Organic-PLUS - grant agreement No [774340]

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

Deliverable: 5.4

Technical paper on organic materials as peat substitute: Experimental investigation of different extruded lignocellulosic materials to determine a suitable substitute for peat. (WP5 SOIL)

Versions

Version 1.0, draft, 3rd of April 2020
Version 2.0, draft, 8th of April 2020
Version 3.0, draft 24th of April 2020
Version 4.0, draft 27th of April 2020
Version 5.0, draft 28th of April 2020
Version 6.0, final 30th of April 2020

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No [774340 — Organic-PLUS]

Programme: **H2020, SUSTAINABLE FOOD SECURITY – RESILIENT AND RESOURCE- EFFICIENT VALUE CHAINS**

Call topic: **SFS-08-2017, (RIA) Organic inputs – contentious inputs in organic farming**

Project Title: **Pathways to phase-out contentious inputs from organic agriculture in Europe**

Project Acronym: **Organic-PLUS**

Proposal Number: **774340**

Lead Partner: **Coventry University, Centre for Agroecology, Water and Resilience, UK**

Time Frame: **01/05/2018 – 31/04/2022**

Authors:

Christian Dittrich, Ralf Pecenka, Anne-Kristin Løes and Ulrich Schmutz

Deliverable Details:

WP: 5 SOIL

Task 5.3: Processing of agroforestry and other plant material for improved characteristics

Lead beneficiary: ATB

Involved Partners: CUT, IRTA, MFAL, NORSØK, ATB

Deadline for delivery: 30.04.2020

Date of delivery: 30.04.2020

Page 3: Additional information related to the COVID-19 pandemic

At the beginning of March 2020 we were just about to start testing several different fibrous materials produced at ATB for physical properties.

Due to the COVID-19 pandemic we were forced to stop all laboratory investigations in Potsdam, Germany. This are investigations of the different materials processed with the twin screw extruder technology. Nevertheless, all extruded material will be investigated in the future. We expect a delay in the delivery of results from this investigation, but we still currently expect all future deliverables by ATB will be met within the lifetime of the Organic-PLUS project.

The water holding capacity, ash content, bulk density, pore space, C/N-Ratio and pH-value measurements were intended as part of this report (see D5.4, Table 3, page 20) and we will deliver this data as soon as the laboratories reopen and these tests can be carried out and analysed.

Table of Contents

1. Introduction

1.1 Processing woody material to fibres for replacement of peat

One important aim of the Organic-PLUS project is to develop a resource and energy efficient technology to produce fibres from lignocellulosic plant materials which may substitute peat. For this purpose, the Leibniz Institute for Agriculture and Bioeconomy (ATB) in Potsdam, Germany leads the work in the task 5.3, "Processing of agroforestry and other plant material for improved characteristics". A previous report (D 5.3) describes the technology applied to extrude woody materials (Dittrich et al 2019). This report (D 5.4) describes initial results of processing various lignocellulosic materials to fibre, applying a twin-screw extruder. The energy consumption of the process as well as the physical properties and the feasibility of different fibres as peat replacements have been investigated.
The purpose of this report is to inform stakeholders interested in peat replacement, including scientists involved in the Organic-PLUS project about the wide range of raw materials (woodchips, forest and herb production residues, grape vine and olive tree pruning) which have been investigated to be used as a peat substitution.
These raw materials have different properties which influence the characteristics of the processed fibres. The water holding capacity of the fibres should resemble that of peat. Storage under moist condition may lead to microbiological activity which would affect the final product so dry storage is essential. Compost addition to the fibres may also significantly affect the final product.

Currently, peat replacement media for organic nursery plants based on woodchip compost require 33% light material (e.g. vermiculite) to improve airflow, structure and density (Tolhurst, 2019 personal communication). Processed fibres which do not need addition of vermiculite and possess 'peat like' properties could facilitate a total phase-out of peat.

1.2 Extrusion technology for woody materials

A twin screw extruder is an energy and resource efficient way to produce natural fibres from woodchips, which should not be completely dry before processing. As seen in Figure 1, two screws operate side by side reaching into each other, crushing and milling the material fed into the extruder and hereby causing heat up to 100 °C and pressure up to about 500 kPa. The woodchips burst apart into fibres and exit the aperture as a highly homogeneous end-product. This is due to the repeated sudden expansion of pressurized heated steam caused by the moisture inside the woodchips, and the high friction forces. (Kuschel 2004).
The heat and pressure levels applied are most likely to kill any plant's regenerative potential and is therefore of interest if biomass from invasive species is processed (e.g. *Arundo donax*). In addition, pests and diseases present in the biomass of e.g. olives or grape vines are also most likely killed by the temperatures and pressures applied. Researching the phytosanitary effect of this method is out of scope for the Organic-PLUS project, but it is worth mentioning these potential benefits of extrusion technology.

