Phasing out peat in growing media – results from Scandinavian studies

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SAMMENDRAG:

Første del av denne rapporten omhandler torv som naturressurs i de skandinaviske landene Danmark, Norge og Sverige. Torv og myrområder er verdifulle naturresurs, som får stor oppmerksomhet i dagens miljø- og klimadiskusjoner. Miljømyndigheter og frivillige organisasjoner driver et omfattende informasjonsarbeid for å begrense bruken av torv. Dette er hovedsakelig rettet mot forbrukere ettersom bruk av torv til vekstmedier er tydelig delt mellom et marked for private og profesjonelle kunder. Privatmarkedet utgjør 50 % eller mer av totalt salg, målt etter volum eller pris. Ettersom private ikke tar samme økonomiske risiko som profesjonelle brukere kan disse kundene gå foran for å redusere eller avvikle av bruken av torv i vekstmedier. Økologiske dyrkere kan ikke bruke vekstmedier tilsatt mineralgjødsel, og kan derfor også bidra til å utvikle alternativer til vekstmedier basert på torv og mineralgjødsel. I regelverket for økologisk produksjon er ikke bruken av torv regulert på annen måte enn at det presiseres at torv kun skal anvendes i hagebruk.

Det har vært gjennomført mange undersøkelser for å utvikle mer bærekraftige vekstmedier i Skandinavia, som ikke alltid er publisert på engelsk. I mange tilfeller har forskning og industri samarbeidet. Studenter har også arbeidet med alternativer til torv i skriftlige oppgaver.

I Skandinavia er det rikelig tilgang på trevirke, og trebaserte erstatninger for torv er svært aktuelle her, eventuelt etter en komposteringsprosess. Andre aktuelle alternativer er organisk restråstoff fra biogassanlegg, papir- og fôrproduksjon, materiale fra hager og parkanlegg og fast husdyrgjødsel. Det er viktig å undersøke materialenes egenskaper både hver for seg og i blanding. Dessuten må man vurdere tilgjengelige mengder, og kostnader til framstilling. Trebaserte substrater er i konkurranse med bruk til andre formål som for eksempel energi. Siden torv har unike egenskaper som vekstmedium er det også interessant å vurdere «Paludi-kultur» med dyrking av kvitmose, og dette er kort beskrevet i rapporten.

Egnetheten av alternativer til torv i vekstmedier må videre vurderes i sammenheng med planteart som dyrkes, om det er oppal av småplanter, og om det dyrkes i potter, innendørs eller ute. Kulturenes varighet er også avgjørende for kravene som må stilles til et vekstmedium.

Rapporten presenterer noen torvfrie produkter som var tilgjengelige på markedet i 2021. Markedet overlapper landegrensene, og endrer seg raskt fra år til år.

Rapporten er skrevet som en leveranse i Horizon 2020-prosjektet «Utfasing av uønska innsatsfaktorer fra økologisk landbruk» (Organic-PLUS), GA774340 (2018-2022), der NORSØK leder en arbeidspakke om gjødsling, vekstmedier og nedbrytbar plast i økologisk hagebruk. Målet med rapporten er å gjøre kjent for et internasjonalt publikum aktuelle undersøkelser av alternativer til torv i vekstmedier som har foregått i Skandinavia, og (foreløpig) ikke er publisert på engelsk.

SUMMARY:

The first part of this report deals with peat as a natural resource in the three Scandinavian countries; Denmark, Norway and Sweden. Mires with peat receive raised awareness today with increased climate change and decreased biodiversity. The authorities and several non-governmental organizations are advocating to reduce the use of peat. Communication is often directed towards private users, who undertake about half of the peat sold for growing media as estimated both by volume and value. Private growers may act as a driver for change to reduce peat use because they can afford to pay more for alternatives than commercial growers, and they can take more risks if growing media do not always perform well. Organic regulations restrict the use of peat to horticulture. Since mineral nitrogen fertilisers may not be applied in organic growing, the development of growing media for the organic sector may increase our knowledge on applicability of organic materials more rich in nutrients than peat e.g. composts.

Scandinavian studies on peat-reduced growing media are plenty but the results are not always translated to or explained in English. Research and industry have cooperated in the attempts to replace peat. Students have done efforts to find solutions and several written works are published.

Wood products, possibly composted, are relevant to replace peat in growing media in Scandinavia where woody material is plenty. Other materials to be applied could be solid digestate from biogas plants, waste from industry and agriculture or residual materials from private gardens and public green areas. Substrates applied in growing media need to be studied both separately and in mixtures. Volume, processing and price are other factors to be considered. Because peat has unique properties as growing media, cultivation of white mosses in "paludi-culture" has received some interest and is briefly described in the report.

