D3.1. Guidelines for Fertiliser End-Users

fertiplay

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101060426.

Deliverable Information Sheet

Version	FINAL
Grant Agreement Number	101060426
Project Acronym	FER-PLAY
Project Title	Multi-assessment of circular fertilisers for Promoting Local sustainable value chains And clean ecosYstems
Project Call	HORIZON-CLD-2021-ZEROPOLLUTION-01
Project Duration	September 2022 – February 2025 (30 months)
Deliverable Number	3.1
Deliverable Title	Guidelines for end-users
Deliverable Type	Report
Deliverable Dissemination Level	PU – Public
Work Package	WP3
Authors	Naturland: Ramona Kinder, Werner Vogt-Kaute Coldiretti: Partick Prociuc
Contributing Partners	CIC, NuReSys. EBA
Reviewers	CETENMA, CIC
Due Date	30 September 2024
Delivery Date	30 September 2024
Document History	Draft 1 shared with WP leaders on 16 August 2024. Draft 2 shared with the Coordinator on 6 September 2024 Draft 3 shard with the Coordinator on 19 September 2024 Final version sent to the Coordinator on 30 September 2024

List of Tables

List of Figures

Keywords list

Guidelines
Recommendations
Fertiliser end-users
Circular fertilisers
Resource efficiency
Circular fertilisers value chains
Agriculture, life cycle assessment
Sewage sludge
Bio-waste
Organic by-products
Wastewater
Spent mushroom substrate
Compost
Digestate
Feather meal
Wastewater

Disclaimer

Table of Contents

1. Executive summary

New alternative circular fertilisers value chains appeared in the last decade as promising options to replace conventional fertilisers. FER-PLAY mapped forty-eight value chains of secondary raw materials and then selected the seven most promising ones on the base of a methodology developed by the project. Further details on this process can be found on D1.2 "**Report on the selection of circular fertiliser value chains**". Finally, following seven value chains have been assessed: Struvite from urban wastewater, struvite from industrial wastewater, stabilised sludge, composted bio-waste, feather meal, solid fraction of digestate, spent mushroom substrate. See more information under www.fer-play.eu.

These guidelines give information for end-users about these selected fertilisers, recommendations for application, effects on soil, production of the fertiliser, regulatory issues and literature. The guidelines help farmers to decide which circular fertiliser can be used under specific conditions and for which crops.

The selected fertilisers are different in their effects. New circular fertilisers can offer several advantages for farmers such as nutrients and carbon for nutrient supply and soil improvement. The recommendations are tailored to the different crop types (cereals, legumes, vegetables, vineyards and orchards). In addition to EU legislation and Common Agricultural Policy (CAP), national and regional regulations may need to be observed since can restrict the use of all these fertilisers.

Main outputs from this document are:

- The range of different circular fertilisers give good options for different needs of a sustainable agriculture.
- Struvite gives the option to recover phosphorus, the most limiting nutrient in agriculture because sources of rock phosphate are not endless and often contaminated.
- Feather meal offers organic nitrogen with not too much phosphorus which can be an important aspect for vegetable and fruit growers.
- Stabilised sludge provides macro and micronutrients usually with a relatively fast release.
- With a high and stabile carbon content composted bio-waste and spent mushroom substrate are the typical "soil improvers". But the other nutrients should not be underestimated as they are not expensive and their availability is quite good.
- Solid fraction of digestate provides both nitrogen with fast availability and some stabile carbon.

2. Introduction

FER-PLAY is a Horizon Europe project facilitating the uptake of circular fertilisers, to protect ecosystems, decrease EU dependence on fertiliser imports, foster circularity and improve soil health. The project mapped and assessed circular fertilisers made from secondary raw materials, such as manure, and highlight their multiple benefits in order to promote their wide-scale production and use on field.

To this last purpose, FER-PLAY foresees an important effort to understand the different perspectives of three stakeholder groups: end-users, fertiliser producers and public administration, as to address their main concerns in specific guidelines for each target group. The guidelines are available in the Resource section of the project website and on Zenodo and their elaboration took into account the results of the multi-topic assessment of the impacts and opportunities at economic, regulatory, social and environmental level that the project has conducted and which results are available in D2.2 "Multi-assessment of impacts, trade-offs and framework conditions". To this aim, a specific Work Package has been dedicated to cover these discussions and the approach selected as most suitable was to follow co-creation principles, meaning to systematically share, mobilise and activate knowledge[1].

The experience of the FER-PLAY consortium members along with the feedback gathered through these activities led to the elaboration of a set of guidelines (included in D3.1, D3.2 and D3.3) that aims to provide an answer to those questions that most commonly arise from the producers of circular fertilisers, the end-users and the Public Administrations. The recommendations of the guidelines for end-users are also based on the outcomes of the dialogue and co-creation process with the farmers groups in Italy, Spain, Belgium and Germany.

This document presents recommendations for use, effects of soil improvement, information about the product and regulatory issues. The information presented are based on traditional knowledge, new research results and publications for farmers. There is little detailed information about the recommendations of use available for some of the new fertilisers. Therefore, some new recommendations based on the ones addressing other fertilisers were developed. The references for literature are in most cases publications for farmers.

Farmers often do not have enough knowledge about new circular fertilisers. For example, many farmers haven't heard that struvite is a new interesting alternative to mineral fertilisers and rock phosphate. This lack of knowledge brings a lack of trust and negative prejudices. But circular fertilisers can offer different benefits: supply of nutrients with relatively fast to slow release and/or

[1] Triste, L. September 2018. Communities of practice for knowledge co-creation on sustainable dairy farming.

increase of carbon content when having a high C:N ratio. Circular fertilisers are not yet widely available in local and international market, but the demand is foreseen to increase making it worth building up more capacities for production and marketing, taking into account that the logistics of some fertilisers, like compost, is not economically profitable over a long distance, while others, like struvite, have a high nutrient density and are suitable for wider markets.

This collection of recommendations has the aim of reducing knowledge gaps about circular fertilisers. Better knowledge helps to reduce prejudices and increases interest. The recommendations try to show the optimal use of the selected circular fertilisers.

Most of the new circular fertilisers are permitted in organic agriculture and offer organic farmers to balance negative nutrient balances (especially phosphorus) for a sustainable production.

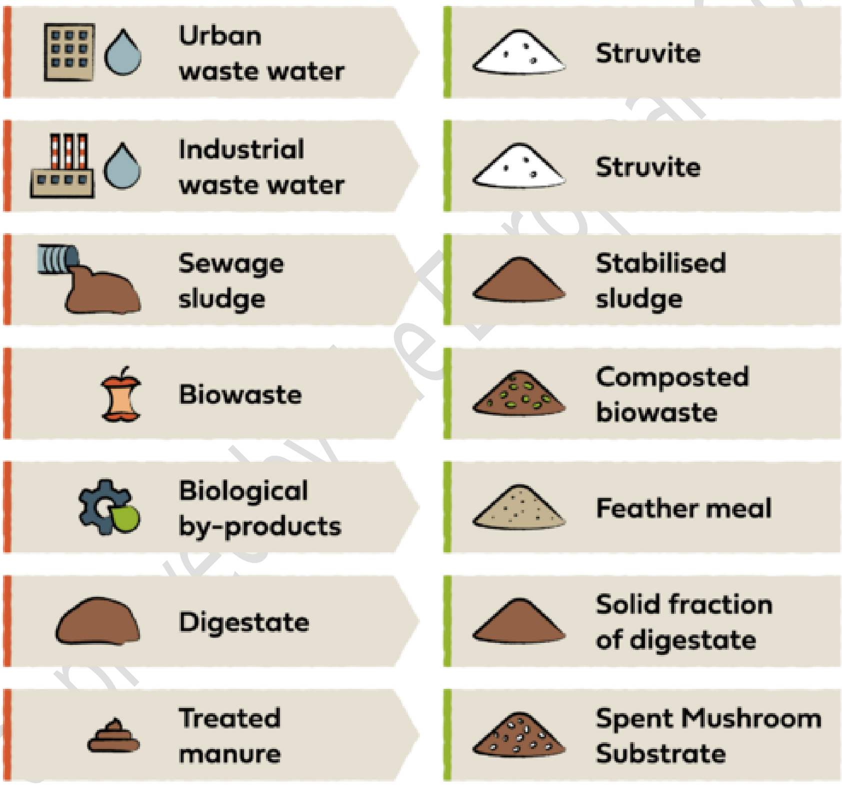

Figure 1. FER-PLAY's selection of the seven most-promising circular fertiliser value chains in the European Union

3. Recommendations

3.1. Feather Meal

3.1.1. Recommendations for use

Feather meal contains a high amount of nitrogen and low amount of carbon. It is similar to other fertilisers from animal by-products like bone meal or blood meal. Work lightly into the top layer of soil after application. Under normal vegetation conditions the effect of nitrogen starts after some days and can be seen clearly after 6 to 8 weeks. The effect of nitrogen is relatively fast for and organic fertiliser and not long lasting. It can be expected that 75 - 80% of nitrogen is released after one year. There are concerns of burnings to plants due to direct contact that can be solved by mixing with other fertilisers or incorporating into soil.

Due to the higher price feather meal is usually not applied to cereals but to vegetables and fruit.

Table 1. Nutrient content in feather meal in dry matter

Nutrient	Mean value
Dry matter	95%
pH value	5,5
Organic matter	92 %
C org	40 %
N	14 %
C:N	3,1
P	0,4 %
K	1,6%
Ca	0,9 %
Mg	0,18 %
S	1,7 %
Fe	520 mg/kg
Mn	21 mg/kg

Nutrient	Mean value
Zn	195 mg/kg
Cu	15 mg/kg
B	< 10 mg/kg
Mo	< 1 mg/kg

Feather meal is available in 25 kg bags and 1000 kg big bags. Store in a cool, dry place, protected from sunlight. Do not mix with feed and avoid contact to animals. Water pollution must be avoided. Pellets can be spread with a normal fertiliser spreader.

Table 2. Recommendations for application of feather meal (please check with your regional regulations)

Crop	Quantity	Time of application
Cereals	30 – 80 kg/N ha depending on crop and soil analysis	Feb – May
Legumes	-	-
Vegetables	N demand depending on crop and on soil analyses	Feb – Sep
Orchards and vineyards	N demand depending on crop and on soil analyses	Jan – May

3.1.2. Soil improvement

As an organic fertilisers feather meal activates soil life, improves soil structure and water-holding capacity. The effect of improving carbon level in soils is lower than in fertilisers with a high C:N ratio like compost.

