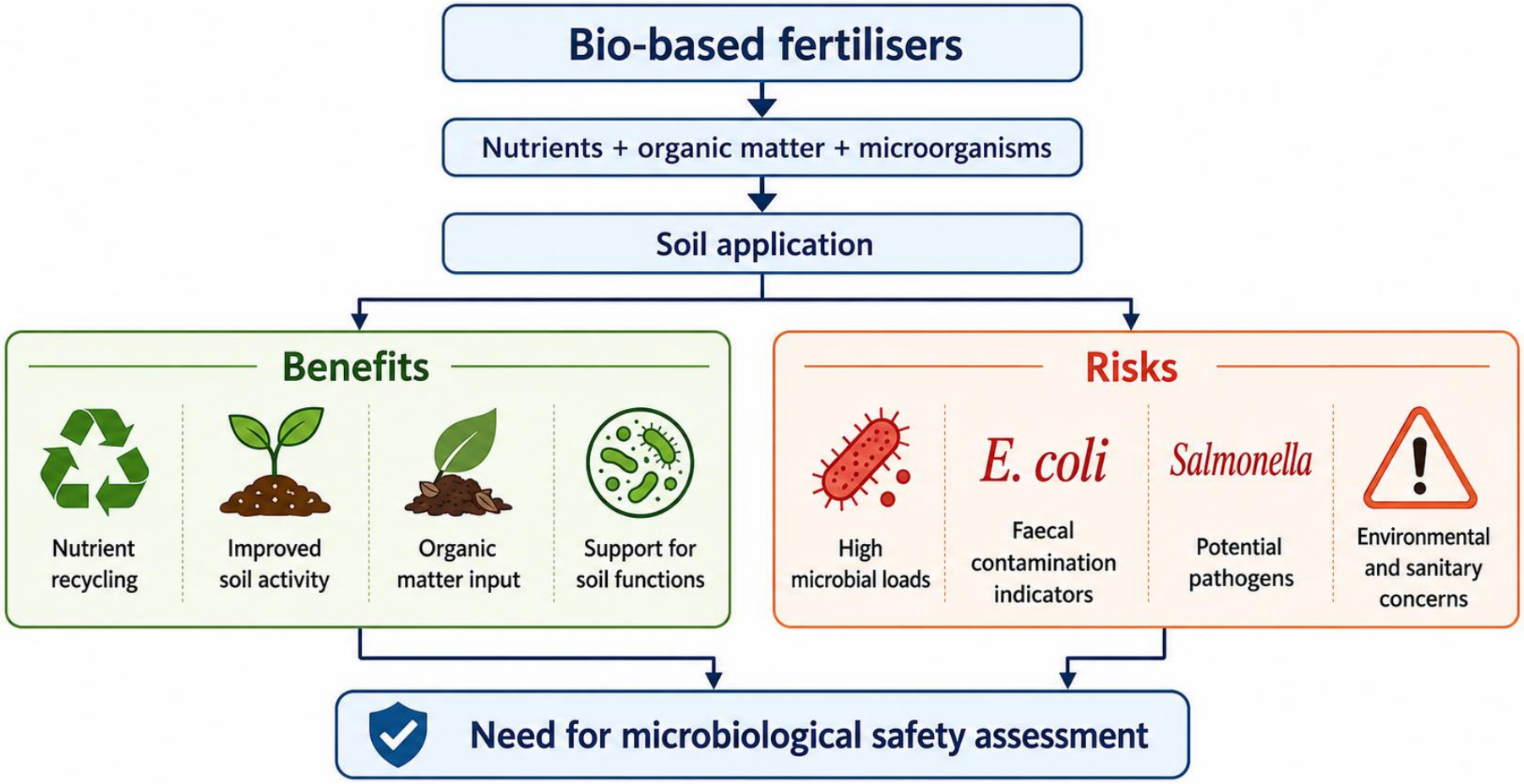


Figure 1. *Overview of the microbial composition of bio-based fertilisers*

AIM OF THE STUDY

To evaluate the microbiological characteristics of 16 bio-based fertilisers across 6 categories, with a focus on sanitary safety and potential effects on soil microbial biodiversity.

RQ1 Are the analysed fertilisers **safe** for soil application based on the occurrence of *E. coli* and *Salmonella*?

RQ2 Can the fertilisers **influence soil microbial biodiversity** through differences in total bacterial and fungal abundance?

ANALYSED FERTILISER PRODUCTS

Products and technology type

Table 1. *Tested fertilisers*

Name	Technology type	Name of value chain
FERT 1	**Anaerobic digestion**	*Dry anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 2		*Semi-dry anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 3		*Wet anaerobic digestion and tunnel composting of biowaste and green waste*
FERT 4		*Anaerobic digestion of manure and digestate upgrading by membrane filtration, evaporation, stripping and scrubbing*
FERT 7	**Composting**	*Tunnel composting of biowaste*
FERT 8		*Open windrow composting of green waste*
FERT 9		*Semi-permeable membrane windrow composting of green waste and biowaste*
FERT 12	**Hydrolysis**	*Hydrolysis of sewage sludge for biostimulant production*
FERT 14		*Hydrolysis of keratin waste for liquid organo-mineral fertiliser production*
FERT 15		*Hydrolysis of digestate for organo-mineral fertiliser production*
FERT 17	**Physical**	*Struvite precipitation of wastewater with stirred tank reactor*
FERT 18		*Struvite precipitation of wastewater with fluidised bed reactor*
FERT 20		*Liquid digestate valorisation through biological treatment and membrane filtration*
FERT 21	**Physicochemical**	*Stripping and scrubbing of wastewater for ammonium nitrate/sulphate production*
FERT 22		*Membrane filtration, stripping and scrubbing of manure and digestate for ammonium sulphate production*
FERT 24	**Thermochemical**	*Pyrolysis of wood chips for biochar production*

Figure 1. Overview of the microbial composition of bio-based fertilisers

METHODOLOGY

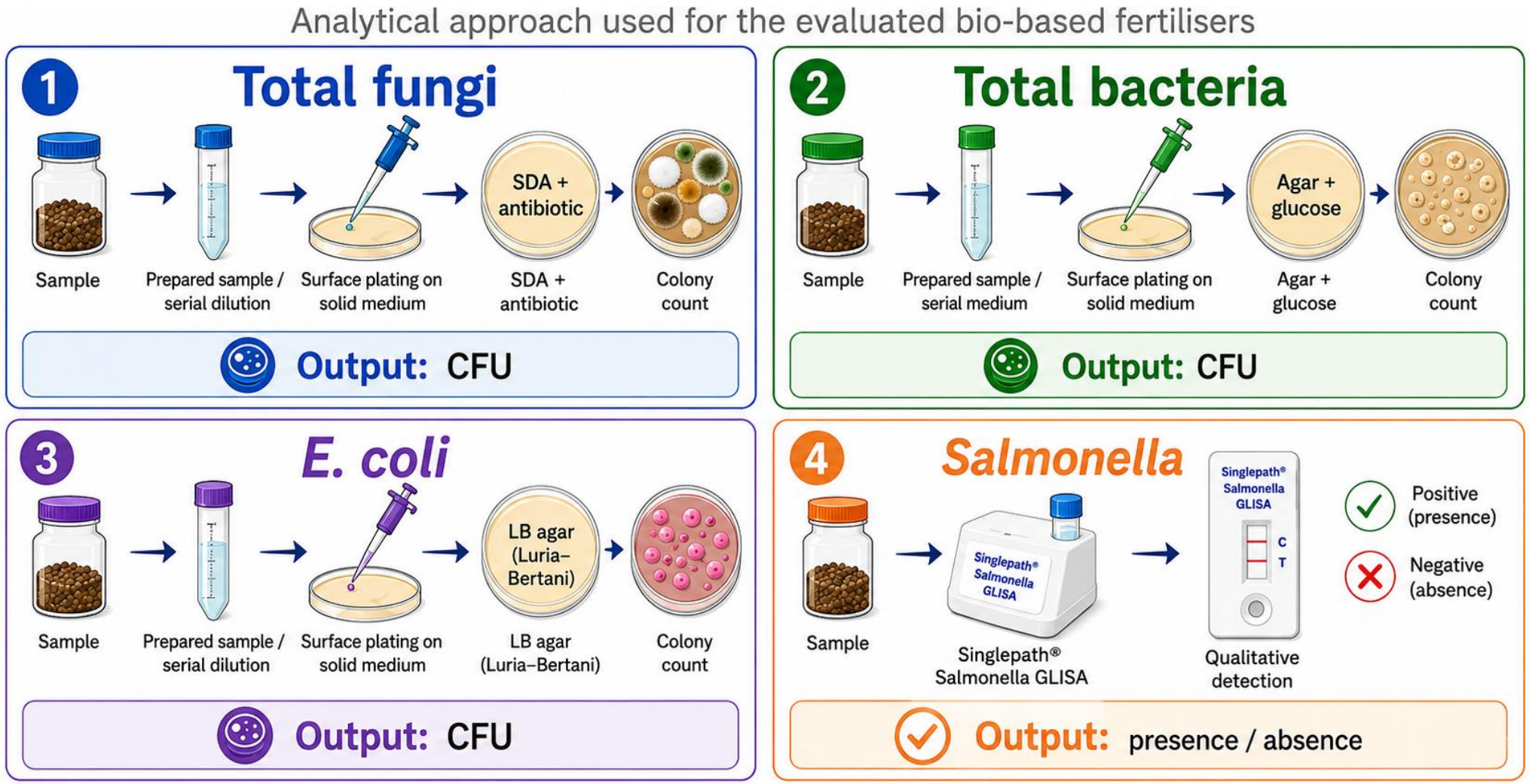
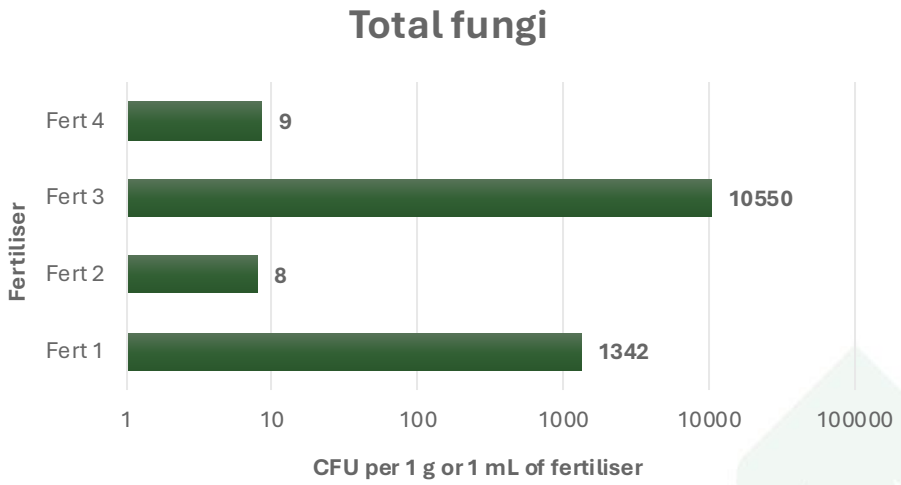
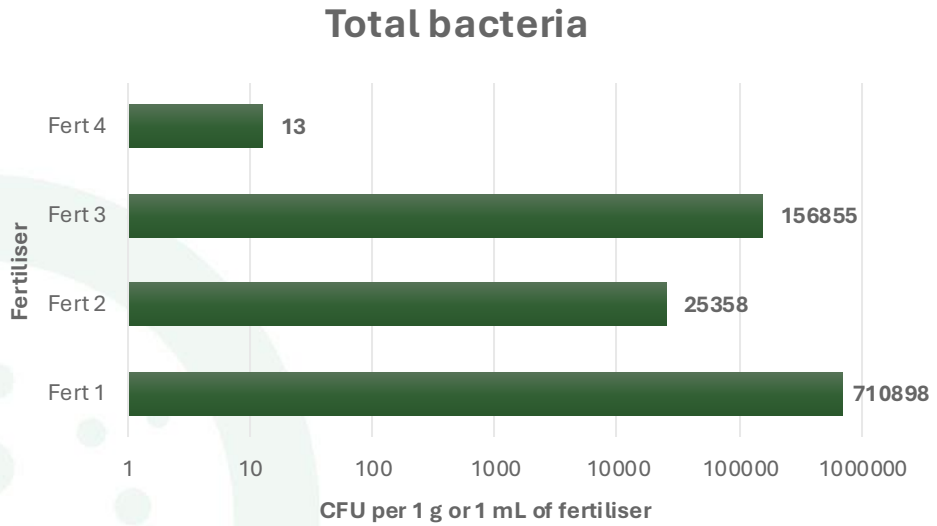