The report briefly presents some peat-free products available on the Scandinavian market in 2021. The markets overlap country boarders and change rapidly from year to year.

The report is written with funding from the Horizon 2020 project "Pathways to phase-out contentious inputs from organic agriculture in Europe" (Organic-PLUS), GA774340 (2018-2022), where NORSØK leads a work package on fertilisation, growing media and degradable plastic in organic farming. The purpose of the report is to present in the English an overview of studies conducted in Scandinavia to phase out peat from growing media.

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Preface

Phasing out peat extraction and peat use has received increasing attention in European countries in recent years. Already about 1980, a headline could be seen in a Danish gardener's magazine asking *Is there anything wrong with our peat?* The worry was linked to a decline in peat quality from old extraction locations. Soon thereafter, the headlines had changed towards initiatives to find alternatives which could replace peat in growing media. More recently, the climate crisis has underlined the crucial importance of stopping peat extraction, and to conserve and restore wetlands for carbon storage. The first international agreement on environment was about the protection of wetlands, and was signed in Ramsar, Iran in 1971.

Peat has many characteristics which makes this material very well suited for growing media. The quality of peat alternatives must be stable, and the access to such alternatives must be reliable. Conditions vary between countries, and relevant studies on peat alternatives are not always published in English. The purpose of the present report is to present an overview of studies and attempts to phase out peat from growing media in the Scandinavian countries – Denmark, Norway, and Sweden in English.

The work has been carried out as a part of the Horizon 2020-project Organic-PLUS, "Pathways to phase-out contentious inputs from organic agriculture in Europe". The aims of this project are to deal with and find alternatives to several contentious inputs in organic farming. It concerns plastic for soil covering, copper for plant protection, antibiotics in animal husbandry, fertilisers derived from conventional animal husbandry, and last but not least, peat in growing media. The project runs 2018-2022. There are 25 partners, from Norway, Sweden, Denmark, Germany, Great Britain, Turkey, Spain, Greece, Italy, Poland and France, coordinated by Dr. Ulrich Schmutz at the Centre for Agroecology, Water and Resilience at Coventry University.

Tingvoll, 17.01.22

Susanne Friis Pedersen

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1 Introduction

Peat is an exceptionally natural material for growing media, formed mostly in raised bogs in the northern hemisphere of the earth. The term raised bog derives from the fact that this type of bog rises in height over time as a result of peat formation (Wikipedia 2021). The peat is composed of mosses, which have compiled in the bog over centuries or thousands of years. The upper layer of the bog contains the top with the growth point of the plant species *Sphagnum* spp. moss (Picture 1). This growth point will only grow 0.5-1 mm per year, which is why peat is considered as a slowly renewable resource. Furthermore, when damaging the growth point, renewing will stop. *Sphagnum* spp. have a long "tail" or prolonged stem which exists for ages and from which the plant continues to grow as long it is maintained in its natural environment. The plant tissue can expand and contain 20 times as much water as its own dry weight (Norwegian Environment Agency, 2018). These unique swelling and water holding capacity characteristics make peat a very suitable growing medium for other plants from a physical point of view. Chemical properties may be seen as less advantageous, especially for organic growers who want to avoid application of mineral fertilisers because the content of plant nutrients as well as the pH level is low. For conventional growing, though, it is easy to produce a well-balanced growing media by application of lime, mineral fertilisers and possibly some mineral soil to increase the bulk density. Biological properties are again valuable, such as absence of plant pathogens, weed seeds and environmental contaminants.

Picture 1: Sphagnum moss comprises the main plant species in peat material. The growing points are at the tip of the small plants. Photo: Susanne Friis Pedersen

The importance of living *Sphagnum spp.* in raised bogs to sequester carbon dioxide (CO_2) and store water, but also to act as a habitat, is crucial, especially when the global climate and biodiversity crises are considered. The bogs are excellent storage swamps for CO_2, and they are also highly important to store precipitation and balance rapid runoff. Raised bogs worldwide have been utilised for several reasons, such as heating, drainage for forest plantations, cultivation to agricultural land, or peat for growing media. The peat industry for growing media in Scandinavian countries took the outset about 1960 (Pindstrup, 2021), commonly as a prolonged activity from bogs where peat was extracted for energy purpose. For heating purposes, the harvest method was to cut small blocks for drying, which were later burned. More modern and efficient harvesting methods developed for producing growing media such as milling and vacuum suction of the surface is more damaging to the growing points of the moss than the cutting of blocks (Thom *et.al.*, 2019).