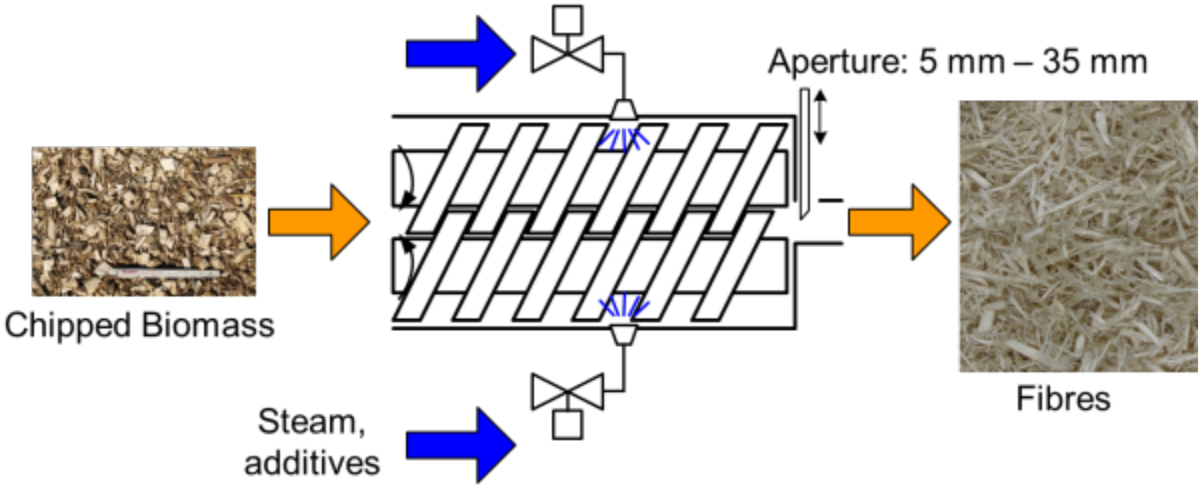


Figure 1. Illustration of the extruder at ATB Wood chips enter the extruder and are crushed by the twin screws to fibres (orange arrows), while steam and additives are added during processing (blue arrows). The fibres exit the twin screw extruder via a 5mm-40mm aperture. [Source ATB]

For the extruded fibres physical properties such as particle size volume weight, total pore volume, pore size distribution, as well as water and air capacity are of interest. Chemical properties like C:N ratio, ash content (minerals) and pH-value are of interest as well.
A good fibre for replacing peat should be homogenous, and have a high volume of air, even with full water saturation (Reinhofer 2006). Further, it should be able to hold a significant volume of water, and it should not decompose easily.

2. Characteristics of extruded fibres from various woody materials

2.1 Process chain from harvest to end product

As shown in Figure 2, very different sources of lignocellulosic raw materials such as agricultural residues or wood from agroforestry can be used for the production of fibres for peat replacement. After harvesting and chipping the raw material, it is transported to a storage location. The chipped biomass can be stored if necessary before processing by a twin screw extruder to fibres. Special attention needs to be paid to the material properties of the chipped biomass and to storage conditions, because high moisture content together with microbiological and chemical processes can cause significant dry matter and quality losses such as contamination with moulds during storage (Jirjis 1995, Pecenka et al. 2018, Idler et al. 2019).
The fibre produced can then be mixed with additives e.g. minerals or fertilisers to fulfil the requirements of a growing media. As a final step the fibre product is packed and stored or shipped. (Dittrich et al. 2019)

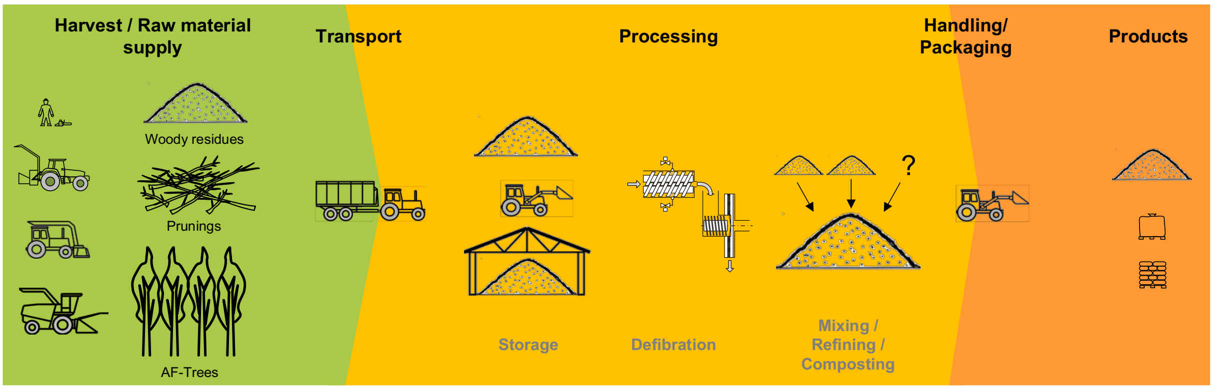


Figure 2. Process chain of lignocellulosic materials from agriculture/ forest residues to fibres. [Source: ATB]

2.2 Twin Screw Extruder for Fibre Processing at ATB

Figure 3 shows how the raw material is passing through the processing line at ATB to be converted to fibre. The raw material is shovelled by hand onto the dosing feeder which produces a constant material flow into the twin screw extruder. The extruder grinds the raw material down to fibre which exits the extruder. Within the extrusion process not all wood chips are ground to fibre completely. Some “larger” particles are left in the fibre. If high fibre quality is desired and no large particles should be left within the fibre, a conveyer belt transports the extruded materiel into a disc mill which can be set to a specific degree of grinding, eliminating oversized particles.
Since this report does not focus on technology, more detailed information about the twin screw extruder technology is found in Deliverable 4.4 page 12 (Dittrich et al. 2019).