Figure 2. Methodology

RESULTS

Technology type: **Anaerobic digestion**





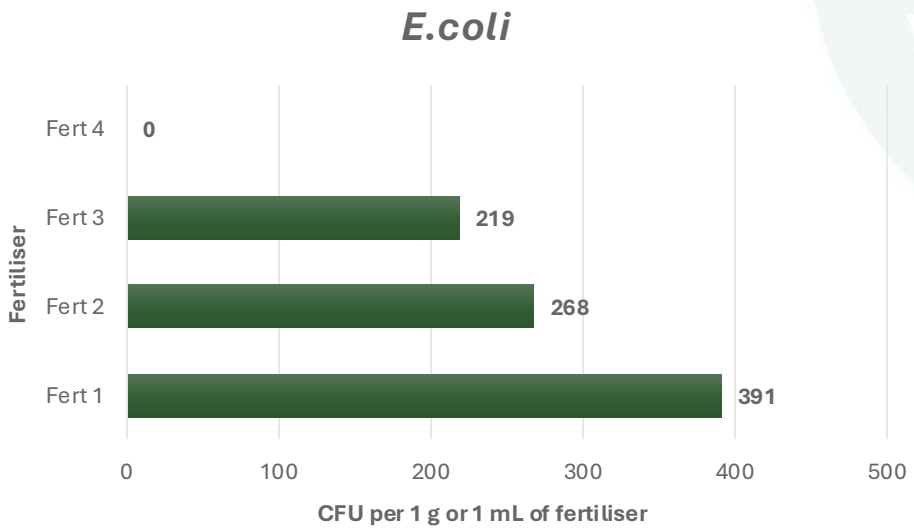
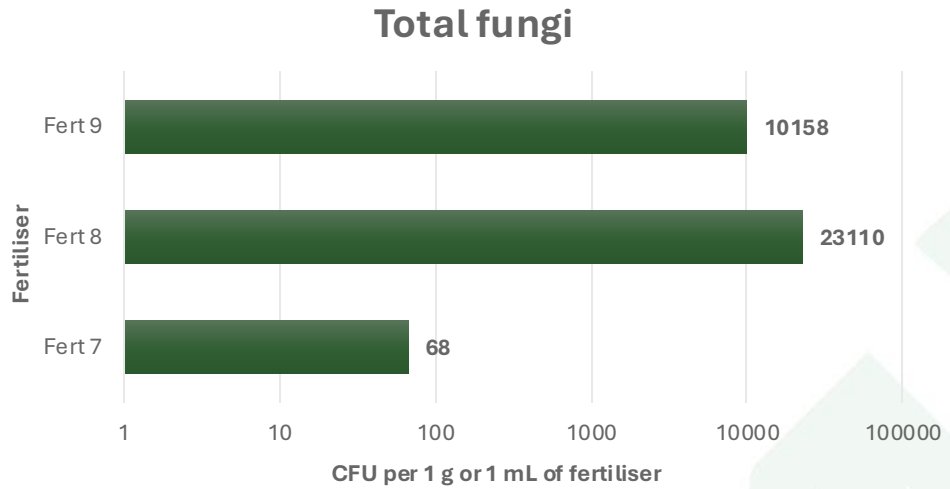


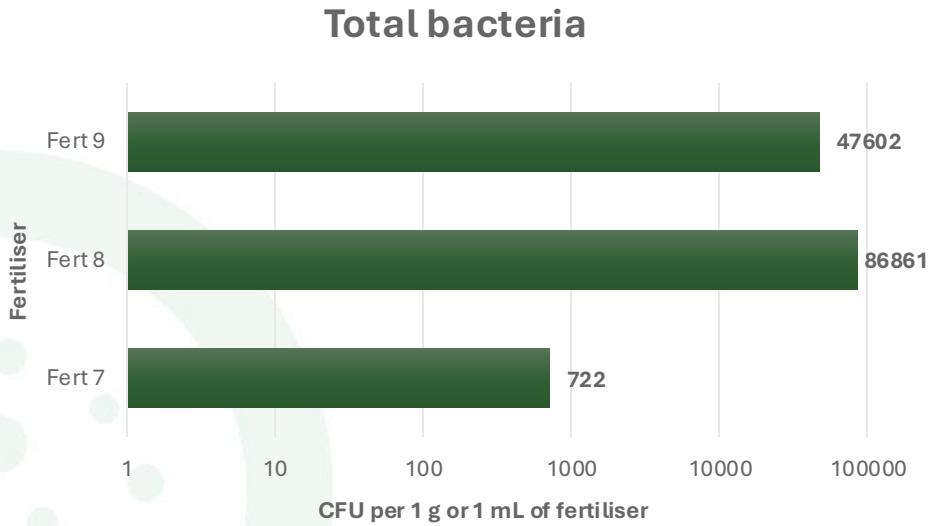
Table 2. Qualitative detection of *Salmonella* spp. in bio-based fertilisers

Fertiliser	*Salmonella sp.*
Fert 1	Not detected
Fert 2	Not detected
Fert 3	Not detected
Fert 4	Not detected

RESULTS

Technology type: **Composting**





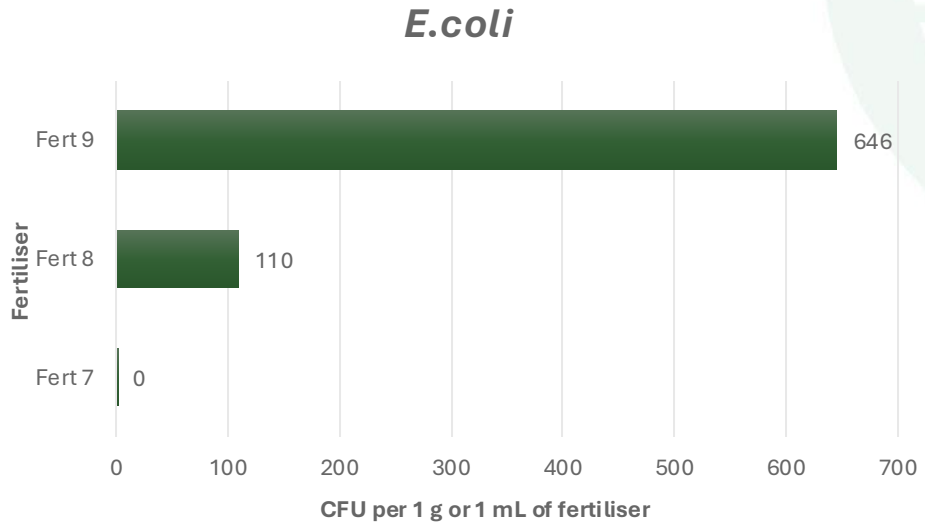
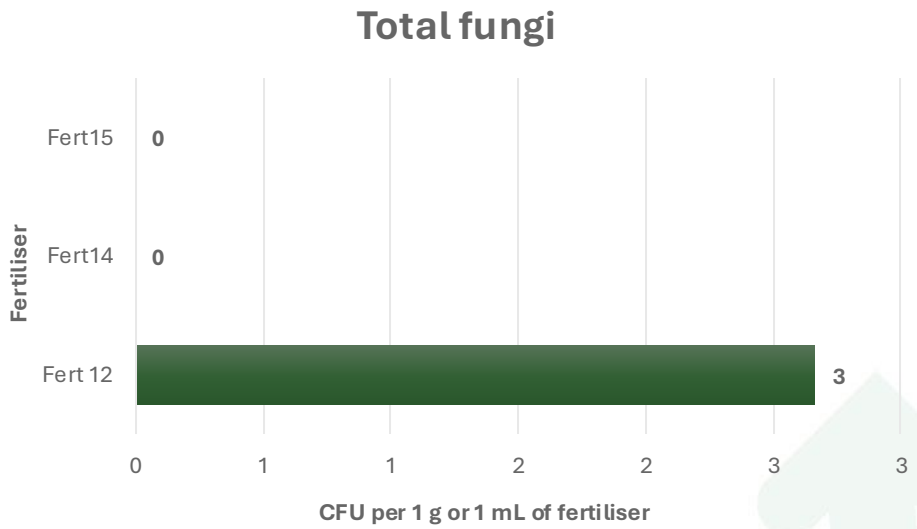


Table 3. Qualitative detection of *Salmonella* spp. in bio-based fertilisers

Fertiliser	*Salmonella sp.*
Fert 7	Not detected
Fert 8	Not detected
Fert 9	Not detected

RESULTS

Technology type: **Hydrolysis**



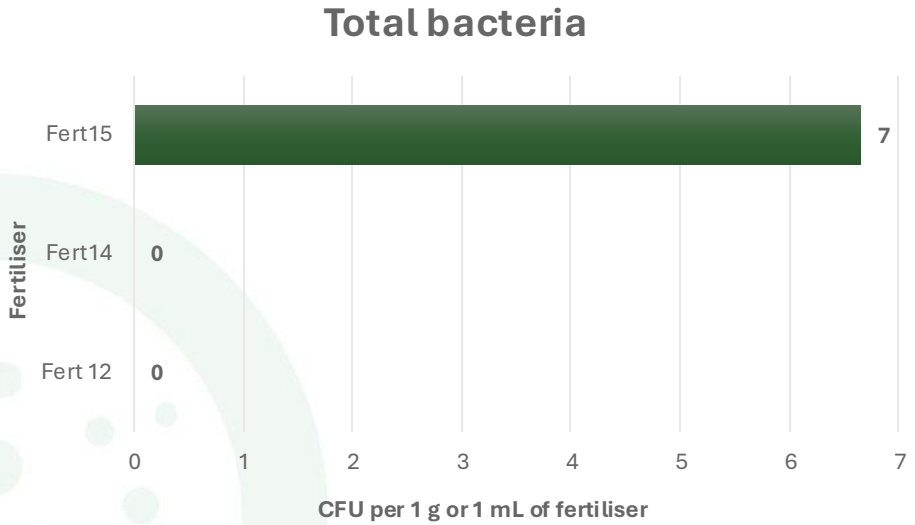


Table 4. *E. coli* occurrence in bio-based fertilisers.

Fertiliser	*E. coli*
Fert 12	Not detected
Fert 14	Not detected
Fert 15	Not detected

Table 5. Qualitative detection of *Salmonella* spp. in bio-based fertilisers

Fertiliser	*Salmonella sp.*
Fert 12	Not detected
Fert 14	Not detected
Fert 15	Not detected

RESULTS

Technology type: **Physical**

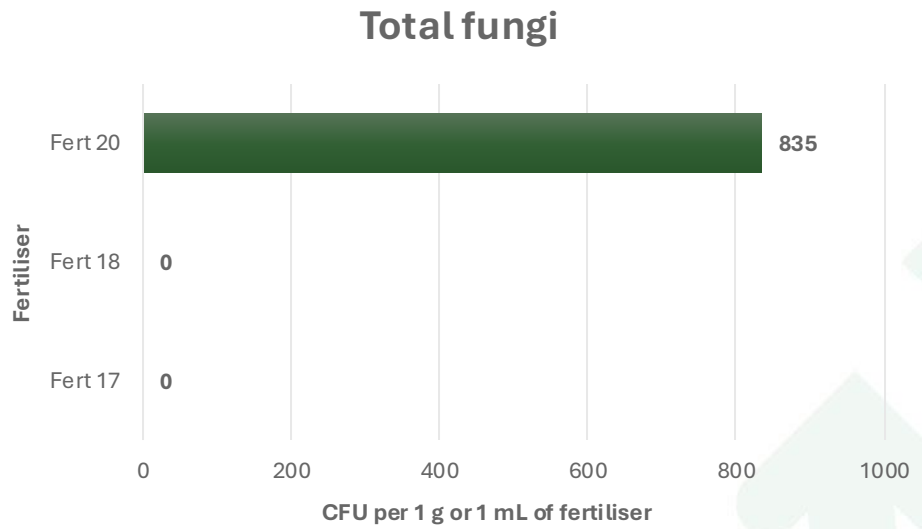


Table 6. Bacteria occurrence in bio-based fertilisers.

Fertiliser	Bacteria
Fert 17	Not detected
Fert 18	Not detected
Fert 20	Not detected

Table 7. *E. coli* occurrence in bio-based fertilisers.