3.1.3. Technical facts

3.1.3.1. PRODUCTION PROCESS

When poultry is slaughtered, the resulting feathers and their adhering skin and feces residues as well as other soiling are collected, pasteurised, dried, crushed and, if necessary, hydrolysed. They can be processed into pellets or granulates. Feather meal is used either as a single fertiliser or as a compound fertiliser in a mixture with other fertilisers (e.g. vinasse, rapeseed meal, cocoa shells), eg. Bioilsa. The hydrolysates are also used for animal feed.

Figure 2. Feather Meal Pellets and Feather Meal (Beckmann & Brehm)

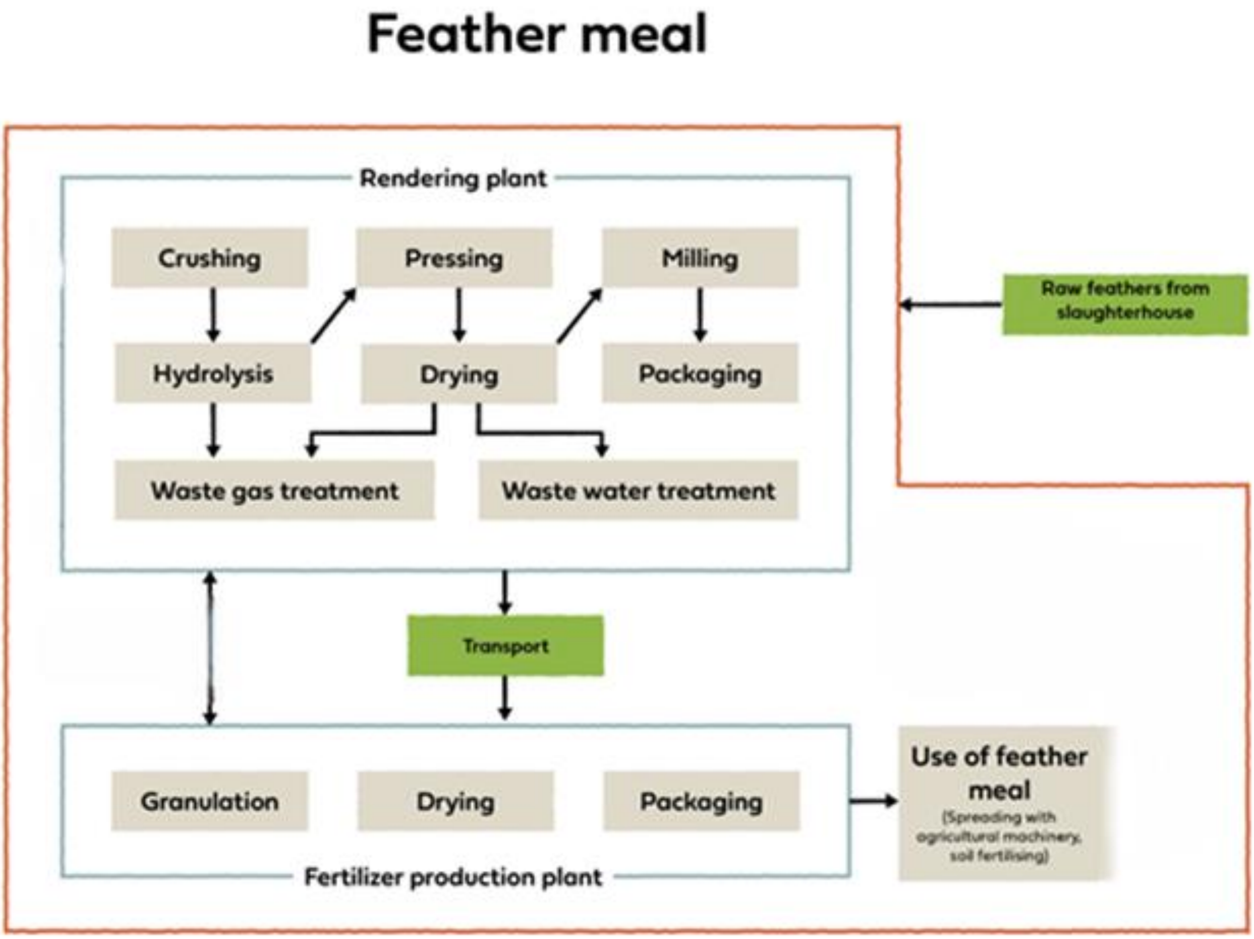

Figure 3. Flow Chart Feather Meal

3.1.3.2. MARKET RELATED ASPECTS

Feather meal is a by-product from slaughtering like bone meal, meat meal, blood meal, horn meal and hair meal which are used in a similar way. Prices are higher than some synthetic fertilisers. Therefore, feather meal is relatively often used in organic agriculture, especially in horticultural and fruit crops. The use of animal by-products can compete with the use as feed which can offer a higher price to the producer. The quantities are limited but can be an important part of a strategy using circular fertilisers as the nitrogen is released quite fast. Production depends on the quantities of poultry production. Transport costs are not an important factor in price so feather meal should be available in every region.

3.1.3.3. REGULATORY ANALYSIS

According to "REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019", feather meal is classified in product category 1A 1 "Solid organic soil fertiliser".
According to the above regulation, an EU fertiliser may only consist of ingredients that meet the requirements for one or more of the component material categories (CMC) listed in this Annex. Feather meal in the form of hydolysed proteins is authorised in the EU and is in process of classified here under CMC 10 "derived products within the meaning of Regulation (EC) No. 1069/2009" (certain derived products from animal by-products).
There are specifications for maximum levels of heavy metals and pathogens.

Pathogens contained in an organic soil improver must not exceed the limits listed in the following table:

Table 3. Thresholds for pathogens for feather meal

Pathogen	Threshold
Salmonella spp	No findings in 25 g or 25 ml
Eschericha coli or Enterococcaceae	1000 in 1 g or 1 ml

Contaminants contained in an organic soil improver must not exceed the following limits:

Table 4. Thresholds for contaminants for feather meal

Contaminant	Threshold
Cadmium (Cd)	2 mg/kg dry matter
Chromium VI (Cr VI)	2 mg/kg dry matter
Mercury (Hg)	1 mg/kg dry matter
Nickel (Ni)	50 mg/kg dry matter
Lead (Pb)	120 mg/kg dry matter
Inorganic arsenic (As)	40 mg/kg dry matter
Copper (Cu)	300 mg/kg dry matter
Zinc (Zn)	300 mg/kg dry matter

Biuret (C2H5N3O2) must not be present in an organic fertiliser. Chrom VI must not be detectable. Feather meal must not be applied on edible parts of the crop. National regulations may also apply.

Feather meal is permitted in organic farming but organic farms may not apply more than 170 kg of nitrogen (EU 2018/448).

In addition to EU legislation and Common Agricultural Policy (CAP), national and regional regulations may need to be observed, e.g. Bio-waste Regulations, Fertiliser Regulations, Farm Manure Transfer Regulations and regulations in water protection areas or areas with other protection status. These regulations may also include temporary restrictions on the spreading of fertilisers, e.g. in winter. It may be that the application of the substrate must be reported to the competent authority under these regulations.

3.1.4. References

Möller, K., Schultheiß U. (2014), Organic commercial fertilisers in organic farming, p.267, ISBN 978-3-941583-89-4.

REGULATION EU 2019/1009: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32019R1009

REGULATION EU 2018/448: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0448

Fertiliser Ordinance: https://www.gesetze-im-internet.de/d_v_2017/index.html, Section 3 para. 5 in conjunction with Annex 3

Beckmann & Brehm, https://www.beckhorn.de/produkt/federmehl-pellets/, aufgerufen am 18.05.2024

3.2. Struvite from urban and industrial wastewater

3.2.1. Recommendations for use

Struvite can be applied to all crops, because all crops need phosphorus (P). It is a very good alternative to rock phosphate.

The release of phosphorus is low but continuous when solubilized by the root exudates or in acidic soils. In contrast to rock phosphate it become available even in alkaline soils (RELACS, 2021)

As struvite releases P rather slowly, application before sowing or at sowing is recommended. Struvite must be incorporated into the soil after broadcast application. Use of struvite in rows is also possible (Bünemann, 2022)

Table 5. Nutrient contents of struvite ($NH_4MgPO_4.6H_2O$)

Nutrient	Mean value
N	5 %
P_2O_5	28 %
Mg	10 %
K_2O	< 1%

Struvite does not contain cadmium, unlike rock phosphate.

Struvite is formulated in granules of about 1 to 3 mm in diameter, allowing the use in normal farm machinery. Store under dry conditions.

Table 6. Recommendations for application of struvite (please check with your regional regulations)

Crop	Quantity	Time of application
Cereals	70 - 100 kg/ha depending on crop and soil analysis	All year
Legumes	70 - 100 kg/ha depending on crop and soil analysis	All year
Vegetables	70 - 100 kg/ha depending on crop and soil analysis	All year

Crop	Quantity	Time of application
Orchards and vineyards	70 - 100 kg/ha depending on crop and soil analysis	All year

The maximum amount to apply corresponds to the expected P removal of the crop. The recommended doses are similar to other P fertilisers.

Struvite can be mixed with other solid fertilisers or can be dissolved in acidic solution.

Struvite has several advantages, especially compared to the non-renewable rock phosphate:

Struvite does not add new P to the cycle as it originates from recycling. Sources of rock phosphate are limited.

There is no soil pollution with cadmium, radioactive minerals and other contaminants.

There is a continuous release even in alkaline soils.

Struvite is easy to apply with existing farm machinery.

3.2.2. Soil improvement

Phosphorus is an essential mineral in soil and plants. A sufficient supply is necessary for plant growth and soil life.

