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

Deliverable 5.2: Version 1.1

Report on alternatives to contentious inputs (WP SOIL)

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1. Introduction

This report is based on the structure of deliverable D5.1 of the Organic-PLUS project (Løes et al., 2018), where we studied the input of peat, plastic and fertilisers in 10 European countries participating in the project. Whereas that deliverable sought to explore the main inputs used in each country, in selected (mostly) horticultural crops where we expected the use of inputs to be most significant, this report summarises the input use across countries for peat, plastic and fertilisers, and puts a special emphasis on the cases where our informants told about alternatives to these, sometimes contentious, inputs.
We have expanded on some alternatives where further work is to be conducted as a part of the Organic-PLUS project activities. We have also described other alternatives. However, as each of the topics (peat for growing media, plastic for mulching and fertilisers derived from non-certified organic production) is broad and complex, this report is not a complete review of all possible alternatives. Changes in crop rotations and farming system design may be required to completely phase out some contentious inputs. Such changes go beyond the scope of this report.

The report gives a review of on alternatives to the contentious inputs peat, fossil based plastic, and fertilisers from conventional origin. For vegan organic production a special paragraph in the fertiliser chapter describes the challenges for this system. The reviewed alternatives are primarily based on those described in D5.1, for specific crops grown by farmers in the project countries. Here alternatives (substances and management measures) that are actually used in practice were gathered. Often the use of the contentious inputs is practiced because there is a lack of alternatives, or the efficiency of alternatives is not documented or more expensive. The main topics fertilisers, peat, and fossil-based plastic each have their own chapters and references.

2. The use of commercial fertilisers and manure

2.1 Introduction and background

Fertilisers (defined as all nutrient inputs except manure and slurry) and manure (defined as all waste products from the living animal) are necessary in organic crop production. They can be imported to the farm (off-farm products) or produced on the farm. Off-farm inputs are limited to EC regulated maximum amounts of N, according to the nitrate directive from 1991; max 170 kg N/ha. Even if manure is from certified organic origin, its use may still be problematic for growers producing for the vegan market, regardless if it is composted or not. Several private organic standards put restrictions to the use of conventional manure, e.g. not permitting manure from pigs or poultry, or demanding that conventional manure must be composted on farm before application.

Off-farm fertilisers which are not of certified organic origin, are regarded as contentious. The fertilisers might contain pesticides or other compounds not accepted in the EC regulation for organic agriculture. Further, such inputs are contentious since they make organic agriculture dependant on conventional agriculture, or they support conventional livestock systems with high animal density and too little area to spread the manure.

Current studies on nutrient flows in organic farming systems e.g. for France show that influxes of nutrients from conventional farming into the organic farming system add up to 23% of the total nitrogen, 53 % of the total potassium and 73% of the total phosphorus (Novak et al. 2013).

There has also been an increasing tendency to process manure and slurry by anaerobic fermentation to digestate and biogas. The biogas digestate from animal source is often mixed with plant material (grass, harvest remains form vegetables etc.). These biogas digestates differ from pure manure and slurry, in efficiency and risks for emissions and leaching, although, when used appropriately, they can boost the spring growth.

For products made from animal residues, such as pig bristles or feather meals it is usually impossible to confirm if the origin is certified organic or not. In addition, many products of animal origin are sourced from non-European countries (e.g. Pakistan, India), which makes a tracing of certified organic raw materials even more challenging. Currently, the use of such fertilisers from conventional farming is strongly debated in the organic sector.

The growing demand for vegan products also calls for a stronger focus on plant based fertilisers. Hence, a separate section on vegan fertilisation is presented below. Moreover, the need to close nutrient gaps by increased utilisation of fertilisers from urban sources in organic farming calls for new concepts of fertilisation. The Expert Group for Technical advice on Organic Production (EGTOP) has proposed that fertilisers derived from human waste, specifically struvite and renewable calcined phosphate, should be allowed in organic production, provided there are no hygienic or other pollutant risks (EC 2016). According to EGTOP, the fact that human waste (excreta, humanure) are not mentioned in current EU regulations for organic production does not imply that they should be prohibited; they should be evaluated in relation to potential pathogens and other contaminants. Utilisation is currently still hampered because these products are not authorised under Regulation EC No 2003/2003, which is the general regulation for fertilisers (EU 2003). If compounds derived from human excreta become included in

Annex 1 of the organic regulations, the situation of organic farmers in Europe would be significantly changed.

Hence, several reasons exist to explore alternatives to existing fertiliser which are commonly used in organic farming but derived from conventional sources or not thoroughly tested. Such fertilisers may be based on plant materials and waste product inputs, or mixtures. At present such fertiliser inputs are often expensive, difficult to obtain and their nutritional effects may be not well known. More studies are required of N availability, application techniques, application timing as well as hygienic and environmental risks. In addition to commercialised fertiliser inputs, new system approaches are needed, which better integrate green manures into existing systems.

2.2 Summary of fertiliser use

In this section the results achieved in the Deliverable 5.1 from the Organic-PLUS project (Løes et al., 2018) will be developed. The fertilisers and manure types mentioned in that report were acquired by merging answers given by selected informants, mainly experienced advisors in ten partner countries, focussing on important crops where significant inputs of plant protection inputs and fertilisers were to be expected. However, the mapping was not a comprehensive review of all commercial fertilisers and manure products used in organic agriculture in these countries. The analysis below shows the most relevant fertilisation inputs used in some important crops per country. From this analysis, two summary tables were made, where fertiliser inputs were divided into products made from animal-derived raw materials, and products made from plant-derived raw materials. Each group was listed alphabetically, with the same words as were used in the national mapping (Table 1 and 2). Thereafter, the recorded fertilisers were grouped into following relevant categories (Table 3). The main categories were 1) products from agricultural production (plants grown for fertilisation purpose/animal by-products), 2) marine products, 3) waste products from food processing and recycling of public waste, 4) processed animal waste, and 5) currently non-certified alternatives which might be considered acceptable for organic agriculture in the future.

2.3 Alternative fertilisers

There is a need to explore the options of using alternative fertilisers based on plant materials, AF digestates and waste products from on-farm and off-farm origin (for a list of potential fertilisers see Table 4) . Organic farmers often act as innovators and they are aware of these alternatives as can be seen from the results for Organic PLUS Deliverable 5.1 (Løes et al., 2018). However, many of the plant-based or waste-based alternatives are expensive, difficult to obtain and, in many cases, needs further research on their properties as fertilisers (N availability, application techniques, application timings) as well as on their hygienic and environmental risks.

Besides animal and plant-based fertilisers from on-farm origin, a wide variety of commercial products permitted according to the EC-Regulation No 889/2008, Annex I is available on the market, in particular for horticulture and the cultivation of other high value crops. These commercial fertilisers from external sources are most often either animal-based (e.g. collagen, keratin, blood, excrements) or derived from food production (e.g. spent brewers grains, vinasse and many others). In other cases, they result from recycling processes (e.g. green waste or source-separated household waste). In the current assessment, we group, evaluate and assess these fertilisers based on their main constituents. Doing this on a product basis would exceed the scope of this review due to the constant changes in commercial

products entering and leaving the market in the different countries. Besides the fertilisers from biological origin, there is a long list of mineral fertilisers allowed in organic farming. There are open access databases where these can be found:
FIBL-DE, https://www.betriebsmittelliste.de/de/bml-suche.html;
SEGES-DK, www.økokataloget.dk;
SKAL-NL, www.skal.nl/inputs
See also Annex I.

To increase the knowledge on alternative fertilisers for organic farming, literature has been reviewed on documentation of nutritional effect, economy, feasibility and possible environmental drawbacks. Some examples of trustworthy literature, are presented in Table 4 and a classification according to nutrient availability in Table 5.

Table 1. Summary of current use of manure fertilisers of animal origin, extracted from tables in D5.1 (Løes et al., 2018).

Manure and fertiliser of animal origin	**Organic Y/N**	**Country**
Blood meal	N	F
Bone meal	N	DK
Cattle manure	Y	F, IT
Chicken manure	Y	DK, GR
Commercially available vermicompost	Y	TU
Compost made from plants + farmyard manure	Y	TU
Composted manure	Y	DE, NO, PO, TU
Composted sheep manure	Y	ES
Cow manure, composted with grass cuts and wood chips	Y	DK
Dehydrated manure pellets	Y	F, UK
Hydrolysed fish protein (likely a liquid)	Y?	UK
Horse muck from local stables	Y	UK
Meat, blood, bone, hoof, feather and horn meals		UK, GE, F
Pig slurry	NO	DK
Pork silk		F
Florapell (commercial wool product)	N	DE
Bioilsa (feather meal, pig bristles, oil press cakes)	N	GR
Agrimartin Fe biológico	?	GR
Azomin	?	GR

Table 2. Summary of current use of non-animal fertilisers extracted from tables in D5.1 (Løes et al., 2018).

Fertiliser Biological origin	**Organic Y/N**	**Country**
Alfalfa pellets	Y	DK
Compost tea	Y	TU
Grass cuttings from between rows	Y	NO
Green fertilisers (lupin, Lucerne etc.)	Y	PO
Green manure, vetches or vetch + barley	Y	TU
Green waste products	Y	UK
Maccerated nettles	Y	PO
Mulched grass cuttings	Y	S
Plant debris	Y	S
Plant extracts on leaves: nettle, seaweed	Y	GR
Plant-based products	Y	UK
Seaweed extract	N	S
Seaweed fertiliser	N	F
Supplementing fertiliser, plant derived	Y	NO
Vinasse products	N	IT, NO
Vinasse, protamylasse	N	DK
Dualspore activator	?	GR
Betabio full	?	GR
Florovit	?	PO

Table 3. Alternative fertilisers grouped into categories

Categories	Subcategories
Plant based fertilisers	
	Fresh “cut and carry” biomass (grass clover, alfalfa)
	Silage (grass clover, alfalfa)
	Legume grits or meal (lupine, field bean, peas, vetches)
	Dense seeding of whole legume grains (lupine, field bean, peas, vetches) followed by tillage and planting in mulch
	Living mulches
	Green manure compost
	Green manure on-site decomposition
	Plant extracts and fermented plant solutions
	Plant-based biogas digestates (grass clover, maize etc.), liquid and solid
Marine Products	
	Seaweed fertiliser
	Seaweed extract
	Algae hydrolysates and extracts
By-products of food production	
	Cocoa husks
	Ground coffee
	Vinasse (sugar cane or sugar beet)
	Press cakes from oil extraction (rapeseed, mustard, linseed, camelina, soy, sun-flower)
	Mash from cereals, potatoes, maize
	Spent brewers’ grains
	Protein and other residues from starch production (potato-, cereal-, maize based)
	By-products of tofu production (okara, soy milk whey)
	Pomace (juice, wine and spirit production)
Residues from technical processes and recycling	
	castor cake from technical oil production
	Residues from penicillium production
	Green waste (public parks, house gardens, etc.)
	Green waste composts
	Composts from household waste
	Biogas digestates from household waste (liquid and solid)
Fertilisers from animal origin	
	Meal or pellets of bone/feather/hide/blood/meat
	Vermicompost
	Poultry pellets
	Digestate from animal origin biogas
Not certified alternatives	
	Sewage products
	Stripped nitrogen
	Fish manure, biochar products (including hydrochar)
	Biochar

Table 4. Key Literature on alternative fertilisers classified by theme **a)** effectiveness **b)** Feasibility **c)** Economy **d)** Drawback (pollution, leaching, climate, energy, etc.).

Categories	**Subcategories**	
Plant based fertilisers		
	Fresh "cut and carry" biomass (grass clover, alfalfa)	
Sørensen and Thorup-Kristensen, 2011 **a) b)**	Plant-based fertilisers for organic vegetable production.	Field experiments with fresh, ensiled, or dry green manure applied to leek and celery showed that the C:N ratio must be low to get a fast response. Further, these field experiments demonstrate the importance of green manures, which can be stored and are easy to handle during transport, crop application, and soil incorporation. It is concluded that it is possible to produce green manures with high concentrations of S, P, K, and B, and low C:N ratios and that these properties have a great impact on the value of the green manure for vegetable production.
	Silage (grass clover, alfalfa)	
Möller and Schultheiß, 2014		Table 5
	Legume grits or meal (lupine, field bean, peas, vetches)	
Möller and Schultheiß, 2014		Table 5
	Green manure compost	
Thomas Kupper et al., 2014 **d)**	Heavy metals in source-separated compost and digestates.	Since heavy metal inputs induced by application of compost and digestates do not necessarily correlate with adverse effects to the soil environment, it seems likely, however, that the various beneficial effects due to the agricultural utilization of these amendments outweigh potential risks related to heavy metals.
	Plant-based biogas digestates (grass clover, maize etc.), both liquid and solid	
De Notaris et al., 2018 **a)**	Nitrogen fertiliser replacement value of digestates from three green manures.	High proportion of legumes and a frequent cutting strategy can ensure a high total N concentration (based on DM (Dry matter)) in the plant material leading to a high NFRV (Nitrogen Fertiliser Replacement Value) of the digestate. In general, anaerobic digestion increased the NFRV of green manure biomass, with a stronger effect for the material with the lowest N concentration (based on DM). In general, NFRV was 46–173% higher in spring barley than winter wheat, due to the different application method and timing, which reflect the common practices in Denmark.
Frøseth et al., 2014 **a) b) d)**	Effects of green manure herbage management and its digestate from biogas production on barley yield, N recovery, soil structure and earthworm population.	Depending on the site, removal of green manure herbage reduced the barley grain yield by 0% to 33% compared to leaving it on-site. Applying digestate, containing 45% of the N in harvested herbage, as fertiliser for barley gave the same yields as. When all herbage was mulched the preceding season. Overall, the apparent N recovery was enhanced from 7% when all herbage was mulched, to 16% when returned as digestate. A positive effect on earthworm density and biomass were seen after one season of retaining mulch material, rather than removing it.