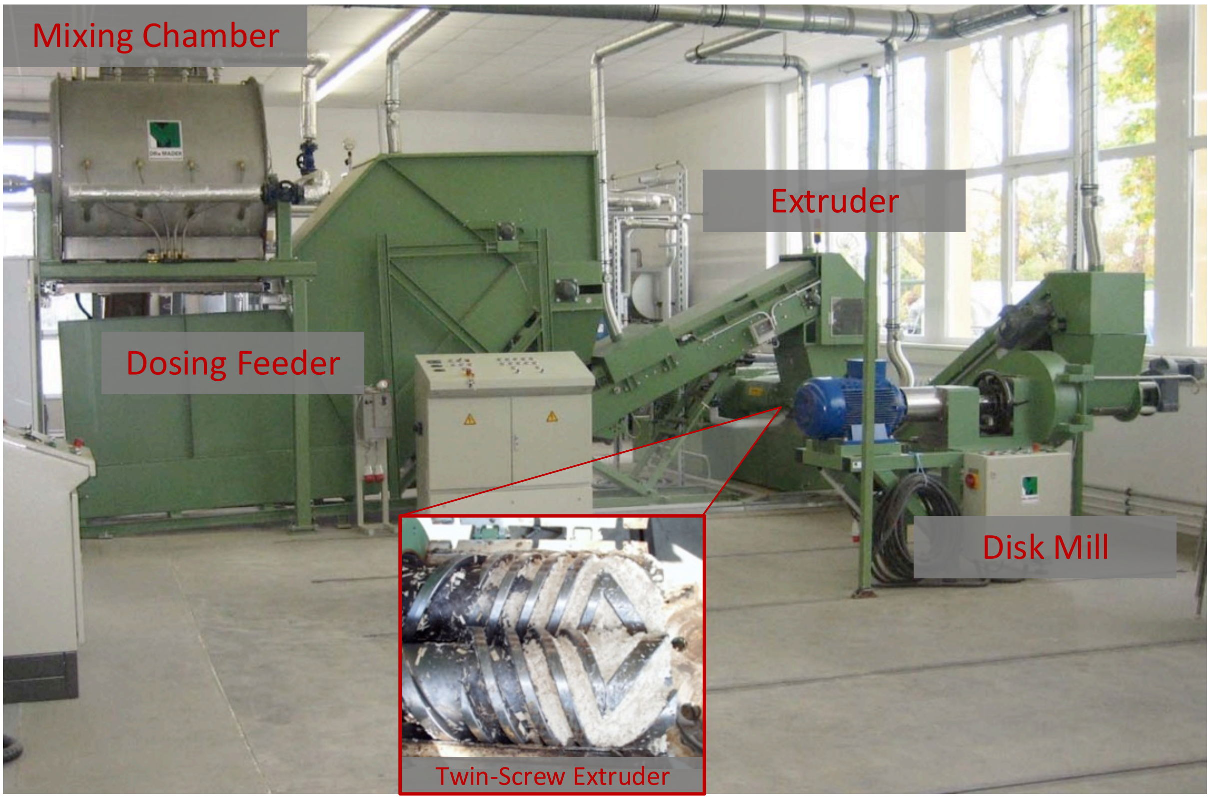


Figure 3. Twin screw extruder processing line [Source ATB.]

2.3 Characteristics of extruded woody fibres and how to measure them

Many different woody materials (Table 1) have been processed at ATB for the Organic-PLUS project. We have tested pruning materials from olives, and from perennial herbs such as sage, thyme, oregano, bay and hop delivered from partners in Turkey (MFAL), and forest biomass delivered from partners in Spain (IRTA). In addition, we have tested material derived from Germany, such as poplar, Black locust, Sea buckthorn, grape vine prunings and wood from short rotation coppice (SRC)

During screening of different materials, grape vine prunings were found to be of interest because of their low content of fines (dust) and initial flocculent (having a loosely clumped texture) appearance in comparison to the other investigated materials, which appeared more compact after extrusion. Therefore, a greater quantity of grape vine prunings, compared to the other materials was investigated.

Table 1. Overview of processed material for fibre production at ATB (SRC = Short Rotation Coppice, AFS = Agro Forestry Systems)

SRC/AFS	Forestry/ Municipal wood	Prunings	Processing residues
• Poplar, (*Populus spp.*) • Black Locust (*Robinia pseudoacacia*)	• Forest Biomass (residues from Spanish forest cleaning to reduce fire risk): mainly Scots pine (*Pinus sylvestris*) and Holly oak (*Quercus ilex*)	• Grape vine (*Vitis spp.*) • Olive (*Olea europaea*) • Sea Buckthorn (*Hippophae rhamnoides*)	• Sage (*Salvia spp.*) • Thyme (*Thymus vulgaris*) • Oregano (*Origanum vulgare*) • Bay (*Laurus nobilis)* • Hop (*Humulus lupulus*)

In general, when extruding woody materials, it is important for high fibre quality that no leaves remain on the trees before harvesting. Leaves are nutrient-rich and can accelerate the decomposition of fibres during storage under moist conditions. Further, they increase the content of fines. However, for peat replacing fibres, both fines and nutrients may actually be desirable. Therefore, leaves could be potentially tolerated in the process of peat replacing fibres but a corresponding quality control accompanying the whole process is necessary for this.