3.2.3. Technical facts

3.2.3.1. PRODUCTION PROCESS

Struvite is magnesium ammonium phosphate with the chemical formula $NH4MgPO4.H2O$. From industrial water it can also contain other minerals like potassium replacing the NH4-N. Struvite is produced by the precipitation of wastewater. Struvite crystallization in the case of both urban wastewater and industrial wastewater mostly follows an anerobic digestion process. In urban wastewater treatment system, the concept is to concentrate the soluble phosphate within the microbial mass in the water line. Waste activated sludge combined with primary sludge is fed to an anaerobic digestor. During the digestion, the phosphorus is liberated from the solids into the water matrix making it available as concentrated soluble PO4-P to be precipitated out as struvite. Then the struvite can be produced within the digestate or after the dewatering of digestate from the centrate. In industrial wastewater treatment, mostly struvite precipitation is followed by an anaerobic wastewater treatment system, for example, UASB.

The precipitation and crystallization is done by addition of $MgCl_2$ and NaOH. (Bünemann et al, 2021). The recovery of phosphor from wastewater is 12 – 22 % depending on the process.

Struvite can be produced locally, wherever there is a wastewater treatment plant.

Figure 4. Struvite granules (Else Bünemann, FIBL)

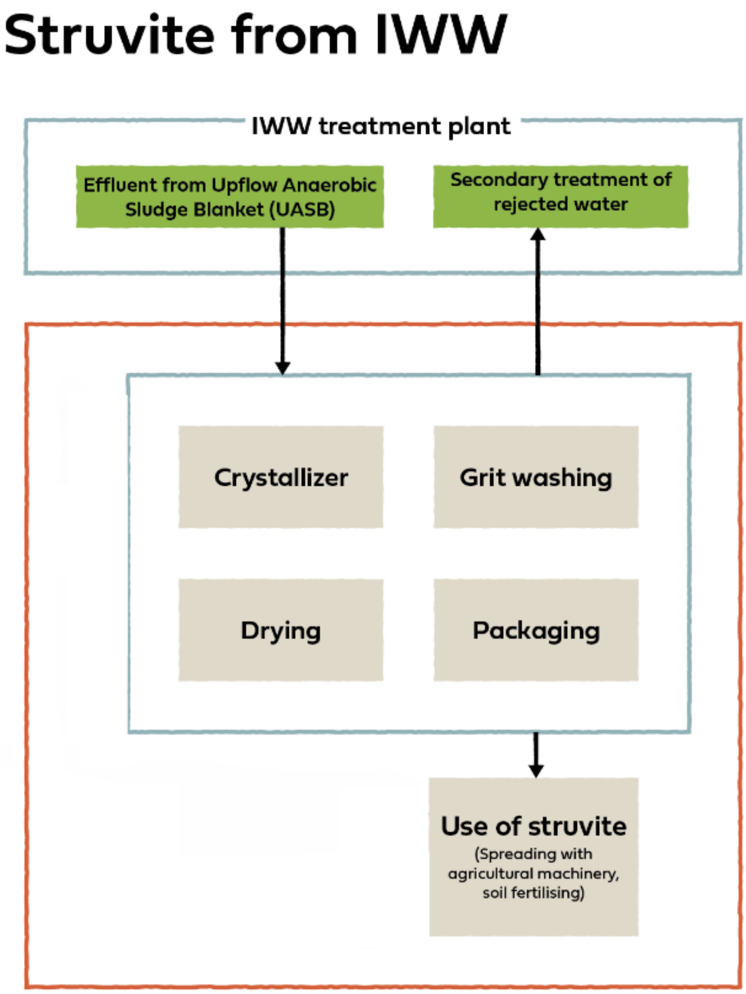

Figure 5. Flow Chart Struvite

3.2.3.2. MARKET RELATED ASPECTS

Struvite a quite new fertiliser that not so well known in agriculture yet. The quantities that are offered are still limited and in some cases there are regulatory barriers. But struvite and other by-products of wastewater have the potential of being the most important source of phosphorus supply in agriculture in future as rock-phosphate is a limited source worldwide. Therefore, using the phosphorus from waste water is a important option for the future. It can be expected that the offers will increase fast within the next year in a good price-cost ratio although there are still some price differences in different regions. Transport costs are not an important factor in price so struvite should be available in every region.

3.2.3.3. REGULATORY ANALYSIS

According to "REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019", an EU fertiliser may only consist of ingredients that meet the requirements for one or more of the component material categories (CMC) listed in this Annex. Struvite is authorised in the EU and is classified here under PFC 1 “solid inorganic macro nutrient fertiliser, CMC 12 "precipitated phosphate salts and derivates”.
There are specifications for nutrients and pathogens.
Pathogens must not exceed the limits listed in the following table:

Table 7. Thresholds for pathogens for struvite

Pathogen	Threshold
Salmonella spp	No findings in 25 g or 25 ml
Eschericha coli or Enterococcaceae	1000 in 1 g or 1 ml

These requirements shall not apply when pressure sterilization, pasteurization or hygienisation under defined conditions have taken place.

The precipitated phosphate salts shall contain a minimum of 16% phosphorus pentoxide (P_2O_5) in dry matter, a maximum content of 3% organic carbon in dry matter, a maximum of 3g/kg of macroscopic impurities above 2 mm in any form (organic matter, glass, stones, metal, plastic) and a maximum of 5 g/kg of the sum in dry matter. National regulations may also apply. There are still restrictions in some countries.

Recovered struvite and precipitated phosphate salts were added to the Regulation (EU) 2018/848 for organic farming with the Implementing Regulation 2023/121 on 17 January 2023. Animal manure as a source may not originate from industrial livestock farming.

3.2.4. References

REGULATION EU 2019/1009: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32019R1009

REGULATION EU 2018/448: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0448

Fertiliser Ordinance: https://www.gesetze-im-internet.de/d_v_2017/index.html, Section 3 para. 5 in conjunction with Annex 3

https://relacs-project.eu/wp-content/uploads/2021/05/RELACS_PA_07_struvite_FiBL_final.pdf

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0121

https://nutriman.net/sites/default/files/2021-05/Thematic_training_material_STRUVITE_DE.pdf

Struvite's potential as an alternative phosphorus source for organic agriculture, RELACS Practice abstract (2021), in: www.organic-farmknowledge.org/tool/40053

STRUVITE: Results about struvite precipitation (2023), NUTRI-KNOW presentation, in: https://eufarmbook.eu/en/contributions/661f794ead7afadbfd522b0a

3.3. Composted Bio-waste

3.3.1. Recommendations for use

Compost is a natural soil amendment that promotes healthy soil by increasing organic matter, enhancing microbial activity, improving nutrient content, and aiding in moisture retention.

Compost can provide essential nutrients to plants. The nutrients like nitrogen utilised are only partially effective and depends on the C:N ratio. For example, the German Fertiliser Regulation considers that 10% of the total nitrogen content of the compost is credited in the year of application. In the first subsequent year, 4% of the total nitrogen is taken into account in the fertiliser requirement calculation and in the second and third subsequent year, 3% of the originally applied total nitrogen must be taken into account. In reality, composts with C:N ratio of higher than 15:1 will release less nitrogen. Phosphate, potassium and sulfur are credited at 100%.

Table 8 shows the average nutrient content in the dry matter. The fluctuations are large. For this reason, the exact contents of the supplying substrate plant should be known - also in order to comply with legal requirements.

Table 8. Nutrient content in bio-waste compost in dry matter (Bundesgütegemeinschaft, 2018; Möller et at, 2014)

Nutrient	Mean value (in dry matter)	Range (in dry matter)
Dry matter	64 %	51 – 74 %
pH value	8	7,5 – 9
Salt content	1,6 %	
Organic matter	64 %	45 – 87 %
C	33 %	26 – 50 %
N	1,4 %	1,1 – 2,6 %
P	0,35 %	0,22 - 0,67 %
K	1,04 %	0,73 – 1,83 %
Ca	3,61 %	2,0 – 6,8 %
Mg	0,50 %	
S	0,3 %	0,15 – 0,4 %
Cu	37 g / t	
Zk	155 g / t	
B	26 g / t	
Mn	414 g / t	
Mo	1 g / t	

Compost can be used on all crops including in orchards. It can be applied before sowing in spring or autumn, in the crop or after harvesting in summer and can be incorporated into soil. The usual application rate is 10 to 20 tons per hectare, of product depending on crop needing and on the fertilizing restrictions in the region. In the case of regular application, permissible maximum application quantities must be observed, particularly with regards to the heavy metal contents to be complied with. Compost with a high C:N ratio can ideally be used for legumes as no N release can be expected – it is even possible, that the N-fixation can be enhanced through a decrease of mineral N, coming from the high CN ratio.

The amount of potassium is relatively high and should be considered, while the phosphorus content is low but readily available.

In horticulture compost can substitute peat in substrates up to 100%.

Spreading is carried out using commercially available manure spreaders or specific machinery designed for compost application. Pelletised compost can be spread by standard fertiliser spreader and can be mixed with other fertilisers.

Table 9. Recommendations for application of bio-waste compost (please check with your regional regulations)

Crop	Quantity	Time of application
Cereals	10 – 30 t/ha	Usually during tillage in pre-seeding
Maize	20 – 40 t/ha	Usually during tillage in pre-seeding
Legumes	10 – 30 t/ha if C:N ratio is higher 16:1	All year
Vegetables	10 – 40 t/ha	All year
Orchards and vineyards (planting)	10 – 40 t/ha	During tillage before planting
Orchard and vineyards	6 15 t/ha	All year

Figure 6. Spreading of compost (photo from CIC)

3.3.2. Soil improvement

Compost is the ideal source to improve soil by increasing organic matter as compost contains more than 30% of C. The carbon is more stabile the higher the C:N ration is. With an average C:N ratio of 16:1, a major part of the carbon is relatively stable and has a positive effect on the humus content. It contributes to carbon storage in soil. The effect is most visible on soils low in humus (<1% humus) to medium humus (2-3% humus). It also improves soil structure, stability of aggregates, volume of pores, water infiltration, water holding capacity, soil biological activity and soil fertility. Long-term yields are Stabilised.

