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Pathways to phase-out contentious inputs from organic agriculture in Europe

Deliverable 5.7

Technical report on alternative fertilisers (arable farming and vegetables).

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1. Introduction

This Deliverable D5.7 is a 'Technical report on alternative fertiliser'. It is a shorter version, containing key facts and characteristics about the material investigated and described in the much longer 'Summary paper of alternative fertilisers' (Deliverable D5.6).

In organic farming, a considerable amount of nutrients and organic matter are derived from conventional farming as fertilisers from organic sources are not available in sufficient quantities, in particular for stockless organic farms or intensive vegetable and fruit production. Furthermore, the EU Regulation on Organic Food and Farming restricts the use of recycling fertilisers from urban sources. Relying on fertilisers from conventional production is a challenge for the integrity of organic production.

The 'contentious fertilisers' include animal manure and other animal-derived products such as hydrolysed proteins or keratins from **non-organic, conventional, animal husbandry**, but also plant-derived products such as vinasse from conventional sugar-beet production. Furthermore, there may be issues with veterinary drugs and pesticide residues in such fertilisers, as shown for liquid vinasse-based fertiliser which contained residues of pyralid, a herbicide used frequently in conventional sugar beet farming (e.g. McKinnon et al. 2021). In addition, the rapidly increasing demand for **vegan products** and the reduced consumption of meat for environmental reasons contributes to the importance of finding alternatives to animal-derived fertilisers in general.

We also addressed other soil-related contentious inputs in Work Package 5 in Organic-PLUS: Within Deliverable 5.1 the current use of peat in growing media, plastic for mulch films and fertilisers in organic agriculture was assessed, followed by a report discussing possible alternatives to these contentious inputs (Deliverable 5.2). The topics of peat in growing media and biodegradable plastic for mulching made from renewable materials have been described in separate deliverables (D5.8; D5.9; D5.10; D5.11).

For alternative fertilisers, several trials have been conducted with funding from Organic-PLUS in five countries: Norway (NORSØK), UK (CU), Denmark (ICOEL), Poland (CUT) and Germany (UHOH). In work package SOIL, Task 5.4 "Examination of promising alternatives, fertilisers" the trials investigated the use of the alternative fertilisers in the open field, protected cropping and in pot trials in organic vegetable production and in arable farming. For some trials, fertiliser effects were assessed for the main crop and the residual effects were tested in subsequent crops. In Task 5.4, we have collaborated to produce two deliverables, D5.6 and 5.7, where D5.6 is a summary paper describing the output of the fertiliser trials. As outlined this deliverable (D5.7) is a technical report describing some essential characteristics of the fertiliser materials which were tested at different locations in Europe and reported in deliverable (5.6).

To structure a scientific discussion about the future fertilisation inorganic agriculture, we have developed three categories to classify the fertilisers applied in Organic-PLUS: **URBAN**, **VEGAN**, and **RESID**:

> **URBAN** fertilisers are defined as materials which contribute to close the rural-urban nutrient and organic matter cycles by recycling resources derived from agricultural land, via urban food systems and back to the land. A relevant example which has been intensively studied in Organic-PLUS is digestate from source-separated organic household waste, which is used for biogas production by anaerobic digestion. These fertilisers are available in several European countries at the level of a municipality.

VEGAN fertilisers do not contain materials derived from any type of animal production. Such fertilisers may be produced for application in organic farming by growing legumes and processing plant parts into pelletized fertilisers, legume grits and legume silage or by extracting nutrients from locally available plant material such as comfrey or stinging nettle. In any case, a VEGAN fertiliser in an organic system should aim at improving the internal nutrient cycles by the use of legume and non-legume plant materials.

RESID fertilisers (residuals) are materials derived from non-contentious sources. This may be waste materials from organic food industry, or organic material collected by sustainable harvesting in natural environments. Tofu whey and acidified fish bones from captured wild fish are examples of RESID fertilisers evaluated in Organic-PLUS.

This report gives an **overview of the alternative fertilisers investigated** in the Organic-PLUS project. The characteristics of the individual fertilisers as well as recommendations for their application are presented, with an overview of nutrient concentrations and other essential characteristics.

2. URBAN – Fertilisers from urban sources for organic open field vegetable and cereal production

2.1 Biogas digestate – Source-separated organic household waste used for open field vegetable production

Using digestate from source-separated organic household waste as fertiliser is a way of returning the nutrients that are exported from rural areas to consumers, facilitating their (repeated) use as fertiliser for agricultural food production. Digestates may be separated into solid and liquid fractions. The liquid phase of the digestate is characterised by a low C/N ratio and rapidly available nitrogen. The nutrient spectrum, with a narrow N/K ratio as well as a low P content, is in line with the **nutrient requirements of vegetable crops.** This minimises the risk of nutrient imbalances, in particular in organic vegetable production if biogas digestates from external sources are applied. After spreading, the digestate must be quickly incorporated into the upper soil layer to avoid gaseous N losses. Biogas digestate is a good source for all nutrients in addition to N, P and K. The liquid digestate used in the Organic-PLUS trial on field vegetable cultivation in Germany originated from a biogas plant whose digestate fulfilled the requirements of the Regulation on Organic Food and Farming ((EC) No.889/2008 Annex 1 (EU, 2008), in effect during the project duration). In Germany, quality criteria ("RAL Gütezeichen") for digestates used in agriculture exist and the digestate used in the trial was certified accordingly (RAL-GZ 245) and is listed in the FIBL input list (No. 125996) for inputs permitted for organic farming.

Type	Characteristics and recommendations
liquid	**Nutrients:** high amount of NH_4^+-N easily available to the crop, high amounts of K and P, adequate N/K ratio for vegetable cultivation **Cost:** free or low costs for the fertiliser itself; transportation cost may be high; high water content **Application:** easy application with standard equipment for slurry application; application on the soil (trailing hoses) or with direct incorporation by rotor tiller or cultivator, direct incorporation in the soil (slurry injectors or trailing shoe) **Availability:** depending on country and region, limited by distance, transportation is expensive and requires specialized equipment **Caution:** nutrient and heavy metal concentration can vary between the batches; may contain macro and micro plastic **Vegan:** no

Table 1: Nutrient concentrations and characteristics of biogas digestate used for the field vegetable trials (source-separated household waste used in trials in Germany).