Raised bogs are a vulnerable and threatened ecosystem which globally has been reduced to only 13 % of the areas which this type of nature used to cover in the 18th century (Miljødirektoratet, 2020). Still, the remaining bogs are estimated to contain 10 % of the global freshwater resources (Miljødirektoratet, 2020).

Bogs are shaped differently, but are always categorized as wetlands. Wetlands and their importance for birdlife, e.g., during breeding and migration, were protected by the first intergovernmental convention on environment signed in Ramsar, Iran in 1971 and later ratified by 172 parties (The Ramsar secretariat, 2021). This highlights the large importance of this habitat for biodiversity.

Conservation of wetlands is one of the main reasons to phase out extraction of peat and to look for other suitable raw materials in growing media. The certified organic sector which is commonly termed as "ecological" for instance in the Scandinavian countries, should be a spearhead in finding alternatives to peat in plant growing since the etiological origin of the word "ecology" means proper household with resources. However, a study of the actual use of contentious inputs in important horticultural crops across Europe, conducted by the Organic-PLUS project (Løes *et. al.,* 2018) revealed that organic growers by 2018 used no less peat in growing media than conventional growers.

The EU regulation on organic production was revised in 2018 ((EU) 2018/848), but the use of peat in growing media was not made more restrictive. In 2009 the European Commission established a council of experts named Expert Group for Technical advice on Organic Production (EGTOP), with the task force to provide technical advice on any matter relating to the area of organic production and especially the evaluation of products, substances and techniques applicable in such production. In a report about protected cropping (EGTOP, 2013), concern was expressed about intensive organic greenhouse production and more efficient use of external inputs was encouraged. Growing media and peat were thoroughly discussed when producing the 2013 report (Tittarelli, 2020). EGTOP proposed to replace a proportion of peat in growing media, and to stop using it as a soil improver. The proportion of peat in growing media could, according to EGTOP, comprise 50-80 % until alternatives aligned with organic principles were found (EGTOP, 2013). Some private organic standards require that growing media should not contain > 80 % of peat (Pascual *et al*., 2018).

In Denmark and Norway, Demeter regulations for biodynamic farming is the only private standard of organic production. In Sweden, a private organic standard is offered by KRAV. All other organic farmers are certified according to the EU regulation. KRAV does not restrict the use of peat to any more extent than the EU regulation but mentions that cultivation of virgin peatland is forbidden in KRAV-certified organic growing (KRAV, 2019). Biodynamic standards (Demeter) restrict the use of peat to 75 % in growing media for pots and transplants (Demeter 2021). General restrictions like avoiding xylitt is pointed out by Norwegian authorities saying that it is only allowed if it is a by-product from mining industry (Mattilsynet, 2017) .

This report describes studies of materials ranging from coco coir to sheep wool, but the most commonly studied materials to replace peat in growing media in Scandinavia are wood products, commonly incorporated in compost from farmyard manure, green waste, or applied as biochar. Completed and ongoing studies are presented, along with the history behind the various products, when relevant. The private market for growing media has a significant economic value and has been considered along with the professional market.

2 Material and Methods

The information presented here is achieved from literature published in Scandinavian languages, e.g. in master theses and reports from public authorities. This is scientific work, but often not peer reviewed.

To search for literature in Scandinavian languages, following terms were used:

- In Danish – vækstmedium, spagnum, dyrkningssubstrat, substrat, dyrkning
- In Norwegian – vekstmedium, torv, dyrking
- In Swedish – torv, odlingssubstrat, jord

Databases listing student's works and other publications from agricultural universities in Denmark (LIFE KU), Norway (NMBU) and Sweden (SLU) were reviewed for relevant titles.

Websites for non-governmental organisations in the organic sector, such as Organic Denmark, Organic Norway and Organic Sweden were reviewed for background information.