		Digestate did not affect the earthworm population but contributed to higher soil aggregate stability. The digestate strategy increased N recovery and reduced the risk of N losses.
	Grass clover and alfalfa pellets, meals, cobs	
Möller and Schultheiß, 2014		Table 5
By-products of food production		
	Vinasse (sugar cane or sugar beet)	
Tejada and Gonzalez, 2006 **a)**	The objective of the paper was to study the effect of foliar fertilization by sugar beet vinasse at different doses on maize production and grain quality.	It can be concluded that under the experimental studied during three experimental seasons, the foliar fertilization with BV produced significant increase in maize yield and grain quality.
Tejada and Gonzalez, 2005 **a)**	Beet vinasse applied to wheat under dryland condition affects soil properties and yield.	The results showed that at low doses, beet vinasse is of agricultural interest due mainly to its organic matter concentration. The application of this by-product to the soil increased soil microbial biomass and mineralization of its organic matter increased NO_3^-–N concentrations in soil. This caused an increase in grain yield in the three seasons. When the vinasse was applied with high doses NO_3^-N concentrations in soil, soil microbial biomass, soil structure, bulk density, electric conductivity, nutrient uptake, crop yield and grain quality was negatively affected.
Tejada et al., 2008 **a)**	Application of a green manure and green manure composted with beet vinasse on soil restoration: Effects on soil property.	When BV was co-composted with a green manure (*Trifolium pratense* L.)(TP), principally at a 2:1 rate, the resulting compost had a positive effect on soil physical and biological properties. After four years, the percentage of plant cover decreased 64.3% in the BV-amended plots respect to the control soil, whereas increased 82.8%, 81.6% and 81% in the (TP + BV)2, (TP + BV)1 and TP treatments, respectively. While the application of BV deteriorates the soil and therefore does not contribute to its restoration, the application of TP, and BV composted with TP protects the soil and will contribute to its restoration.
	Press cakes from oil extraction (rapeseed, mustard, linseed, camelina, soy, sunflower)	
Möller and Schultheiß (2014)		Table 5
	Mash from cereals, potatoes, maize	
Möller and Schultheiß (2014)		Table 5
	Spent brewers' grains	
Möller and Schultheiß (2014)		Table 5
	Protein and other residues from starch production (potato-, cereal-, maize based), proteamylasse	
Landsforsøgene (Field trials in Denmark) 2015, 2016. **a)**		2016: In the field trials there were a high utilisation of potassium in 2015 and 2016. 2015: Concentrated potato-starch waste water containing 11 kg N, 2 kg P, 2 kg Mg, and 4 kg S per tons (25% DM). Nitrogen efficiency is high (80%).

		Pomace (juice, wine and spirit production)
Möller and Schultheiß (2014)		Table 5
Residues from other technical processes and recycling		
	Green waste (public parks, house gardens, etc.)	
Casper Laursen, 2018		Fact sheet: Garden and Park waste. The N-content of the compost is relatively high however the availability is low. The compost can contain non-compostable material such as plastic.
	Green waste composts	
Möller and Schultheiß (2014)		Table 5
	Composts from household waste	
Jayet and Petel, 2015 **a) c)**	Economic valuation of the nitrogen content of urban organic residue by the agricultural sector.	Per tonne valuation of raw UOR (Urban Organic Residue - Urban organic residue (UOR) is the biodegradable part of household and yard wastes, including the organic residues in wastewater.) for farming system use ranges from €1.5 to €7. Mineral fertiliser demand decreases by 18% in the case of optimal UOR sharing between regional farming systems, which leads to an 8.7% reduction in agricultural N_2O emissions. Moreover, the per hectare gross marginal output increases by €39 for the region's utilised agricultural area.
Haraldsen et al., 2011 **a) d)**	Liquid digestate from anaerobic treatment of source-separated household waste as fertilizer to barley.	There was significantly increased leaching of nitrate N from the treatments receiving 160 kg N ha^{-1} of CN and NLAD (nitrified liquid anaerobic digestate) in comparison with all the other organic fertilisers. In this study LAD (Liquid anaerobic digestate – sourced from separated household waste) performed to the same degree as Fullgjødse NPK fertiliser and it was concluded that LAD can be recommended as fertiliser for cereals. Nitrification of the ammonium N in the digestate caused significantly increased nitrate leaching and cannot be recommended.
	Biogas digestates from household waste (liquid and solid)	
Möller and Schultheiß (2014)		Table 5
Not organically certified alternatives		
	Sewage products	
Pedersen et al., 2019	Assessment of risks related to agricultural use of sewage sludge, pig and cattle slurry.	Based on the review, it is the expert opinion that sewage sludge does not represent a higher risk for propagation and transmission of antibiotic resistance than animal manure, and propagation from sludge or slurries via soil to humans most likely represent a much lower risk as compared to international travel.
	Struvite	
EC2016		
	Stripped nitrogen	

(Melse and Ogink, 2005)		In the last years, a number of methods of nitrogen capture have been developed, in order to eliminate substances such as ammonia from gases and/or liquids. The primary motivation is to clean the air or slurry, for purposes such as workplace safety, environmental protection and preservation of installations (ammonia is corrosive). The by-products of nitrogen capture are nitrogen-rich substances, which may be used as fertilisers.
	Fish manure, biochar products (including hydrochar) Biochar	
Fertiliser from animal origin		
		Bone/feather/hide/blood/meat
Möller and Schultheiß (2014)		Table xx
		Poultry pellets
Landsforsøgene (Fieldtrials) Denmark.		Different kinds of poultry pellets have been tested over the years. The commercial products usually contain 4-1-3 (N, P, K, kg /tons) with a Nitrogen efficiency of 60% for the first year of application

Table 5. Classification of fertilisers based on origin (animal vs. plants) and internal (on-farm production) and external (commercially available) and their nutrient efficiencies and environmental risks

Fertiliser	**N % DM**	**NH_4^+-N % DM**	**C/N ratio**	**N-Availability %[1)]**	**N-Efficiency %[2)]**	**P % DM**	**K % DM**	**mg Cd kg^{-1} P[3)]**
Animal based fertilisers								
Cattle manure	2.27	0.36	23.6	10-20	60	0.52	3.21	68.2
Horn products	14.9	0.47	3.3	75-80	80	0.31	0.24	109
Blood meal	14.2	0.85	3.5	70-80	80	0.42	0.50	26.9
Wool	11.0	0.13	3.7	50-60	75	0.03	0.07	686
Plant based fertilisers - on-farm origin								
Legume grains (peas, lupine, field beans)	3.96 – 5.87	n.d.	7.6-13.3	30-60	65-75	0.47-0.65	0.83-1.39	33.4-42.0
Legume based silage, meals, pellets	3.00	0.06	17.1	25-50	70	0.50	2.98	58.4
Plant based fertilisers external origin – by-products from food production								
Spent brewers grains	4.23	n.d.	8.2	n.d.	65	0.68	2.21	7.1
Press cakes from oil production	5.74-7.61	0.01	5.3-8.4	40-60	65-70	0.65-1.22	1.05-2.11	9.1
Mash	4.79-4.93	n.d.	7.9-9.7	30-40	70	0.60-0.99	1.79-6.26	36.4
Vinasse (sugar beets)	5.23	0.72	7.0	50-60	80	0.21	7.30	158
Pomace	1.20	0.10	42.3	0.10	40	0.25	1.04	-
Plant based fertilisers external origin – residues from waste recycling								

Compost from household waste	1.45	0.05	15.5	0-10	40	0.31	0.98	113
Compost from green waste	1.15	0.01	19.6	0-10	40	0.22	0.85	184
Biogas residue from household waste (solid)	1.84	0.13	13.6	10-20	60	0.60	1.32	47.8
Biogas residue from household waste (liquid)	4.47	1.55	8.6	50-60	80	0.68	3.24	24.7

[1]Short term availability in the year of application, [2]Long-term availability (N availability in the year of application + N availability in the following years), [3]Fertilisers with > 137 mg Cd per kg P applied led to a long-term enrichment of Cd in the soil, DM: Dry matter

2.4 Vegan' 'organic' fertilisers – Definitions & issues with labelling

2.4.1 Fertilisers used by vegan (organic) farms

There are broadly two types of vegan organic fertilisers: those which are commercially available (online, shops, see next section) and those which can be produced on-farm or sourced locally to the farm e.g. from forestry, agroforestry, nearby beaches (in terms of maritime resources) or by-products from local food or biomass processing industry.

Several possible vegan fertilisers are currently not acceptable under EU organic regulations e.g. urine and humanure (Price, 2009), or are presently under discussion e.g. vermicompost. Rutherford-Fortunati (2012) showed that a large number of commercial vegan fertiliser products are available. This author also encouraged composting as well as on-site vermicomposting. However, the private standard organisation *The Vegan Society* "understands the word 'animal' to refer to the entire animal kingdom, that is all vertebrates and all multicellular invertebrates", and further states that "The manufacture and/or development of the product, and where applicable its ingredients, must not involve, or have involved, the use of any animal product, by-product or derivative", and therefore vermicompost as a source of nutrients is not accepted (The Vegan Society, 2019).

Examples of on-farm produced or locally sourced fertilisers:

- Green manure crops or hay mulches
- Meal of crops e.g. lucerne, soybean, field beans specifically grown as fertiliser
- Leaves and prunings from trees or agroforestry and specifically grown as fertiliser
- Compost
- Biocyclic humus soil
- Compost teas
- Seaweed (if near the sea)
- By products of local processing brewers grain (spent malt), lavender
- Digestate from anaerobic digestion fed with certified organic inputs

Examples of currently not accepted fertilisers:

- Not allowed in certified organic but used in non-certified organic: human urine http://veganorganic.net/fertilizing-with-human-urine/

- Humanure
- Vermicompost (in discussion - accepted by some excluded by others)

Commercial fertilisers – see next section

2.4.2 Commercial fertilisers - current use of the terms ‘vegan’ and ‘organic’ within the EU legal framework

There are many fertilisers on the market which are called **organic**, because they have or may have organic ingredients, but they are <u>not</u> sourced form certified organic sources. This can be confusing to consumers. The ingredients are often not clearly labelled and explained, despite the fact that claims of suitability for organic farming or growing are being made.

Example 1 Green Future Organic Garden Fertiliser (Figure 1). It claims: *“this product is ideal for use in ecological growing”* but then it lists three ingredients which are not sourced from organic agriculture or from any other certified sustainable source:

- *“Refined organic nutrients”* - these could be from animal residues, or possibly petroleum refinery?
- *“humic and fluvic acids”* - where are they sourced from?
- *“kelp extracts”* - it the kelp sourced sustainably as a marine bio-fertiliser?

Figure 1: Example of misleading and confusing consumer labelling

There is EU regulation which captures product safety. For this specific product the ‘Safety Data Sheet’ contains information concerning the potential risks to those involved in handling, transporting and working with the material, as well as describing potential risks to the consumer and the environment. This information must be made available to those who may come into contact with the material or are responsible for the use of the material. This Safety Data Sheet is prepared in accordance with formatting described in the Regulation (EU) No 453/2010, and described in CLP Regulation (EC) No 1272/2008. For this specific product the information is:

> Section 2. Hazards Identification: MIXTURE: 2.1 Classification of the mixture
> *No classification required* in accordance with Directive 67/548/EEC and Regulation EC No. 1272/2008
> Section 3. Composition/Information on ingredients: *No information on % composition and name of ingredient is required.*
>
> (Source: Growth Technology Ltd., Taunton, Somerset, TA2 6BX, United Kingdom, Green Future Organic Nutrients Version 1, 31 July 2013, online available at www.focus-on-plants.com/modules/downloads/download.php?file_name=21)

In conclusion, this product can currently be legally sold with the information given and the claims made being "*organic*", "*green future*" and "*ideal for use in ecological* (organic/biological) *growing*", despite the fact that the real source of the ingredients is hidden and no ingredients are from a certified organic origin.

Example 2 An organic fertiliser labelled with a Vegan label (Figure 2). Again, the product ingredients are not given. It is stated that it is "*a plant-based alternative to animal-based fertiliser"* assuming it is totally plant based. (Source: Fruit Hill Farm, Colomane, County Cork, P75 HV08, Ireland www.fruithill-farm.com/soil-plant-food/organic-fertilisers/vegan-plant-based-fertilizer-5-3-8.html)

Figure 2: Complete Organic Fertiliser 5:3:8 (Vegan) with Vegan label

Further information can be found based on product data required in accordance with the fertiliser declaration (Regulation EC 2003/2003 European fertilisers). It gives the N-P-K and micro-nutrient composition, the organic matter content and the treatment aids. Here the only specific ingredient information is: *"contains Vinasse as a pelletising aid"*. Vinasse is a by-product of conventional sugar-beet production, which requires intensive herbicide and insecticide use. Vinasse is currently allowed under EU organic regulation but considered as a contentious input.

Again, the product can be legally sold as **organic** fertiliser with the word **vegan**, despite the fact that it is not clearly stated on the product that 100% of the ingredients are not animal based, and that no ingredients are derived from certified organic farming or without animal manure in its production. The only product which has to be specified is the pelletising aid (Vinasse).

2.4.3 Vegan logo

The Vegan logo (registered as the Vegan Society Trademark) and shown in Figure 2 is a private standard held by the Vegan Society (The Vegan Society, 2019). The following information is given there regarding the criteria to be eligible for registration.

> *"Animal ingredients*
> The manufacture and/or development of the product, and where applicable its ingredients, must not involve, or have involved, the use of any animal product, by-product or derivative.
>
> *Animal testing*
> The development and/or manufacture of the product, and where applicable its ingredients, must not involve, or have involved, testing of any sort on animals conducted at the initiative of the company or on its behalf, or by parties over whom the company has effective control.
>
> *Genetically Modified Organisms*
> The development and/or production of genetically modified organisms (GMO) must not have involved animal genes or animal-derived substances. Products put forward for registration which contain or may contain any GMOs must be labelled as such".
>
> "The Trademark licence run for 12 or 24 month and the annual fee is linked to number of products and company turnover… Products that are at high-risk of cross contamination with non-vegan ingredients are liable to be audited, to ensure that consumers can trust the Vegan Trademark registered products".