	Dry matter (%)	**N_{total}** (g kg^{-1} FM)	**NH_4^+-N** (g kg^{-1} FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** (g kg^{-1} DM)
Mean value	9.3	5.4	4.2	27.8	2.57	4.8	5.7
Range	(8.43-10.2)	(5.02-5.7)	(4.03-4.45)	(26.9-2.87)	(2.51-2.64)	(4.24-5.42)	(5.5-5.86)
No. of anal.	2	6	6	4	4	4	4

	K (g kg^{-1} DM)	**S** (g kg^{-1} DM)	**Ca** (g kg^{-1} DM)	**Mg** (g kg^{-1} DM)	**Na** (g kg^{-1} DM)	**Cl** (g kg^{-1} DM)	**Zn** (mg kg^{-1} DM)
Mean value	34.3	4.30	30.2	7.62	9.82	10.1	210
Range	(30.4-38.3)	(4.19-4.42)	(28.2-32.2)	(7.31-7.93)	(8.87-10.8)	(1.86-18.4)	(206-213)
No. of anal.	4	4	4	4	4	4	4

	As (mg kg^{-1} DM)	**Cd** (mg kg^{-1} DM)	**Cr** (mg kg^{-1} DM)	**Cu** (mg kg^{-1} DM)	**Ni** (mg kg^{-1} DM)	**Pb** (mg kg^{-1} DM)	**Hg** (mg kg^{-1} DM)
Mean value	4.47	0.45	54.7	58.9	19.1	24.7	0.11
Range	(4.11-4.99)	(0.43-0.47)	(49.6-59.6)	(58.5-59.3)	(17.9-20.1)	(23.9-25.6)	(0.10-1.2)
No. of anal.	4	4	4	4	4	4	4

	pH *
Mean value	7.9
Range	(7.4-8.2)
No. of anal.	64

No. of anal.: number of analyses.

*pH value is cited from Möller and Schultheiß (2014).

Methods: **C, N and S**: Dry combustion; **N_{total} and NH_4^+-N:** Kjeldahl; **P, K, Mg, Ca, Na, Zn:** Microwave digestion with HNO_3, measurement with Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-EOS); **As, Cd, Cr, Cu, Ni, Pb and Hg:** Microwave digestion with HNO_3; measurement with ICP- Mass Spectrometry (MS); **Cl**: Hot water extraction and ion chromatography.

Figure 1: Field after application of biogas digestate (household waste) by hand and before incorporation during the field trial.

Figure 2: Biogas digestate before (left) and after incorporation (right).

2.2 Biogas digestate – Source separated household waste used for cereal production

Organic cereal production (e.g. in Denmark) often occurs on farms with limited access to organic animal manure, and thus commercial fertiliser products are widely applied. Often, such products are made from dried conventional poultry manure amended with other materials e.g., vinasse to increase the concentrations of various nutrients and adapt the products to the needs of various crop plants. As the edible plant organ in cereals develops after the application of fertilisers, **cereals are better suited than leafy crops for utilisation of recycled fertilisers** which should not be applied directly to edible crop parts. Anaerobically digested source-separated organic fraction of household waste is a promising alternative fertiliser to recycle nutrients and organic matter back to agricultural soils. Currently, in Denmark, no commercial biogas plants use source-separated organic household waste as the only substrate. Therefore, digestate for testing in Organic-PLUS was prepared in a pilot plant by VARGA as well as imported from Germany (by Daka).

Type	Characteristics and recommendations
liquid	**Nutrients:** high amount of NH_4^+-N, comparable to pig slurry; high amounts of K and P **Cost:** low costs; transportation costs high **Application:** easy application with standard equipment for slurry application; application on the soil (trailing hoses) or with direct incorporation by rotor tiller or cultivator; direct incorporation in the soil (slurry injectors or trailing shoe) **Availability:** depending on country and region; limited by distance, transportation is expensive and requires specialized equipment **Caution:** nutrient/heavy metal concentration can vary between the batches; contains macro and micro plastic **Vegan:** no

Three types of fertilizer from field trials in Denmark in 2019 are presented below:

a. Digested source-separated organic household waste collected from households in Denmark (Table 2)

b. Digested source-separated organic household waste collected from households and restaurants in Germany (Table 3)

c. Digested substrate containing source-separated organic household waste (12.5 %) and slurry from cattle (87.5 %) (Table 4)

Table 2: Nutrient concentrations and characteristics of biogas digestate used in field trials in arable farming (source-separated organic household waste used in trials in Denmark).

	Dry matter (%)	**N_{total}** (g kg^{-1} FM)	**NH_4^+-N** (g kg^{-1} FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** (g kg^{-1} DM)
Mean value	2.90	3.80	2.83	n. d.	13.2	n. d.	13.2
Range	(2.6-3.2)	(3.6-4.0)	(2.6-3.0)		(12.5-13.9)		(6.9-25.0)
No. of anal.	3	3	3		3		3

	K (g kg^{-1} DM)	**S** (g kg^{-1} DM)	**Ca** (g kg^{-1} DM)	**Mg** (g kg^{-1} DM)	**Na** (g kg^{-1} DM)	**Cl** (g kg^{-1} DM)	**Zn** (mg kg^{-1} DM)
Mean value	60.8	n. d.	n. d.	n. d.	n. d.	n. d.	710
Range	(44.8-87.5)						(-)
No. of anal.	3						3

	As (mg kg^{-1} DM)	**Cd** (mg kg^{-1} DM)	**Cr** (mg kg^{-1} DM)	**Cu** (mg kg^{-1} DM)	**Ni** (mg kg^{-1} DM)	**Pb** (mg kg^{-1} DM)	**Hg** (mg kg^{-1} DM)
Mean value	n. d.	0.31	13	200	6.7	8.6	0.08
Range		(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.		3	3	3	3	3	3

	pH
Mean value Range No. of anal.	n.d.

No. of anal.: number of analyses; n. d.: no data;

Methods: **N_{total} and NH_4^+-N**: Kjeldahl; **Dry matter**: Dry combustion; **N, P, K, Zn, Cd, Cr, Cu, Ni, Pb, and Hg**: ICP-OES.

Table 3: Nutrient concentrations and characteristics of biogas digestate (organic source-separated household and catering waste - Germany) used in field trails in arable farming in Denmark.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	3.18	7.23	5.63	n. d.	22.8	n. d.	24.70
Range	(3.1-3.3)	(7.2-7.3)	(5.4-5.8)		(22.1-23.2)		(12.1-54.84)
No. of anal.	4	4	4		4		4

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (g kg^{-1} DM)	Cl (g kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	79.19	n. d.	n. d.	n. d.	n. d.	n. d.	201
Range	(59.4-110)						(206-213)
No. of anal.	4						4

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	n. d.	0.34	13.7	40.7	13.2	1.91	0.05
Range		(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.		4	4	4	4	4	4

	pH
Mean value	n. d.
Range	
No. of anal.	