3.3.3. Technical facts

3.3.3.1. PRODUCTION PROCESS

Composting is a process of decomposition of organic matter under aerobic conditions (with air) influenced by temperature and water content. All kinds of organic materials can be composted: harvest residues, by-products from agro-industry, farmyard manure, leaves, prunings, branches and organic household food waste. An important factor when producing compost is the ratio of carbon and nitrogen (C:N ratio). To ensure successful decomposition, the C:N ratio should be higher than 20:1 at the beginning. Materials like household bio-waste or some green waste materials like grass might need an addition of C-rich materials like wood chips. If the materials are too dry, water should be added. In the first phase, called active composting time, the material reaches temperatures between 55°C and 70°C or even up to 80°C; high temperature is necessary to kill weed seeds and pathogens. Such high temperatures are reached and maintained due to the intense degradation of the labile organic fraction. For this to occur, the microorganisms performing the degradation must have access to oxygen. There are two main technologies to achieve this: one option is to use static heaps with air insufflated from below, and the other is to use dynamic heaps, where the heap is continuously turned and mixed. After the first phase with rapid bacteria development, they are substituted by fungi when the cooling phase begins. When matured, compost presents a dark colour, crumbles easily and smells like forest soil. The duration of composting lasts few months, depending on the method, the intensity of turning and the final aim of the product. It is possible to perform an anaerobic digestion process on the bio-waste before composting the digestate with the same process as for fresh bio-waste. This way is possible to produce biomethane or renewable energy while managing a waste and producing a fertiliser.

There are some special methods of composting like microbial carbonization with lower temperatures, vermicompost with earth worms and high-speed methods but these methods are not topic of this guideline. Composting is mostly produced by industrial composting plants but also can be done on-farm.

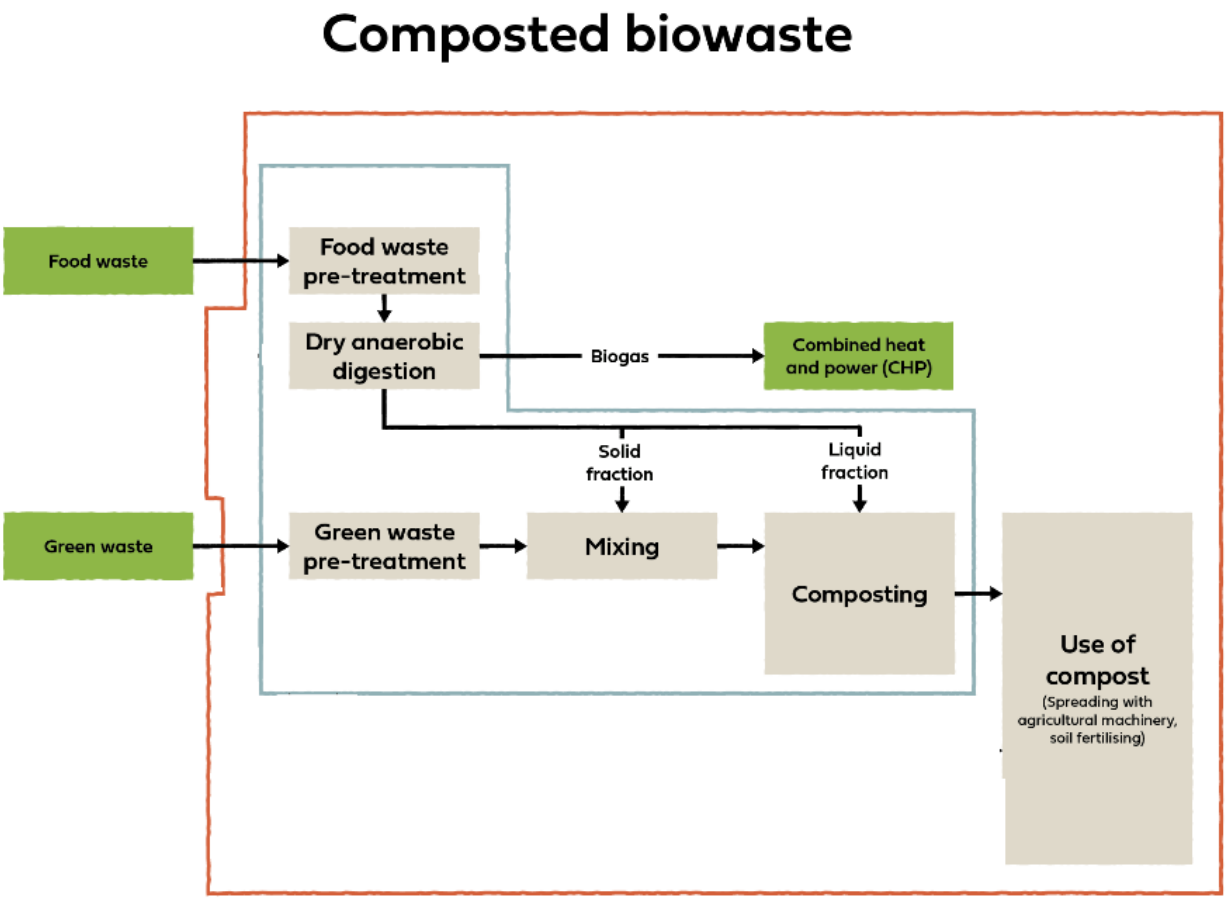

Figure 7. Flow Chart Bio-waste compost

Figure 8. Turning of compost heap and compost plant of Vienna city (Hartl, 2014)

3.3.3.2. MARKET RELATED ASPECTS

Compost is an ideal source for improving soil. The prices of compost are low and very competitive. Even if you only calculate the prices for the macro-nutrients without carbon the price is still very competitive. The availability of nutrients like phosphorus is relatively good. As compost cannot transported very far the regional supply is different from region to region. The production of compost could be increased a lot by enhancing selective food waste collection systems. Therefore, compost is an important part for supply of circular fertilisers for a future sustainable agriculture.

3.3.3.3. REGULATORY ANALYSIS

According to the EU Fertilising Products Regulation "REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019", compost is classified in product category function 3A "Organic soil improver. Compost is classified here under CMC 3 "compost". Furthermore, if it has manure as ingredient, it should comply with the nitrate directive and may not apply more than 340 kg/ha of nitrogen or 170 kg/ha of nitrogen in vulnerable zones. (EU 2018/448).

The above-mentioned Regulation establish certain requirements that should be taken into consideration.

Regarding pathogens contained in an organic soil improver, they must not exceed the limits listed in the following table. These values should not be relevant for compost, since if the process has undergone the active composting time the pathogens should be absent.

Table 10. Threshold for pathogens for bio-waste compost

Pathogen	Threshold
Salmonella spp	No findings in 25 g or 25 ml
Eschericha coli or Enterococcaceae	1000 in 1 g or 1 ml

In what concerns heavy metals contained in an organic soil improver, the limits to be respected are included in the following table.

Table 11. Threshold for contaminants for bio-waste compost

Contaminant	Threshold
Cadmium (Cd)	2 mg/kg dry matter
Chromium VI (Cr VI)	2 mg/kg dry matter
Mercury (Hg)	1 mg/kg dry matter
Nickel (Ni)	50 mg/kg dry matter
Lead (Pb)	120 mg/kg dry matter
Inorganic arsenic (As)	40 mg/kg dry matter
Copper (Cu)	300 mg/kg dry matter
Zinc (Zn)	300 mg/kg dry matter

There are requirements on a minimum Rottegrad (grade of deterioration) III, maximum of 6 mg/kg dry matter of PAH16, maximum of no more than 3 g/(kg dry matter of macroscopic impurities above 2mm in form of glass, metal or plastic and no more than 5 g/kg dry matter of sum of the impurities.

National regulations may also apply and can be different.

Compost from bio-waste is permitted in organic agriculture, in case that the product contains manure as raw material, it should do not originate from industrial livestock farming. There are additional thresholds for heavy metals in bio-waste compost in the EU organic standards.

In addition to EU legislation and Common Agricultural Policy (CAP), national and regional regulations may need to be observed, e.g. Bio-waste Regulations, Fertiliser Regulations, Farm Manure Transfer Regulations and regulations in water protection areas or areas with other protection status. These regulations may also include temporary restrictions on the spreading of fertilisers, e.g. in winter. It may be that the application of the substrate must be reported to the competent authority under these regulations.

3.3.4. References

Möller, K., Schultheiß U. (2014), Organic commercial fertilisers in organic farming, p.267, ISBN 978-3-941583-89-4.

REGULATION EU 2019/1009: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32019R1009

REGULATION EU 2018/448: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0448

Fertiliser Ordinance: https://www.gesetze-im-internet.de/d_v_2017/index.html, Section 3 para. 5 in conjunction with Annex 3

https://www.oekolandbau.de/fileadmin/redaktion/dokumente/Forschung/Praxismerkblaetter/18OE009_Pflanzenernaehrung_ProBio_Qualitaet.pdf

GUIDE ON HIGH-QUALITY ON-FARM COMPOSTING, in: https://academy.naturland.org/pluginfile.php/1184/mod_resource/content/7/Compost%20Guide_EN_V3.pdf

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Compost: Advantages and Disadvantages, Best4Soil Factsheet (2020), in: https://eufarmbook.eu/en/contributions/6694f31f1f007009947658a4

Compost - Practical Information, Best4Soil Factsheet (2022), in: https://eufarmbook.eu/en/contributions/6694efffcdbe474b40ec1bd7

3.4. Stabilised Sludge

3.4.1. Recommendations for use

Stabilised sludge promotes healthy soil by increasing organic matter, enhancing microbial activity, improving nutrient content, and aiding in moisture retention (Kamizela, 2022). It can provide essential macro-nutrients (N, P, K) which are only partially effective and micro-nutrients to plants. The C:N ratio is often less than 20:1. (Novosel, 2022). Combination with other organic materials like compost can optimize C:N ration and nutrient balance.

Table 12 shows the average nutrient content in the dry matter. The fluctuations are large. For this reason, the exact contents of the supplying substrate plant should be known - also in order to comply with legal requirements.

Table 12. Average nutrient content of stabilised sludge in the dry matter

Nutrient	Range
Organic matter	40 - 80 %
N	3,6 - 5 %
P	0,8 – 2,5 %
K	0,1 – 0,3 %
Ca	4 - 6 %
Mg	0,6 – 2 %

Stabilised sludge can be used on all crops including in orchards. It can be applied before sowing in spring or autumn, in the crop or after harvesting in summer and has to be incorporated into soil. The usual application rate depends on the restrictions.