Based on this information, the consumer could expect a product 100% free of animal ingredients, animal testing and GMO's with animal genes. Other GMOs involving plant genetic modification are apparently acceptable, if labelled. This is a clear difference from certified organic production, where no GMOs are accepted, neither plant, animal or human genes being used in modification of any product.

Consumers could also expect that in the production and growing of, for example, a legume fertiliser no manure or animal derived fertiliser is to be used ("*manufacture and/or development of the product, and where applicable its ingredients, must not involve, or have involved, the use of any animal product, by-product or derivative"*). This is however not clearly stated, and potentially confusing to consumers. Completely "animal-free" production systems can include conventional manure and insecticides and molluscicides with are specifically designed to harm animals. Even when certified such production organic may well still include the use of contentious inputs (e.g. copper. sulphur and mineral oils) killing insects and affecting agro-biodiversity.

2.4.4 Vegan organic standards

Vegan and Organic standards combine the values of vegan and organic consumers. The Stockfree-Organic standard (Vegan Organic Network, 2007) was the first vegan organic standard in the world written in 2007 in the United Kingdom. This was described and discussed at the 3rd International Symposium on Organic Greenhouse Horticulture in Turkey 2016 (Schmutz and Foresi, 2017). Since then, in November 2017, a second standard, the Biocyclic-Vegan standard, based on work in Germany and Greece has become available worldwide as a global IFOAM (International Federation of Organic Agriculture Movements) stand-alone standard. The Biocyclic Standard goes back on earlier work since 2005 by the Biocyclic Network Services in Greece and Cyprus. The IFOAM accredited standard focusses on vegan organic fertilisers produced *on-farm* and ‘biocyclic humus soil’. ‘Biocyclic humus soil’ is a key part of the standard and defined as compost which has undergone a post-maturing process leading to a soil-like state beyond substrate maturity. In order to obtain humus soil on the basis of a purely plant-based compost it requires a controlled rotting process and a longer post-maturing period. This standard does not exclude the use of contentious input pesticides currently permitted in organic farming, such as copper, sulphur and mineral oils (Biocyclic Vegan Standards 2017).

Commercial fertilisers (according to Biocyclic Annex A) can be from conventional sources, similar to those certified for organic agriculture. For products where organic certification is available (e.g. seaweeds and seaweed products) or for potentially treated products (e.g. sawdust and wood chips, composted bark, wood ash) no specific mention of untreated material or sustainable sourcing certification is made. The products allowed in Annex B also include ‘potent 10% N’ fertilisers e.g. the product BIocat-G from Atlantica (Figure 3). The label only states high content of organic matter, humic and fluvic acids. No source of the material and its sustainability is given so consumers of vegan organic fruit and vegetables may wonder why those ‘contentious inputs’ are used in Biocyclic vegan agriculture.

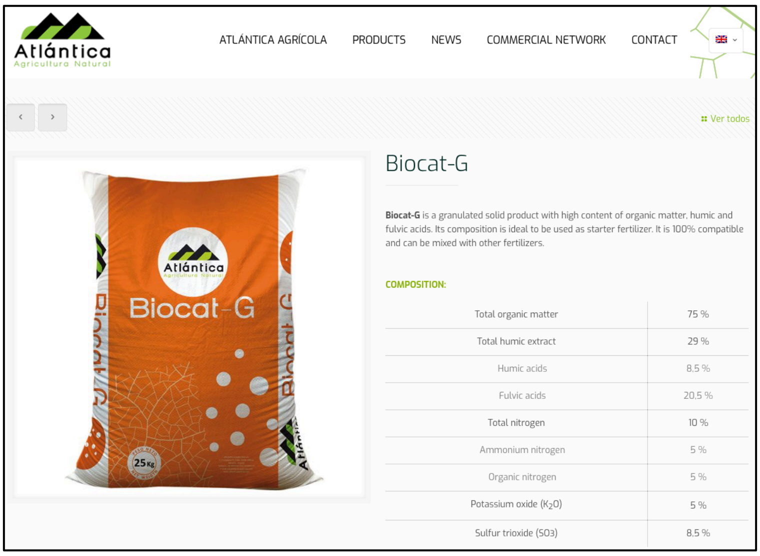

Figure 3: Example of a product allowed in Biocyclic vegan standards

Fertilisers derived from seaweed and other non-animal marine ingredients are of special relevance for vegan production. In the US, a good certification system has been developed for seaweed fertiliser products, by the Organic Materials Research Institute (OMRI, 2019). Three products are returned as vegan or veganic and they have a ‘OMRI certificate’ (Figure 4) showing they can be used in certified organic farming. Still, such products may include ingredients from non-organic farming.


OMRI Listed®

The following product is OMRI Listed. It may be used in certified organic production or food processing and handling according to the USDA National Organic Program regulations.

Product
Down To Earth Vegan Mix 3-2-2 All Natural Fertilizer

Company
Down To Earth Distributors, Inc.
Chris Bradway
P.O. Box 1419
Eugene OR 97440 United States

Status	Category	Issue date
Allowed	NOP: Fertilizers, Blended	21-Feb-2017
Product number	**Class**	**Expiration date**
det-7955	Crop Fertilizers and Soil Amendments	01-Jun-2019

Restrictions
Not applicable.

Peggy Miars
Executive Director/CEO

Product review is conducted according to the policies in the current *OMRI Policy Manual©* and based on the standards in the current *OMRI Standards Manual©*. To verify the current status of this or any OMRI Listed product, view the most current version of the *OMRI Products List©* at OMRI.org. OMRI listing is not equivalent to organic certification and is not a product endorsement. It cannot be construed as such. Final decisions on the acceptability of a product for use in a certified organic system are the responsibility of a USDA accredited certification agent. It is the operator's responsibility to properly use the product, including following any restrictions.

OMRI LISTED For Organic Use

Organic Materials Review Institute
P.O. Box 11558, Eugene, OR 97440-3758, USA
541.343.7600 · info@omri.org · OMRI.org

Figure 4: Example of an OMRI certificate for a vegan Mix 3-2-2 fertiliser allowed in the Class of Crop Fertilisers and Soil Amendments.

2.4.5 Conclusions

Regarding vegan and organic fertilisers, we conclude that there is a labelling gap. The broad use of the word 'organic' is confusing when it refers to organic materials, but not certified according to regulations for organic production. However, as shown here, the use of plant-derived nutrients is sourced from conventional sources not only in vegan organic or biocyclic vegan growing, but also in current certified organic farming following the EU organic regulation.
With the growth of the vegan and organic markets, consumers may ask more detailed questions than before. Concurrently, consumers know less about food production and opinions get more extreme. In any case, more transparency would be welcome. Those purchasing a fertiliser product should be informed about the contents and the sources they are derived from.

We summarise that 'vegan' 'organic' fertilisers according to the current legal situation are fertilisers accepted by the current certified vegan organic standards, which are by 2019 the Vegan Organic Standard and the Biocyclic Vegan Standard as approved by IFOAM. They must also be permitted by the EU regulation on organic production, and in addition have no animal sourced ingredients.

2.4.6 Going forward

Vegan organic could be a frontrunner to demand labelling changes by the EU legislator so that the use of the word “organic” actually refers to certified organic production, when inputs are assessed and labelled.

In addition, vegan organic private standards could phase-out all conventional derived plant fertilisers and help to create a market for certified organic inputs. That would imply that a certified ‘vegan‘ ‘organic’ fertilisers `would be made exclusively with ingredients from certified organic farming, e.g.:

- Legume pellets (from certified organic legumes) mixed with seaweed (certified organic) and rock salt (salt cannot be certified organic).
- Comfrey pellets certified organic, meaning from comfrey grown to organic standards

2.5 Discussion

When mapping the use of fertiliser inputs in the 10 countries participating in this project activity (Løes et al., 2018), our aim was to reveal the types, rather than the amounts of fertilisers being applied for important crops in various countries. We found that the application of commercial certified organic fertiliser products seems to be higher in some countries, e.g. Greece, whereas other countries use much less. This may be explained by economic conditions of the growers, cultural differences (less livestock), by the extent of organic production and development of a market for such products, by the availability of national fertiliser companies and by other factors. Information about raw materials used to produce these fertilisers is commonly not readily available but may sometimes be found under information about the company’s history. These website sections also reveal that mergers of fertiliser companies often occur.

Many fertiliser products seem to be derived from residuals from sugar or starch production. Horn grit, meat and bone meal, blood meal and feather meals are well known organic fertilisers but were not so much observed in this study. Instead, we observed that animal hides are an important raw material for organic N fertilisers. Seaweed products are quite common, whereas fish-based products were only mentioned from UK. Non-organic manure (from conventional farms) is used in nearly all countries, commonly as pelletised dry poultry manure, but also as manure or slurry or digestate.

A hierarchy of fertilisers could be made to identify the most contentious ones. In some countries, the national certification bodies are phasing out some problematic fertilisers. For instance, BioAustria, the largest organic farmers’ association in Austria, has developed a ranking for fertilisers from conventional agriculture to be phased out until 2020. Criteria for this ranking is the source of origin, processing, risk of contents of pollutants etc., sustainability and effect as a fertiliser. Since 2015, the products “Biosol”, pellets from fur and bristles (Haarmehlpellets in German), and particles of horn (Horngries, Hornmehl, Hornspäne) are not permitted (BioAustria, 2019). Biosol (6-8% total N, granules), produced in Austria by Sandoz company, is produced from agricultural raw materials containing proteins, sugar, syrups, trace elements and vitamins which are converted to fungal biomass by means of a fungi, *Penicillium chrysogenum*.

2.5.1 Management to prevent the use of contentious inputs

Legume/grass leys, legumes as short-term green manures or as mobile fertilisers (fresh biomass for mulching, silage, pellets) could serve as an option to reduce external nutrient fluxes from conventional farming as legumes are the most important source for N inputs in organic farming. The use as mobile fertilisers enhances N fixation by cutting and removal of the biomass. If only mulched on site, N fixation will be reduced (Helmert et al. 2003; Stinner et al. 2008) and N_2O emissions may increase (Helmert et al. 2004). In a pot trial, silage from grass clover and freshly cut grass clover biomass showed steady mineralisation and N release (Benke et al. 2017). Legume based fertilisers are available options which do not include off-farm inputs and which can be fully controlled by the organic farmer. In particular, in stockless arable and horticultural systems or in stock-free vegan farming the use of dedicated 'mobile' legume grasses can replace the use of forage crops.

In addition, due to their composition of N, P and K these fertilisers are suitable for intensive horticultural systems as they match the nutrient demand of many vegetables (van der Burgt et al. 2013) leading to a more balanced nutrient supply. However, N-availability in the year of application is lower than that of animal based commercial fertilisers like keratin products (Tab. 9) which may render silage as well as clover grass pellets unsuitable for high N demanding crops like e.g. cauliflower, cabbage or broccoli. Therefore, new strategies for horticultural crops with a high N demand in a short time or prolonged during the whole growing season are needed.

Besides legume grass leys grain legumes (vetches, field beans, peas) may also serve as mobile alternative fertilisers which can be produced on farm. These grain legumes are usually grown within arable rotations, are threshed and milled afterwards to grits or meal in order to enhance mineralisation and prevent germination. For cost reasons their use is not feasible for arable crops but for high value horticultural crops. Even though their N availability is lower than the one of animal based commercial products like horn grit (Table 5), they are suitable fertilisers for vegetable production (Müller and Fragstein von Niemstorff, 2006a, 2006b, Li et al. 2015).

2.5.2 Anaerobic fermentation of manure or plant materials.

Biogas digestates show similar properties, but much higher N availability in the year of application compared to fertilisers like farmyard manure or compost due to their high contents of NH_4^+-N (Table 5). These fertilisers are interesting for arable farming in cold countries, as the lack of mineralisation in the spring, limits yield. Digestates could also be an option for intensive organic farming systems like horticulture. In addition, improved long-term N efficiency is maintained due to lower N losses during the fertiliser treatment compared to manure, slurry and composts (Benke et al. 2017). However, such fertilisers, especially from urban origin (household waste, food waste), may face regulatory challenges (Farrell and Jones, 2010) as their permission for organic farming is not always provided and high demands on hygiene and microbiological risk assessment exist which are not applied to animal manures and slurries. Also glass and plastic remains can be found in the material. The often-mentioned concern of losses of carbon in the biogas process is not an issue; research has shown the easily decomposed part of the carbon (which is converted to methane) would under all circumstances be oxidised quickly when incorporated in the soil.

2.5.3 Mineral composition

Often the combination of nutrients in the alternative fertilisers is not optimal (e.g. too much P, too little K in legume grits causing problems in horticulture) and there is a need for specific care with application with extra potassium (Patentkali) in order to balance K losses. However, some of the fertilisers e.g. biogas residues show better fits of the nutrients (lower N losses compared to composting and manure storage). Vinasse from sugar production is another alternative that serves the K-needs of vegetable crops and can be easily applied in fertigation systems as it is one of the few liquid fertilisers available in organic farming. However, the vinasse currently on the market is derived from conventional sugar production. In intensive horticultural systems – those organic systems that use currently the largest share of commercial fertilisers from contentious inputs – N availability is often the yield determining factor. If a farmer tries to avoid contentious inputs e.g. by using composts from green waste or household waste with low N availabilities and a too high P content as a base dressing, an additional N source as top dressing is still needed to comply with crop demand. Currently, keratin based products are the only fertilisers that can supply N without adding too much P. None of the plant based alternatives can fulfil this demand as they are all multiple nutrient fertilisers. Contrary to intensive horticultural systems, organic arable farming systems, especially when managed stockless or with low livestock numbers, are very often characterised by very low P and K inputs. In the long run, this will lead to unsustainable nutrient mining. Fertilisers from urban waste cycles could be a solution for this – the former animal-based on-farm-recycling of nutrients will be extended to urban consumers. This approach includes, however, several difficulties: 1) The fertilisers from urban sources can never be fully organic unless all agriculture globally is done organically, 2) some of the materials may pose environmental risks (e.g. sewage products or even composts due to their contamination with plastic particles) and may be prohibited from organic farming and 3) these fertilisers are often bulky or contain high amounts of water and low nutrient densities at the same time which makes transport from too costly for arable production. Therefore, research is still needed to design nutrient management strategies that maintain balanced nutrient flows without using contentious inputs.