Figure 4. Poplar wood chips after extrusion and blow drying. Left side (coarser end product) extruded at 40 mm aperture opening, middle image (medium coarse product) at 25 mm, right side (finer end product) at 15 mm. [Source: ATB]

It is useful to condition the raw material before processing to have an even moisture distribution. If the woodchips are too dry, water has to be added prior to extrusion. Also, when the moisture content varies throughout the raw material it has to get levelled out. Conditioning is carried out in a barrel tumbling machine where barrels are filled with woodchips and water can be added. Higher moisture contents result in lower energy consumption because the friction in the extruder is reduced.

Figure 5 shows the simplified twin screw extrusion process that the raw material is going through to be processed into fibres. Especially the volume expansion affects many characteristics from Table 3 as well as the moisture content which is set before extrusion can be adjusted during extrusion. The aperture (see Figure 5) has a significant effect on the final product as well.

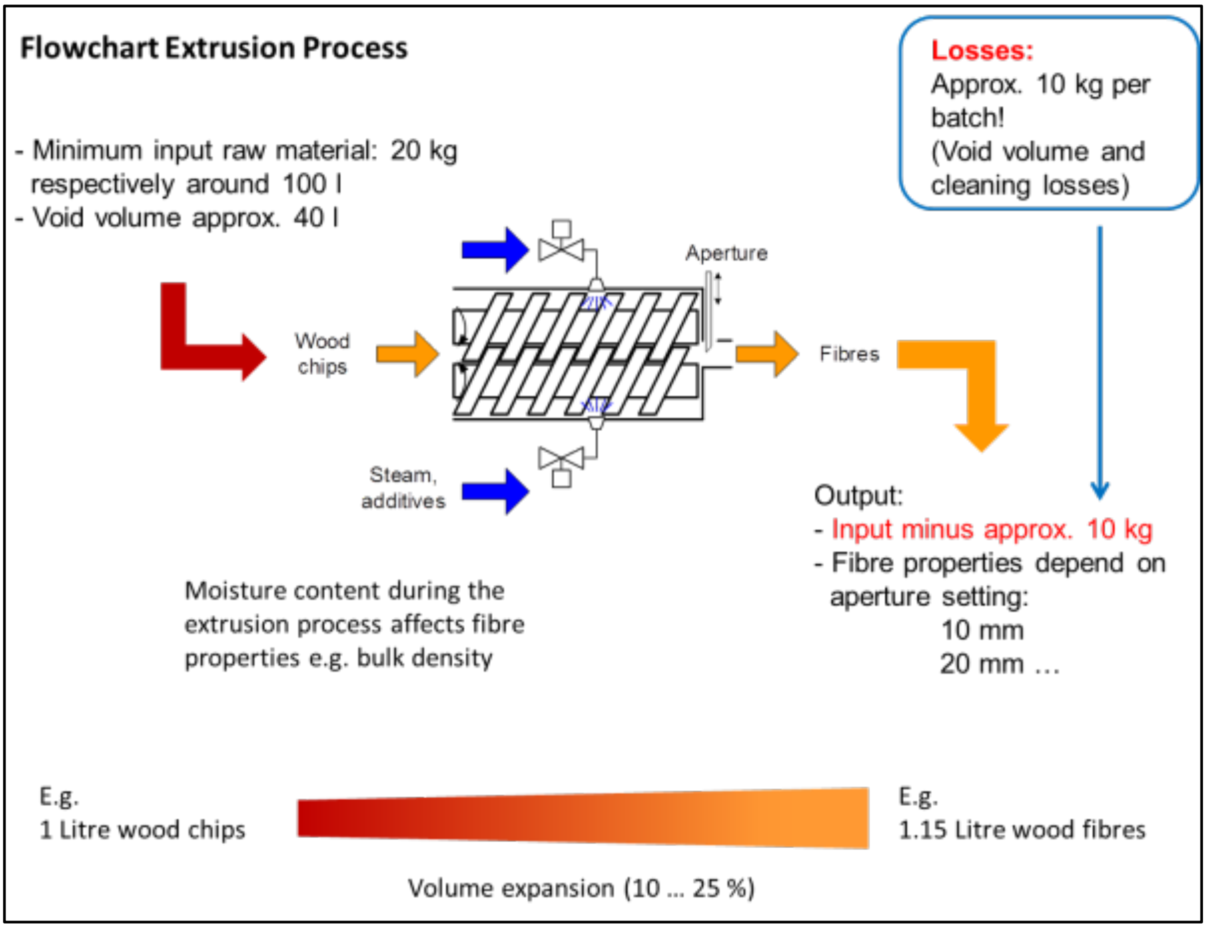
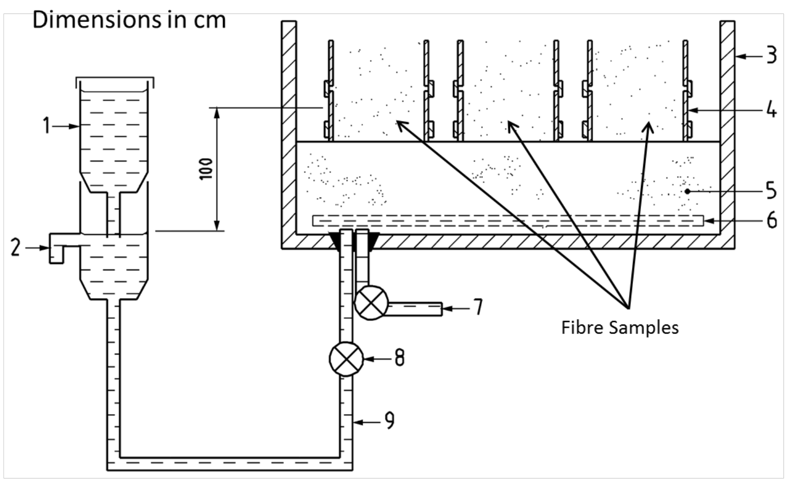