Stabilised sludge should have less than 50% of moisture for application with a normal manure spreader. Pelletised sludge can be spread by standard fertiliser spreader and can be mixed with other fertilisers.

Sewage sludge can contain contaminant like heavy metals, organic pollutants, pharmaceutic residues or micro plastic. It cannot be applied on soils in which fruit and vegetable crops are grown (except fruit trees) and on grassland or forage land that will be grazed by animals or harvested in the next three weeks.

Table 13. Recommendations for application of stabilised sludge (please check with your regional regulations)

Crop	Quantity	Time of application
Cereals	1 - 3 to/ha	All year
Legumes	1 – 3 to/ha if C:N ratio is higher 16:1	All year
Vegetables	1 – 3 to/ha	All year
Orchards and vineyards	1 – 3 to/ha	All year

Spreading is carried out using commercially available manure spreaders.

Figure 9. Spreading of stabilised sludge

3.4.2. Soil improvement

Stabilised sludge is a good source for organic matter and nutrients. Stabilised sludge increases organic matter especially with a C:N ratio of 16:1 or higher and can contribute to carbon storage in soil (Glodnik, 2022). It also improves soil structure, stability of aggregates, volume of pores, water infiltration, water holding capacity, soil biological activity and soil fertility (Novosel, 2022). In the long-term yields are stabilised.

3.4.3. Technical facts

3.4.3.1. PRODUCTION PROCESS

Sewage sludge is a byproduct of the urban wastewater treatment process, from the primary sedimentation tank, secondary sedimentation tank and other linked processes. It contains organic matter and nutrients, which make it attractive as a fertiliser product.

To ensure it can be safely applied for agricultural purposes, sludge must be Stabilised first, and its water content reduced. Several technologies are available for stabilization. The most commonly used in Europe are anaerobic digestion, aerobic digestion, composting, chemical treatment and thermal drying.

- Anaerobic digestion aims at reducing, stabilizing, and partially disinfecting sludge. It consists of confining the sludge in a vessel at a temperature of about 35 °C for a period of time. During this process biogas (mixture of methane and carbon dioxide) is generated as a by-product and usually used to maintain the temperature of the vessel (European Commission, 2001).

- Composting is an aerobic process consisting of aerating sludge mixed with a co-product such as sawdust or animal manure. Composting produces excess heat, which can be used to raise the temperature of the composting mass. The mix then evolves for several weeks. Composted sludge reaches a good level of disinfection and is stabilised, reducing therefore the arising of odours. The final dry matter content in composted sludge can reach over 60% making it easy to handle (European Commission, 2001).

- Chemical treatment refers mostly to lime treatment, meaning the addition of lime to sludge in order to raise its pH to 12, thus destroying or inhibiting the biomass responsible for the degradation of the organic compounds. The treatment also helps disinfecting sludge, increasing its dry matter content, and making handling easier (European Commission, 2001).

- Thermal drying implies delivering energy to the system to evaporate the water resulting in its densification. A dry matter content of at least 45% is necessary to inhibit the re-growth of bacteria (European Commission, 2001).

- Aerobic digestion stabilises sludge by degrading the organic matter by microorganisms under aerobic conditions (i.e., in the presence of oxygen). Although a simpler process than Anaerobic digestion, it requires a significant amount of energy (5 to 10 times more than anaerobic digestion) (European Commission, 2001).

Stabilisation processes already take place in most urban wastewater treatment plants, as it is encouraged by EU regulation (Directive 91/271/EEC) before any form of disposal. Depending on the characteristics of the treatment plant, i.e., size, and influent characteristics and the geographical region, one of the five technologies presented before is chosen.

Figure 10. Stabilised sludge after pressing (Bundesarchiv)

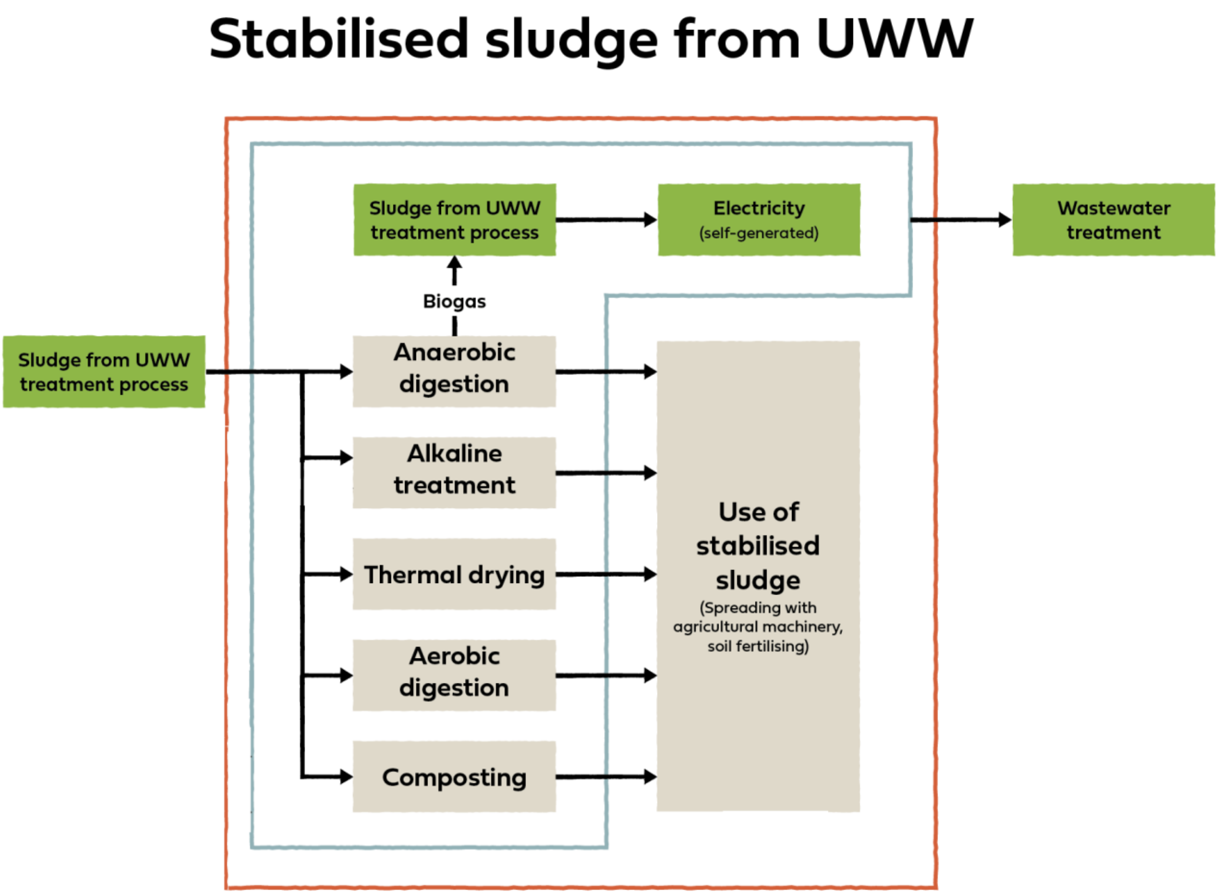

Figure 11. Flow Chart Stabilised sludge of urban wastewater

3.4.3.2. MARKET RELATED ASPECTS

Flow chart Stabilised sludge of urban wastewater

Stabilised sludge is a good source of nutrients with a very competitive price. For being accepted by farmers and consumers values of heavy metals, pathogens and other contaminants have to be as low as possible. Supply can be different from region to region as qualities can fluctuate. Stabilised sludge should be available at every wastewater treatment plant but also can be transported some distance.

3.4.3.3. REGULATORY ANALYSIS

According to the EU Directive 86/278 there are limit values for concentrations of heavy metals in soils, in sludge for use in agriculture and for the amounts of heavy metals that may be added annually to agricultural land based on a 10-year average. Member states may permit values to be exceeded.

Table 14. Thresholds of contaminants (mg/kg dry matter) for stabilised sludge

Parameter	Heavy metals in soil	Heavy metals in sludge	Annual addition
Cadmium (Cd)	1 – 3	20 – 40	0,15
Copper (Cu)	50 – 400	1000 – 1750	12
Nickel (Ni)	30 – 75	300 – 400	3
Lead (Pb)	50 – 300	750 – 1200	15
Zinc (Zn)	150 – 300	2500 – 4000	30
Mercury (Hg)	1 – 1,5	16 - 25	0,1

Normally sewage sludge has to be treated before using them in farming. There may be exemptions in some EU countries.

National and regional regulations have to be observed, e.g. Bio-waste Regulations, Fertiliser Regulations and others. Under the Fertilising Products Regulation, sewage sludge is not allowed in CMC 5 “Digestate other than fresh crop digestate” or in CMC 3 “Compost”. Sewage sludge is not permitted in organic agriculture.

3.4.4. References

EU Directive 2001/C 14/26): https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2001:014:0141:0150:EN:PDF

EU Directive 91/291 (1991): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991L0271

EU Directive 86/278 (1986): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31986L0278

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Novosel, Barbara, Vesna Mislej, and Viktor Grilc. "Basic Morphological, Thermal and Physicochemical Properties of Sewage Sludge for Its Sustainable Energy and Material Use in the Circular Economy." Recent Perspectives in Pyrolysis Research (2022).

Kamizela, T., Lyng, K. A., Saxegård, S., Švédová, B., & Grobelak, A. (2021). Bionor sewage sludge technology–Biomass to fertiliser and a soil addition. Journal of Cleaner Production, 319, 128655.

3.5. Solid fraction of digestate

3.5.1. Recommendation for use

Digestate is an excellent source of nutrients for crops, but its application must be managed carefully to maximize its benefits and minimize environmental risks. The solid fraction of digestate is particularly important as a fertiliser due to its high nutrient content and organic matter. It offers nitrogen which is available quite fast and it offers stabile carbon. It can contain up to 87% of the total nitrogen and 71% of the phosphorus present in the original digestate. Here are several recommendations for the effective use of stabilised solid fraction of digestate:

- *Incorporation into Soil:* This involves spreading the digestate on the soil surface and then incorporating it into the soil using tillage equipment. This method also helps reduce ammonia emissions and odors, though it may not be as effective as injection.