2.5.4 Technical problems

Other options besides legume grass leys as described above is the integration of clover species in cropping systems as undersown crops or in intercropping systems as living mulches. In arable systems, e.g. in organic maize production these systems are well established in Central Europe and lead to good results in nutrient acquisition, erosion control, weed control and yields of the main crop. In horticultural crops, however, it seems to depend very much on location, climatic condition and timing of seeding of the mulch or planting of the main crop whether such systems work or not. For example, Canali et al. (2018) found similar yield levels of broccoli in different organic systems in Central and Southern Europe when the leguminous living mulches were sown after planting of the main crop. If the living mulch was already established before the main crop was planted, major yield differences occurred due to competition of the living mulch with the main crop. Other authors, e.g. Bath et al. (2008) describe that additional measures like root pruning are necessary to maintain the yield level of the main crop, in this case cabbage. So far, these systems are not yet fully developed to be implemented in practice. In addition, intercropping of living mulches with vegetables in strips decreases the number of crop plants per unit area, which may render such systems unfeasible for farmers (Thorup-Kristensen et al. 2012). Under drier conditions (e.g. Mediterranean climates), water use by green manures (as pre-crop or living mulch) may pose another constraint to the applicability of such systems. As intercropping with legumes restrict tillage, a reduced N mineralisation may lead to low yield levels in cool and humid climates as described for reduced tillage systems in organic farming by Cooper et al. 2014.

2.5.5 Economic assessment

For the farm-based alternatives (e.g. silage) prices per kg N still need to be quantified (e.g. labour and machinery requirements). Grain legume grits/meals (at least in Germany) can be a real alternative as costs are comparable to commercial plant based fertilisers e.g. Maltaflor (Hummel et al. 2011). Availability, however, is sometimes a constraint (e.g. for plant based biogas products).

2.5.6 Environmental assessment

Life cycle assessments on specific fertilisers could give a good overview of the environmental impact. Some products can be found in the eco-invent database, but many are missing. In the literature that was assessed some environmental hazards for alternatives have been mentioned. This can be excessive energy consumption (making pellets out of grass etc.), heavy metal pollution (manure and pig slurry, household waste), problems with emissions of methane and ammonia (digestate storage). Climate issues should also be considered, as both energy and nitrogen efficiency (balance and leaching) can be severe, also for alternatives. In the Organic-PLUS project these issues will be addressed in WP 6.

2.5.7 Ethical aspects

For many of the fertilisers discussed above, competing uses exist, mainly for those that are nutrient-dense and contain low amounts of water which eases transport: Many by-products from food industries serve as animal feed (e.g. press-cakes, mash, pomace, tofu whey) as do some of the fertilisers produced on-farm (legume grits, legume pellets). In particular, while we aim at using fertilisers from organic origin only and at the same time shortages of organically produced protein still exist - especially for monogastrics – in order to maintain animal health and organic integrity, using such fertilisers also introduces ethical problems. When growing legume grits for fertilisation, additional land area is needed and it is questionable if it is possible to cover a large proportion of the N demand of organic cropping systems using such fertilisers. Fresh or ensiled legume grass mixtures are less problematic as they are usually only used as fertilisers if no other uses in animal husbandry exist in closer neighbourhood of the farm, otherwise organic farmers will exchange fodder with manure and avoid contentious inputs anyway.

2.6 Literature on alternatives

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2.7 Annex

Proprietary names of permitted fertilisers in various countries can be found on the following online-sources:

Denmark:
www.landbrugsinfo.dk/Oekologi/Planteavl/Goedskning/Sider/oe_17_3694_opdateretversion-vaerktoej-til-valg-goedninger.aspx

Germany:
www.betriebsmittelliste.de/de/bml-startseite.html

Greece:
www.minagric.gr/index.php/el/for-farmer-2/crop-production/lipasmata/278-mitroa

Italy
www.sian.it/vismiko/jsp/indexConsultazione.do

Norway:
https://debio.no/driftsmiddelregisteret/#gjodsel-og-jordforbedringsmidler

Poland:
http://iung.pl/images/pdf/Wykaz_ekologia.pdf

Spain:
http://interecoweb.com/insumos-certificados

UK:
http://ofgorganic.org/approved-input/?app-incategory%5B%5D=358&term=&company_id

3. Peat alternatives

3.1 Introduction

3.1.1 Peat use in horticulture.

Peat has several uses besides its role in growing media for containerised plant production and vegetable transplants (Caron et al., 2015). It is used as a fuel, as a bedding material in livestock production, to cover windrows of compost and as a substrate for composting toilets. Peat is also often used in mushroom production in the casing layers, where fungal mycelium proliferates (Noble et al., 2005). These are laid on top of other growing materials, which may also include peat but more often decomposing straw, manure, woodchips or other ingredients. Peat may even be used as a food supplement, for therapeutic purposes (in baths), in aquariums and as an oil binding substance. Peat as bedding material, especially for horses, has fallen out use over the last 50 years but has recently received increased attention. Especially in southern European countries, peat is used predominantly in horticulture.

The volume of growing media for plants sold in Europe has been estimated to about 37 million m^3 per year (Aleandri et al., 2015). Peat represents about 80% of this volume; about 30 million m^3 annually. This figure is quite similar to the one stated by other authors that have revealed that 32 million m^3 are used per year in European horticulture (Blievernicht et al., 2011). The use of peat in the expanding growing media industry in the European Union is estimated to be worth € 13,000 million and generates approximately 11,000 jobs (Pascual et al., 2018).

3.1.2 History of the use of growing media

The use of peat as growing media increased through the twentieth century. The specific reasons for this vary from country to country but can broadly be attributed to the discovery of new techniques for extracting peat and manufacturing growing media, and the growth of a horticultural industry directed towards gardeners as consumers. For example, in the 1960s, the Netherlands developed a technique for turning 'black bog peat' into easier to use 'garden peat' and improved trade with Germany resulted in a bigger market for this material (Gerding et al., 2015).

In the UK, the first standardised growing media recipes and production methods came about in response to an expanding horticultural industry during the 1930s and were developed primarily by the John Innes Centre in Norfolk (Alexander, 2019). These mixes were then adopted by UK manufacturers, became available for sale and increasingly used during the 1940s. John Innes mixes include ingredients such as peat and sand but are based on 'loam' (Royal Society of Horticultural Science. 2019). This loam is generally derived from turves of grass which are skimmed off the soil surface along with a few millimetres of topsoil, then stacked upside down for several months to encourage the living grass to die and decompose. This result is a media that is similar to topsoil but contains a higher percentage of organic matter. Sales of containerised plants increased through the 1950s and 1960s with peat gaining favour as a lightweight, predictable growing media. In the 1970s, the rise of large 'garden centre' retailers, resulted in sales of high-percentage peat growing media and container plants grown in peat expanding more rapidly. This growing demand for peat products resulted in increased extraction.

3.1.3 Properties of peat

Peat is relatively cost effective and much lighter than soil/loam-based mixes, making it easier to handle and much cheaper to transport than many other growing media. It has the advantages of behaving in a predictable and consistent way, being able to absorb and release nutrients from added fertilisers. It has a good water holding capacity and holds root balls together during planting (Schmutz et al., 2018). Peat is also free from weed seeds, pathogens, heavy metals and other toxic elements, so many growers are reluctant to desist in its use. However, it should be remembered that peat was not adopted over-night and users had to become accustomed to its behaviour. Peat also requires adjustment before it is suitable for use although this could be considered an advantage as the growing media producer essentially starts with a 'blank canvas':

- The pH value of extracted peat is typically around 3.5 - 5, whereas the majority of crops are suited to 5.5 - 6.5. So some form of lime (such as ground limestone) has to be added to reduce acidity
- Peat dries out quickly and is difficult to re-wet if allowed to become completely desiccated, so wetting agents are commonly added, which can be mineral, synthetic or natural products
- There are very low levels of plant nutrients in peat, so both macro- and micronutrients must be added and these are usually synthetically derived (though not in organic certified growing media blends)

3.1.4 Environmental impact of peat

Exploitation of peatlands, which are located mainly in Northern European countries, has the disad-vantage of causing severe environmental damage. Peat bogs are an important habitat for several plant and animal species, and are regarded as an important site of biodiversity (Bosse, 2017). For example, the lowland raised bogs (or mires) that develop slowly in areas of impeded drainage host a range of specially adapted vascular plants including cotton grasses *Eriophorum* spp. and increasingly scarce spe-cies such as bog rosemary *Andromeda polifolia* and the carnivorous great sundew*, Drosera anglica*. (UK Biodiversity Action Plan, 2008, Conroy, 2016).

Peat extraction is a large scale, mechanised process which involves stripping off the surface 'living layer' to expose the peat beneath, slicing channels in the exposed peat and allowing it to drain prior to removal. Any adjoining bog which has not been subjected to this process but is part of the same hydrological system will also be affected as it too will drain. This process can result in huge CO_2 emis-sions. Peat accumulates at a typical rate of just 1-2mm per year, so a 1m layer can take 1,000 years to form – it is not a renewable resource. In line with this, peat cut for fuel is classified by the EU as a fossil fuel.

For southern countries, where the quantity of high-quality peat available is low and it has to be im-ported from the north, transport adds to its environmental impact and also affects the price.

Taking into account that peat resources are declining and that organic regulations, at least private standards (e.g. Soil Association), are gradually becoming more restrictive towards the use of peat, the market for peat-free alternatives is expected to grow and further research to identify and develop appropriate alternatives is required (Freyer and Gollner, 2006). It is also true that increasing demand and rising costs for peat as a growing media in horticulture have led to a search for high-quality and low-cost alternatives. The average price of growing media shows a clear upward trend (increasing by

13% between 2006-2010) due to the increasing scarcity of peat and its non-renewable nature. This may affect the competitiveness for the nursery and greenhouse growing sector (Pascual et al., 2018).

Peat extraction is continuing, with restrictions, in several Organic-PLUS countries (e.g. Norway, Germany, Poland and the UK) but much is also imported (e.g. from Ireland and the Baltic States).

3.1.5 Regulation

EU regulations for organic production published in 2018 (EU 2018) will be implemented from January 1, 2021. These regulations, further referred to as EC 2018/848, will need detailed rules for implementation, including Annexes listing permitted inputs. The regulation 2018/848 mentions the term "peat" only once, under organic mushroom production, where it is stated that peat for mushroom substrates must not be chemically treated. This is identical to the regulation which is still used in practice, EC 889/2008 (EU 2008), where peat is also mentioned in Annex 1, Fertilisers and Soil Conditioners, as a permitted input restricted to horticulture (market gardening, floriculture, arboriculture, nursery). Regulations for organic production could well do more to restrict or eliminate peat use in organic systems, to maintain the reputation of organic production as sustainable and environmentally sound.

Concerns have been expressed about the environmental impact of extracting peat for horticulture since at least the 1980s. There has been relatively little legislative action, though some countries, e.g. Denmark, have protected remaining unexplored sites, and taken actions to reduce peat extracting activities. In 2006, the Environmental board told the company "Pinstrup Mosebrug" to stop further extraction of peat in one area, "Lille Vildmose", due to a scarcity of peatland in Denmark and EU regulations to protect habitats. The ban was brought to court, and a decision was not reached until 2018 when the company got a compensation of 40 million DKK as a refund for peat not being extracted from this site (Danmarks Radio, 2018). The Environmental Board also had to pay the costs of the court.

Some steps have also been taken in the UK - in 2010, the government set targets to phase out peat from the amateur gardening market by 2020 and from professional horticulture by 2030. These targets are voluntary and rely on the action of the industry itself, but in June 2011, the Sustainable Growing Media Task Force (which later became the Growing Media Association) was formed by members of the industry in UK to address the issue.

In June 2016, the Growing Media Association, a network organisation representing the majority of UK and some Irish suppliers of growing media into the UK horticultural market, launched the Growing Media Calculator which assesses the environmental impact of not only peat, but the other main ingredients used in growing media (Growing Media Association, 2019). Materials are scored on seven criteria: energy use, water use, social compliance, habitat and biodiversity, pollution, renewability and resource use efficiency, to give a score out of 20. The calculator looks in detail at the life cycle of materials, though it should be noted that certain aspects have been considered to be 'out of scope' such as the function of peatland as a site of carbon sequestration and the use of plastic packaging. Peat scores between 0 and 20, though higher scores are only available for peat that is proven to be recycled (up to 20) or from a site that was previously used for agriculture (up to 8). If this is not the case, the maximum available score is 5 out of 20.

3.2 Alternatives identified in Organic-PLUS Deliverable 5.1

In the framework of Organic-PLUS, the use of peat as contentious input has been mapped in selected organically produced crops in ten countries across Europe; the output of this mapping was described in Løes et al (2018). It was concluded that, for the crops that were mapped, the main utilization of peat was for production of young plants (transplants or seedlings) or strawberry production. Most organic growers purchase plants e.g. for citrus, olive and grafted tomatoes and the growing media has usually a high proportion of peat. Vegetable transplants are also commonly produced by specialist growers. Peat is also used for casing layers for organic mushrooms, and as a potting media for aromatic plants.

Informants from the organic horticultural sector were also asked about possible alternatives to peat that they use or are feasible. This information, detailed in Annexes of Løes et al (2018) is gathered in Table 6. One informant also mentioned the use of composted wild plant materials.

Table 6. Summary of alternatives to peat in growing media identified in Løes et al (2018).