No. of. Anal.: number of analyses; n. d.: no data;

Methods: **N_{total} and NH_4^+-N:** Kjeldahl; **Dry matter:** Dry combustion; **N, P, K, Zn, Cd, Cr, Cu, Ni, Pb, and Hg:** ICP-OES.

Table 4: Nutrient concentrations and characteristics of biogas digestate (organic source-separated household waste + cattle slurry) used in field trials in arable farming in Denmark.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	4.24	3.30	2.12	n. d.	7.84	n. d.	10.46
Range	(3.7-4.7)	(3.2-3.4)	(2.0-2.2)		(6.96-8.92)		(8.51-14.29)
No. of anal.	5	5	5		5		5

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (g kg^{-1} DM)	Cl (g kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	62.98	n. d.	n. d.	n. d.	n. d.	n. d.	220
Range	(50.0-76.2)						(-)
No. of anal.	5						5

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	n. d.	0.41	4.8	150	4.2	< 2	0.017
Range		(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.		5	5	5	5	5	5

	pH
Mean value	n. d.
Range	
No. of anal.	

No. of anal.: number of analyses; n. d.: no data;

Methods: **N_{total} and NH_4^+-N:** Kjeldahl; **Dry matter:** Dry combustion; **N, P, K, Zn, Cd, Cr, Cu, Ni, Pb, and Hg:** ICP-OES.

Figure 3: Application of different kinds of biogas digestate including source-separated household waste in one of the field trial, 2019. Photo: Casper Laursen, Innovation Centre of Organic Farming

Figure 4: Machinery/equipment used for establishment of fertilizer experiments (ordinary slurry tanker. Machinery size fitted for field trials). Photo: Casper Laursen, Innovation Centre of Organic Farming.

Figure 5: Application of different kinds of biogas digestate including source-separated household waste in one of the field trial, 2019 (drone perspective). Photo: Casper Laursen, Innovation Centre of Organic

Figure 6: Digestate from source-separated household waste: Looks and functions just like slurry. Photo: Innovation Centre of Organic Farming.

3. VEGAN – Plant-based fertilisers for vegan organic vegetable production

3.1 Clover pellets

For fertiliser application, clover, clover-grass and other legume crops or crop mixtures may be applied as pellets, silage or meal for base fertilisation in organic farming. These fertilisers release nutrients slowly (wide C/N ratio), being suitable for crops with a long growing period. Purely legume-based fertilisers such as clover pellets are characterised by a lower C/N ratio and a faster nutrient availability compared to fertilisers with a higher grass content. The nutrient spectrum, with a narrow N/K ratio as well as a low P content, is in line with the nutrient requirements of vegetable crops. This minimises the risk of nutrient imbalances, in particular in organic vegetable production if legume/legume-grass pellets from external sources are applied. For the Organic-PLUS trials, commercially available pellets of white clover were used. After application on the soil surface, the pellets were incorporated in the upper soil layer with a rotor tiller.

Type	Characteristics and recommendations
solid	**Nutrients:** rich in K and low in P; nutrient content suits the requirements of vegetables **Cost:** still high per kg N, but cheaper products are expected as soon as the fertilisers become more widely used **Application:** easy, same application as for all pelleted fertiliser **Availability:** commercially available, on-farm production maybe possible if machinery is available, in Germany mobile machines for pelleting (hay, straw, grass etc.) are tested or already in use for fodder and bedding purposes **Caution:** - **Vegan:** yes

Table 5: Nutrient concentrations and characteristics of clover pellets used in vegetable field trials.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	91.8	29.7	3.22	43.2	3.24	13.3	2.58
Range	(90.9-92.8)	(28.6-30.9)	(3.08-3.36)	(43.1-43.2)	(3.15-3.33)	(13.0-13.7)	(2.4-2.79)
No. of anal.	2	6	6	4	4	4	4

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (mg kg^{-1} DM)	Cl (mg kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	28.5	1.67	12.5	2.31	119	3.44	27.0
Range	(27.3-30.0)	(1.55-1.80)	(12.2-12.8)	(2.27-2.33)	(71-163)	(2.6-4.3)	(26.1-28.3)
No. of anal.	4	4	4	4	4	4	4

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	0.12	<0.025	1.16	9.53	1.7	0.27	0.03
Range	(0.11-0.13)	(-)	(1.09-1.25)	(8.18-10.1)	(1.59-1.79)	(0.24-0.30)	(0.03-0.3)
No. of anal.	4	4	4	4	4	4	4

	pH
Mean value	n. d.
Range	
No. of anal.	

No. of. anal.: number of analyses; n. d.: no data.
Methods: **C, N and S**: Dry combustion; **N_{total} and NH_4^+-N:** Kjeldahl; **P, K, Mg, Ca, Na, Zn:** Microwave digestion with HNO_3, measurement with Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-EOS); **As, Cd, Cr, Cu, Ni, Pb and Hg:** Microwave digestion with HNO_3; measurement with ICP- Mass Spectrometry (MS); **Cl**: Hot water extraction and ion chromatography.

Figure 8: Clover pellets (white clover) after application in the field.

Figure 7: Clover pellets before incorporation (top) and after incorporation with rotor tiller (bottom).

3.2 Clover-grass silage

As fertiliser, clover-grass can be applied as silage, too. Silage is a fertiliser which releases nutrients slowly (wide C/N ratio), being suitable for crops with a long growing period. The nutrient spectrum of legumes, with a narrow N/K ratio and a low P content, matches the nutrient requirements of vegetable crops. However, as silage is in most cases derived from within the farming system, it cannot compensate for losses of P, K and other nutrients in produce sold. Other fertilisers are therefore needed to compensate for such losses. In the Organic-PLUS trials, clover-grass silage from the farm itself was produced and used for fertilisation. Before spreading, the silage needs to be chopped to ensure uniform distribution over the area (e.g. with a manure spreader) and good incorporation with the rotor tiller.