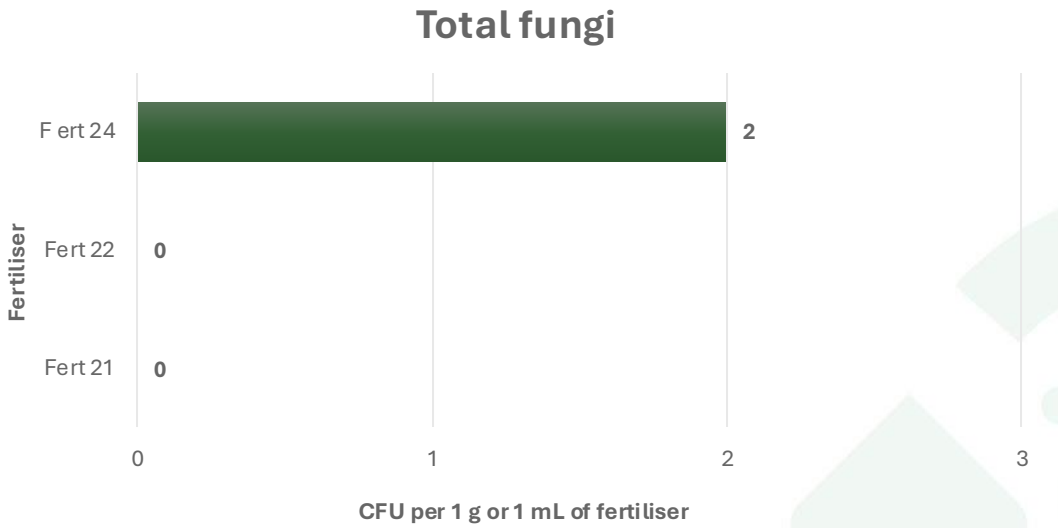
Fertiliser	*E.coli*
Fert 17	Not detected
Fert 18	Not detected
Fert 20	Not detected

Table 8. Qualitative detection of *Salmonella* spp. in bio-based fertilisers

Fertiliser	*Salmonella sp.*
Fert 17	Not detected
Fert 18	Not detected
Fert 20	Not detected

RESULTS

Technology type: **Physicochemical** (Fert 21, Fert 22) **Thermochemical** (Fert 24)



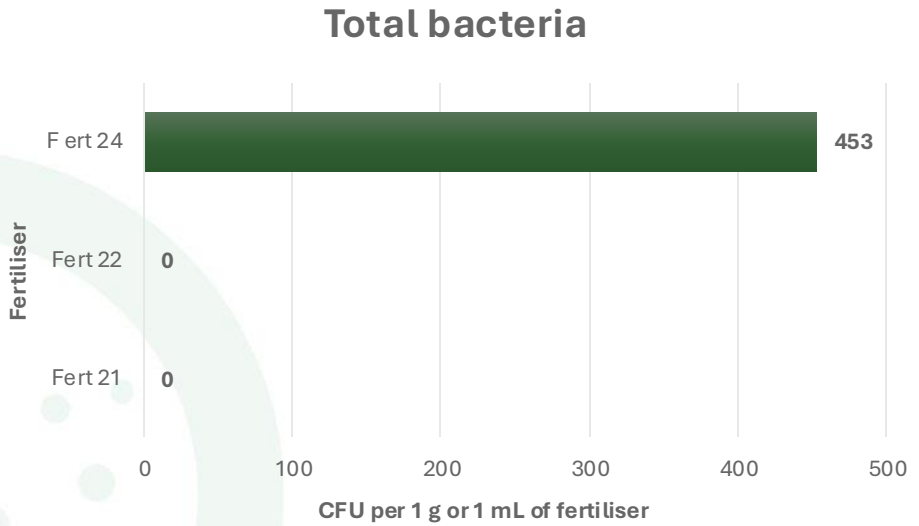


Table 9. *E. coli* occurrence in bio-based fertilisers.

Fertiliser	*E. coli*
Fert 21	Not detected
Fert 22	Not detected
Fert 24	Not detected

Table 10. Qualitative detection of *Salmonella* spp. in bio-based fertilisers

Fertiliser	*Salmonella sp.*
Fert 21	Not detected
Fert 22	Not detected
Fert 24	Not detected

CONCLUSIONS

Microbiological safety and potential soil impact of the tested bio-based fertilisers

Sanitary safety

Salmonella not detected
No qualitative evidence of this pathogen in the tested fertilisers.

***E. coli* mostly not detected**
Detected only in some composting products, indicating product-specific hygienic variability.

Safety interpretation
E. coli should be treated as a sanitary indicator, not just a microbial count.

Potential soil impact

Strong variation in microbial abundance
Total bacteria and fungi differed markedly between technology types.

Highest microbial loads
Anaerobic digestion and composting products showed the highest bacterial/fungal abundance.

Lower microbial input
Hydrolysis, physical, physicochemical and thermochemical products generally showed low or non-detectable counts.

Important nuance
Total CFU values suggest possible influence on soil microbiology, but do not directly measure biodiversity.

Overall message

Most tested fertilisers showed a favourable sanitary profile, while their potential influence on soil microbiology depends strongly on technology type and microbial abundance.

RECOMENDATIONS

Practical guidance for safe and soil-oriented use of the tested bio-based fertilisers

Safety monitoring



- Screen *E. coli* and *Salmonella* routinely before soil application.
- Use *E. coli* as a key indicator of hygienic quality.
- Apply product-specific sanitary assessment rather than category-wide assumptions.

Product management



- Products with detectable *E. coli* should undergo additional verification or improved hygienisation.
- Use higher-risk products with caution in edible-crop systems or short pre-harvest intervals.
- Low-microbial products may be safer hygienically, but may provide less direct microbial input to soil.

Soil impact assessment



- Evaluate high-CFU products for their effects on soil microbial activity and community structure.
- Combine safety screening with soil-based assays such as respiration, enzyme activity, pot trials or community profiling.
- Treat bio-based fertilisers as both nutrient sources and microbiological inputs to soil.

Take-home message

Bio-based fertilisers can support circular nutrient management, but their safe and effective use requires both sanitary control and soil-oriented evaluation.

Funded by the European Union

FertiCovery

Online workshop:

Fertilising Products from Secondary Raw Materials: From Evidence to Practice

TESTING RECOVERED FERTILISERS: WHAT DOES THE EVIDENCE TELL US?

Does It Work? Plant Response and Pot Tests

Dawid Skrzypczak, Mateusz Samoraj

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27 October 2026

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FertiCovery

GERMINATION TEST

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METHODOLOGY

Germination tests

TESTED PLANT: **WHEAT, CUCUMBER**

TESTED PREPARATIONS: **BIO-BASED FERTILIZERS**

TEST DURATION: **14 DAYS**

1. Control *(without fertilization)*
2. Reference fertiliser *(100% of the wheat nitrogen requirement (120 kg/ha)*
3. Bio-based fertilisers (16) *(100% of the wheat nitrogen requirement (120 kg/ha)*