Material	**Country**
Coir	UK
Sheep manure, soil and perlite	TU
Coir and perlite	S, GE
Bark, wood fibres, green waste compost and xylitol	GE
Compost and sand	DK
Bark compost	E

3.3 Alternative raw materials that can replace peat

In order to have more extensive information on alternatives to peat, relevant scientific papers and reports have been reviewed. This is summarized in Tables 7 and 8.

Whereas single products such as rock wool are often used to support root growth in soilless culture, growing media are often blends of different raw materials with complementary characteristics.

The ideal features of a growing media have been described in a recent review (Pascual et al., 2018):

- Porous enough both to easily drain excess water and to allow sufficient oxygen and carbon dioxide exchange at the root level
- Enough water holding capacity
- pH around neutrality
- Electrical conductivity feasible for root growth and seedling development
- Cation exchange capacity level able to provide nutrients for healthy plant development by creating a reservoir of available nutrients
- Appropriate level of nutrient ratios, mainly N, P and K related to C.
- Ability to hold transplants firmly in place
- Keep constant volume when wet or dry and generally retain consistent properties
- Free from weeds, nematodes, and diseases
- Easy storage for long periods of time without changes in physical and chemical properties
- Easy handling and blending

- Light in weight for easy transport to the planting site
- Low content of silt, clay, and ash

3.3.1 Main characteristics of key alternative ingredients to peat in growing media

Main peat alternatives are from wood, industrial by-products of organic materials, or composted plant materials (Eymann et al., 2015). Figure 5 illustrates various products and materials used in peat replacement that are described in Table 7.

Figure 5. Products and materials used in peat replacement

Bark compost is crushed, composted bark. Bark is a by-product of lumber production in sawmills or paper mills. This material cannot be used in its raw state because it has a high lignin content that leads to low mineralization rate and high N immobilization. The bark is shredded in a first step and then composted in windrows for about a year. If nitrogen is added to the shredded material, microbial degradation will occur, causing the temperature to rise to 70 ° C. Due to the elevated temperatures, pathogens and weed seeds are killed.

Coir or Coco fibre is the name given to the thick mesocarp or husk of the coconut fruit. When the husk is industrially processed, huge amounts of dust and short-length fibres are produced. The coir dust is commonly called coco peat (e.g. Dutch Plantin 2019). This dust may be dried, compressed into bricks or bales, wrapped and shipped for use as an organic substrate in growing media (Pascual et al., 2018). In order to obtain the substrate components coconut fibres and cocopeat, the dense fibrous web is first removed from the fruits. Then there are several ways to separate the fibres and the cocopeat. By 'retting' or rotting is meant the process of fibre extraction by fibber pulping - the shells are softened for several weeks or months in water to separate the fibres separate from the dust. Coconut fibres are produced in various countries, with India, Sri Lanka, the Philippines and Vietnam being the leading exporting nations. Cocopeat is dried after extraction and pressed into blocks. Following rewetting the material swells up to six times the original volume. Cocopeat is rich in sodium and potassium. To be used in horticulture, the material is buffered with a calcium solution. Some of the coir products had, in the past, serious drawbacks, mainly related to the salinity (high sodium and chloride content) (Abad et al., 2002); however, the products have improved significantly over the last 10-15 years.

Compost is produced by aerobic treatment of organic materials by microbial action, during which process humus substances accumulate. In the first phase of composting, readily degradable components are degraded within a few days to a few weeks to a fresh compost. If the compost is not well stabilised afterwards, "pot-rotting" may occur when compost is used in growing media. This implies a continued decomposition of the less degradable compounds, which may affect negatively on seed germination and plant growth.

Composted green waste is a key ingredient in many growing media. Both local authorities and private companies collect organic waste materials from parks and private gardens, and compost them on a large scale to produce a material with a high nutrient content, but also a high pH. This product may be an excellent soil improver for acidic soils but causes problems of plant nutrient availability if used alone. Another problem related to green waste compost, especially when other types of waste are included (such as household and retail waste) is a high content of plastic fragments. Due to its high pH and high nutrient content, green waste does not usually comprise more than 30% of a typical growing media product overall. Even if composting implies a sanitation of weed seeds and pathogens this is not always achieved and hence this ingredient may represent a risk.

Solid animal manure may be composted and used as ingredient in growing media (e.g. McKinnon 2018; Cáceres et al., 2016). Well-maturated compost from horse manure may even function well as a separate growing media. Materials from wild plants, e.g. leaves from deciduous trees, may be composted and used as ingredient in growing media (e.g. McKinnon 2018). Well-maturated compost from birch leaves may also function well as a separate growing media, but better results have been obtained with horse manure, or a mixture of these substrates (Figure 6).

Figure 6. Representative plants of cauliflower after 39 days of growing in various growing media (Mc Kinnon, 2018). Pots 1-7 from different commercial growing media; 8 = composted leaves, 9 = composted horse manure, 10= composted mix of horse manure and leaves, 11 = commercial growing media.

Rice husks are the outermost layer of rice grains that are commonly separated during the milling process. The rice can either be peeled mechanically (for example for the production of risotto rice) or soaked with a parboiling process, treated with steam, dried and then peeled. Parboiling offers the advantage that the rice husks are free from weed seeds. In contrast, the mechanically peeled rice is not subjected to sanitation, which explains why such husks are less suitable for inclusion in growing media.

Maize stalks: Efforts have been made to produce a peat alternative from corn fibre, by chopping corn stalks remaining on the field after harvesting grain maize. Subsequently, the spongy tissue inside the stems is separated from the outer cortex. A commercial product, called TEFA, has been developed by Sorba Absorber GmbH in Switzerland (http://www.sorba-absorber.ch/?page_id=7846&lang=en).

Olive mill pomace has been tested as an alternative to peat (Gómez-Muñoz et al., 2012). Oil mill pomace is mixed with a blend of natural organic residues (e.g. olive leaves and twigs collected after cleaning the olive fruit in the mill, and/or straw, or manures), which is then allowed to decompose in aerated piles for 7 to 9 months. https://www.theguardian.com/lifeandstyle/2019/jan/12/were-humus-sapiens-the-farmers-who-shun-animal-manure

Wood fibres are produced from residual wood being defibred with different thermo-mechanical technologies. The defibration can be carried out by heating the wood chips to temperatures above 100 °C followed by milling in a refiner or an extruder.

Fine wood chaff is a coarse sawdust, with similar characteristics as rice husks. Chaff can be used unprocessed as a component of a growing media.

Xylitol is a constituent of tertiary lignite coal (commonly called brown coal) and is a by-product of lignite mining. It is a lignite precursor and is formed during the charring of peat. The material consists of remnants of former woods, which have undergone a structural change in the coalification, but whose original wood structure is still clearly visible. Depending on the biochemical degree of coalification different degrees of decomposition of xylitol can be distinguished. It should be considered a fossil product.

Mineral soil: Addition of sand, silt and clay to growing media stimulates microbiological activity and promotes nitrification, affects positively the structure of the growing media, and increases cation activity and water retention, and reduces the problem of re-wettability in mixtures with a high proportion of peat.

3.3.2 Selected literature on alternatives to peat and their environmental impact

Peat replacement is a topic widely studied for many decades. Thus, many papers and initiatives have been devoted to this topic. This literature is referred to in a Table 7, presenting some important characteristics of the main materials that may be realistic alternatives to peat in growing media, such as the process needed to obtain the final product from the raw material, the advantages and drawbacks of the materials and studies where the material was tested in practice.

For this purpose, a Swiss project, “Peat and peat replacement products in comparison: properties, availability, environmental sustainability and social impact” (Eymann et al., 2015) was very useful. A German project “Optimisation of quality of bio substrates for nursery plants under ecological vegetable production with special concern to transformation to praxis of peat replacement by fermented wood fibre” funded in 2006 by the Federal Ministry of Food, Agriculture and Consumer Protection as part of the Federal Organic Farming Program (BÖL) was carried out by one German partner in Organic-PLUS, Forschungsring e.V., in close cooperation with manufacturers of growing media, organic plant producers and vegetable farmers. Fermented wood fibre was a main substrate to be tested in this project (König, 2006).

Table 7. Literature relating to the main characteristics of key alternatives to peat in growing media that can be used in certified organic growing.

Product	Origin	Treatment	Advantages	Drawbacks	References
Bark compost	Bark obtained from different trees after processing the wood	It should be well composted (in combination with N-rich materials)	Favourable pH, and salinity (low)	Competes with other applications (e.g. landscape mulch, bioenergy. Long composting period required	Bosse, 2017 Pascal et al., 2018
Coir	Husk of the coconut fruit. Generated when coconut is industrially processed	Composting not needed Milling is needed, salt leaching at production sites	Favourable pH and salinity, high available K content for plant nutrition	Long transport High water use for processing. Pollution + health issues with processing dust	Abad et al., 2002; Arenas et al., 2002; Bartz et al., 2017; Mokhtari et al., 2013; Xiong et al., 2017.
Green waste compost	Green waste from parks and gardens (fallen leaves, grass clippings, branch cuttings etc) or Selected green waste compost	It is composted. Selection of raw materials is needed. And composting.	High availability Moderate salinity. Higher quality than mixed green waste	Diverse material; composition varies with season and location; standardization increases costs Long composting period required pH usually too high pH is still quite high but this property can be amended during the culture period Additional costs because of the selection process	Kazamias et al., 2017 Gong et al. 2018 Ceglie et al., 2015 Zhang et al., 2013 McKinnon, 2018 Massa et al., 2018. Schmilewski, 2008, Schmilewski, 2019
Vermicompost	Green waste precompost	Pre-composting + composting	Vermicomposted material performs better than green waste compost in plant experiments	Management of the worms can be problematic	Gong et al., 2018
Plant biomass (bamboo)	Single species	Composting	Low pH and moderate salinity Homogeneous product	Only available in some countries.	Zhong et al., 2018)
Plant biomass (*Miscanthus*)	Single species	Shredded, chipped, extruded or fibber (double screw extruder) production	Available locally, low in nutrients	Only available in some countries	Clemmensen, 2004; Kraska et al., 2018; Vandecasteele et al., 2018.
Plant biomass (tomato, onion and vineyard production)	Different species	Composting	Effect of quality of the lettuce. Suppressiveness of *Pythium*.	High pH and salinity	Giménez et al., 2019
Plant biomass (mountain birch leaves)	Gathered in the garden	A composting + maturation process is needed	Free of pollutants, Appropriate pH and salinity (low),	Locally generated (case study in Norway)	McKinnon, 2018

			good growing media when mature		
Distillery waste	Waste from distilleries	Composting		Only locally available	Bustamante et al., 2008.
Biochar / Hydrochar	Softwood, green waste	Thermal decomposition of organic matter under conditions of oxygen deficit	High porosity, low density and high cation-exchange capacity	pH can be very high. Energy is needed for obtaining biochar.	Margenot et al., 2018 ; Tian et al., 2012 ; Vaughn et al., 2013; Dalias et al. 2018
Wood fibres	Different tree species	Defibration and/or composting of chopped material	Weak fertility, free of pollutants, pH and salinity relatively low	Low in N. Possible N immobilization	Gruda and Schnitzler, 2004a; 2004b; 2006; Makas et al., 2000; König, 2006; Kharazipour et al., 2007; Schmilewski, 2008; Vandecasteele et al., 2018.
Separated animal slurry with pine debris or green waste	Manure from cattle or pig with woody material	Composting	Nitrification within composting can naturally acidify the compost	Composting can be slow; Salinity can be moderate; Reduced pH through the process	Cáceres et al., 2006; 2013: 2016; 2018. Jayasinghe et al., 2010
Solid horse manure	Solid horse manure	Composting + maturation	Locally available product, often costly to get rid of for horse keepers	Long-term treatment required	McKinnon, 2018
Compost (in general)	Very diverse. Ex: Green compost with fibre trunk Or waste from flower, tomato, broccoli, laying hen manure by-products	Composting + maturation needed for at least 6 months	Demonstrated use in seedlings Physical properties are usually satisfactory	pH, salinity, low stability, N immobilization pH and salinity are usually high.	Ceglie et al., 2015 Gavilanes-Terán et al., 2017.

Table 8. Agronomic properties, future availability, environmental impacts and social risks of substrate components. Those that can be used directly as peat substitutes in certain areas are marked with an asterisk (*). The remaining products are suitable as components of mixtures. The total environmental impact is included and exclusive of heavy metal emissions (SM) during the use phase. The colour coding indicates whether the result can be assessed as positive (■), more positive (■),negative (■), or more negative (■). (■): no data / no assessment made. (Eymann et al., 2015).