Type	Characteristics and recommendations
solid	**Nutrients:** slow release of N; high K content and low P content; nutrient content suits the requirements of vegetables **Cost:** low, can be produced within the farm if machinery for silage production is available or can be rented; if done on-farm, additional labour and area are needed to grow the legumes **Application:** easy on arable land, manure spreader can be used; silage bales have to be shredded before application **Availability:** depending of the farm **Caution:** timing of cutting and composition of clover and grasses have a large influence on nutrient composition and C:N-ratio (N availability) **Vegan:** yes

Table 6: Nutrient concentrations and characteristics of clover-grass silage.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	68.2	14.8	1.61	42.9	2.91	19.8	2.87
Range	(51.1-85.3)	(12.7-17.0)	(0.91-2.3)	(42.9-42.95)	(2.90-2.93)	(17.3-22.0)	(2.55-3.18)
No. of anal.	2	6	6	4	4	4	4

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (g kg^{-1} DM)	Cl (g kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	28.4	1.49	10.3	2.52	0.04	1.63	25.5
Range	(28.1-28.8)	(1.37-1.61)	(9.97-10.6)	(2.15-2.90)	(0.02-0.06)	(1.17-2.09)	(22.8-29.4)
No. of anal.	4	4	4	4	4	4	4

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	0.07	<0.025	0.54	10.12	1.45	0.14	0.02
Range	(0.03-0.11)		(0.38-0.72)	(8.91-11.3)	(1.29-1.58)	(0.1-0.17)	(0.01-0.03)
No. of anal.	4	4	4	4	4	4	4

	pH*
Mean value	5.9
Range	(-)
No. of anal.	2

No. of anal.: number of analyses.
*Data of clover-grass silage, alfalfa meal cited from Möller and Schultheiß (2014).
Methods: **C, N and S**: Dry combustion; **N_{total} and NH_4^+-N:** Kjeldahl; **P, K, Mg, Ca, Na, Zn:** Microwave digestion with HNO_3; measurement with Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-EOS); **As, Cd, Cr, Cu, Ni, Pb and Hg:** Microwave digestion with HNO_3; measurement with ICP- Mass Spectrometry (MS); **Cl**: Hot water extraction and ion chromatography.

Figure 9: Clover-grass silage after application on the field.

Figure 10: Clover-grass silage after incorporation with rotor tiller.

3.3 Bean powder

Legume seeds contain high concentrations of nitrogen and are also a source of other plant nutrients. In the Organic-PLUS trials *Vicia faba* beans were used. These had been ground into flour intended for human consumption although waste beans (e.g. insect damaged) could be used in commercial production – they could even be grown on-farm as a fertility building crop. The flour was suspended in water immediately before application to the soil in order to spread it more evenly.

Type	Characteristics and recommendations
solid/ liquid	**Nutrients:** rich in N **Cost:** very cost effective per kg N; if done on-farm, additional labour area needed to grow the legumes **Application:** easy, same as application of fertigation **Availability:** could utilise commercially rejected beans or beans could be grown on-farm **Caution:** suspended solids could clog a fertigation system **Vegan:** yes

Table 7: Nutrient concentrations and characteristics of bean powder used in polytunnel trials. The bean powder was applied as a suspension in water to make it comparable to the other liquid feeds but it could also be incorporated into the soil as a powder.

	Dry matter (%)	N_{total} (g l^{-1})	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g l^{-1})
Mean value	89	52	n. d.	38	4.7	8	6.3
Range	-	-	-	-	-	-	-
No. of anal.	1	1	-	1	1	1	1

	K (g l^{-1})	S (g l^{-1})	Ca (g kg^{-1} DM)	Mg (g l^{-1})	Na (mg kg^{-1} DM)	Cl (mg kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	12.4	1.8	0.4	1.3	0.2	0.8	44
Range	-	-	-	-	-	-	-
No. of anal.	1	1	1	1	1	1	1

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	0.000	0.000	0.000	23	2	0.7	0.000
Range	-	-	-	-	-	-	-
No. of anal.	1	1	1	1	1	1	1

	pH
Mean value	n. d.
Range	-
No. of anal.	-

No. of anal.: number of analyses; n. d.: no data.
Methods: **N_{total}**: Persulphate Nitrogen, **NH_4^+-N**: flow injection analysis, **Total N and C**: Dumas analysis, **Total P, K, S, Ca, Mg, Na, Cl, Zn, As, Cd, Cr, Cu, Ni, Pb, and Hg**: Microwave digestion in HNO_3 and H_2O_2 followed by ICP-OES.

3.4 Comfrey liquid

Comfrey (*Symphytum* spp.) is a herbaceous perennial with a deep taproot that produces abundant leafy growth in the spring and summer - it is tolerant of a wide range of climatic conditions. It has been used for animal fodder and even human food although there are health concerns due to its alkaloid content. It can be readily cultivated on a field scale. The foliage can be used as a source of fertility, either as a mulch, in compost or in a liquid extract. Although it is widely used for this purpose, particularly by amateur gardeners, it has received little scientific study. In the Organic-PLUS trials comfrey leaves (*Symphytum* spp. cultivar 'Bocking 14' grown on-farm) were packed tightly into barrels that were then topped up with water. After at least two months the contents were stirred (Figure 11) and strained through a 10mm sieve before application to soil grown tomato plants in a polytunnel (Figure 12).

Type	Characteristics and recommendations
liquid	**Nutrients:** rich in K **Cost:** very cost effective per kg N; additional labour is needed **Application:** easy, same as application of fertigation **Availability:** on-farm production and collection and is available commercially in some countries **Caution:** suspended solids could clog a fertigation system **Vegan:** yes

Table 8: Nutrient concentrations and characteristics of comfrey liquid used in the polytunnel trials.