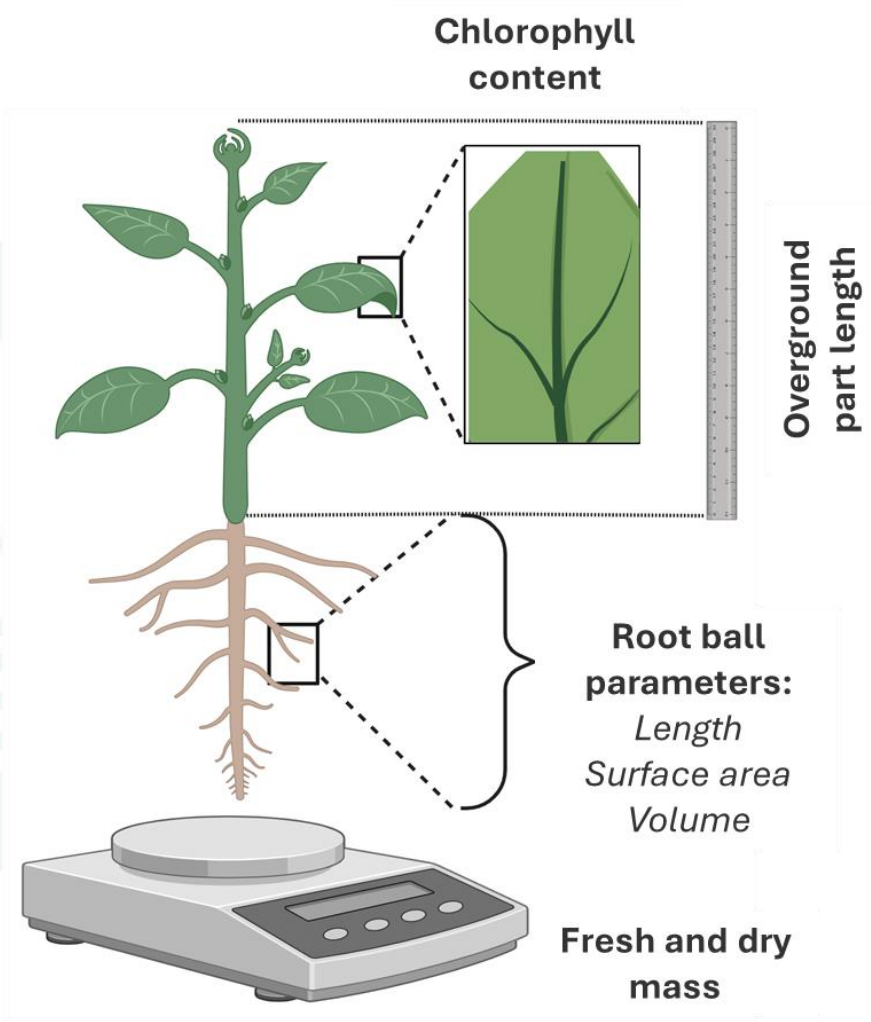


Figure 1. *Location of the experimental center*

RESULTS

Technology type: **Anaerobic digestion**

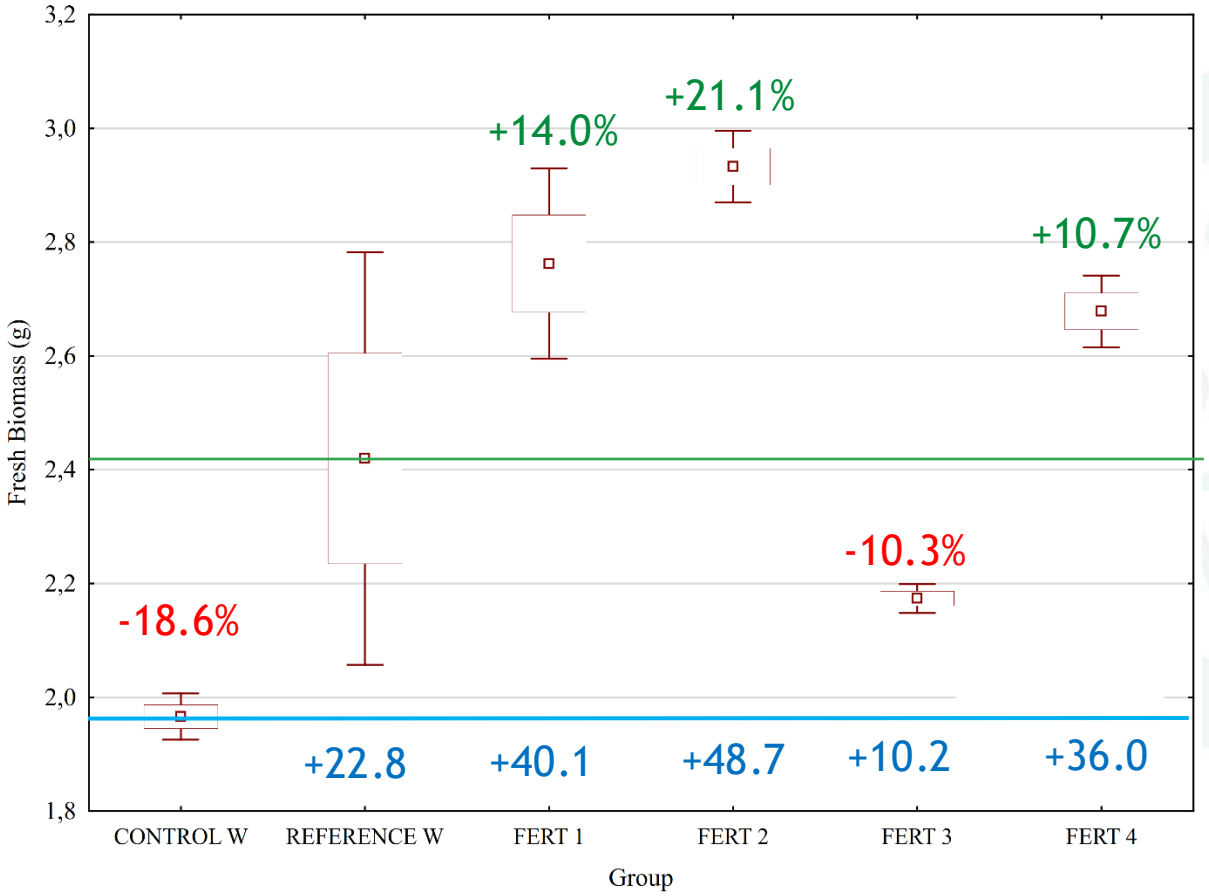


Figure 2. *Fresh seedling mass on day 14 of the test*

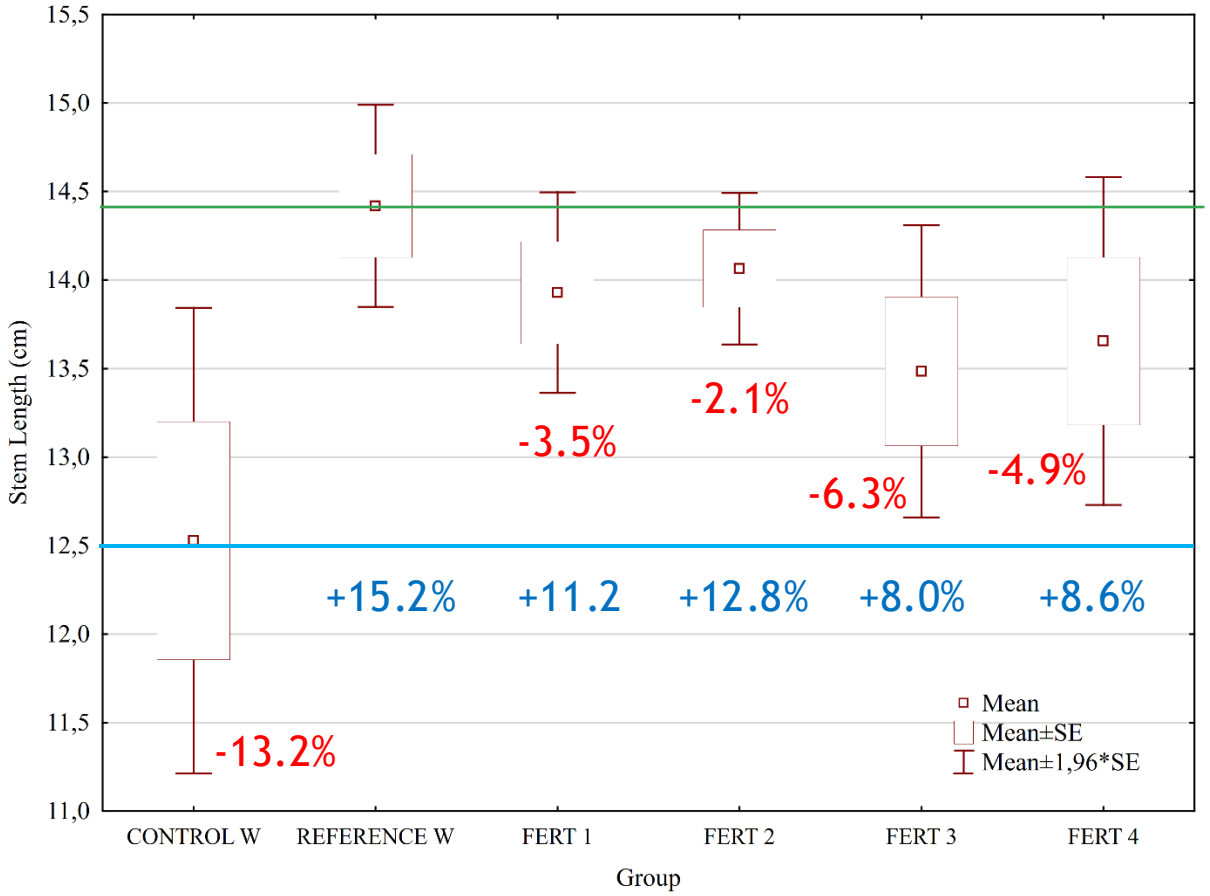


Figure 3. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Anaerobic digestion**

Table 1. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m^2		cm		cm^2		cm^3		%	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349$^{a.b.c}$	22	43.0$^{a.}$	6.0	5.37$^{a.}$	0.98	0.0536^{a}	0.0133	86.7	6.7
REFERENCE	387	27	55.9$^{b.}$	11.0	6.69b.	1.27	0.0646^{b}	0.0152	**91.1**	3.8
FERT 1	380	17	67.0	19.7	8.37c.	2.10	0.0837^{c}	0.0193	**91.1**	3.8
FERT 2	**400^{a}**	28	**88.5$^{a.b.c.d}$**	16.7	**10.0$^{a.b.c.d}$**	1.4	**0.0904$^{a.b.d.e}$**	0.0110	**91.1**	3.8
FERT 3	394^{b}	17	47.9^{c}	10.8	5.95^{c}	1.16	0.0589$^{c.d}$	0.0108	84.4	3.8
FERT 4	390^{c}	24	63.6^{d}	22.8	7.06d	2.53	0.0626^{e}	0.0234	86.7	6.7

Low Mean value
Medium Mean value
High Mean value

RESULTS

Technology type: **Anaerobic digestion**

Table 2. *Comparison of anaerobic digestion-based fertilisers in terms of technology characteristics and wheat response in the germination test*

Product	Technology profile	Wheat response
FERT 1	Dry AD + tunnel composting; biowaste/green waste; compost	Good biomass and root response
FERT 2	**Semi-dry AD + tunnel composting; biowaste/green waste; compost**	**Best overall response**
FERT 3	Wet AD + composting; biowaste/green waste; compost	Weakest response
FERT 4	AD of manure + membrane/stripping/scrubbing; digestate-derived products	Good biomass, weaker root effect than FERT 2

- **Wheat response differed between products** within the same technology group.
- The differences may result from **process configuration, digestate post-treatment** and final product characteristics.
- Products combining **anaerobic digestion with composting** may provide a more balanced effect due to both nutrient supply and stabilised organic matter.

RESULTS

Technology type: **Composting**

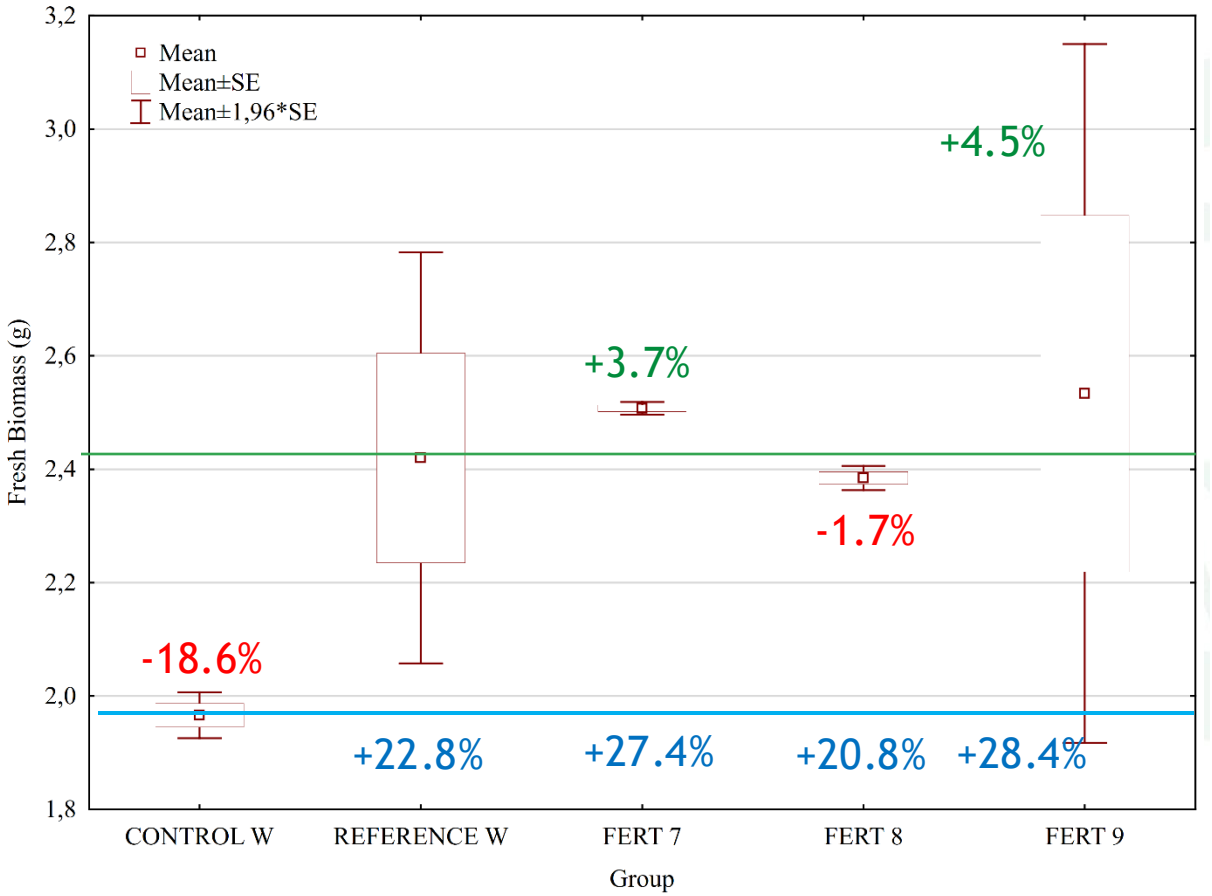


Figure 4. *Fresh seedling mass on day 14 of the test*

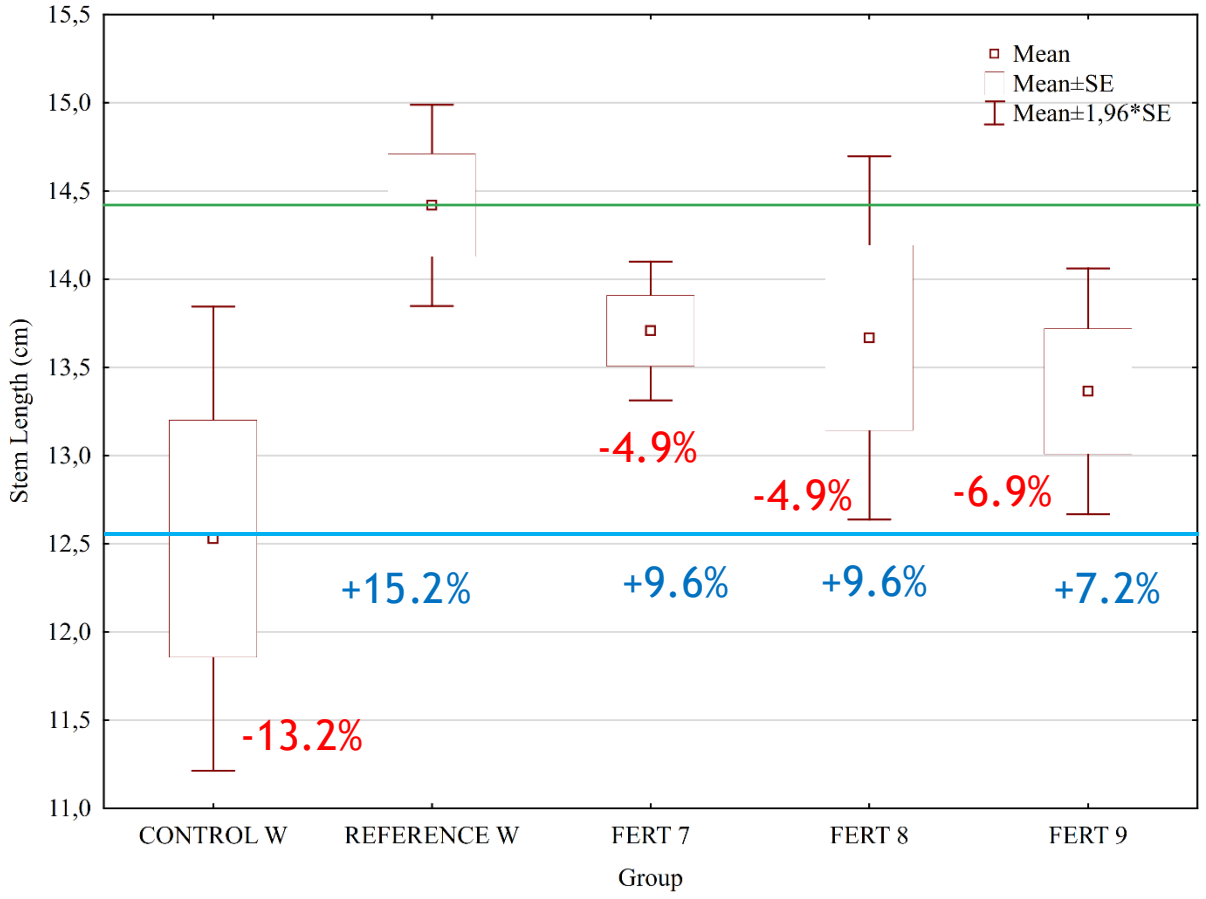


Figure 5. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Composting**

Table 3. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m²		*cm*		*cm²*		*cm³*		*%*	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349	22	43.0	6.0	5.37	0.98	0.0536	0.0133	86.7	6.7
REFERENCE	387	27	**55.9**	11.0	**6.69**	1.27	0.0646	0.0152	**91.1**	3.8
FERT 7	**397**	14	38.5	11.8	5.45	0.84	0.0630	0.0089	88.9	10.2
FERT 8	395	23	46.7	8.8	5.75	1.20	0.0568	0.0146	86.7	6.7
FERT 9	385	17	50.6	12.5	6.40	1.41	**0.0648**	0.0140	**91.1**	3.8

Low Mean value
Medium Mean value
High Mean value

RESULTS

Technology type: **Composting**

Table 4. *Comparison of composting -based fertilisers in terms of technology characteristics and wheat response in the germination test*

Product	Technology profile	Wheat response
FERT 7	Tunnel composting; biowaste; compost	Highest chlorophyll content, but weaker root development
FERT 8	Open windrow composting; green waste; compost	Moderate response, no clear advantage over reference
FERT 9	Semi-permeable membrane windrow composting; green waste/biowaste; compost	Best overall root response and biomass increase

- Composting-based products **showed different effects on early wheat development.**
- The response may depend on **feedstock composition, compost maturity and the composting system used.**
- Products derived from **mixed biowaste and green waste may offer a broader nutrient** and organic matter profile than products based mainly on green waste.