- *Precision Agriculture Techniques* (GPS Tracking): Utilising GPS technology ensures that the digestate is applied evenly across the field, avoiding over-application in some areas and under-application in others. Precision agriculture techniques can help farmers apply the exact amount of nutrients needed by the crops, enhancing nutrient use efficiency and reducing environmental impact.

- Application Timing:

Pre-Sowing Applications: Applying digestate before sowing crops ensures that nutrients are available during the critical early growth stages. This timing can also help reduce the risk of nutrient losses through leaching or volatilization.

Cover Crop Applications: Digestate can be applied to cover crops, which can take up the nutrients and prevent them from being lost during periods when the main crops are not growing. Cover crops can also improve soil structure and organic matter content.

- *Optimal Conditions for Application:* Avoid applying digestate during heavy rainfall or when the soil is saturated, as this can lead to nutrient runoff and water pollution. Similarly, application during windy conditions can increase the risk of ammonia volatilization.

- Soil Conditions: Apply digestate when the soil is not frozen or waterlogged to ensure that the nutrients can be absorbed by the soil and taken up by the plants.

- *Use of Nitrification Inhibitors:* can slow down the conversion of ammonium to nitrate, reducing the risk of nitrate leaching and improving nitrogen use efficiency. This can be particularly useful in areas prone to heavy rainfall or irrigation.

- *Compliance with Regulations:* ensure that the application of digestate complies with local and EU regulations, including the EU Nitrates Directive. Adhering to these regulations helps prevent nitrate pollution and promotes sustainable agricultural practices.

By following these recommendations, farmers can optimize the use of digestate, enhancing crop productivity while protecting the environment. The use of digestate not only contributes to sustainable nutrient management but also supports the circular economy by recycling organic waste into valuable agricultural inputs.

Table 15 shows the average nutrient content in the dry matter. The fluctuations are large. For this reason, the exact contents of the supplying substrate plant should be known - also in order to comply with legal requirements.

Table 15. Nutrient contents in solid fraction of digestate in dry matter (Bundesgütegemeinschaft, 2018)

Nutrient	Mean value in solid fraction of digestate from plant based NaWaRo* material (range)	Mean value in solid fraction of digestate from bio-waste (range)
Dry matter	27,5 % (21 – 30 %)	35,6 % (25 – 48 %)
pH value	8,6 (8,1 – 8,9)	8,1 (7,5 – 8,7)
Organic matter	48 % (34 – 51 %)	55 % (37 – 72 %)
C	28 % (20 – 30 %)	31 % (21 – 40 %)
N	2,4 % (1,5 – 3,7 %)	2,6 % (1,3 – 6,0 %)
C:N ratio	21,7 (13,1 – 29,2)	15,4 (5,0 – 23,4)
P	1,1 % (0,4 – 3,3 %)	0,8 % (04 – 1,4 %)
K	2,3 % (1,1 – 2,4 %)	1,0 % (0,6 – 1,5 %)
Ca	1,8 % (0,4 – 4,6 %)	4,6 % (1,1 – 9,9 %)
Mg	0,7 % (0,4 – 1,8 %)	0,7 % (0,3 – 1,2 %)

* Pure plant based ingredients without animal manure

Table 16. Recommendations for application of solid fraction of digestate (please check with your regional regulations)

Crop	Quantity	Time of application
Cereals	30 – 80 kg/N ha depending on crop and soil analysis	Feb – May
Legumes	-	-
Vegetables	N demand depending on crop and on soil analyses	Feb – Sep
Orchards and vineyards	N demand depending on crop and on soil analyses	Jan – May

3.5.2. Soil improvement

Solid fraction of digestate is the ideal source to improve soil by increasing organic matter as solid fraction of digestate contains more than 25% of C. The carbon is quite stabile as it survived the digestion and has a positive effect on the humus content. It contributes to carbon storage in soil. The effect is most visible on soils low in humus (<1% humus) to medium humus (2-3% humus). It also improves soil structure, stability of aggregates, volume of pores, water infiltration, water holding capacity, soil biological activity and soil fertility. In the long-term yields are stabilised.

Solid fraction of digestate is a unique mixture of offering both nutrients with high and relatively fast availability and stabile carbon. By converting organic waste materials into a valuable fertiliser, this process not only generates renewable energy but also enhances nutrient availability, soil health, and environmental sustainability. The sanitized, nutrient-rich digestate produced through this process represents a significant advancement in organic waste management and agricultural productivity, aligning with the goals of circular economy and sustainable development.

Its use can significantly reduce the reliance on synthetic fertilisers, lower the risk of nitrate pollution, and enhance soil health. By adopting this approach, farmers can contribute to a more circular and environmentally friendly agricultural system. Both liquid and solid fractions of digestate contain relevant levels of nutrients, which represents an opportunity when using both of them as fertilisers.

3.5.3. Technical facts

3.5.3.1. PRODUCTION PROCESS

Anaerobic digestion (AD) is a biological process through which microorganisms break down organic matter in the absence of oxygen, producing a mix of gases: 50 – 75% of methane (CH_4), 25 – 50% carbon dioxide (CO_2), water vapor, and traces of oxygen (O_2), nitrogen (N_2), and hydrogen sulfide (H_2S) (European Biogas Association, 2013). The relevance of biogas is that it can either be burned to produce energy (electricity and heat) or be upgraded to biomethane which can be used as vehicle fuel or injected into gas grid to be used as a substitute of natural gas.

AD's main product is biogas; the rest (digestate) was considered a waste for several years. Now, it's being harnessed as a circular fertiliser to recover the nutrients it contains. Digestate is a heterogeneous mix composed by a liquid and a solid phase (i.e., liquid and solid fraction of digestate). Both are rich in nutrients, and both are being used for fertilization purposes.

There are several waste streams that may be subjected to AD to obtain biogas: manure, food waste, and sewage sludge. For the purposes of this assessment the three of them were considered. There are two differentiated types of AD: wet and dry. The food waste system was modeled considering dry AD given that it is the most widely used in Europe; for sewage sludge the only option possible is wet AD, and for manure also wet AD was modeled, since it is the one for which there is greater data availability.

Food waste's system include a pretreatment stage from which ferrous metals are recovered, and rejects are sent to waste management, and solid and liquid fractions are separated using a screw press; liquid fraction is applied on soil, therefore substituting the usage of fertilisers. Sewage sludge system, on the other hand, takes primary and secondary sludge from the waste water treatment plant (WWTP), mixes and thickens them before AD, and afterwards, through a dewatering processes liquid and solid fractions are separated; liquid fraction is sent back to WWTP. Manure's system starts directly with AD, its digestate goes through liquid-solid separation, and liquid fraction is used to substitute the usage of fertilisers.

In conclusion, the production of Stabilised digestate through anaerobic digestion offers a multifaceted solution for sustainable agriculture. By converting organic waste materials into a valuable fertiliser, this process not only generates renewable energy but also enhances nutrient availability, soil health, and environmental sustainability. The sanitized, nutrient-rich digestate produced through this process represents a significant advancement in organic waste management and agricultural productivity, aligning with the goals of circular economy and sustainable development.

Solid fraction of digestate from food waste

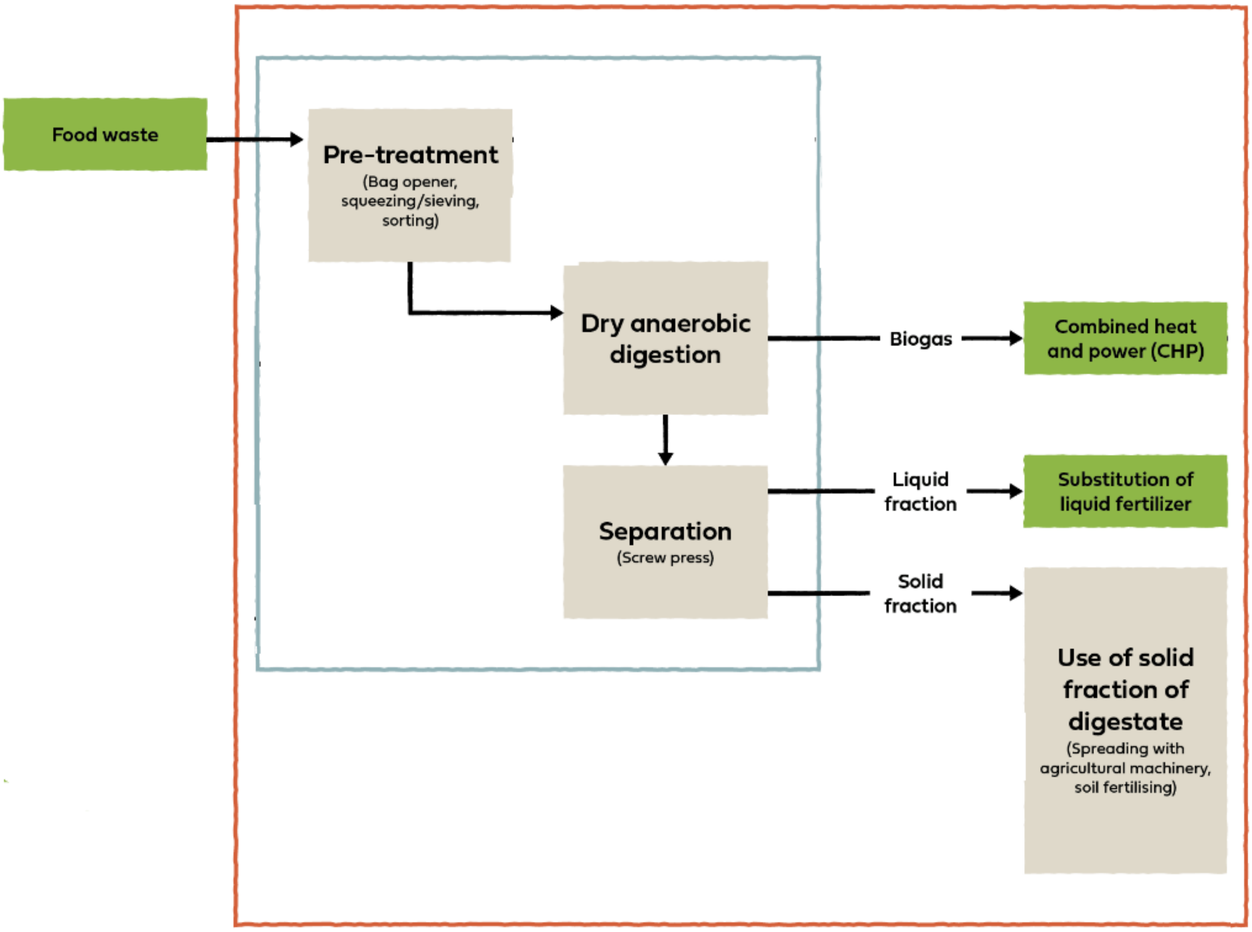

Figure 12. Flow Chart Solid fraction of Digestate from food waste

Figure 13. Biogas plant with technical room, silos, fermentation tank, repository and gas storage (left) and separator of the solid fraction (right; E. Räder)

3.5.3.2. MARKET RELATED ASPECTS

In Europe, digestate is produced differently depending on the installed capacities in each country. Therefore, it is not available in every region. There is a high variation in nutrients and price but prices are often very competitive. The solid fraction is regarded as cost-effective to transport compared to the liquid fraction. The production can be scaled up a lot but depends on the national electricity strategies.