	Dry matter (%)	**N_{total}** (g l^{-1})	**NH_4^+-N** (g kg^{-1} FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** (g l^{-1})
Mean value	1.1	0.52	n. d.	n. d.	4.7	n. d.	11
Range	0.7-1.5	-	-	-	-	-	9-45
No. of anal.	5	1	-	-	1	-	5

	K (g l^{-1})	**S** (g l^{-1})	**Ca** (g kg^{-1} DM)	**Mg** (g l^{-1})	**Na** (mg kg^{-1} DM)	**Cl** (mg kg^{-1} DM)	**Zn** (mg kg^{-1} DM)
Mean value	225	0.5	20	4.8	2.7	23.5	0.000
Range	181-445	0.0-3.0	12-28	3.5-5.3	0.2-6.2	12.0-37.6	-
No. of anal.	5	5	5	5	5	5	5

	As (mg kg^{-1} DM)	**Cd** (mg kg^{-1} DM)	**Cr** (mg kg^{-1} DM)	**Cu** (mg kg^{-1} DM)	**Ni** (mg kg^{-1} DM)	**Pb** (mg kg^{-1} DM)	**Hg** (mg kg^{-1} DM)
Mean value	0.000	0.000	0.000	0.000	0.000	5.6	0.000
Range	-	-	-	-	-	0-22	-
No. of anal.	5	5	5	5	5	5	5

	pH
Mean value	6.0
Range	5.4-7.3
No. of anal.	5

No. of anal.: number of analyses; n.d.: no data.
Methods: **N_{total}**: Persulphate Nitrogen, **NH_4^+-N**: flow injection analysis, **Total N and C**: Dumas analysis, **Total P, K, S, Ca, Mg, Na, Cl, Zn, As, Cd, Cr, Cu, Ni, Pb, and Hg**: Microwave digestion in HNO_3 and H_2O_2 followed by ICP-OES.

Figure 11: Preparation of plant-based fertilisers in plastic barrels.

Figure 12: Tomato trial in polytunnel: applying plant-based fertilisers to the plots at two different rates.

3.5 Nettle liquid

Stinging nettle (*Urtica dioica*) is an herbaceous perennial that produces leafy growth in the spring and summer, re-growing from underground stolons. It is a wild plant but often associated with human activity as it thrives on high fertility soil. Although usually regarded as a weed the foliage can be collected and used a source of fertility, usually after being made into a liquid feed. Small scale intensive vegetable growers could cultivate a permanent area for 'fertility building' using nettles. This can be combined with agroforestry using leaf litter as additional nutrient source. In the Organic-PLUS trials nettle leaves and stems were packed tightly into barrels that were then topped up with water. After at least two months the contents were stirred and strained through a 10mm sieve before application to soil grown tomato plants in a polytunnel.

Type	Characteristics and recommendations
liquid	**Nutrients:** relatively rich in N **Cost:** very cost effective per kg N; additional labour is needed **Application:** easy, same as application of fertigation **Availability:** on-farm production and collection **Caution:** appropriate personal protection required when collecting nettles **Vegan:** yes

Table 9: Nutrient concentrations and characteristics of nettle liquid.

	Dry matter (%)	**N_{total}** (g l^{-1})	**NH_4^+-N** (g kg^{-1} FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** (g l^{-1})
Mean value	1.7	0.9	n.d.	n.d.	5.2	n.d.	8.1
Range	1.3-2.4	-	-	-	-	-	6.9-9.4
No. of anal.	3	1	-	-	1	-	

	K (g l^{-1})	**S** (g l^{-1})	**Ca** (g kg^{-1} DM)	**Mg** (g l^{-1})	**Na** (mg kg^{-1} DM)	**Cl** (mg kg^{-1} DM)	**Zn** (mg kg^{-1} DM)
Mean value	63	5.3	51	8.4	1.2	7.9	31.9
Range	40-84	3.8-7.8	32-69	5.1-10.7	0.1-2.3	4.5-13.3	0-71
No. of anal.	3	3	3	3	3	3	3

	As (mg kg^{-1} DM)	**Cd** (mg kg^{-1} DM)	**Cr** (mg kg^{-1} DM)	**Cu** (mg kg^{-1} DM)	**Ni** (mg kg^{-1} DM)	**Pb** (mg kg^{-1} DM)	**Hg** (mg kg^{-1} DM)
Mean value	0.000	0.000	0.000	0.000	3.8	2.9	0.000
Range	-	-	-	-	0-34	0-9	-
No. of anal.	3	3	3	3	3	3	3

	pH
Mean value	5.2
Range	5.0-5.3
No. of anal.	3

No. of anal.: number of analyses; n. d.: no data.
Methods: **N_{total}**: Persulphate Nitrogen, **NH_4^+-N**: flow injection analysis, **Total N and C**: Dumas analysis, **Total P, K, S, Ca, Mg, Na, Cl, Zn, As, Cd, Cr, Cu, Ni, Pb, and Hg**: Microwave digestion in HNO_3 and H_2O_2 followed by ICP-OES.

4. RESID – Fertilisers from non-contentious external sources

4.1 Biogas digestate (Clover-grass & pig slurry from an organic farm)

In organic farming, most biogas plants run on animal slurry, although, in some cases, clover-grass is added as a feedstock. Such biogas digestates can be produced in an internal on-farm cycle but co-operations with neighbouring organic farms are possible, too. Therefore, cross-company approaches in nutrient management could provide non-contentious fertilisers for organic growers, in particular those who have no animal husbandry but can cooperate with neighbours. A digestate made from clover-grass and pig slurry is characterised by a low C/N ratio and a high content of easily available nitrogen. In the Organic-PLUS trial at UoH, the digestate was obtained from a nearby organic farm with a biogas plant digesting clover-grass with pig slurry and small amounts of maize. Digestates have to be incorporated directly after application to avoid gaseous N losses.

Type	Characteristics and recommendations
liquid	**Nutrients:** high amount of easily available NH_4^+-N; high content of K and P **Cost:** n/a **Application:** easy application with standard equipment for slurry application; application on the soil (trailing hoses) or with direct incorporation by rotor tiller or cultivator; direct incorporation in the soil (slurry injectors or trailing shoe) **Availability:** produced on-farm or cooperation with neighbouring farms **Caution:** Lower risk of contamination with macro and micro plastic compared to digestates from source-separated organic household waste, very little risk for other contaminants (animal drugs, heavy metals) **Vegan:** no

Table 10: Nutrient concentrations and characteristics of the digestates from an organic farm used in the field vegetable trials.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	8.7	6.4	5.3	37.6	3.31	5.1	10.5
Range	(8.59-8.71)	(6.24-6.5)	(5.19-5.31)	(37.5-37.7)	(3.30-3.32)	(5.03-5.18)	(10.6-10.8)
No. of anal.	2	6	6	4	4	4	4

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (g kg^{-1} DM)	Cl (g kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	75.6	5.28	24.3	5.61	8.31	13.6	240
Range	(72.1-79.1)	(4.97-5.59)	(24.2-24.4)	(5.11-6.11)	(8-8.61)	(3.14-24.1)	(223-255)
No. of anal.	4	4	4	4	4	4	4

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	0.61	0.12	6.58	46.2	7.38	0.89	0.07
Range	(0.56-0.69)	(0.11-0.12)	(4.69-8.04)	(43.2-49.2)	(7-7.82)	(0.83-0.96)	(0.06-0.07)
No. of anal.	4	4	4	4	4	4	4

	pH *
Mean value	7.8
Range	7.5-8.1
No. of anal.	85

No. of anal.: number of analyses.
*Data of biogas digestates of renewable resources cited from Möller and Schultheiß (2014).
Methods: **C, N and S**: Dry combustion; **N_{total} and NH_4^+-N:** Kjeldahl; **P, K, Mg, Ca, Na, Zn:** Microwave digestion with HNO_3; measurement with Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-EOS); **As, Cd, Cr, Cu, Ni, Pb and Hg:** Microwave digestion with HNO_3; measurement with ICP- Mass Spectrometry (MS); **Cl**: Hot water extraction and ion chromatography.