Figure 5. Flowchart showing inputs and outputs of the extrusion process at the ATB extruder plant. [Source: ATB]

2.4 Determining Water Holding Capacity (EN 13041)

There are several different standards and methods to test the described properties of the produced fibre. For our purpose in the Organic-PLUS project, the international standard EN 13041 Soil improvers and growing media was found to be suitable.
Determination of physical properties dry bulk density, air volume, water volume, shrinkage value and total pore space is applied. A general setup of the water tension measuring box is shown in Figure 6. Initial studies of extruded plant materials, and discussions about their suitability, were carried out. Measuring all these characteristics in fibres is time and resource consuming. For example, one measurement takes 9 days to be completed. The samples inside a double ring (Figure 6 and Figure 7) made from polyvinyl-chloride have to be watered first for 24 hours. Then they are drained for 48 hours at negative 10 kPa before watered again for 24 hours. The following drainage at a negative overpressure of 10 kPa is the first measurement that is carried out. After 48 h of drainage the samples weighed and drained another 48 hours at negative 50 kPa. Afterwards they are weighed again. Then dry weight is determined at 105 °C. With the water being eliminated during drying the water holding capacity can be calculated by the weight difference only caused by water.
Only three research institutes in Germany are able to determine the water holding capacity for fibrous material. It was not an option to get our large variety of samples measured at one of them because either the waiting time would have been too long or the costs would have been too high.
This is the reason why we decided to build two of these water-tension measuring boxes according to the mentioned standard EN 13041 ourselves.



Legend

1 compensation tank
2 water tension regulator
3 water tension measuring box
4 double ring container
5 set sand
6 draining system
7 outlet tap B
8 tap A
9 flexible hose (nylon)

Figure 6. General se setup of the water tension measuring box [Source: EN 13041, 2012*]*

It took 6 months to get this measuring device set up right. It was especially tricky to get the sand bed to set without falling dry or cracking while draining. If this happened, the whole process of filling the boxes with an even sand bed had to be started over again. The standard EN 13041 did not describe every detail of the setup of the water tension measuring box. In order to get it right we got technical

advice from the University of Hannover, Germany. At Hannover several of these measuring devices are running for many years.
Finally, we were able to get the soil water tension measuring box working in March 2020 (Figure 7). However, unfortunately, this date coincided with the onset of precautions related to the Covid-19 pandemic (see Page 3 of this report). At ATB all lab work was stopped and employees have not been permitted into the premises from March 20th 2020, until further notice.

Figure 7. Soil water tension measuring box (top left), sample container (bottom left), complete system including water drainage system (right). [Source ATB]

3. Results of processing woody material

3.1 Energy Consumption during extrusion

For 11 different raw materials figure 8 shows that the specific energy consumption ($W_{spec.}$) values varied significantly between different raw materials. It was also significantly affected by aperture settings.

The lowest specific energy consumption was determined for olive prunings at 98 kWh/t_{DM} whereas the highest was found for poplar at 260 kWh/t_{DM} with an aperture setting of 20mm.
Forest biomass from Spain also had high energy consumption, whereas prunings from grapevine and perennial herbs and sea buckthorn had intermediate values. Sea buckthorn and hop were added to the investigation matrix to have the wide range of material processed at ATB and these materials are available in large amounts as residues from agriculture in some regions in Europe. Figure 8 is an updated version of Figure 13 of Deliverable 4.4 page 22 which shows the ongoing work on investigating new woody material sources.