3.5.3.3. REGULATORY ANALYSES

According to the EU Nitrates Directive (91/676/EEC), digestate used as fertiliser must meet specific criteria to prevent nitrate pollution. This directive, targeting agricultural practices as major sources of nitrate pollution, sets annual nitrogen application limits in vulnerable zones to safeguard water quality across Europe. Stabilised digestate can help meet these requirements by providing a controlled release of nitrogen and other essential nutrients, enhancing nutrient efficiency while minimizing environmental impact.

The EU Nitrates Directive mandates that member states identify Nitrate Vulnerable Zones (NVZs) where nitrate pollution is a concern and implement action programs to control and reduce nitrate leaching. This involves setting annual nitrogen application limits to ensure that the amount of nitrogen applied does not exceed the crop's requirements and the soil's absorption capacity. Excess nitrogen from fertilisers can leach into water bodies, causing eutrophication and negatively impacting aquatic ecosystems.

Solid fraction of digestate, produced through the anaerobic digestion of organic materials, offers a viable solution for meeting the EU Nitrates Directive's requirements. The controlled release of nitrogen from Stabilised digestate ensures efficient nutrient uptake by crops, reducing the risk of nitrate leaching. Additionally, Stabilised digestate contains other essential nutrients like phosphorus and potassium in balanced proportions, contributing to overall soil fertility and crop health.

According to REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of June 5, 2019, solid fraction of digestate meets CMSC 5 “digestate other than fresh crop digestate” and PFC 1(A)(I) “solid organic fertiliser” or PFC 3(AQ) “solid soil improver”. But sewage sludge is not allowed in CMC 5.

Digestate from manure, green waste and bio waste is permitted in organic agriculture but organic farms must provide proof that the ingredients of the substrate do not originate from industrial livestock farming and may not apply more than 170 kg of nitrogen (EU 2018/448).

3.5.4. References

REGULATION EU 2019/1009: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32019R1009

REGULATION EU 2018/448: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0448

Bundesgütegemeinschaft Kompost e.V. (2018): Organische Düngung – Kompost für die Landwirtschaft, in: Organische_duengung_Juli_2018_.pdf (kompost.de)

European Biogas Association. (2013). *EBA's Biomethane factsheet.* Retrieved from https://www.europeanbiogas.eu/wp-content/uploads/files/2013/10/eba_biomethane_factsheet.pdf

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Organic fertilisation of young apple orchards, DOMINO Practice Abstract (2021), in: www.organic-farmknowledge.org/tool/42596

SOS Aquae: More efficient carbon and nitrogen agrosystems with biogas, NUTRI-KNOW presentation (2023), in https://eufarmbook.eu/en/contributions/662113c30beeac6e7e385efb

3.6. Spent Mushroom Substrate

3.6.1. Recommendation for use

The fungal substrate has a corrective effect on soils with a pH value that is too low (Lakaria, 2019). Attention should be paid to the salt content of salt-sensitive crops. With its high content of sulfur spent mushroom substrate is a good option for crops with a high need of sulfur like oil seed rape and legumes (Möller et al, 2014)

Spent mushroom substrate can provide essential nutrients to plants. The nutrients like nitrogen utilised are only partially effective. In the German Fertiliser Regulation, 10% of the total nitrogen content of the spent mushroom substrate is credited in the year of application. In the first subsequent year, 4% of the total nitrogen is taken into account in the fertiliser requirement calculation and in the second and third subsequent year, 3% of the originally applied total nitrogen must be taken into account. Phosphate, potassium and sulphur are credited at 100%. Different regulations are possible in other regions.

Table 17 shows the average nutrient content in the dry matter. The fluctuations are large. For this reason, the exact contents of the supplying substrate plant should be known - also in order to comply with legal requirements.

Table 17. Nutrient contents in spent mushroom substrates in dry matter (Möller et al, 2014)

Nutrient	Mean value	Range
Dry matter	38,0 %	23,2 – 79,1 %
pH value	6,5	5,3 – 8,1
Salt content KCl	2,1 %	1,1 – 2,4%
Organic matter	64,6 %	36,7 – 86,0 %
C	33,6 %	23,8 – 43,9 %
N	2,12 %	0,34 – 6,2 %
P	0,89 %	0,28 – 1,8 %
K	2,02 %	0,85 – 3,2 %
Ca	4,24 %	0,29 – 12,6 %
Mg	0,85 %	0,21 – 1,84 %
S	2,35 %	0,86 – 4,03 %

Spent mushroom substrate can be used on all crops including in orchards and for other species of mushroom production. It can be applied before sowing in spring or autumn, in the crop or after harvesting in summer and can be incorporated into soil. The usual application rate is 10 to 20 tonnes per hectare, provided there are no other restrictions in the region. In the case of regular application, permissible maximum application quantities, e.g. 30 tons DM in 3 years, must be observed, particularly with regard to the heavy metal contents to be complied with.

Table 18. Recommendations (please check with your regional regulations) for spent mushroom substrates

Crop	Quantity	Time of application
Cereals	10 – 30 to/ha	All year
Legumes	10 – 30 to/ha if C:N ratio is higher 16:1	All year
Vegetables	10 – 30 to/ha	All year
Orchards and vineyards	10 – 30 to/ha	All year

3.6.2. Soil improvement

Spent mushroom substrate often contains more than 30% of C. With an average C:N ratio of 16:1, a major part of the carbon is relatively stable and has a positive effect on the humus content. It contributes to carbon storage in soil. The effect is most visible on soils low in humus (<1% humus) to medium humus (2-3% humus). It also improves soil structure, stability of aggregates, volume of pores, water infiltration, water holding capacity, soil biological activity and soil fertility. In the long-term yields are stablised.

3.6.3. Technical aspects

3.6.3.1. PRODUCTION PROCESS

After the mushrooms have grown and have received treatment by high temperatures, the mushroom substrate is returned to agriculture as finished compost to be used as fertiliser. Mushroom substrates are mixtures of different components depending on the species of mushrooms: manure, straw, gypsum, water but also clay, sand, marl, peat and sugar beet manure.

Figure 14 shows a schematic diagram of mushroom and spent mushroom production. The substrate producer composts manure with lime, gypsum and wheat straw.

This “fresh compost” (Phase 1) is then pasteurized (Phase 2) and spawned (Phase 3).

Some mushroom producers get the spawned (Phase 3) substrate, others prefer to get the pasteurized (Phase 2) substrate and make the spawning themselves.

The spawned substrate is covered with casing soil (usually peat), and mushrooms are grown.

After the harvesting of the mushrooms, the mushroom producer disposes of the spent substrate either by conducting a second composting stage and then distributing the fertiliser, or by sending it back to the substrate producer who will harness it as a raw material.

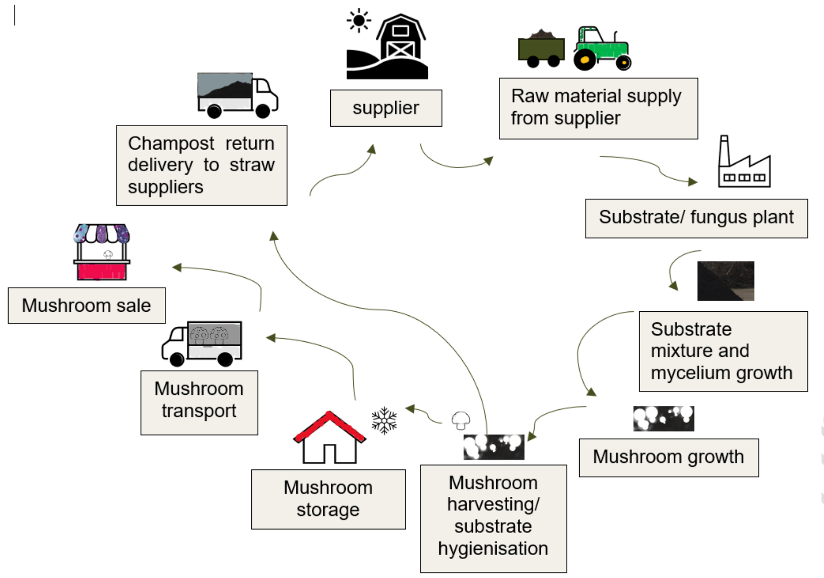

Figure 14. Production scheme of the spent mushroom substrate

Figure 15 shows an example of a timeline for mushroom production. Note that the production and production time may vary depending on the mushroom substrate and substrate plant.