	Crop properties											Availability	Price dependency	Umweltaspekte				Social aspects
	Bulk density, dry	pH	Buffer capacity	Nutrient content			Salt content	Nitrogen mobilization	Water retention capacity	Air capacity	Structure stability	Medium to long term availability	Dependence of the price on the energy industry	Greenhouse gas potenzial	Overall environmental impact		Cumulative non-renewable energy expenditure	Social risks
	kg TS/m^3	-	-	mg /l NO_3-N, NH_4-N	mg /l P_2O_5	mg /l K_2O	g/L	-	Vol-%	Vol-%	-	-	-	kg CO_2-eq/m^3	1000 UBP/m^3 incl. SM from use	1000 UBP/m^3 excl. SM from use	MJ/m^3	
Black peat	120-250	2.5-3.5	Small	≤50	≤30	≤40	≤0.4	None	60%-87%	6%-33%	Medium	+ / -	Small	250	200	190	3700	Small Risk
White peat	80-150	2.5-3.5	Small	≤50	≤30	≤40	≤0.4	None	40%-85%	11%-58%	Medium							Small Risk
Bark compost(*)	200-300	5.0-7.0	High	≤400	≤150	≤600	≤1.5	Medium	40%-55%	40%	Medium	+ / ++	None	33	67	38	310	No risk
Green compost	300-500	7.6	Medium	70	720	2100	2.2	Medium	>50%	-	Small	+ / ++	None	180	900	160	460	No risk
Rice husks	90-100	5.0-6.0	None	-	-	700-800	0.6	Small	7%-10%	84%-88%	Medium	++	High	29	63	48	270	From Asia / From EU
Wood fiber*	60-130	4.7-6.0	Small	≤50	50-100	100-150	0.03-0.2	Medium	≥35%	45%-65%	Small	+	Medium	9.9	23	15	200	No risk
Fine wood chop	130-140	3.5-4.0	Small	≤50	50-100	100-150	0.15-0.2	Small	25%-30%	>70%	Medium	++	Medium	9.9	38	14	120	No risk
Coconut fiber*	50-150	4.5- 6.5	Small	< 50	< 50	400-800	0.5-1	High	20%-50%	40%-70%	Small	+ / ++	High	85	510	500	900	Noteworthy
Cocopeat*	80	4.0-5.5	Small	<5	5-20	130-850	0.2-1.0	High	60%-85%	30%	Small	+ / ++	Medium	41	120	120	410	Noteworthy
Xylit*	160-230	4.5	Small	<10	<10	<50	0.5	Medium	40%-50%	30%-50%	Medium	+ / -	Small	-	-	-	-	-
Landerde	1030	5.5-6.5	Medium	-	-	-	-	None	-	-	Medium	++	None	5.0	7.4	7.4	59	No risk
TEFA (from corn straw)*	100	6.8	Medium	180	< 5	150	0.35	-	54.4%	37.7%	Medium	++	Small	28	97	75	410	No risk

3.3.3 Discussion

Only few of the papers on peat alternatives that have been reviewed are specific for organic horticulture (Bosse, 2017; Pascual et al., 2018). However, most of the growing media components listed in Table 7 could be used in containerised organic plant production. Alternatives to peat in growing media for horticulture should consider key characteristics: high stability, satisfactory availability of N, slightly acid pH and low or moderate salinity.

The first important peat alternative was bark compost that was studied and introduced to the market by 1980. Extensive research was done on the composting of this recalcitrant material, using different doses of urea to balance the C/N ratio and also to speed up the composting process. The second alternative material is coir, which is now one of the most widely used peat alternatives, mimicking peat in several ways. Despite originating a long distance from Europe , coir makes the majority of its journey in a compressed state (12 m^3 reduced to $1m^3$) and some of the processing is carried out using renewable energy. The use of water is probably the largest concern, especially in water-deprived regions. Dangerous working conditions, dust emissions creating air pollution and health problems can be further issues. Both products (bark compost and coir) are extensively used but alternatives are still necessary; bark is also in demand for landscape mulching or for bioenergy.

Composts are readily available products that, in theory, could be good alternatives. However, they often have several drawbacks as high pH and salinity and the stability should be ensured to avoid “pot rotting”. The composting time depends on the raw material, but for a several feedstocks at least six months are needed. The selection of raw material is a key point in the preparation of mixtures to be composted for obtaining growing media. The literature review has shown that green waste and solid manure composts can be suitable products if some final properties are improved. On the other hand, experiments at an intermediate scale have demonstrated that it is possible to naturally acidify the compost during the process itself in order to make these products more suitable. Water availability and air space are normally not restrictive for the use of compost in growing media.

Plant biomass that are locally generated (like bamboo or *Miscanthus*) or fallen leaves could be particularly good alternatives that can be composted on farm, thus promoting a local bioeconomy (Kraska et al., 2018). An inventory of potential products available at regional or national level is recommended (Abad et al., 2001).

Good alternatives to take into account are woody-based materials. In general terms, these products have high physical stability, but problems of N immobilization can arise during the crop period. On the other hand, they should usually be composted to increase their stability. The composting process of the woody materials is generally quite slow. Hence, experiments (2019-2020) in Organic-PLUS will consider the extrusion process as a way to treat the woody materials for improving their stability, physical characteristics and also to speed the composting process. The most important findings of König (2006), in a project that focussed on wood fibre were:

a) The degree of fineness of the wood fibre plays a decisive role for the compressibility of the substrates. The finer the fibre, the better the ability to compress the substrate. On the other hand, the fibre must not be too fine, because then the pore volume of the substrate would be too small.

b) The logistical problems of getting wood fibre, or ready-made mixtures, into practice are still great and currently have an extremely restrictive effect on the spread of the new substrates. Only in large companies the availability is easily guaranteed.
c) Regionally produced wood fibre from hedge trimmings represents an alternative for the future if a suitable processer can be found.
d) Another factor of uncertainty is the declaration of the substrates: clean organic certification is still lacking, so that mineral stabilized substrate components (e.g. bovine compost or wood fibre with urea) or conventional sources (e.g. coconut fibre from conventional farming) can be clearly identified.

Biochar is a promising material to include in peat-free mixtures, since it improves water retention and the cation exchange capacity of the media. However, environmental effects of its production should be assessed, as well as further investigation to check its benefits (EC, 2018).

Problems with continuity of consistent supply of all these products can deter growers from using them, even in small proportions, in a growing media (Schmutz et al., 2018).
In order to comprehensively assess the environmental effects of peat and peat alternative products, the study of Eymann et al (2015) produced life cycle assessments for ten substrate components and seven exemplary substrate mixtures. In addition to the environmental impact, the agronomic-specific properties, the future availability and the social impact of the production were assessed for the individual substrate components. The authors conclude, that from the investigated substrates mineral soil, bark compost, maize fibres, wood fibres and wood chips are characterized by low environmental impacts as well as a positive assessment of social aspects and future availability (Table 8). Of these substrate components, reclaimed wood fibres, maize fibres and, under certain conditions, also bark compost have the potential to substitute peat directly. Mineral soil and wood chips can be used as additives in peat-free growing media.

3.4 Conclusion on alternatives to peat

Coir from coconut has become a successful alternative to peat. The oldest peat substitute is composted bark, which is still an important alternative to peat. However, other alternatives should be considered to respond to the market demand.

Generally speaking, it is necessary to gain deeper insight into the treatments to obtain high quality products (through good mixtures to avoid N immobilization or to control salinity or pH), to speed up the composting process and to properly manage nutrients in the new growing media. Therefore, there is still room for investigating the effect of processing high available materials (e.g. woody biomass).

The agronomic behaviour of peat substitutes should be complemented with studying environmental and economic aspects of the use of such ingredients (Barrett et al., 2016; Bosse, 2017). In this regard, a key point is to promote the local by-products that would promote good practices in organic agriculture, using and recycling organic materials in the same area promoting on-farm processing (e.g. composting) of the materials.

3.5 References

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4. The use of plastic in organic agriculture with specific reference to soil mulches

4.1 Introduction

The use of fossil fuel derived plastic in organic agriculture is contentious because of their dependence on the petrochemical industry. As they degrade they can release micro-plastic fragments into the environment. In addition they often contain plasticisers that can act as hormone disturbing chemicals, which can be transported in the soils water and be taken up by crops. Bioplastics or compostable plastics could be an alternative but might also have the same problems, or other conflicts with human health and food quality. Since the use of plastic is not yet regulated in the organic growing certified by the EU, we have, in the subsequent text, not distinguished between the use of bioplastic and petroleum-derived plastic. Some private standards, e.g. Soil Association (SA) has some requirements. Plastic is extensively used in horticultural production, for crop protection (fleece and mesh), for crop supports during growth, for water application (e.g. non-reusable water tubes lasting only for one season), for wrapping of products and as a soil covering mulch.

4.2 Alternatives identified in Organic-PLUS Deliverable 5.1

In deliverable 5.1 of the Organic-PLUS project (Løes et al., 2018) a number of alternatives to fossil fuel derived plastic mulch were highlighted by the experts consulted in each country (Table 9).

Table 9. Summary of alternatives to plastic mulch mentioned per country in D 5.1 (Løes et al., 2018)

Materials	Countries
Photodegradable plastic from corn starch	UK
Compostable film from starch	UK, GE, F
Woven ground cover	UK, F
Mesh cover	UK, GR
Fleece/foil/paper cover	UK, GE, DK
Straw	TU, PO, F
Fibber	PO
Thick plastic which can be recycled	NO, UK
Glass	NO
Polyethene (PE) and polypropylene (PP)	GE
Management alternatives	
Mechanical weeding	DK
No shelters over fruit and berries	all

4.3 Literature review

4.3.1 Background information on plastics

Plastics constitute a diversified group of different materials that can be classified by: (1) chemical structure, (2) chemical processes used for manufacturing, and also (3) properties required for a selected application or a product. Plastics have a wide range of applications in many areas, including agriculture. They are mostly used in greenhouses and tunnels but also for mulching, wrapping silage and other. At present the majority of plastic materials that are used in agriculture come from fossil fuels.

Petrochemical or fossil plastics are made of fossil feedstocks like petroleum and natural gas (EIA, 2016) which have taken millions of years to be formed. Nowadays, about 7% of all petroleum is converted into plastics (European Bioplastics, 2015; IEA, 2016). Examples of fossil-based plastics are polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS). Whereas at present these materials are predominantly made from fossil feedstock, they could also be produced from biomass, and would then be bio-based. For example, biodegradable non fossil plastics include polylactic acid (PLA) or polyhydroxyalkanoates (PHA). This is illustrated in Figure 7.

The production of bio-based plastics is expected to grow rapidly, with greater concern about environmental issues and the exhaustion of available oil reserves (Shen et al., 2010). According to Posen, Jaramillo and Griffin (2016), bio-based plastics only accounted for less than one percent of the global thermoplastic production. This was expected to grow to 4.4 percent, reaching nearly seven million tonnes (Mt) by 2018. Polylactic acid (PLA) is a bio-based biodegradable plastic that is heat resistant and can be best compared to LDPE for tensile strength and usage (Shen, 2017). PLA is one of the most used alternatives for fossil-based plastics. It is described as follows by Shen, et al. (2010, p.35): '*PLA is an aliphatic polyester, produced via the polymerization of lactic acid which is a sugar fermentation product. PLA became the first bio-based plastic produced on a large-scale. PLA will be used to investigate the CO_2 emissions of bio-based biodegradable plastics*'.

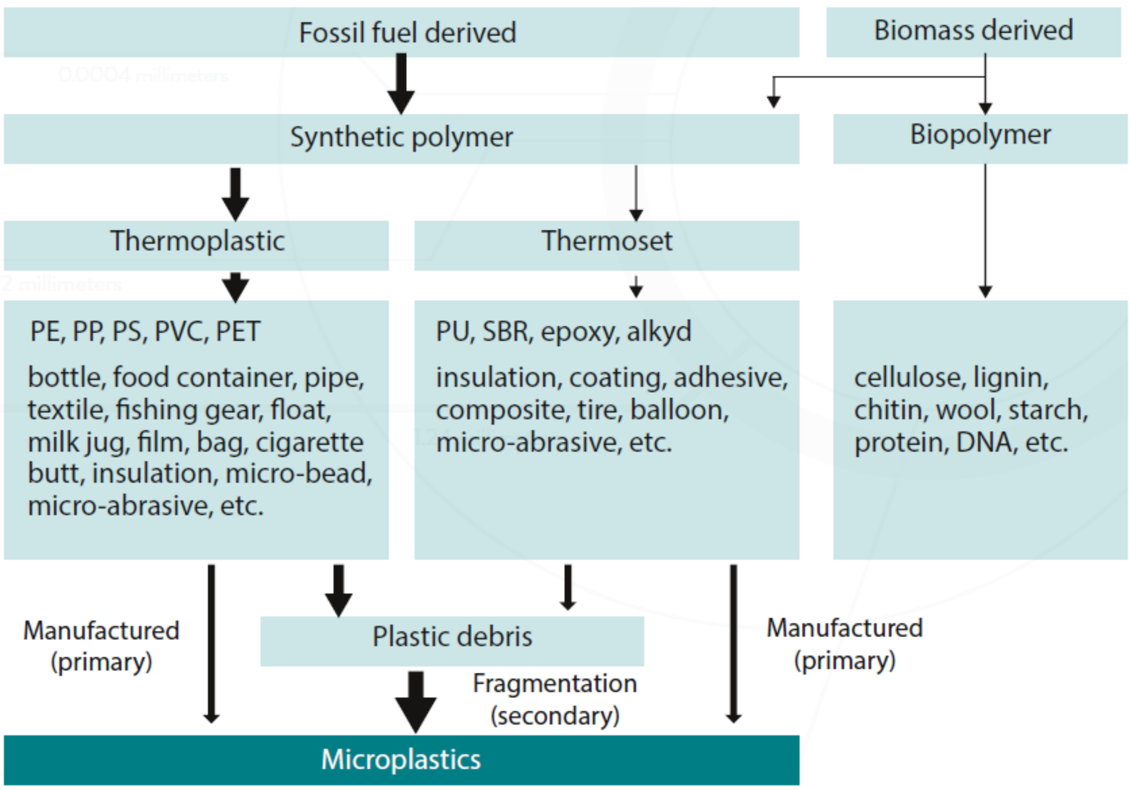

Figure 7. Schematic diagram illustrating the relationships between primary material source, synthetic and natural polymers, thermoplastic and thermoset plastics and their applications (from GESAMP, 2015)

Fully fossil-based non-biodegradable plastics will not leave the ecosystem and are often disposed of by incineration or land-filling. In the course of time more biodegradable plastics have entered the market in order to contribute to achieving a more sustainable society. However, there are different types of biodegradable plastic, mainly fossil-based and bio-based. Fully bio-based plastics should to be more sustainable, but this is sometimes questionable – for example if much agricultural land and agrochemical inputs are used to produce the feedstocks.

4.3.2 Plastics for mulching of soil

The use of plastic films for soil mulching reduces weed growth, water use and the leaching of nutrients from the soil. Therefore, soil mulching contributes to a more sustainable agricultural production system.

An estimated 2-3 million tons of plastics are used in agriculture each year and the use of plastic in agriculture is so prevalent it is now sometimes referred to as 'plasticulture'. By far the biggest use of plastic in agriculture is for plastic mulch films and silage wrap. These are typically made from polyethylene (PE) because it is cheap, easily processed, highly durable and flexible. However, because of PE's non-biodegradable nature it is now becoming an environmental concern. Rather than biodegrading, PE undergoes a process of light induced 'oxo degradation', which results in the breakdown of PE film, in the presence of light, to microplastics, that are unobservable to the human eye. The concern here is that microplastics are finding their way into the food chain and the effects of microplastic bioaccumulation on animal and human health are not yet fully understood.