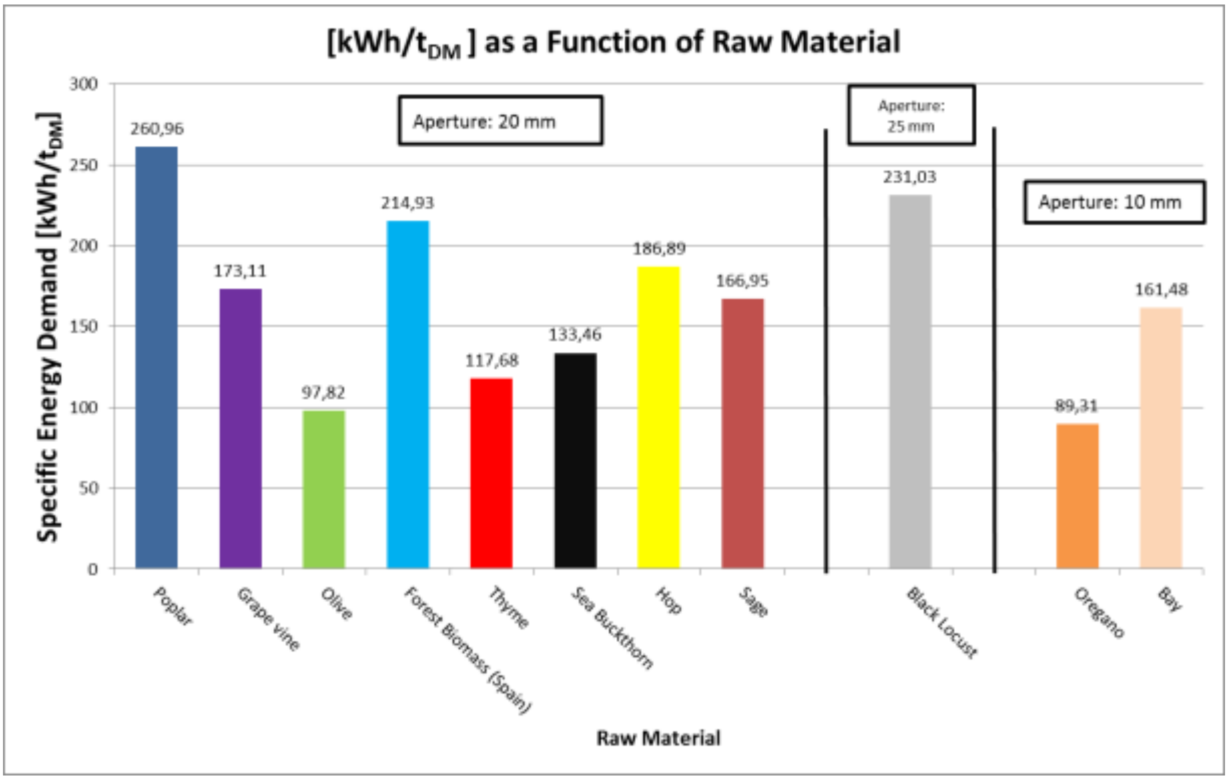


Figure 8. Specific energy demand at different aperture settings by the extruder at ATB in kWh/t_{DM} at moisture content of approx. 50 % for various types of raw material. [Source: ATB]

3.2 Fibre Particle Size Distribution

A particle size distribution analysis has been carried out for all processed lignocellulosic material for the Organic-PLUS project. The analysis is carried out with a sieve tower (Figure 9) in a three-fold determination. Each sample can be separated into different particle size classes.

Figure 9. Sieving tower [Source ATB]

As shown in Figure 10, four out of seven distributions are very similar to each other (Poplar, Thyme, Forest Biomass and Sage). The aperture was set at 20 mm during extrusion and the moisture content was approximately at 50 %. A considerably coarser structure was found to be in fibres from grape vine, sea buckthorn and olive. To be able to find a suitable peat substitute coarse and fine material needs to be investigated. For this reason and additional availability reasons **Grape vine (coarse)**, **Olive (medium coarse)** and **Poplar (fine)** were sent to Spanish partner IRTA for further potting trails.

Figure 10 is an updated version of Figure 1 from deliverable 4.4 page 6 (Dittrich et al. 2019). Additional sieving test have been carried out for poplar, forest biomass and grape vine. The ‘Sea Buckthorn 20’ result data are new and have been added to the existing data in Figure 10.