RESULTS

Technology type: **Hydrolysis**

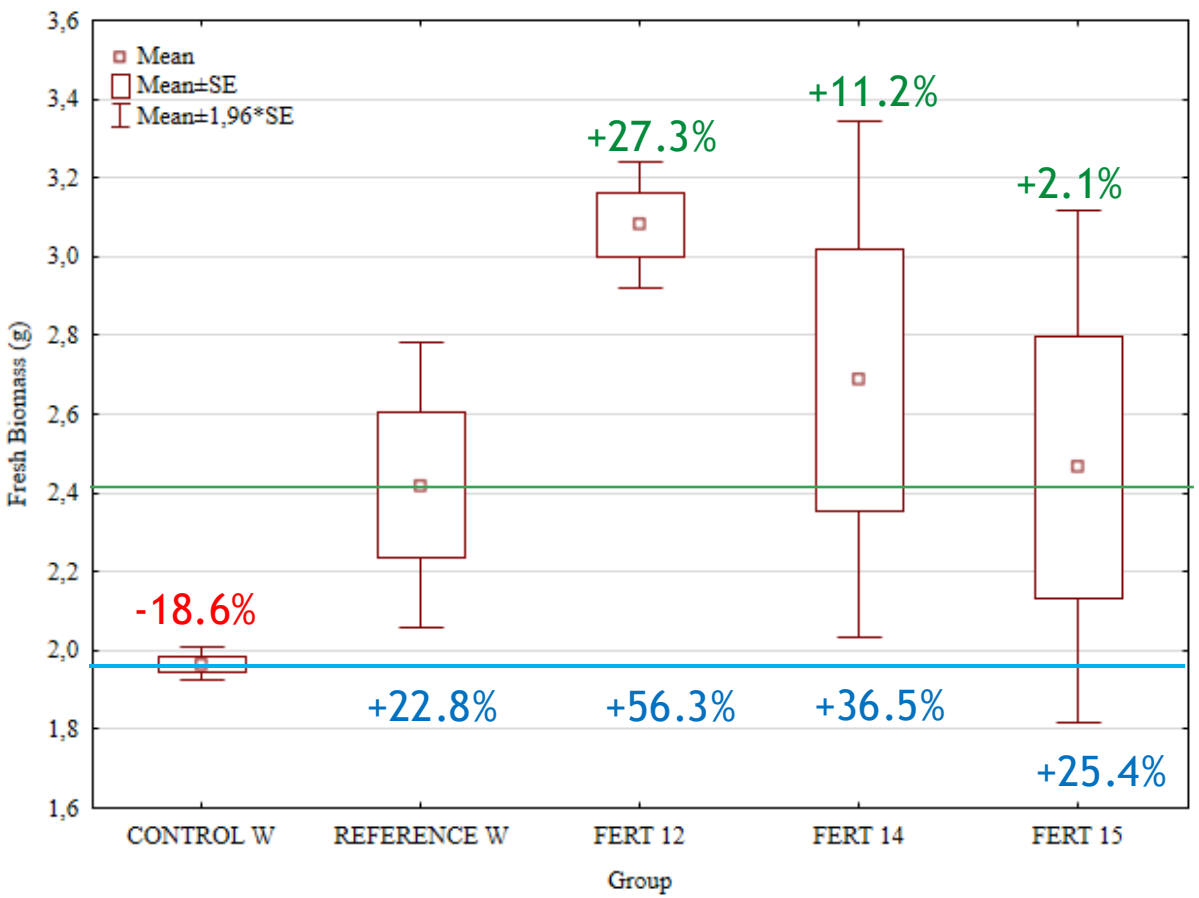


Figure 6. *Fresh seedling mass on day 14 of the test*

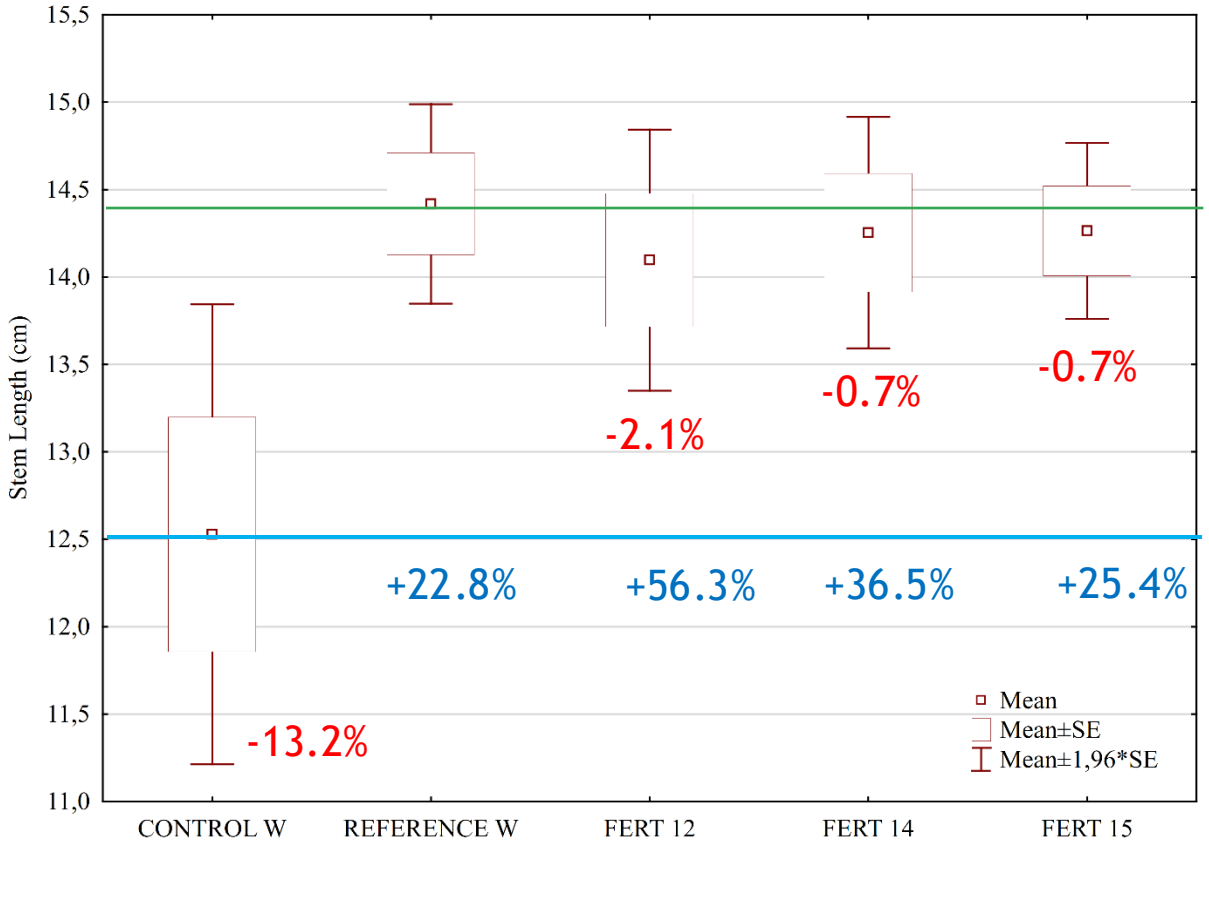


Figure 7. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Hydrolysis**

Table 5. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m²		*cm*		*cm²*		*cm³*		*%*	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349[a.b]	22	43.0[a.b]	6.0	5.37[a]	0.98	0.0536[a]	0.0133	86.7	6.7
REFERENCE	387[a]	27	55.9	11.0	6.69	1.27	0.0646	0.0152	91.1	3.8
FERT 12	**391[b]**	15	**69.9[a]**	16.0	7.76	1.52	0.0688	0.0136	**97.8**	3.8
FERT 14	386	31	54.0	16.6	6.94	1.90	0.0711	0.0186	91.1	3.8
FERT 15	365	16	68.4[b]	11.8	**8.56[a]**	1.63	**0.0859[a]**	0.0217	75.6	21.4

Low Mean value
Medium Mean value
High Mean value

RESULTS

Technology type: **Hydrolysis**

Table 6. *Comparison of hydrolysis conversion-based fertilisers in terms of technology characteristics and wheat response in the germination test*

Product	Technology profile	Wheat response
FERT 12	Hydrolysis of sewage sludge; biostimulant-type product	**Best overall response**
FERT 14	Hydrolysis of keratin waste; liquid organo-mineral fertiliser	Moderate and balanced response
FERT 15	Hydrolysis of digestate; organo-mineral fertilise	Strong root surface/volume, but low germination power

- Hydrolysis-based products showed a **differentiated wheat response.**
- The effect may be related to the **type of hydrolysed feedstock** and the concentration of readily available organic and mineral compounds.
- The balance between **nutrient availability and biostimulant-like compounds appears critical for early plant development.**