Figure 13: Biogas digestate before (right) and after incorporation with rotor tiller (left).

4.2 Tofu whey

Tofu whey is a residue from tofu production and so far, no use of this by-product of food production exists. Therefore, the tofu whey is simply disposed of and companies have to pay for its disposal via the municipal sewage system. Nutrients still contained in the whey are therefore lost in the disposal process in the sewage treatment plant. By reusing the tofu whey as fertiliser, these nutrients can be maintained in the nutrient cycle and returned to farms. Tofu whey is characterised by a high water content, resulting in a very low nutrient concentration per volume of fertiliser applied. Therefore, further technical innovations to concentrate nutrients are necessary to use tofu whey (cost-) efficiently as a fertiliser. In the Organic-PLUS trial with tofu whey at UoH, the tofu whey was provided by a regional organic tofu producer. Due to its high water content, the tofu whey was applied overhead to the already planted white cabbage. If the N content is below 0.1%, it is recommended to divide the fertilisation into two applications to avoid flooding of the field.

Type	Characteristics and recommendations
Liquid	**Nutrients:** low N concentration - can vary depending on the batch and content of solid components in the tofu whey; high K and low P content; nutrient ratio in the whey suits the requirements of vegetables **Cost:** free or low cost; but: low N content and high water content results in high transportation cost per kg N **Application:** easy, can be applied as all other liquid fertilisers after planting but high water content **Availability:** only regionally available **Caution:** organic certification – necessary to contact control body for the permission of the use of tofu whey as fertiliser **Vegan:** yes

Table 11: Nutrient concentrations and characteristics of tofu whey used in the field vegetable trials.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	NH_4^+-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	2.0	1.5	0.2	37.6	6.55	5.4	2.4
Range	(1.95-2.24)	(0.96-1.96)	(0.1-0.22)	(35.6-39.5)	(6.31-6.79)	(4.5-7.24)	(1.46-3.38)
No. of anal.	6	6	6	6	6	6	6

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (g kg^{-1} DM)	Cl (g kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	32.4	0.00114	4.64	3.84	1.26	9.24	45.5
Range	(14.4-50.4)	(0.0011-0.0017)	(4.51-4.77)	(0.76-6.91)	(0.61-1.9)	(1.84-16.64)	(21.9-102)
No. of anal.	6	6	6	6	6	6	6

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	0.08	0.08	0.18	44.8	10.89	0.15	0.05
Range	(0.06-0.15)	(0.06-0.15)	(0.06-0.38)	(41.5-48.6)	(6.46-13.2)	(0.05-0.44)	(0.05-0.05)
No. of anal.	6	6	6	6	6	6	6

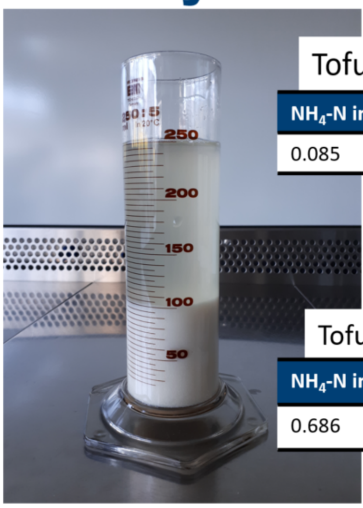
	pH
Mean value	4.3
Range	(-)
No. of anal.	2

No. of anal.: number of analyses.

Methods: **C, N and S**: Dry combustion; **N_{total} and NH_4^+-N:** Kjeldahl; **P, K, Mg, Ca, Na, Zn:** Microwave digestion with HNO_3; measurement with Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-EOS); **As, Cd, Cr, Cu, Ni, Pb and Hg:** Microwave digestion with HNO_3; measurement with ICP- Mass Spectrometry (MS); **Cl**: Hot water extraction and ion chromatography.

Figure 14: Application of tofu whey by hand (left) and field after application of tofu whey on cabbage plantlets (right).

Tofu whey



Tofu whey – Upper layer

NH_4-N in FM (g kg^{-1})	Total N in FM (g kg^{-1})
0.085	0.51

Tofu whey – Mixed

NH_4-N in FM (g kg^{-1})	Total N in FM (g kg^{-1})
0.326	2.23

Tofu whey – Bottom layer

NH_4-N in FS (g kg^{-1})	Total N in FM (g kg^{-1})
0.686	4.66

Figure 15: Total N and NH_4-N concentrations of liquid (upper) and solid (bottom) fractions and mixed tofu whey (in fresh matter (FM)).

4.3 Algae fibre

Algae fibre is produced from rockweed, *Ascophyllum nodosum* which is harvested in Northern Norway, dried, ground and chemically extracted to produce liquid fertilisers. The residual material is a black paste with high C but low N content, high pH and 25-30% dry matter. The material comes in two types, where one is produced by extraction with HNO_3, content of total N about 1.5% of DM, and the other with a more "gentle" extraction and about 0.3% total N in DM. Algae fibre is a paste with about 25% DM, and needs to be separated into smaller clumps before or during application in field, for even distribution. It should be possible to spread it by equipment applied for farmyard manure. Incorporation in field was done by hand rake or a rotovator in experimental plots. In the subsequent season, black colour from the fibre was not visible in the soil at the experimental field. Composting the material before application may also be an option, to facilitate even spreading in field and reduce the concentration of potentially toxic elements.