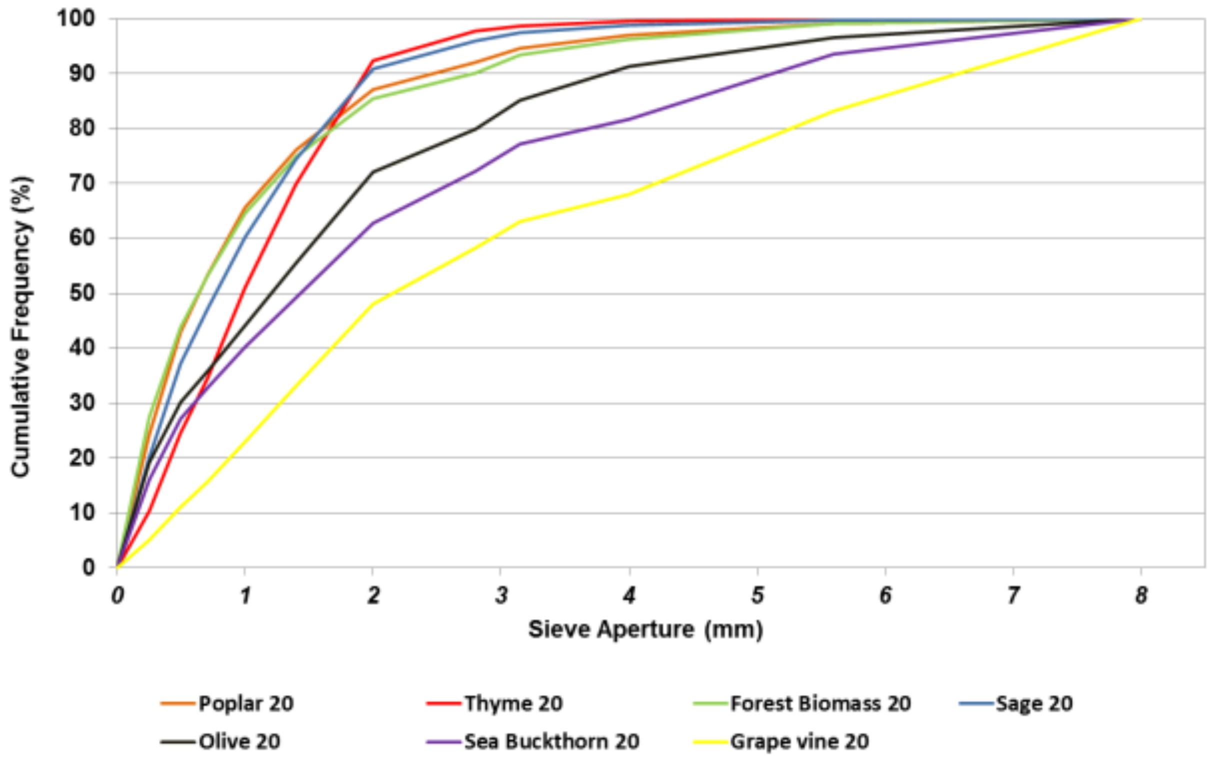


Figure 10. Particle size distribution of various plant fibre produced by the extruder at ATB at identical aperture setting (20 mm). [Source: ATB]

Three woody materials are of interest for more detailed investigation. Olive is predestined to be used as a peat substitute due to its high availability in southern European countries and its low energy consumption during processing.

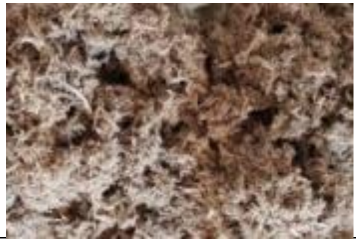
Forest biomass has a high energy consumption compared to the other investigated material but the high availability offsets that. It is also cheap because of its highly available due to forest cleaning carried out in Spain to prevent forest fires.

Grape vine has a high quality fibre and moderate energy consumption during processing. It is also highly available and therefore cheap since no use is made of the vines once they are pruned annually. At present, in most cases they are mulched and left to rot down in the plantations.

3.3 Summary of Results

Table 2 shows every material that has been processed with the twin screw extruder at ATB. Basic information about the raw material the availability as well as the supply and needed preparation is listed. Additionally, the specific energy demand of each material processed at 20 mm aperture setting is displayed. It is also mentioned in the table if material had to be processed at a different aperture setting (e.g. 10 mm for laurel and oregano, 25 mm for black locust). In addition, the range of aperture setting and moisture content is given.

Table 2. Summary results of processed raw materials regarding availability, supply/preparation, processing, specific energy demand and images of raw materials and processed fibres [All images in the table are by ATB].

Raw Material	Availability	Supply / Preparation	Image of Raw Material	Processing in Twin screw extruder	Specific-Energy-Demand at 20 mm Aperture [kWh/t_{DM}]	Image of Produced Fibre
Olive pruning	Maintenance of olive yards	Pre crushing of whole branches to bulkable wood chips		at aperture opening from 10 mm to 20 mm Moisture Content from 48% to 50 %	97.82	
Poplar	AFS SRC	Mower Chipper, Forage Harvester		at aperture opening from 15 mm to 40 mm Moisture Content from 12 % to 57 %	260.96	

Raw Material	Availability	Supply / Preparation	Image of Raw Material	Processing in Twin screw extruder	Specific-Energy-Demand	Image of Produced Fibre
Sage	Herb Production	none		At aperture opening from 10 mm to 25 mm Moisture Content from 36 % to 50 %	166.95	
Thyme	Herb Production	none		at aperture opening from 10 mm to 25 mm Moisture content from 47 % to 50%	117.68	
Forest Biomass	Forest fire prevention	Chipping		at aperture opening from 20 mm to 30 mm Moisture content from 39 % to 50 %	214.93	

Raw Material	Availability	Supply / Preparation	Image of Raw Material	Processing in Twin screw extruder	Specific-Energy-Demand	Image of Produced Fibre
Grape Vine	Wine yard maintenance	Cutting to 6 cm sticks with guillotine cutter		at aperture opening from 15 mm to 30 mm Moisture content from 13 % to 50 %	173.11	
Hop	Residues after Harvest	Metal wire extraction		at aperture opening from 20 mm to 30 mm Moisture content from 39 % to 50 %	186.89	
Sea Buckthorn	Residues after Harvest	chipping		at aperture opening from 20 mm to 30 mm Moisture content from 39 % to 50 %	133.46	

Raw Material	Availability	Supply / Preparation	Image of Raw Material	Processing in Twin screw extruder	Specific-Energy-Demand	Image of Produced Fibre
Black locust	SRC AFS	Mover Chipper, Forage Harvester		at aperture opening from 20 mm to 30 mm Moisture content from 39 % to 50 %	Here 25 mm 231.03	
Oregano	Herb Production	none		at aperture opening from 6 mm to 10 mm Moisture content from 45 % to 50 %	Here 10 mm 89.31	
Laurel	Herb Production	Stones and plastic had to be picked out		at aperture opening at 10 mm Moisture content of 50 %	Here 10 mm 161.48	

Physical properties of fibre produced by the twin screw extruder at an aperture setting of 20 mm are listed in Table 3. The average particle size as well as coarse fraction (>4 mm) and fine fraction (< 0.25 mm) are listed. As previously mentioned some physical-property-investigations were stopped due to lab closure. That includes ash content, bulk density, pore Space, water holding capacity, C/N-ratio, pH-Value. These measurements will be resumed as soon as possible.