The results section comprises two chapters, 3 and 4. Chapter 3 provides an overview of the occurrence of raised bogs in each country, the national policies to protect and/or utilise these areas and examples of available peat-free products by 2021. Chapter 4 presents results of studies to reduce peat in growing media published in Scandinavian languages, possibly with an abstract in English. For student works we have referred three PhD-theses; three Master theses; and four student reports. Chapter 4 is initiated by a presentation of several attempts to compare alternatives to peat in growing media (4.1), followed by a section on woody materials (4.2). Wood fibre from industry have proven useful in several Norwegian studies (4.2.1, 4.2.3) and woodchips have been tested after application as animal bedding (4.2.2). Composted plant materials where composting is the main process is described in section 4.3. First from some non-woody plant (4.3.1, 4.3.2), some in combination with paper pulp (4.3.3) and some with wool from sheep (4.3.4). Manure in the compost plays a significant role too in section 4.3. Cultivated mosses is described in paludiculture in section 4.4.

3 Current extraction of peat and use of growing media in Scandinavia

The occurrence of raised bogs differs significantly between the Scandinavian countries. Hence, also the traditional use differs, and extraction has been phased out in one country (Denmark) while maintained in two countries (Norway and Sweden). While peat use in growing media has received a lot of attention, significant application of peat for energy consumption still pertains in some European countries, where Sweden is one. In total for Sweden, Finland, Estonia, Latvia, Lithuania and Ireland, nearly 9.4 million tonnes of peat were consumed for energy purpose in 2018 (EC 2021). The global demand for growing media is expected to increase by 400 % until 2050 (Holgersen, 2020). A complete phasing out of peat extraction is obviously more challenging in countries where the applications are broad and peat as a national resource is highly available.

3.1 Denmark

Denmark has registered 43 Ramsar sites (Ramsar secretariat, 2021a). Raised bogs are rare and mostly small in Denmark. They cover 92 241 hectares (ha) equal to 2 % of land surface, but 80 % of them are less than 2 ha (Miljøministeriet, 2021). One company, Pindstrup Mosebrug, has for more than a century extracted peat from Lille Vildmose in Northern Jutland. The environmental authorities ordered them to stop extraction in 2006 according to the EU Habitat directive and the fact that raised bogs are the rarest habitat in Denmark. After a trial in court raised by the company, extraction was finally stopped in 2018 (Oudshoorn *et. al.,* 2019). Pindstrup Mosebrug was established in 1905, and until about 1960 peat was extracted for heating (Oudshoorn *et.al.*, 2019). The Danish market for peat applied in growing media is approximately 100.000 tons per year equally divided between the professional and private market (Priess Hansen, 2016). It is covered by imported peat, commonly from Estonia and Latvia. The former area of peat extraction is the biggest area of protected landscape on a national level in Denmark, and the protection was assigned in 2007 (Anon., 2021).

The industry association, Danish Biomass Recycling Association was formed in 2006 and includes 25 companies. Among them are waste management companies commonly offering free compost as bulk ware in spring, made from green waste from recreational areas. This offer is often connected to green festivals and dissemination of public information.

Some peat-free products produced and sold in Denmark by 2021 are:

- ”Køkkenhave- og drivhusmuld” from Farmergødning, made from composted willow woodchips and deep litter from organic hens and cattle (Picture 2). In products for export, deep litter is replaced by grass cuttings (Mortensen, pers.comm.)
- “Spagnumfri krukkejord” from Champost. Made from composted horse manure, formerly applied for mushroom production (Picture 3).

Picture 2: Growing media made from composted willow wood chips and deep litter from organic raised hens or cows is peat-free and sold in bags or bigbags. http//www.farmergodning.dk

Picture 3: "Spagnumfri krukkejord" is a Danish peat-free growing media made by composted horse manure, designed for container production. *https://champost.dk/*

3.2 Norway

Norway has registered 63 Ramsar sites (Ramsar secretariat, 2021b). Raised bogs cover 38 000 km^2 = 9 % of the Norwegian land area. The bogs comprise a mosaic of different types; raised bogs are categorized into at least five types referring to the way they were formed or their geographical location (Øien *et. al.*, 2017). The diversity among *Sphagnum* species is broad as well; 47 out of 50 distinctive European *Sphagnum* species have been identified in Norway (Øien *et. al.*, 2017).

Peat extraction is mainly conducted by about 12 companies organised in the national industry association (Norske Jord- og Torvprodusenters Bransjeforbund, 2021) totally managing 21 extraction sites, expecting to continue their extraction for at least 20 years (Miljødirektoratet, 2018).

About 400 000 m^3 of Norwegian peat is consumed in growing media per year; about 75 % of this is for the private market (Miljødirektoratet, 2020). Despite the significant national resources of peat, 25 000 tons were imported in 2018 (Lystad *et.al.*, 2019).