Most mulch films are produced from petroleum-based plastics, usually polyethylene (PE) which result in a considerable waste disposal problem. Because of the non-biodegradable nature of PE, disposal options are limited to being burnt, sent to landfill, recycled or simply left in the field, with each option presenting different environmental burdens. Burning of plastics releases aromatic hydrocarbons and results in indiscriminate exposure and it is, for these reasons, that the EU Incineration Directive (Directive 2000/76/EC) was drafted, which prohibits uncontrolled burning of waste. The useful life of mulch film exceeds the duration of crop cycles so is usually left in the soil. Collection of the residual plastic is time consuming and involves the use of machines and hand labour whilst the collected plastic requires ongoing collection and disposal costs.

If left buried, PE films will never completely disappear from the field, leaving remnants which remain in the soil, which clog and choke agricultural machinery. PE is recyclable. However, when contaminated with soil, sand, silage or other materials, this becomes more challenging. There are currently only two facilities in the UK that can recycle contaminated agricultural plastic. The environmental issues associated with landfill is being addressed by the Landfill Directive (2014), which will phase out the landfilling of all recyclable waste by 2025.

4.3.3 Alternatives to fossil-based plastic mulches

There are a variety of alternatives to fossil based plastic that can be used in agriculture, particularly for mulching. They can include non-fossil biodegradable plastic, bio-based plastics and also paper and living mulches. Within Organic-PLUS the alternatives to fossil based plastic applied in agriculture have been identified in different countries. The examples include photodegradable plastic from corn starch, compostable film from starch, woven ground cover, mesh cover, fleece/foil/paper cover, straw, fibber, thick plastic which can be recycled, glass or polyethene (PE) and polypropylene (PP) (Table 10).

Biodegradable plastic mulch sheets have been used in Spain in recent years and have shown promising results in terms of achieving a desired rate of biodegradation and high tomato yields. The main advantage is the complete degradation into non-toxic compounds although the cost of producing this is three to four times that of conventional PE mulch films. Several feasibility studies have been performed on starch-based plastics, and starch blends, all of which come to the same conclusion that the greater the percentage of starch incorporated into a mulch film, the faster they biodegrade. However, no significant difference to the yield and quality of lettuce (which was the test crop) was observed in these studies. This theme seems to be consistent with the other reported literature on this topic with a range of different crops and different biodegradable plastics being used.

Another field trial was performed to investigate the feasibility of replacing PE mulch film with mulch films made from paper and Mater-Bi, for tomato cultivation in Spain. Bare soil was used as the control. In terms of tomato yield, the Mater-Bi film had similar performance to PE mulch, both of which outperformed the paper mulch film. The highest production, both in terms of total fruit weight and as number of fruits per plant, was found with the biodegradable mulch and polyethylene mulches. Early fruit development was enhanced in plants cultivated with polyethylene and biodegradable mulch and delayed in the control and paper mulch treatments. Furthermore, differences between treatments in fruit quality were small and negligible and all mulch treatments were successful at controlling weeds. At the end of the cropping period, all treatments showed a good covering of the soil surface, but in the buried part of the mulches, the paper degraded the most, and the biodegradable mulch showed initial biodegradation processes taking place. At the start of the study, the durability and strength of each film were assessed, the results of which indicated that the biodegradable mulch had lower durability levels when compared to the PE film but did show greater degradation (45%) than the PE film (38%) at the end of the cropping period. These results showed that the biodegradable mulch tested was a good alternative to PE and paper mulches for organic tomato production.

Table 10. Degradation time (Biodegradable Polymers: An Eco-friendly Approach, Patel et al., 2011).

Product	Time to Biodegrade	Product	Time to Biodegrade
Vegetables	5 days-1 month	Plastic coated milk carton	5 years
Orange peels	6 months	Leather shoes	24-40 years
General paper	2-5 months	Nylon fabric	30-40 years
Paper towel	2-4 weeks	Tin cans	50-100 years
Cardboard box	2 months	Aluminium cans	80-100 years
Tree leaves	1 year	Glass bottles	1 million years
Wool socks	1-5 years	Plastic bags	500 years-forever

While being produced from a renewable resource, bioplastic is often still reliant upon petroleum as an energy source, for transport, and not least, for the production of the renewable material, commonly maize. Commonly, bioplastic also include some materials derived from petroleum.

The Italian bioplastic manufacturer Novamont states in its own environmental audit that producing one kilogram of its starch-based product uses 500g of petroleum and consumes almost 80% of the energy required to produce a traditional PE polymer. Environmental data from NatureWorks, the only commercial manufacturer of PLA (polylactic acid) bioplastic, says that making its plastic material delivers a fossil fuel saving of between 25 and 68 per cent compared with polyethylene, in part due to purchasing of renewable energy certificates for its manufacturing plant.

Key publications concerned with alternatives to plastic are highlighted in Table 11.

Table 11. Selected publications on alternatives for plastic

Alternatives	Reference	Characteristics/Application	Research findings
(1) Composites based on biomass	Jawaid et al., 2017	(1) Organic wastes and biomass were used as additives or reinforcements, (2) Polypropylene hybrid composites by using coir fibres (coconut), (3) PP + coffee ground powder, (4) Rice straws are reinforced in phenol formaldehyde resin to fabricate particleboard composites, (5) PP + household waste of mate tea and Eucalyptus benthamii particles, (6) Polycaprolactone with almond skin residues.	(1) Possible ways for the utilization is simpler because of natural fibres and organic wastes. (2) Environment-friendly and cost-effective. (3) High performance. (4) Properties showed that PCL reinforced with almond skin filler are environmentally friendly materials as films; disintegration rate is high.
(1) Mater-Bi (Novamont) (2) LLDPE (Plastika Kritis)	Briassoulis & Giannoulis, 2018	(1) Thermoplastic biodegradable in soil black mulching film based on aromatic/aliphatic biodegradable polyesters and starch; contains renewable resources - non-food derivative, Properties are very similar to conventional PE films. It is used for the production of mulching films which can be completely biodegradable in soil, (2) Linear Low Density Polyethylene 3-layer black mulching film This material is used for many applications in agriculture, packaging and mulching films.	(1) Conclusion: water vapour transmittance is better for Mater-Bi than LLDPE. (2) The impact resistance of the mulching films appears to be much higher for the thin bio-based films (15, 12 µm) as compared to the conventional LLDPE film (20 µm) resistance. (3) Penetration resistance are similar for both; tensile properties – the elongation for both is reduced under conditions of low temperatures.
(1) PP (2) PS (3) PETE (4) Plastarch (5) Copolyester (6) Wheat starch	Gómez & Michel Jr., 2013	(1) PP + 2% additive, (2) Blend of polypropylene (PP) with 2% ECM MasterBatch Pellets™ additive (ECM BioFilms Inc., OH, U.S.), (3) PS + 2% additive, (4) Blend of polystyrene (PS) with 2% ECM MasterBatch Pellets™ additive (ECM BioFilms Inc., OH, U.S.), (5) PETE + 1% additive,	(1) Plastics containing additives to PE and PP did not improve the biodegradability. 2) SEM confirmed that no degradation of polypropylene and polyethylene occurred, even after amendment with additives meant to confer biodegradability. 3) The biodegradability of the materials during long-term soil

		(6) Blend of polyethylene terephthalate (PETE) with 1% Eco-Pure® additive (Bio-Tec Environmental LLC., NM, U.S.), (7) Plastarch, (8) Blend of polypropylene with corn starch, (9) Co-polyester + corn-based plastic, (10) Blend of an aliphatic aromatic co-polyester with a corn starch-derived polymer (Ecobras™, BASF), (11) Wheat starch-derived plastic Made from a wheat starch-derived resin (OP-47 Bio®, Summit Plastic Company, OH, U.S.).	incubation was: PHA > co-polyester + corn-based plastic > composted cow manure > plastarch > paper pulps > natural fibres > conventional plastics containing additives to enhance biodegradability = conventional plastics. 4) For anaerobic digestion and composting the relative biodegradability was plastarch > co-polyester + corn-based plastic > conventional plastics with additives and plastarch > conventional plastic with additives.
(1) PP (Prolen), (2) Ecoflex® F BX 7011, (3) (PE-g-GMA), (4)Calcium stearate (CaSt) (powder), (5)Cobalt stearate (CoSt) – flakes, (6)Magnesium stearate (MgSt) – powder.	Rosa et al., 2009	(1) PP, (2) Ecoflex, (3) (PE-g-GMA) Polyethylene-graft-glycidyl methacrylate, (4) CaSt, (5) CoSt, (6) MgSt. Ecoflex - a biodegradable aliphatic-aromatic co-polyester based on the monomers, applications are packaging films, agricultural films	(1) The incorporation of pro-oxidants increased the fluidity of PP and probably enhanced polymer degradation at high temperature. (2) CoSt and MgSt reduced the Tm compared to CaSt, indicating that the former two stearates made the blends more susceptible to thermal degradation.
(1) Polyethylene glycol (PEG) mixed with hydrolysed proteins, (2)Natural fillers (as wood cellulose up to 18 wt%) and additives.	Adhikari et al., 2016	(1) Polyethylene glycol was used for modulating the durability of protein due the PEG's ability to link at the protein surface.	(1) Mulching effect lasted at least 12 month. (2) Good agronomic and mechanical performance. (3) The film had average thickness 0.6 – 0.8 mm with high capacity to diffuse solar radiation, physical integrity was maintained. (4) It is expected that ongoing development of sprayable biodegradable polymer formulations will in time contain enzymes to trigger biodegradation or stimuli-responsive features that are capable of triggering rapid depolymerisation in response to specific stimuli.

(1) Mater-Bi	Costa et al., 2014		(1) In comparison to PE, biodegradable mulches rise soil temperature and WVC (water volume content). (2) Under controlled conditions, the aerobic biodegradation increase of 55.8% when comparing the continuous and the batch system for 72 days of test. (3) This material could be good option for the replacement of conventional PE on strawberry crop production.
(1) LDPE (2) BIO	Qia et al., 2018	(1) LDPE, (2) Starch-based biodegradable plastic (Bio) – 37,1% Pullulan, 44,6% PET and 18,3% PBT.	1) Type of plastic mulch films has strong effects on wheat growth with the biodegradable film showing stronger negative effects compared to polyethylene. 2) Size of plastic residues has weak effects on wheat growth with microplastics showing more negative effects than macroplastics. 3) This specific type of biodegradable plastic mulch film residue showed more severe effects on wheat growth than the polyethylene film in both macro and micro sizes. 4) Study revealed that macro- and micro- plastic residues of polyethylene and biodegradable mulch films have negative effects on both above-ground and below-ground parts of wheat and affect both vegetative and reproductive growth.
(1)PVA polyvinyl alcohol	Chiellini et al., 1999	(1) Commercial PVA-based blown films (Montecatini Terme from Italy): two different grades.	(1) Investigations carried out in the presence of the culture filtrate of PVA-degrading mixed culture highlighted the presence of an extra cellular enzymatic system active in the degradation of the polymer backbone. (2) The observed PVA degradation was fairly limited under solid incubation conditions, such as controlled composting and simulated soil burial.
(1)PVA polyvinyl alcohol, (2) Starch (St),	Priya et al., 2014	(1) Poly(vinyl alcohol) is an important synthetic biodegradable polymer having excellent gas barrier properties, high strength, tear and flexibility.	(1) TGA analysis confirmed the good thermal properties of blend films. (2) Addition of GLU increases the tensile strength and degree of swelling of St/PVA blend films. The mechanical

(3)Gluter-aldehyde (GLU), (4) Citric acid (CA).		It has poor dimensional stability due to high moisture absorption. Moreover, it has relatively high price compared to other commercial polymers.	properties of fibre reinforced St/PVA composite blend films were found to be higher than those of the St/PVA cross-linked blend films with 20% of G.
(1) Poly(butylene adipate-co-terephthalate) (PBAT) (Basf – Ecoflex).	Bilck et al., 2010	(1) Black film PE (Agroplas), (2) PBAT.	(1) PBAT film provided efficient mulching for strawberry production because it produced very similar quality and average fruit fresh weight to polyethylene film. (2) Weed growth was observed in beds covered with WBF (white biodegradable film) due to its transparency. (3) The mechanical properties of PBAT film was altered after 8 weeks on the ground, and grammage decreased due to variations in temperature, humidity and solar radiation, which led to its biodegradation, crosslinking and photo- and biodegradation.
(1) PE, (2) Mater-Bi.	Borreani and Tabacco, 2015	(1) Black-on-white PE film, (2) Milky-transparent Mater-Bi biodegradable plastic films (blown film processing, MB1, monolayer, (3) MB2, 3 coextruded layers of MB to improve mechanical properties and stability), (4) Materials were used to produce the silage bags.	(1) Landfill and burning are the current disposal options for used plastic film, and finding new alternatives to conventional plastic films to cover silages is therefore necessary. (2) Results showed that MB2 performed more consistently than MB1. (3) Results suggested that this formulation is worthy of further study and could represent the first step for development of film that could be used for bunker-silo studies. (5) The development of new degradable materials to cover silage could be possible. (6) The maintenance of a high degree of anaerobiosis during conservation is crucial for silage quality.
(1) Cover silage	Borreani et al., 2018	(1) LDPE	(1) Leaving the silage uncovered results in an average 47 and 11% total loss of OM in the upper 0.5 m and in the next 0.5 m below, respectively, while covering with low-density polyethylene (LDPE) film reduced these losses to 20 and 5%, respectively.