RESULTS

Technology type: **Physical**

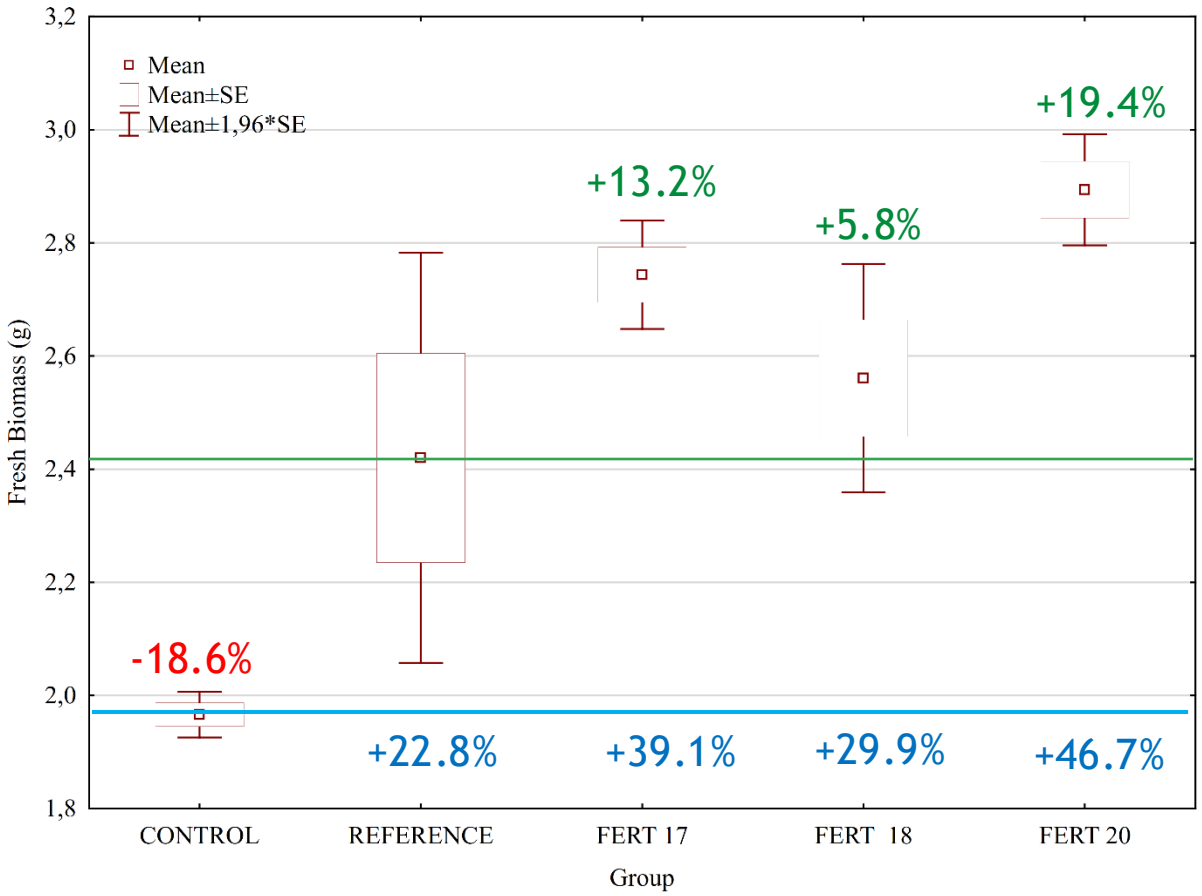


Figure 8. *Fresh seedling mass on day 14 of the test*

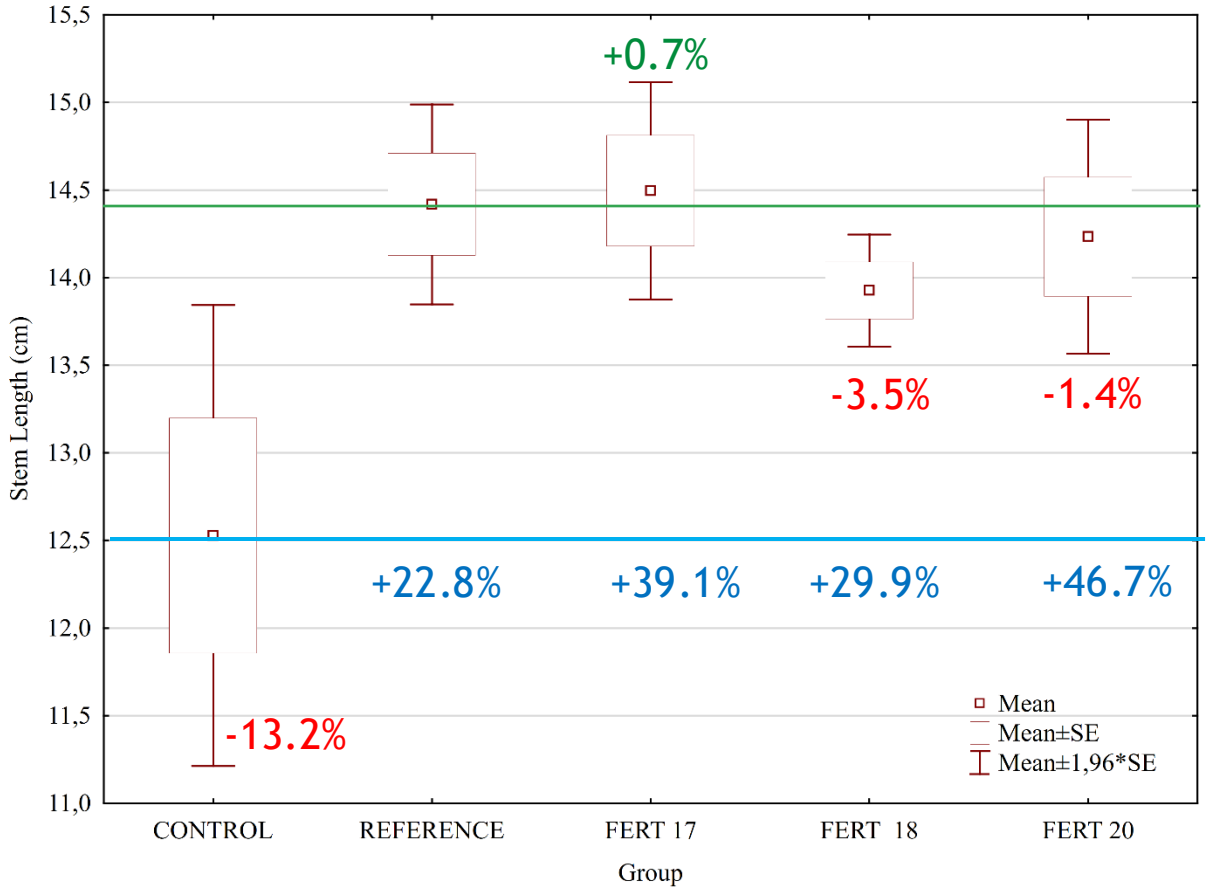


Figure 9. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Physical**

Table 7. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m²		*cm*		*cm²*		*cm³*		*%*	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349[a.b]	22	43.0	6.0	5.37	0.98	0.0536	0.0133	86.7	6.7
REFERENCE	387	27	55.9	11.0	6.69	1.27	0.0646	0.0152	91.1	3.8
FERT 17	**407[a.c]**	29	53.7	10.3	6.81	1.13	0.0688	0.0112	84.4	3.8
FERT 18	366[c.d]	19	**57.9**	16.8	**7.52**	2.13	**0.0781**	0.0241	82.2	10.2
FERT 20	402[b.d]	19	54.0	11.2	6.52	1.34	0.0630	0.0148	**93.3**	6.7

Low Mean value
Medium Mean value
High Mean value

RESULTS

Technology type: **Physical**

Table 8. *Comparison of physical-based fertilisers in terms of technology characteristics and wheat response in the germination test*

Product	Technology profile	Wheat response
FERT 17	Struvite precipitation from wastewater; stirred tank reactor	High chlorophyll content, moderate biomass response
FERT 18	Struvite precipitation from wastewater; fluidised bed reactor	Strongest root development, but low germination power
FERT 20	Liquid digestate valorisation through biological treatment and membrane filtration	Best biomass and germination response

- Physical recovery processes produced products with **different modes of action.**
- **Struvite-type products may mainly support root development** through gradual nutrient release.
- Liquid digestate-derived concentrates may provide **more readily available nutrients for biomass formation** and early seedling establishment.

RESULTS

Technology type: **Physicochemical**

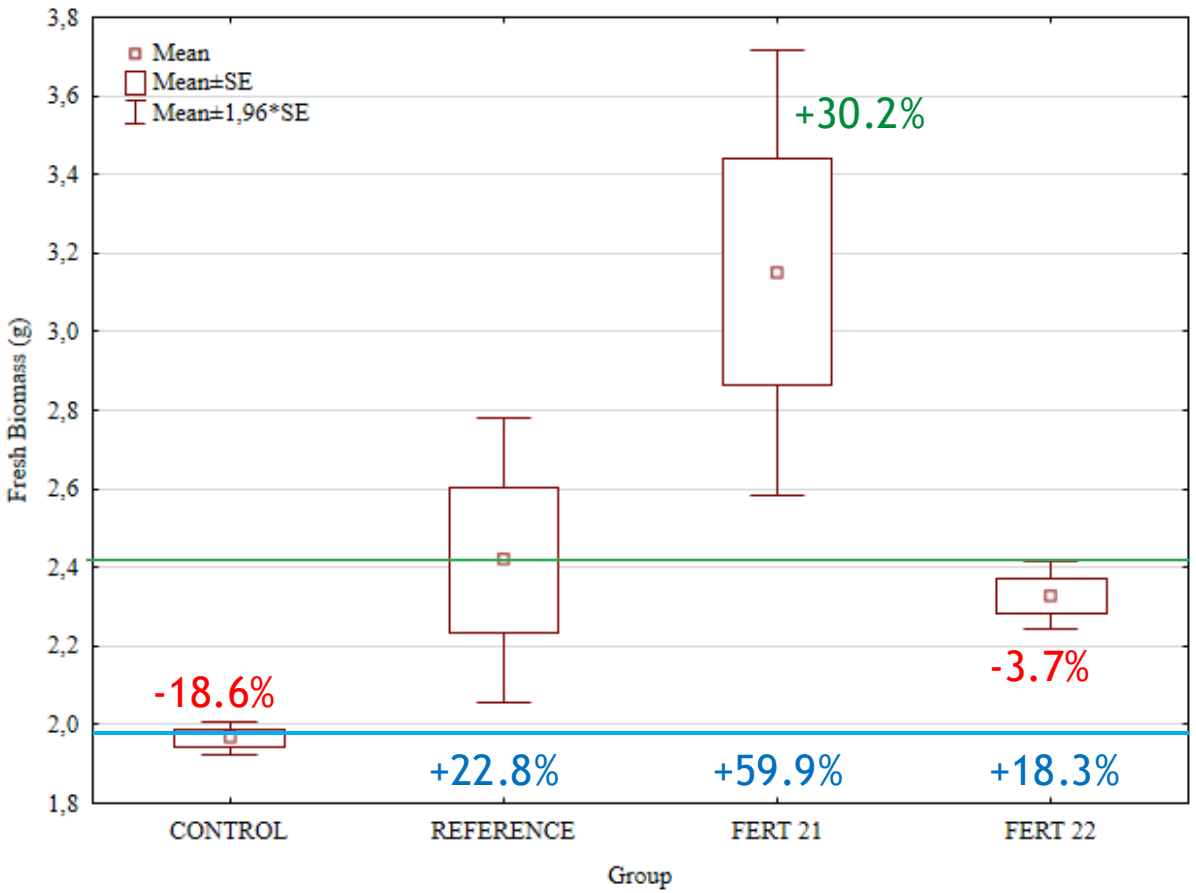


Figure 10. *Fresh seedling mass on day 14 of the test*

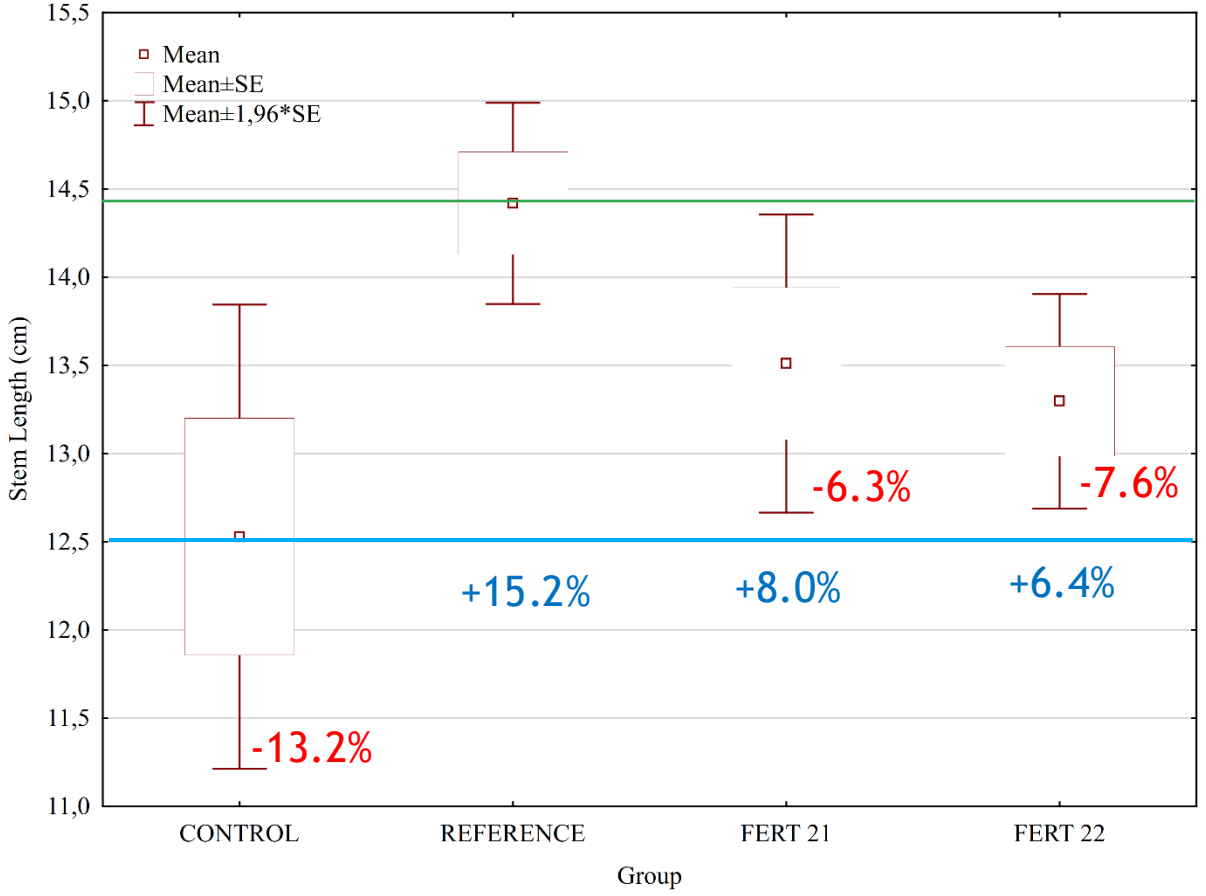


Figure 11. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Physicochemical**

Table 9. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m²		*cm*		*cm²*		*cm³*		*%*	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349[a]	22	43.0	6.0	5.37	0.98	0.0536	0.0133	86.7	6.7
REFERENCE	387	27	55.9	11.0	6.69	1.27	0.0646	0.0152	91.1	3.8
FERT 21	**393[a]**	30	**68.2**	32.7	**8.48**	3.96	**0.0843**	0.0387	**97.8**	3.8
FERT 22	380	22	44.1	13.2	5.74	1.47	0.0596	0.0137	93.3	6.7

Low Mean value
Medium Mean value
High Mean value

RESULTS

Technology type: **Physicochemical**

Table 10. *Comparison of physicochemically conversion-based fertilisers in terms of technology characteristics and wheat response in the germination test*

Product	Technology profile	Wheat response
FERT 21	Stripping and scrubbing of wastewater; ammonium nitrate/sulphate-type product	**Best overall response**
FERT 22	Membrane filtration, stripping and scrubbing of manure/digestate; ammonium sulphate-type product	Moderate biomass and germination response, weaker root development

- Physicochemical products showed a **clear dependence on the recovered nutrient form** and feedstock origin.
- Readily available mineral forms, such as ammonium salts, **may strongly support early wheat growth.**
- However, product composition and possible salinity effects should be considered when interpreting plant response.