Type	Characteristics and recommendations
Solid, paste	**Nutrients:** quite low N concentration; derived from application of mineral acid (HNO_3) during extraction of seaweed, hence currently not permitted for use in certified organic growing; high K and S, low in P, hence not well balanced as single fertiliser; observe content of sodium, arsenic and cadmium **Cost:** free or low cost near production plant **Application:** material has 25-30% DM and is a soft paste, must be split into smaller clumps before/during spreading; will mould with long-term storage **Availability:** only available near production site in coastal areas **Caution:** not certified in organic growing **Vegan:** yes

Table 12: Nutrient concentrations and characteristics of algae fibre 1.4 % N (DM). (For sodium (Na), only ammonium acetate-lactate soluble concentrations were available. For analytical values of Ni, Pb and Hg, 1, 4 and 1 values which were below limit of detection were set equal to the level of detection to calculate the average value.)

	Dry matter (%)	**N_{total}** (g kg^{-1} FM)	**NH_4^+-N** (g kg^{-1} FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** (g kg^{-1} DM)
Mean value (Range) No. of anal.	25.5 (22.6-29.4) 4	3.6 (2.9-4.8) 4	0.0098 (0.001-0.005) 3	31.7 (31.0-32.3) 6	1.41 (1.21-1.80) 6	23 (17-26) 6	2.78 (2.3-3.6) 6

	K (g kg^{-1} DM)	**S** (g kg^{-1} DM)	**Ca** (g kg^{-1} DM)	**Mg** (g kg^{-1} DM)	**Na** (mg kg^{-1} DM)	**Cl** (mg kg^{-1} DM)	**Zn** (mg kg^{-1} DM)
Mean value Range No. of anal.	91.8 (74-130) 4	11.5 (8.7-15) 5	54.3 (48-68) 4	14.8 (11-25) 4	23 (13-52) 4	13 (10-16) 4	95 (82-110) 55

	As (mg kg^{-1} DM)	**Cd** (mg kg^{-1} DM)	**Cr** (mg kg^{-1} DM)	**Cu** (mg kg^{-1} DM)	**Ni** (mg kg^{-1} DM)	**Pb** (mg kg^{-1} DM)	**Hg** (mg kg^{-1} DM)
Mean value Range No. of anal.	28 (27-33) 5	1.0 (0.9-1.1) 5	6 (3.8-9.2) 5	11 (4-34) 5	4.4 (1.5-10) 5	1.4 (0.3-4) 5	0.044 (0.02-0.8) 5

	pH
Mean value Range No. of anal.	n. d.

No. of anal.: number of analyses; n. d.: no data.

Methods: **Tot-N:** Kjeldahl; **tot C:** oxidation; **NH_4:** photometric detection by thymol method; **total elements:** digestion with nitric acid and hydrogen peroxide, detection by ICP-MS.

Figure 16: Left Picture: Application of algae fibre in field, on one of the Organic-PLUS trials at NORSØK. Right picture: close-up photo of fresh algae fibre

Table 13: Nutrient contents and characteristics of algae fibre 0.3% N (DM). (For sodium (Na), only ammonium acetate-lactate soluble concentrations were available. For analytical values of Ni, Pb and Hg, 1, 4 and 1 values which were below limit of detection were computed from level of detection.)

	Dry matter (%)	**N_{total}** ($g\ kg^{-1}$ FM)	**$NH4^{+}$-N** ($g\ kg^{-1}$ FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** ($g\ kg^{-1}$ DM)
Mean value	22.3	0.7	0.05	33.2	0.32	74	3.5
(range)	(21.8-22.7)	(0.43-0.98)	(-)	(-)	(0.19-0.45)	(-)	(-)
No. of anal.	2	2	1	1	2	1	1

	K ($g\ kg^{-1}$ DM)	**S** ($g\ kg^{-1}$ DM)	**Ca** ($g\ kg^{-1}$ DM)	**Mg** ($g\ kg^{-1}$ DM)	**Na-AL** ($g\ kg^{-1}$ DM)	**Cl** ($mg\ kg^{-1}$ DM)	**Zn** ($mg\ kg^{-1}$ DM)
Mean value	68	13	84	13	4	<3	38
(range)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.	1	1	1	1	1	1	1

	As ($mg\ kg^{-1}$ DM)	**Cd** ($mg\ kg^{-1}$ DM)	**Cr** ($mg\ kg^{-1}$ DM)	**Cu** ($mg\ kg^{-1}$ DM)	**Ni** ($mg\ kg^{-1}$ DM)	**Pb** ($mg\ kg^{-1}$ DM)	**Hg** ($mg\ kg^{-1}$ DM)
Mean value	19	0.91	35	<2	18	3	0.10
(range)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.	1	1	1	1	1	1	1

	pH (H_2O)
Mean value	8.9
Range	(-)
No of anal.	1

No. of anal.: number of analyses.

Methods: **Tot-N:** Kjeldahl; **tot C:** oxidation; **NH_4:** photometric detection by thymol method; **total elements:** digestion with nitric acid and hydrogen peroxide, detection by ICP-MS.

Figure 17: For application in field experiments, algae fibre was split into smaller clumps by hand. In field scale, a spreading equipment for solid animal manure would do the job.

4.4 Acid-preserved fish bones

Residues from captured white fish (cod (*Gadus morhua)*, saithe (*Pollachius virens)* etc.) contain heads, backbones, skin, viscera etc. This material may be grinded and conserved with preservation to pH < 4 e.g. by formic acid. During storage, the material will hydrolyse and split into a top layer of oil, followed by hydrolysed proteins and a bottom layer of sediments. Oil and hydrolysed proteins may be applied for fish feed in aquaculture, whereas the sediment has too high a content of minerals to be applied as feed. The sediment has a large proportion of fish bone, and contains significant amounts of calcium and phosphorus, but is also rich in proteins such as collagen, and hence has a very rapid growth effect due to easily available nitrogen.

Type	Characteristics and recommendations
Solid, particles 0-5 cm	**Nutrients:** high N concentration; permitted for use in certified organic growing in Norway; low in K, high in P and Ca; not well balanced as single fertiliser **Cost:** free or low cost near production plant **Application:** material has about 50% DM and low pH; easy to spread after drying **Availability:** only available near few production sites in coastal areas **Caution:** preserved by formic acid to pH < 4; formic acid may emit carbon monoxide and is corrosive **Vegan:** no

Table 14: Nutrient contents and characteristics of acid-preserved fish bones. (For sodium (Na), only ammonium acetate-lactate soluble concentrations were available. For analytical values of As, Cd, Ni, Pb, Hg 8, 6, 1, 2, 5 values which were below limit of detection were computed from level of detection.)