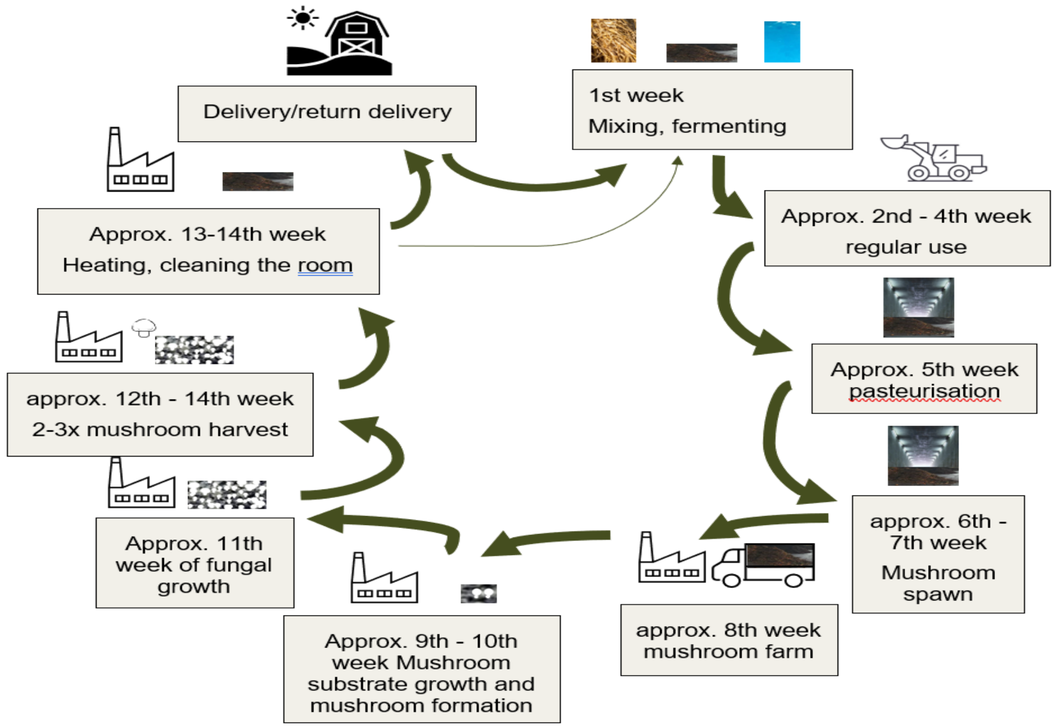

Figure 15. Timeline from the delivery of the raw materials to the return delivery of the spent mushroom substrate

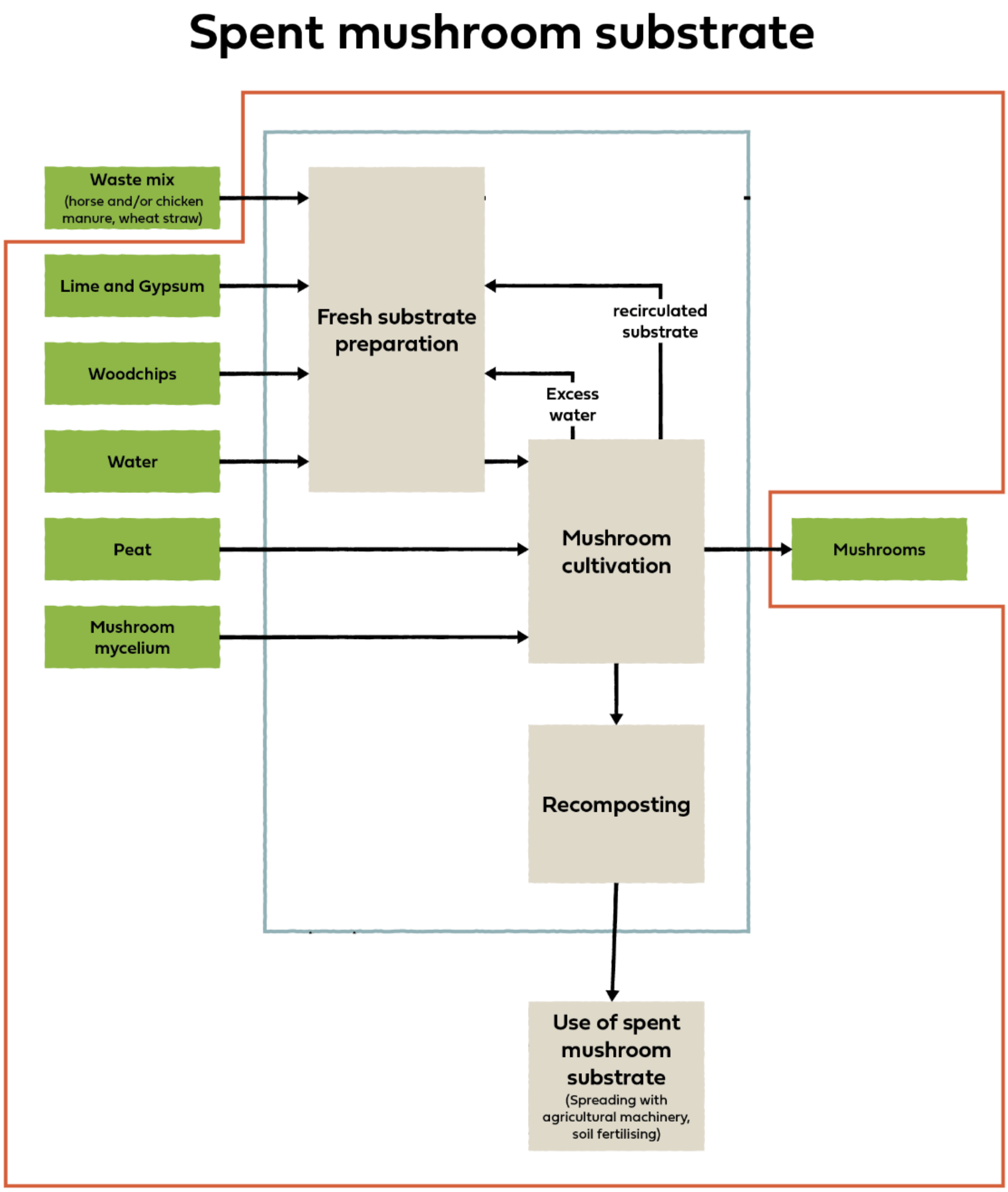

Figure 16. Flow Chart Spent Mushroom substrate

3.6.3.2. MARKET RELATED ASPECTS

Spent mushroom substrate is an ideal source for improving soils like compost. The prices of compost are low and very competitive. Even if you only calculate the prices for the macro-nutrients without carbon the price is still very competitive. The supply is limited to the production of mushrooms. As spent mushroom substrate cannot transported very far the regional supply is different from region to region.

3.6.3.3. REGULATORY ANALYSIS

According to the EU Fertilising Products Regulation "REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019", spent mushroom substrate is classified in product category function 3A "Organic soil improver".

According to the regulation, an EU fertilizing product, which is CE marked when made available on the market may only consist of materials that meet the requirements for one or more of the component material categories (CMC) listed in this Annex. Spent mushroom substrate is authorised in the EU and is classified under CMC 10 "derived products within the meaning of Regulation (EC) No. 1069/2009" (certain derived products from animal by-products) or CMC 3 “compost” if the end point for manure has been reached.

There are specifications for maximum levels of heavy metals and pathogens.

Pathogens contained in an organic soil improver must not exceed the limits listed in the following table:

Table 19. Thresholds for pathogens for spent mushroom substrates

Pathogen	Threshold
Salmonella spp	No findings in 25 g or 25 ml
Eschericha coli or Enterococcaceae	1000 in 1 g or 1 ml

Contaminants contained in an organic soil improver must not exceed the following limits:

Table 20. Threshold of contaminants for spent mushroom substrates

Contaminant	Threshold
Cadmium (Cd)	2 mg/kg dry matter
Chromium VI (Cr VI)	2 mg/kg dry matter
Mercury (Hg)	1 mg/kg dry matter
Nickel (Ni)	50 mg/kg dry matter
Lead (Pb)	120 mg/kg dry matter
Inorganic arsenic (As)	40 mg/kg dry matter
Copper (Cu)	300 mg/kg dry matter
Zinc (Zn)	300 mg/kg dry matter

National regulations may also apply.

Spent mushroom substrate is permitted in organic agriculture but organic farms must provide proof that the ingredients of the substrate do not originate from industrial livestock farming and may not apply more than 170 kg of nitrogen (EU 2018/448).

In addition to EU legislation and Common Agricultural Policy (CAP), national and regional regulations may need to be observed, e.g. Bio-waste Regulations, Fertiliser Regulations, Farm Manure Transfer Regulations and regulations in water protection areas or areas with other protection status. These regulations may also include temporary restrictions on the spreading of fertilisers, e.g. in winter. It may be that the application of the substrate must be reported to the competent authority under these regulations.

3.6.4. References:

Möller, K., Schultheiß U. (2014), Organic commercial fertilisers in organic farming, p.267, ISBN 978-3-941583-89-4.

REGULATION EU 2019/1009: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A32019R1009

REGULATION EU 2018/448: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0448

Fertiliser Ordinance: https://www.gesetze-im-internet.de/d_v_2017/index.html, Section 3 para. 5 in conjunction with Annex 3

Champost – RPZ Rheinische Pilz-Zentrale (rhpz.de)

Lakaria, B. L., et al. "Soil health: Concept, components, management and opportunities." *Advances in compost production technology* (2019): 95-103.

4. Conclusions

Circular fertilisers are a sustainable option compared to energy-intensive synthetic fertilisers and offer many different options – both for conventional and organic farmers. They are suitable for all crops – from vegetables and fruits to arable crops including legumes.

Struvite gives the option to recover phosphorus, the most limiting nutrient in agriculture because sources of rock phosphate are not indefinite and often contaminated. Feather meal offers organic nitrogen with not too much phosphorus which can be an important aspect for vegetable and fruit growers. Stabilised sludge provides macro- and micro-nutrients usually with a relatively fast release.
With a high and stabile carbon content composted bio-waste and spent mushroom substrate are the typical "soil improvers". But the other nutrients should not be underestimated as they are not expensive, and availability of nutrients is quite good.
Solid fraction is quite unique in comparison providing both nitrogen with fast availability and some stabile carbon.
Many of the circular fertilisers have large fluctuations. For this reason, the exact contents of the supplying substrate plant should be known.

A critical aspect is that regulatory issues can restrict use of all these fertilisers. However, even though prices of most circular fertilisers are competitive, the acceptance of famers to circular fertilisers must be improved. Circular fertilisers availability should be also ameliorated by enhancing production.

To know more than 60 circular fertiliser value chains, visit the FER-PLAY database and if you want to dive deep into the environmental, social, economic, regulatory and scaling-up assessment of the seven presented fertilisers, check out D2.2 "Multi-assessment of impacts, trade-offs and framework conditions".

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"This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101060426."

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 European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.