Table 3. Physical properties of produced fibre at extruder aperture of 20 mm

Fibre	Average Particle size (x50) [mm]	Percentage of Particles > 4 mm [%]	Fine Fraction < 0.25 mm	Ash content	Bulk density	Pore Space	Water Holding Capacity	C/N-Ratio	pH Value
Olive	1.20	8.7	19.2	Data will be delivered as soon as laboratories reopen					
Poplar	0.65	3.0	24.3						
Sage	0.80	1.2	20.1						
Thyme	0.95	0.4	10.4						
Forest Biomass	0.65	3.7	27.5						
Grape Vine	2.15	32.0	5.0						
Sea Buckthorn	1.40	18.2	16.1						

4. Conclusions

From the results we conclude that **extrusion technology for woody materials** opens the opportunity to make bespoke fibres based on the specific needs of a growing media additives. This is to phase-out peat and vermiculite in growing media, by using the most suitable wood resources as inputs in different European countries.
Materials from specifically planted Agroforestry Systems (AFS) or Short Rotation Coppice (SRC), may still be suitable, but the results show that there is also an abundance of other woody materials (Table 1) mainly from Forestry/ Municipal wood clearings done anyway e.g. for fire protection, large-scale orchard prunings, and various woody plant processing residues which is suitable and can be used before agroforestry and short rotation coppice mature.
We also conclude that in order to get a suitable fibre for peat substitution the extruder needs to be adjusted to very specific settings. As described in this deliverable (as well as in Deliverable 4.4), extruder settings, as well as raw material properties, have an influence on the produced fibre.

Going forward, fibre characteristics for various raw materials and extruder settings will be studied further in the ongoing work within task 5.3 of the Organic-PLUS project and it is too early to draw further firm conclusions, however current data suggest that the most promising candidates so far are **grape vine, poplar and forest biomass**.
Grape vine as raw material is by far the most promising to produce fibres despite its moderately high energy demand during production. In most southern European countries, the availability of grape vine is high and prunings are done annually in many wine growing regions.
Poplar is also highly available due to existing AFS and SRC. The energy requirement for fibre production is also moderate and fibre quality is acceptable.
Forest biomass had the highest energy demand during production and the fibre quality was acceptable. However, the availability of this raw material is very high, especially in Spain a lot of this material is harvested to prevent forest fires and this can also be an issue in all other Mediterranean climates.

An additional option would be **Olive** fibre. In certain regions olive prunings are also highly available. The fibre has good quality and is quite low in energy demand during production. But only 100 kg were tested so far. Therefore, we conclude, collecting more data on olive pruning is essential to learn more about this very promising fibre.
In cooperation with a new H2020 project AGROMIX we will also be in a position to make recommendations on species planted in AFS and SRC, if some of those new plantings are intended to be optimised for tree species that produce good fibres to replace peat. Planting species specifically for the purpose of peat replacement has a long time-horizon, but it offers the opportunity to make even more bespoke fibres.

5. References

AGROMIX (2020) AGROforestry and MIXed farming systems - Participatory research to drive the transition to a resilient and efficient land use in Europe www.coventry.ac.uk/research/research-directories/current-projects/2020/agromix

DIN EN 13041 (2011). Soil improvers and growing media – Determination of physical properties – Dry bulk density, air volume, water volume, shrinkage value and total pore space

Dittrich, C et al. (2019). Organic-PLUS D4.4 Production of livestock bedding pellets from fibre processed by a twin-screw-extruder https://organicplusnet.files.wordpress.com/2019/11/d4.4-o-production-of-livestock-bedding-pellets-from-lignocellulosic-material.pdf (Accessed April 2020)

Dittrich, C et al. (2019). Organic-PLUS D5.3: Technical paper on twin screw extruder processing technology for fibres as raw material for peat substitution https://organicplusnet.files.wordpress.com/2019/04/d5.3-o-technical-paper-on-twin-screw-extruder-processing-technology-for-fibres-as-raw-material-for-peat-substitution.pdf (Accessed April 2020)

Idler, C., R. Pecenka, H. Lenz (2019). Influence of the particle size of poplar wood chips on the development of mesophilic and thermotolerant mould during storage and their potential impact on dry matter losses in piles in practice, Biomass and Bioenergy 127, 105273.

Jirjis, R. (1995). Storage and drying of wood fuel, Biomass and Bioenergy 9(1-5), 181-190.

Kuschel, M. (2004). "Veredlung von Holzhackschnitzeln durch Aufschluss, Modifizierung und Pressverdichtung." (Improving of woodchips by digestion, modification and compacting. ") Dissertation at TU Bergakademie Freiberg

Pecenka, R., H. Lenz, C. Idler (2018). Influence of the chip format on the development of mass loss, moisture content and chemical composition of poplar chips during storage and drying in open-air piles, Biomass and Bioenergy 116 140-150.

Reinhofer, M. (2006). "Torfersatz durch biogene Rest-und Abfallstoffe. Vorproject Endbericht Model B." (Peat substitute by biogenic residues and wastes. Preliminary Project Final Report Model B.) https://www.abfallwirtschaft.steiermark.at/cms/dokumente/10293261_46555/c87dc02f/Torf_Endbericht_Internetversion.pdf (accessed April 2020)

Tolhurst, I. (2019) Personal communication in Organic-PLUS farmer video: Wood innovation to phase-out peat, Organic grower Iain Tolhurst (www.tolhurstorganic.co.uk) source: www.organic-plus.net/videos