Environmental authorities in Norway proposed in 2018 a plan for phasing out extraction and use of peat (Miljødirektoratet, 2018). Remedies within legalisation, economy, and information were considered for the private and the professional market: 1) An information campaign lasting until 2025; 2) Remedies like juridic directives and/or economic incentives were proposed towards the professional market. However, a ban on peat could not be implemented due to the EEA agreement. Further investigations were needed. A national goal for phasing out peat was proposed to be set to 2030, and scenarios for closing and restoration of peat extraction locations were outlined, as well as benefits for environment and climate which would follow from a future ban (Miljødirektoratet, 2018).

A new proposal in 2020 emphasized a need for more studies to develop peat alternatives, especially for the professional market. A proposed measure is to make it mandatory for public bodies to apply growing medias without peat, and to consider a labelling of growing media according to environmental impact (Miljødirektoratet, 2020).

About 80 Norwegian waste treatment plants produce compost permitted for sale as growing media (Mattilsynet, 2021). One example is a municipal treatment plant close to Oslo, Romerike avfallsforedling IKS (ROAF) which offers matured compost from garden waste for soil amendment ("Kompostjord", Picture 4), and compost mixed with 50 % sand ("Rett i potta", Picture 4) as a growing media in plastic bags for sale at all sites where inhabitants may deliver waste. About 8 000 tons are sold each year (ROAF, 2021).

Picture 4: Compost for sale at waste plant . ROAF, 2021.

A study conducted in 2015 revealed 50 different growing media for the private market sold from 15 retailers in Norway, but only three of them were peat-free products (Lindahl, 2015).

In 2017, 180 growing media products were available on the Norwegian market and 25 of them were peat-free based on compost, coconut coir, wood chips, perlite or rockwool. Some had 20 % peat reduction (Miljødirektoratet, 2017). The website of a Norwegian NGO, "Sabima", working for the protection of raised bogs, offered (by 2021) links to retailers selling 12 types of peat-free growing media and 6 products where the content of peat was < 50 % (Morsund 2021). In addition, several waste companies offer "compost soil" made from composted organic household waste and/or green waste from recreational areas.

3.3 Sweden

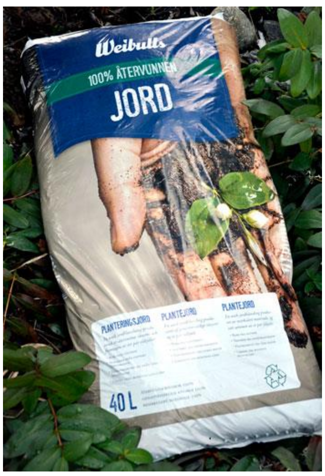
Sweden has registered 68 Ramsar sites (Ramsar secretariat, 2021c). Approximately 6.350.000 ha = 15 % of the land surface in Sweden is bogs and by 2015, 13 % of the annual global peat extraction occurred in this country (Naturvårdsverket, 2016). Domestically, it is used for energy production, animal bedding, and growing media. However, peat for energy use is decreasing, from 3.9 TWh produced from peat in 2009 to 1.3 TWh in 2017 (Lundberg, 2018). Approximately 2,000,000 m^3 of peat are extracted for growing media and 1,500,000 m^3 for energy purposes yearly (Svensk Torv, 2019). National regulations claim that after extraction, peatlands must be restored, either by reforestation or by constructing a new area of wetland (Naturvårdsverket, 2016). As in Denmark, private use represents about 50 % of the market of growing media/soil amendment products (Naturvårdsverket, 2016).

Sweden implemented a new law on peat in 2016 which followed up their "Myrskyddsplan" (in English: Mire Protection Plan) from 2007 (Swedish Environmental Agency, 2021) protecting the most unique bogs over long time. Existing concessions on peat extraction by January 1 in 2017 were not altered. The normal length for a concession is 20-30 years. Any new extraction must include a plan for restoration (Swedish Environmental Agency, 2016).

An important stakeholder is the Swedish industry association for peat producers, "Svensk Torv", with close to 50 members (https://svensktorv.se/in-english/). The association has transnational members like Degernes Torvstrøfabrikk (Norway). Hasselfors Torv is a large producer covering a significant part of the Norwegian market for growing media (Svensk Torv, 2021). Vapo Oy is an international consortium based in Finland and the largest peat producer in Scandinavia. Vapo Oy operates 56 active production areas for peat in Sweden (Vapo Oy, 2020).

The Swedish industry association supports their European association, GrowingMedia Europe GME, in the work towards including EU Eco labelling on growing media (Holmberg, 2020).