			(2) In farm corn silages, DM losses in the 0.9-m layer immediately below the PE plastic film can exceed 30% of the original ensiled crop, especially in the summer season. (3) The main characteristics of an ideal film to cover silage should be high mechanical strength properties. These properties need to be maintained over a long period (more than 1 yr) in a natural environment.
(1) PE, (2) EVOH, (3) HOB.	Borreani and Tabacco, 2014	(1) Black-on-white polyethylene, UV-protected film (PE), (2) Black-on-white coextruded polyethylene-special grade EVOH (SoarnoL SG611B, Nippon Gohsei) film, (3) High oxygen barrier and UV protected (HOB). 2 treatments: silage stored close to the wall (CW), and silage stored far from the wall (FW).	(1) The quality of the silage throughout the entire silo face was improved by use of the HOB film, and spoiled silage was minimized. (2) The HOB film helped to create a more anaerobic environment than the PE film in the upper layer of the silo, reduced the yeast count during conservation, and increased the aerobic stability of the silage. (3) The use of the HOB film ensured a longer shelf life of silage after air gained access to the silo during consumption, by delaying the growth of yeasts, molds, and aerobic and anaerobic spore-formers and by reducing their detrimental effect on the nutritional and microbiological quality of silage in the upper layer of the silo.
(1) Yellow plastic, (2) Green plastic, (3) Black plastic, (4) Blue plastic.	O'Loughlin et al., 2017	(1) Miscanthus is closely related to maize, a crop in which the application of plastic mulch film has been proven to boost yields in Ireland.	(1) Yellow and green plastic performed well in each growing season and displayed similar characteristics. Blue plastic used in the 2016 trial remained intact until harvest. (2) The application of plastic mulch film accelerates establishment and growth rates in newly sown miscanthus crops and reduces the time needed to achieve mature biomass yields. (3) The application of perforated plastic mulch film treatments accelerated early growth in the first growing season. (4) The application of plastic mulch film caused an increase in yield through increases in

			establishment rate, plant height and the number of stems per plant.

Natural mulches could be used as alternatives to plastic as they provide a number of benefits including the increase in microbial activity in the soil, prevention of soil erosion, conservation of nutrients and suppression of weeds (Gerhards, 2018). They can be produced from post-production waste from crops, leaves, stems, fragments of plants not used in further processing or weeds collected by mechanical methods. In addition to living and organic mulches, other alternatives include paper or paper-based mulches that can be mixed into soil after the completion of growing season and they do not accumulate in soil as they undergo biodegradation (Ahokas et al., 2014).

Living mulches are slow growing plants that are planted to reduce weed competition around crops, protect soil, reduce evaporation and erosion, and stabilize soil temperature. The most commonly used plants as living mulches include: annual clovers, alfalfa, annual rye grass. Living mulches are similar to cover crops, with the exception of those that are used when the fields are active instead of after pulling the plants or during dormancy.

Living mulches demonstrate many additional benefits beyond traditional mulches, including:

a. increasing populations of insects pollinating plants,
b. increasing the number of pests predators and the diversity of insects
c. improving the condition of the soil,
d. introducing nutrients and organic matter during their decomposition (
e. increasing weeds suppression.

Living mulches have physical, chemical and biological effects on soil. Physical effects on soil include maintaining soil moisture, increasing root growth, reducing evaporation, reducing compaction and stabilising the soil structure. Chemical effects on soil mostly depend on the time of decomposition (between 2 and 5 months). It was reported that nitrogen deficiency may occur in plants due to nitrogen intake by microorganisms that break down litter, but some living mulches (legumes) lead to increased nitrogen content. They can also increase or decrease the pH of the soil. Living mulches also demonstrate biological effects as they serve as food for many microorganisms found in the soil. Living mulches can reduce the ranges of temperature fluctuations of the soil between day and night.

However, living mulches as alternatives to plastics demonstrate also some disadvantages, for example too dense structure of live mulch around plants can limit root growth or live litter can limit the air movement around crops - especially during wet years, which can cause fungal growth. Organic mulches can introduce unwanted organisms into the soil, such as fungi, bacteria and nematodes. Table 12 lists key publications concerned with the use of paper and living mulches as plastic alternatives.

Table 12. Selected publications on paper and living mulches as alternatives for plastic

Alternatives	Reference	Application	Research findings
Parrenial ryegrass (*Lolium perenne* L.)	Gerhards, 2018	Weed suppression and increasing yield in cereals (spring wheat, spring barley, oats)	Parennial ryegrass reduced the average weekd density in the control plots from 45 weeds m^{-2} to 22 plants m^{-2}. No competition of living mulch with the cereal crop was observed. Cereal grain yield was not affected by application of living mulch.
White clover (*Trifolium repens* L.)			White clover reduced the average weekd density in the control plots from 45 weeds m^{-2} to 25 plants m^{-2}. No competition of living mulch with the cereal crop was observed. Cereal grain yield was not affected by application of living mulch.
Italian ryegrass (*Lolium multiflorum* L., Husnot)	Warren et al., 2015	Competition of living mulches in the absence of supplemental fertilization in cultivation of broccoli	Broccoli yields were similar in the living mulch and bare soil controls under the highest rates of fertilizer application in Expt. 1. In Expt. 2, living mulch reduced broccoli yields from 28% to 63%, depending on fertilizer rate. Despite yield reductions, the living mulch reduced the prevalence of hollow stem in broccoli in Expt. 1. Organic fertilizer may have inconsistent effects on broccoli yields in living mulch systems
White clover (*Trifolium repens* L., cv. New Zeland)			
Buckwheat (*Fagopyrum esculentum*),	Pfeiffer et al., 2016	Living mulches for space-limited organic vegetable production.	Living mulches contributed to weed suppression. However, lower vegetable yields were seen in the living mulch treatments, most likely due to resource competition among vegetables, living mulches and weeds.
Field pea (*Pisum sativum*)			
Medium red clover (*Trifolium pratense*)			
Coriander *(Coriandrum sativum L.),* fenugreek *(Trigonella foenum-graecum L.)*	Pouryousef et al., 2015.	Living mulch as fenugreek leads to a considerable reduction in weed biomass.	Seedbed preparation techniques (e.g. stale seedbed) are very serious. More competitive cultivars and the use of cover crops with more allelopathic capability are important considerations for achieving complete weed control.
Hairy vetch *(Vicia villosa Roth),* Birdsfoot trefoil (*Lotus corniculatus L.),* Sweet woodruff (*Galium odoratum (L.) Scop.),*	Sullivan et al., 2018.	Four living mulches installed in young apple orchards.	Sweet woodruff and creeping thyme both reduced abundance of orchard herbs compared with the control forage grasses and this effect was maintained for two of three growing seasons.

Creeping thyme (*Thymus serpyllum L.).* Forage grasse as a "control"			

4.4 Discussion and conclusions on alternatives to plastic

It should be noted that only 4 to 6% of the extracted oil and gas being currently extracted is used for the production of plastics (Plastics – Facts 2017, Plastics Europe). At present, it is estimated that 355 million tons of plastics are produced annually in the world, where 58 million tons are produced annually in Europe alone. There are many types of thermoplastic polymeric materials. However, they share common features: they do not undergo biodegradation in natural conditions and can be recycled. Agriculture uses about 3.3% of the annual polymer production in Europe. In the production process of plastic, greenhouse gases are emitted. This differs between the types of plastic and for the different groups since they have different production processes. However, since most plastics are made out of fossil fuels, the greenhouse gas emissions are considerable. According to Miller and Spoolman (2009) 43 percent of the global CO_2 is caused by burning oil. This is however, including oil for transportation. Thus, the materials of which the plastics are made are of great importance for the amount of greenhouse gas emitted (Geyer et al., 2017). Since the Netherlands incinerate most of their waste, greenhouse gases are also emitted during the waste management (CPB, 2017). This is accountable for the non-biodegradable plastics. For the biodegradable plastics this does not have to be of importance, since these plastics can decompose in a relatively short time if well managed (Iwata, 2015). However, some of the fossil-based plastics are recycled and therefore are not contributing to an increase in greenhouse gases emitted.

The increasing requirements for environmental protection require the introduction of new regulations regarding waste management and the use of plastics having less impact on the natural environment. However, at the moment the use of biodegradable plastics is not enough. Taking into account the scale of using traditional polymers and the quantities of materials to be processed it is anticipated that the quantity of biodegradable plastics will be increasing with time (Figure 8).

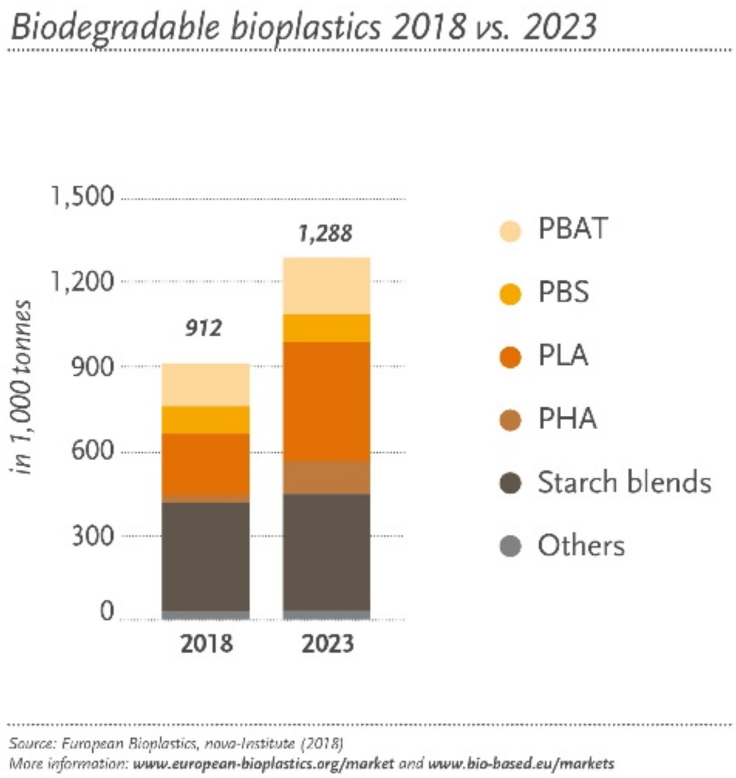

Figure 8. Production of the most popular biodegradable plastics in 2018 and estimated in 2023 (European Bioplastics Insitute, 2018).

Currently, most of the films used in agriculture are produced from fossil based polymers which is a serious problem for the technology of recycling and its economic justification. According to personal communications with recycling companies they face a number of problems associated with the recycling of non-renewable mulch materials. The most pressing problems of the recycling processes of plastic films used in agriculture are:

f. a large amount of soil residues and parts of plants on waste,
g. the need to clean processed plastics in multi-stage washes
h. significant amount of waste after the washing process,
i. significant amounts of technological water necessary in the washing processes,
j. the need to store waste from settlers,
k. it is impossible to remove odors from the recycled material (in particular from those coming from silage)
l. it is impossible to obtain a material without visible inclusions of plant residues, which disqualifies the obtained regranulate for further applications.

All the above-mentioned problems associated with the recycling of conventional materials used for the production of films used in agriculture indicate the necessity of using a film made of non-fossil biodegradable plastics. In addition, many research studies and scientific publications point to adverse effects of film particles from used polymers films on the physicochemical properties of the soil. Therefore, there is a growing interest in the use of biodegradable polymers in crop production. The circular economy assumptions also require manufacturers to re-use all polymer waste in the production cycle. A major problem in the use of non-biodegradable materials is the formation of microplastics that, due to their size, can be absorbed by living organisms. All effects of the impact of microplastics on living organisms are not yet fully understood, however, they must be eliminated by applying, non-fossil polymers.

The application of non-fossil and fossil biodegradable plastics for mulching in agriculture in comparison to non-biodegradable conventional plastics is not significant. The reasons why petroleum derived plastic mulches are predominant in agriculture can be numerous:

1. Costs associated with manufacturing of biodegradable plastics which is significantly higher for biodegradable polymers which is significantly higher than the conventional ones (Table 13).
2. Costs associated with the adjustment of existing technologies (for conventional plastics) or implementation of new technologies for efficient processing of biodegradable plastics.
3. Proper and efficient selection of biodegradable plastics for applications according to the obtained properties as an important factor for application in the field (e.g. mechanical, thermal, optical properties) and expected requirements (e.g. growing methods, biodegradation time).
4. Awareness and knowledge among farmers are still very low as for the common understanding of the origin of biodegradable plastics (i.e. fossil and non-fossil), properties and applications, as well as disposal.
5. Management of post-application biodegradable plastics (i.e. collection of used materials and methods for management, available facilities, etc.).

Table 13. Examples of prices of biodegradable and conventional plastics

Plastic Type	Price Euro/kg	Density kg/m^3
Biodegradable plastics		
CA	5	1200-1300
Bio-PA	+(10 – 20%)	1040-1190
Bio-PE	+(20-40%)	910-970
Bio-PET	No information	1370-1390
Bio-PP	+(80-100%)	900-920
PBAT	3,5	1250
Bio-PBS	4	1260
PHA	5	1200-1250
PLA	2	1250
PTT	4	1320
Starch blends	2-4	1250-1350
Conventional plastics		
LDPE	1,25-1,45	910-940
HDPE	1,2-1,5	930-970
HIPS	1,35-1,52	1080
PET	0,85-1,05	1370-1390
PP	1,0-1,2	900-920
PS	1,25-1,43	1040
PVC	0,8-0,93	1100-1450

Source: Oever, Martien van den; Molenveld, Karin; Zee, Maarten van der; Bos, Harriëtte. Bio-based and biodegradable plastics : facts and figures : focus on food packaging in the Netherlands Wageningen : Wageningen Food & Biobased Research (Wageningen Food & Biobased Research 1722) - ISBN 9789463431217 - 65

The reasons are all considered to be significant drawbacks for application of biodegradable non fossil alternatives in agriculture, in particular for mulching. However, due to anticipated changes in legislation and requirements towards environment and agriculture it is anticipated that, despite the costs related to manufacturing, the quantity of biodegradable alternatives will increase in the next twenty years. In recent years, extensive research has been conducted on non-fossil biodegradable alternatives that can be efficiently used in agriculture whereas the costs and environmental pressures will be reduced.

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