	Dry matter (%)	**N_{total}** ($g\ kg^{-1}$ FM)	**$NH4^+$-N** ($g\ kg^{-1}$ FM)	**C** (% DM)	**N** (% DM)	**C:N ratio**	**P** ($g\ kg^{-1}$ DM)
Mean value	48.5	28.5	18.3	17.2	4.23	4.13	103
(range)	(47.2-49.5)	(14.8-53.0)	(3.1-47)	(12.7-21.8)	(2.88-5.94)	(3.00-4.79)	(69-120)
No. of anal.	6	15	12	12	15	12	12

	K ($g\ kg^{-1}$ DM)	**S** ($g\ kg^{-1}$ DM)	**Ca** ($g\ kg^{-1}$ DM)	**Mg** ($g\ kg^{-1}$ DM)	**Na-AL** ($g\ kg^{-1}$ DM)	**Cl** ($g\ kg^{-1}$ DM)	**Zn** ($mg\ kg^{-1}$ DM)
Mean value	1.1	3.6	139	1.0	0.36	14	125
(range)	(0.8-1.4)	(2.5-4.4)	(110-180)	(0.81-1.2)	(0.17-0.77)	(7.5-29)	(88-180)
No. of anal.	10	10	10	10	9	11	12

	As ($mg\ kg^{-1}$ DM)	**Cd** ($mg\ kg^{-1}$ DM)	**Cr** ($mg\ kg^{-1}$ DM)	**Cu** ($mg\ kg^{-1}$ DM)	**Ni** ($mg\ kg^{-1}$ DM)	**Pb** ($mg\ kg^{-1}$ DM)	**Hg** ($mg\ kg^{-1}$ DM)
Mean value	2.86)	0.13)	7.94	5.68	4.09	1.49)	0.23
(range)	(2.0-7.1)	(0.1-0.3)	(3.5-13)	(1.9-17)	(1.5-7)	(1-2.3)	(0.04-0.7)
No. of anal.	12	12	12	12	12	12	12

	pH
Mean value	4.63
Range	(4.1-5.1)
No. of anal.	15

No. of anal.: number of analysis.

Methods: **Tot-N:** Kjeldahl; **tot C:** oxidation; **NH_4:** photometric detection by thymol method; **total elements:** digestion with nitric acid and hydrogen peroxide, detection by ICP-MS.

4.5 Compost from organic fish pond sediments

Fishpond sediments (FPS) constitute a mixture of fish waste, decaying plant, dead algae, uneaten feed and faeces and they are rich in organic matter and nutrients. The sources of nutrients in ponds cover fish feed and organic and inorganic fertilizers. Characteristics of FPS differ depending on many factors including the type of aquaculture system (organic, conventional), type and age of fish, water quality, feeding type and regime, weather conditions, etc. Also, these factors can have an impact on the quantities of FPS generated during the process and removed from the fish farming systems.

The aim of this work was to investigate the potential of organic fishpond sediments composted together with selected waste materials in the laboratory and to and evaluate the fertilizing potential of the obtained compost. Organic fishpond sediments collected from rainbow trout farms (Złoty Potok, Poland) were characterized by a low organic matter content of 30 % and a high water content of 63 %. The content of organic matter was quite low due to the high content of clay material in the collected samples. To improve the parameters of the compost mixture, wheat straw and grass were added, which caused the addition of additional organic matter. In this treatment, the composting process was fully carried out and the obtained compost was used for further research.

Our research has shown that organic fishpond sediments have a composting potential, and the finished compost can be used as a fertilizer for plant growth. The addition of FPS compost to the soil along with additives such as cardboard and biochar additionally stimulated plant growth, by increasing the content of organic matter and carbon in the soil. This research work also allowed us to partially fill the gaps in the literature on the use and potential of organic fishpond sediments.

Type	Characteristics and recommendations
Solid, particles (ground fraction)	**Nutrients:** low N concentration, fertiliser from organic fish pond sediment with high clay contents showed improved nutrient availability if mixed with e.g., biochar, straw **Cost:** windrow composting - free or low-cost near-production plant, composting reactors - low cost, better control of composting conditions than in windrow composting, faster composting process than windrow composting **Application:** add on or mix with soil; addition of water to the compost to make an extract **Availability:** depends on the country/region/frequency of sweet water fish farming; organic fish pond sediments are more difficult to access than sediments from non-organic farms (in Poland) **Caution:** Check content of heavy metals, presence of micro plastic, etc. **Vegan:** no

Table 15: Nutrient concentrations and characteristics of compost from organic fishpond sediments.

	Dry matter (%)	N_{total} (g kg^{-1} FM)	$NH4^{+}$-N (g kg^{-1} FM)	C (% DM)	N (% DM)	C:N ratio	P (g kg^{-1} DM)
Mean value	32.6	n. d.	n. d.	17.4	1.43	12	1.47
Range	(-)			(-)	(-)	(-)	(-)
No. of anal.	3			3	3	3	3

	K (g kg^{-1} DM)	S (g kg^{-1} DM)	Ca (g kg^{-1} DM)	Mg (g kg^{-1} DM)	Na (mg kg^{-1} DM)	Cl (mg kg^{-1} DM)	Zn (mg kg^{-1} DM)
Mean value	1.21	n. d.	52.7	0.76	83.2	n. d.	73.5
Range	(-)		(-)	(-)	(-)		(-)
No. of anal.	3			3	3	3	3

	As (mg kg^{-1} DM)	Cd (mg kg^{-1} DM)	Cr (mg kg^{-1} DM)	Cu (mg kg^{-1} DM)	Ni (mg kg^{-1} DM)	Pb (mg kg^{-1} DM)	Hg (mg kg^{-1} DM)
Mean value	<0.04	<0.09	7.04	6.54	1.14	10.1	No detection
Range	(-)	(-)	(-)	(-)	(-)	(-)	(-)
No. of anal.	3			3	3	3	3

	pH
Mean value	8.54
Range	(-)
No. of anal.	3

No. of anal.: number of analyses; n. d.: no data.

Methods: **DM:** drying at 105°C and 550°C; C: organic carbon analyzer; **N_{total}:** Kjeldahl; **P:** Spectrophotometric method with ammonium molybdate; **K, Ca, Mg, Na, Zn, As, Cd, Cr, Cu, Ni and Pb**: Aqua regia followed by ICP-OES MS determination; **pH:** in aqueous solution.

5. References

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