RESULTS

Technology type: **Thermochemical**

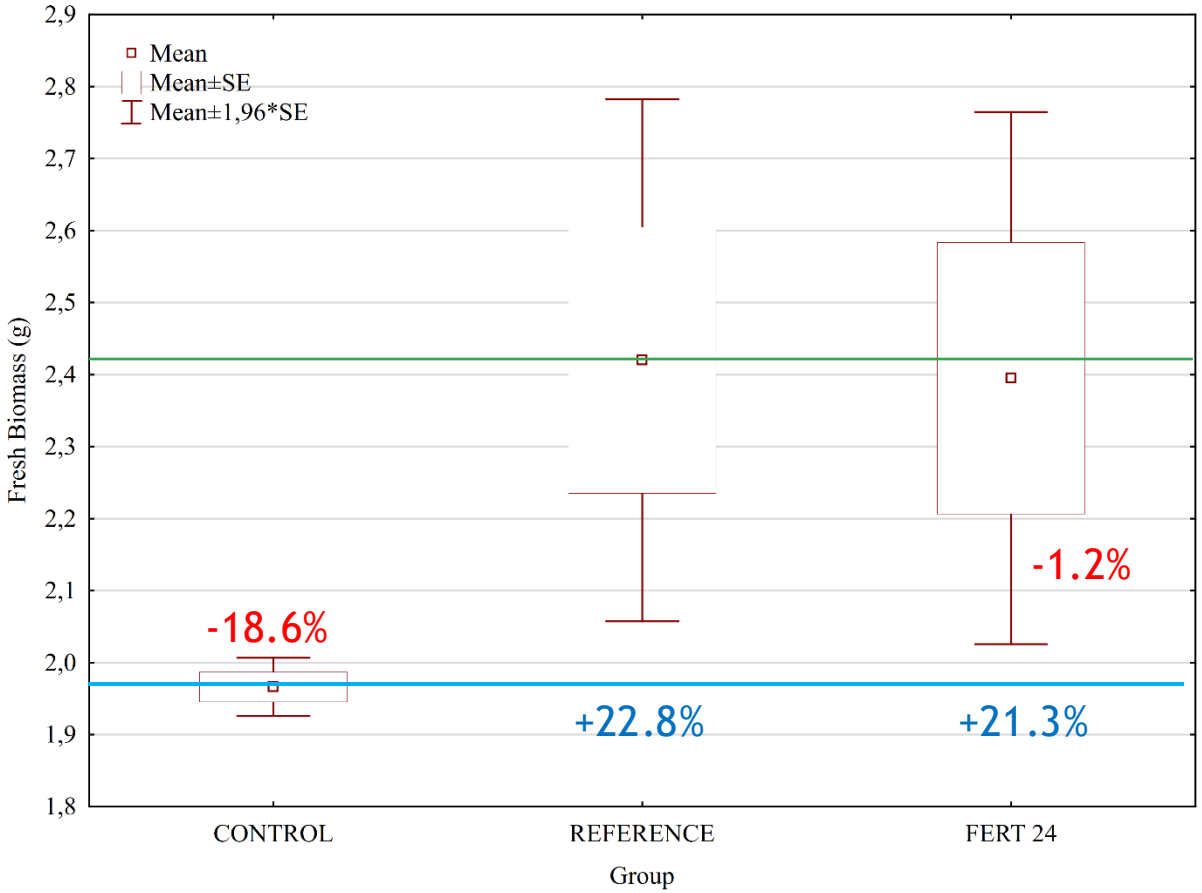


Figure 12. *Fresh seedling mass on day 14 of the test*

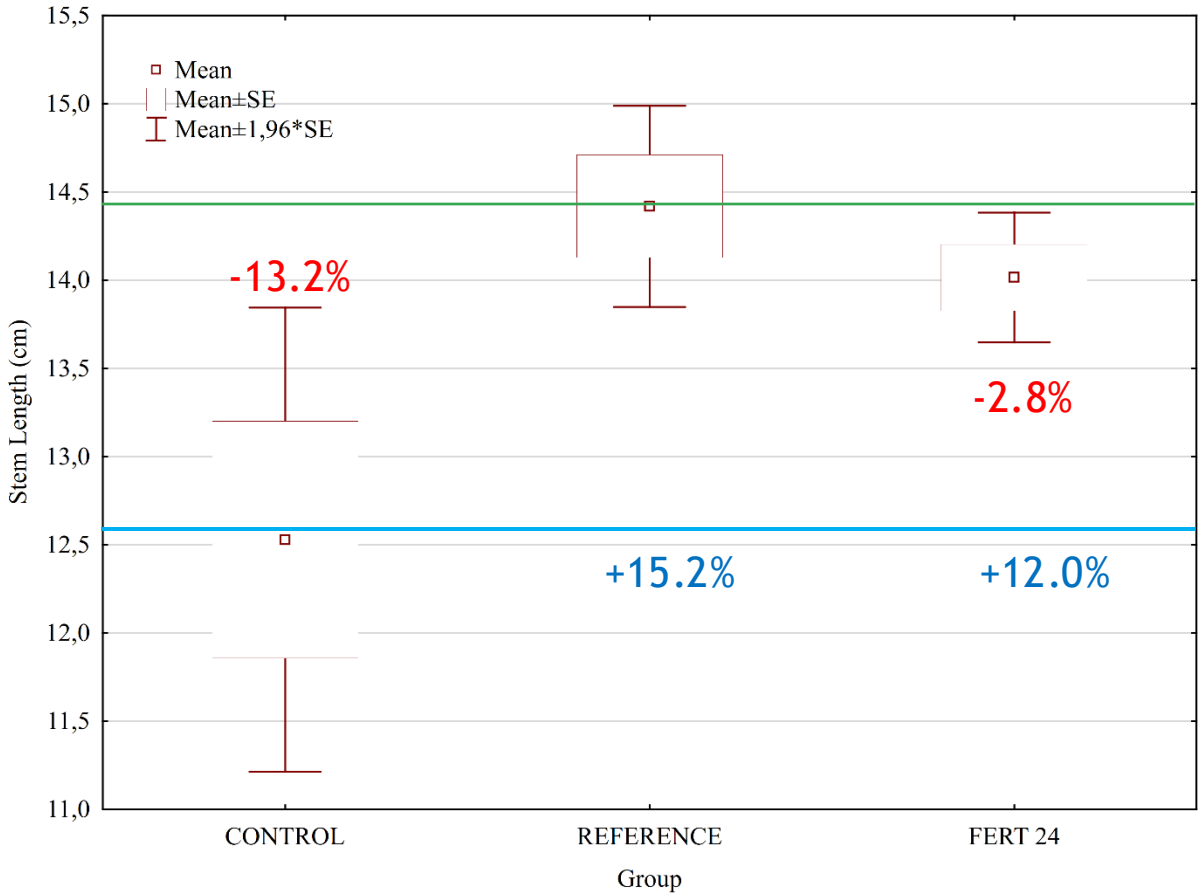


Figure 13. *Steam seedling length on day 14 of the test*

RESULTS

Technology type: **Thermochemical**

Table 11. *Chlorophyll content and root ball parameters*

Group	Chlorophyll Content		Root Length		Root Surface Area		Root Volume		Germination Power	
	mg/m²		*cm*		*cm²*		*cm³*		*%*	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
CONTROL	349[a.b]	22	43.0	6.0	5.37	0.98	0.0536	0.0133	86.7	6.7
REFERENCE	**387[a]**	27	**55.9**	11.0	**6.69**	1.27	**0.0646**	0.0152	**91.1**	3.8
FERT 24	384[b]	18	54.9	8.2	6.31	0.68	0.0578	0.0069	86.7	6.7

Low Mean value
Medium Mean value
High Mean value

- The thermochemical product showed a specific response pattern related to its biochar-like character.
- **Biochar may influence early wheat growth indirectly by modifying nutrient retention**, water availability and root-zone conditions.
- Its effect may be less immediate than that of soluble or nutrient-rich products, but potentially relevant for soil-related benefits – pot test.

FertiCovery

POT EXPERIMENT

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METHODOLOGY

Pot experiment

TESTED PLANTS: **WHEAT, CUCUMBER**

TESTED PREPARATIONS: **16 BIO-BASED FERTILISERS**

TEST DURATION: **5 MONTHS (GREENHOUSE)**

	Standard Conditions	Simulated Drought	Simulated Salinity	Alkaline Soil
Bio-Fertilizer Prototypes				
Positive Control (Commercial Mineral Fertilizer)				
Negative Control (Unfertilized Soil)				

1. Control *(without fertilisation)*
2. Mineral reference fertiliser *(120 kg N/ha wheat, 150 kg N/ha cucumber)*
3. Bio-based fertilisers (16) *(same N dose, applied as fresh product)*

4 regimes × 18 treatments × 2 species · 4 pots per treatment



Soil Health Metrics (Pre- & Post-Trial)

Chemical
- pH
- Multi-elemental composition

Biological
- Microbiological analysis (e.g., microbial diversity)

METHODOLOGY

Pot experiment: **set-up and stress regimes**

Standard

No additional stress factor

Drought

Irrigation withheld for 3 days until the substrate dried out completely

Salinity

Single dose of 5 mL of 1% NaCl solution per pot

Alkaline soil

Quicklime added to the substrate to raise its pH

Each stress was applied once, in the third week of the experiment.

Set-up

- 1 L pots: de-acidified peat (pH 5.5) + sand, 2 : 1
- Dose on N basis: **120 kg N/ha** (wheat), **150 kg N/ha** (cucumber)
- 4 pots per treatment, 1 plant per pot; watered daily, free drainage

Measured at harvest

- Shoot length; root length, surface area and volume (scanner)
- Elemental composition of plant biomass and substrate
- Statistics: one-way ANOVA + Tukey HSD ($p < 0.05$)

RESULTS

Overview: **16 products × 4 regimes**

Table 1. *Mean response vs unfertilised control (%) – shoot and root parameters, both species*

Product	Technology	Standard	Drought	Salinity	Alkaline	Mean
Reference	–	+57.8	+63.1	+84.9	+88.3	+73.5
FERT 1	Anaerobic digestion	+10.0	+25.8	+31.6	+67.5	+33.7
FERT 2		+8.8	+9.7	+7.4	+62.3	+22.0
FERT 3		-2.7	+38.3	+12.9	+53.0	+25.4
FERT 4		+20.9	+26.3	+46.7	+9.5	+25.9
FERT 7	Composting	-18.6	+23.3	+11.4	+54.9	+17.8
FERT 8		+6.2	+33.0	+30.9	+22.5	+23.1
FERT 9		+25.9	+29.8	+34.3	+66.8	+39.2
FERT 12	Hydrolysis	+56.0	**+117.5**	+53.9	+24.1	+62.9
FERT 14		-20.8	+40.9	+47.9	+6.6	+18.7
FERT 15		+57.2	+46.0	+50.1	+69.0	+55.6
FERT 17	Physical	**+70.5**	+41.6	**+88.3**	+45.8	+61.6
FERT 18		+45.2	+17.8	+13.7	+45.6	+30.6
FERT 20		+36.6	**+80.7**	+42.2	+47.1	+51.7
FERT 21	Physicochemical	-16.2	-9.1	+0.5	+16.1	-2.2
FERT 22		-30.3	+16.2	-5.9	-9.8	-7.4
FERT 24	Thermochemical	+25.0	+4.2	+26.6	+15.9	+17.9

Below unfertilised control

Below ½ of reference effect

≥ ½ of reference effect

Bold green = matches or exceeds the mineral reference

- **14 of 16** products improved plant performance over the control (mean of 4 regimes).
- The mineral reference (**+74%**) stays ahead on average; closest: **FERT 12** (+63%) and **FERT 17** (+62%).
- Only the ammonium salts **FERT 21–22** fell below the control.
- Colours shift between columns: **the regime matters as much as the product**.

RESULTS

Regimes: **standard vs drought**

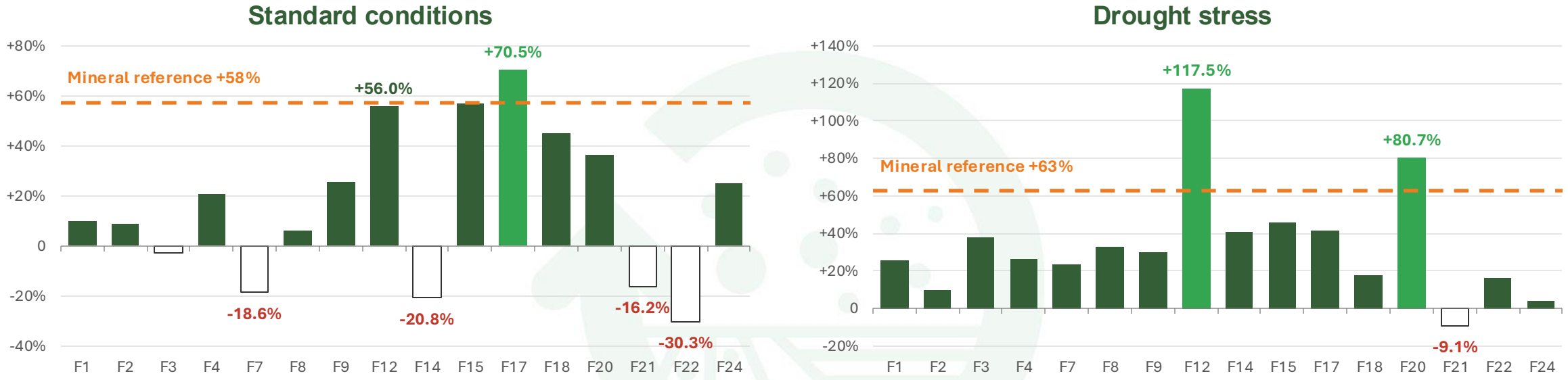
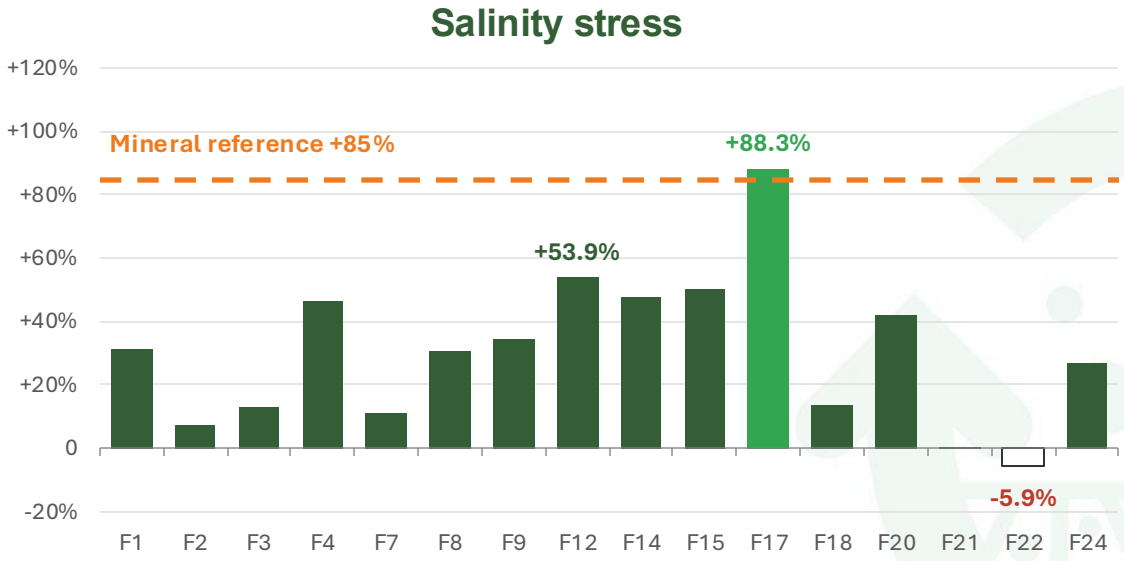


Figure 1. *Mean biometric response vs unfertilised control; dashed line = mineral reference*

- Standard: struvite **FERT 17** best (+71%) – unremarkable in the 14-day screen, a sparingly soluble P source pays off over a season.
- Drought: **FERT 12** (+117%) and **FERT 20** (+81%) clearly exceeded the mineral reference (+63%); 15 of 16 products beat the control.
- Both drought leaders are liquid, biostimulant-type products with a large dissolved organic fraction (hypothesis to test).

RESULTS

Regimes: **salinity vs alkaline soil**



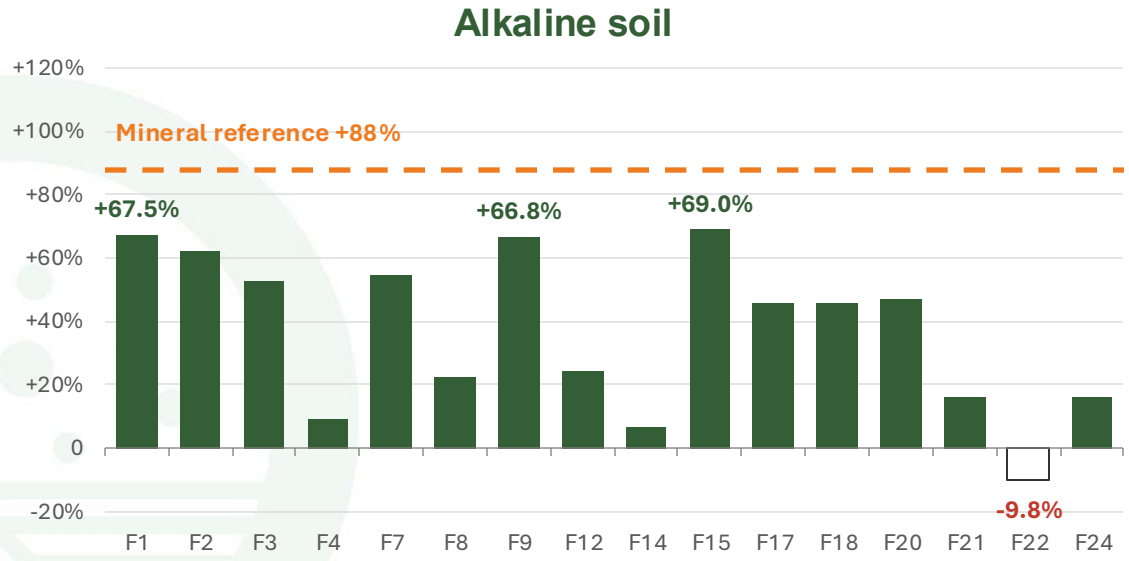


Figure 2. *Mean biometric response vs unfertilised control; dashed line = mineral reference*

- Salinity: only **FERT 17** matched the reference (+88% vs +85%); ammonium sulphate **FERT 22** fell below control – extra salt load.
- Alkaline soil reversed the ranking: composts and digestates led (**FERT 1, 9** +67%, **FERT 15** +69%); struvite FERT 17 dropped.
- Organic complexation protects P, Fe, Mn and Zn at high pH; struvite needs an acidifying rhizosphere to dissolve.

RESULTS

Statistics: **the effect grows with stress**

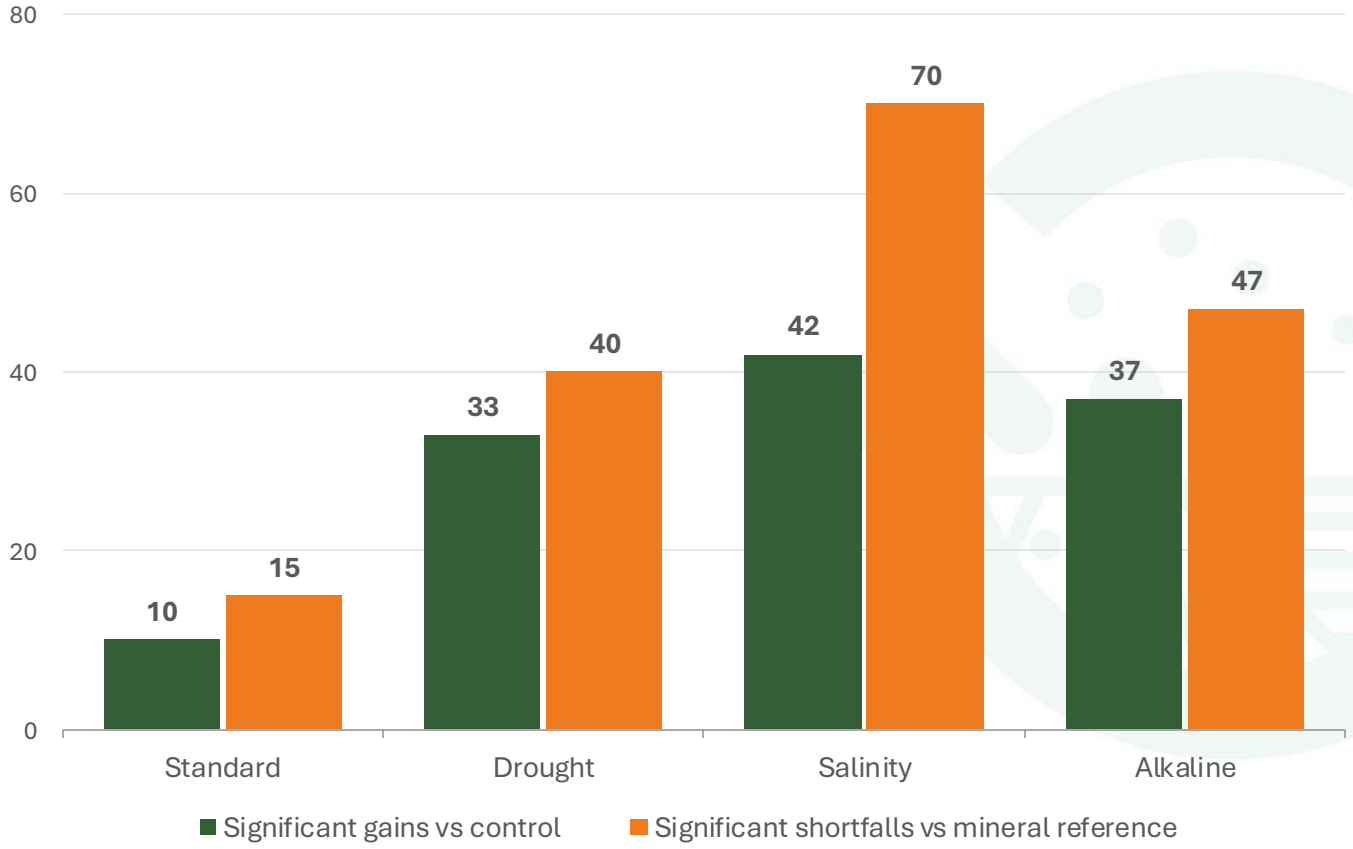


Figure 3. *Number of significant contrasts (ANOVA + Tukey HSD, $p < 0.05$; 4 parameters × 2 species × 16 products)*

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endpoint × regime analyses with a significant treatment effect (30 at $p < 0.001$)

10 of 25

significant advantages over the mineral reference occurred under drought

$\rho \approx 0.39$

rank correlation of products between standard and alkaline soil

- Products do **most measurable good when conditions are hard**.
- The gap to the mineral reference is real, but **endpoint- and regime-specific** – no single substitution factor.

RESULTS

Comparison: **germination test vs pot test**

Table 2. *Wheat germination test (14 days) compared with the pot experiment (5 months, mean of 4 regimes vs control)*

Technology type	Germination test (14 days)	Pot test (5 months)
Anaerobic digestion	FERT 2 best overall (+21% biomass vs reference)	+22% to +34%; all below reference; strongest in **alkaline soil** (FERT 1 +67%)
Composting	Moderate; FERT 9 best root response	FERT 9 best (+39%); slow release of organic N – value builds over seasons
Hydrolysis	FERT 12 best overall (+27% vs reference)	**FERT 12 +63%**, closest to reference; +117% under drought
Physical	FERT 20 best biomass; struvite FERT 17 only moderate	**FERT 17 +62%**, best in standard and salinity; FERT 20 +81% under drought
Physicochemical	FERT 21 among strongest (+30% biomass vs reference)	**Only products below control** (FERT 21 −2%, FERT 22 −7%)
Thermochemical	Close to reference	+18%; soil-mediated effects need more than one season

- A 14-day screen ranks products by **how fast** nutrients become available; a pot test by **how long** supply lasts and how it holds under stress.
- Fast-acting ammonium salts lost ground over the season; the sparingly soluble struvite gained.

INTERPRETATION

Pot tests: **what they tell us and their limitations**

What pot tests can tell us

- Whether the early response is **sustained over a growing season**
- How products perform **under stress** – drought, salinity, alkaline soil
- That the ranking is **conditional on soil and climate** – no single "best" product
- Where nutrients and elements end up: **plant biomass and substrate**

What they cannot tell us

- 1 L pots, peat–sand substrate, greenhouse – **not a field soil profile**
- **One season only** – slow-release organic N of composts is undervalued
- Free drainage, leachate not collected – **read together with leaching tests**
- Single stress pulse; 4 pots per treatment; many endpoints – **conclusions are endpoint- and regime-specific**

CONCLUSIONS

Pot experiment

14 / 16

products improved plant performance over the unfertilised control

2

products outperformed the mineral reference under drought (FERT 12, FERT 20)

0

products ranked best in every regime – the ranking depends on soil and climate

- Recovered fertilisers work over a full season, but a fully soluble mineral fertiliser still **outperforms most of them in a pot**.
- Their benefit is **largest under stress**; the drought response of liquid, biostimulant-type products justifies a dedicated follow-up.
- A 14-day germination test is a screen, not a verdict: **struvite gained and ammonium salts lost** over the season.
- Recommendations must be **product-, soil- and climate-specific**; multi-season field trials are needed for composts and biochar.

FertiCovery

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