The Swedish market shows peat-free growing media like the one from Weibulls (Picture 5) with recycled woody material from paper industry and sawmills combined with manure and compost. Emmaljunga and Änglamark with reduced peat content are also manufactured in Sweden.



Picture 5: Weibulls 100 % återvunnen jord (100 % recycled soil) is made from composted industrial wood materials, garden waste compost and farmyard manure.
www.weibulls.com

4 Scandinavian studies of alternatives to peat in growing media

Several materials have been tested as alternatives to peat in growing media, such as composts from various substrates (farmyard manure, green waste from gardens or recreational areas, source-separated organic household waste), wood-derived materials (bark, fibre, woodchips), coconut coir (fibre) and even biochar (Oudshoorn *et. al,.* 2019), separately or in mixtures. Many characteristics should be fulfilled for a satisfactory alternative to peat in growing media, and three quality aspects are essential (e.g., Brod & Haraldsen, 2017):

- Physical quality – there must be at least 85 % pore volume with 20-30 % air capacity and 60-70 % total water holding capacity (WHC). The bulk density should not exceed 300 kg per m^3.
- Chemical quality – the pH level should be 5.5- 6.5, a significant proportion of the nitrogen (N) content should be plant available, and the material should not contain toxic compounds such as heavy metals or phytotoxic compounds such as organic acids.
- Biological quality – the media should not contain any plant pathogens, vital seeds or other propagating organs of weeds, or compounds hampering the germination of plant seeds.
- General quality – the media should have a pleasant odour and not contain large residual particles, e.g. of wood, and should not be subject to rapid decomposition while being applied as growing media.

Peat replacement will probably mean chance of some cultivation practices like watering regime. When peat is replaced with other materials, it will often be necessary to irrigate more often but in lesser amount to avoid dry conditions or water saturation (flooding conditions), because few materials are able to compete with peat in WHC (Brod & Haraldsen, 2017).

Brod & Haraldsen (2017) argue that a complete replacement of peat in growing media for professional production demands more testing in different plant cultures and more research on mixing rates of materials. Mixing rates may solve challenges of too high pH-level, too high cation exchange capacity and challenges linked to structural homogeneity (Brod & Haraldsen, 2017).

4.1 Comparing alternatives to peat

The Norwegian Institute for Sustainable Research, NORSUS, compared peat and peat alternatives by several Life Cycle Analyses, LCAs, and climate load by calculated CO_2 equivalents (Tellnes *et al.* 2017). The LCAs were divided into production, distribution, use and waste phase. The comparison was challenging because assessed alternatives were only substituting a proportion of peat. For instance, coconut coir comprised 20-50 % of the assessed growing media, and compost 30 %. Another obstacle for applying the LCA method to growing media was the assessment of plant nutrients. Peat barely contains any plant nutrients, while composts, dependent on which substrates they are made from, may provide 60 % or more of the nutrients required for transplant production (Tellnes *et.al.*, 2017).

GrowingMedia Europe, an international non-profit organisation representing the producers of growing media and soil improvers at European level is currently working on LCA-criteria applicable to growing media. The purpose is to elaborate a database with growing medias constituents. The work is based on EU acknowledged Product Environmental Footprint (PEF). The guidelines for life cycle inventory (LCI) explains the information for such LCA. It addresses 19 different environmental impacts e.g., climate change, ozon depletion, acidification, eutrophication, human- and/ or ecotoxicity, use of land, water and / or fossil resources. Growing media is principally assessed by its constituents e.g., peat, perlite, coir, wood fibre and / or compost. Additives like limestone, clay and / or fertilisers are also following mentioned. Application of growing media is divided into 1) pot plants and ornamentals; 2) Soft fruit or tree nursery stock; 3) hobby market and 4) tomatoes and fruity vegetables. Growing media for hobbymarket is constituted of lesser peat (50 %) than growing media applied in pot plants and ornamentals (75 % mostly milled white peat) or applied in soft fruit or tree nursery stock (75 % mostly different fractions of white peat). Life stages are broken down to: constituent / additive; inbound transport; processing and packing; outbound transport; use; end-of-life. The database is not functioning or available yet (GME, 2021).

Grønt Udviklings- og Demonstrationsprogram, GUDP, (Eng.: Green Development and Demonstration Programme) supports in 2019-2021 a Danish project "Biobaserede vækstsubstrater til planteproduktion" (BioSubstrate) (Miljøstyrelsen, 2021). A first important step in this project was to do a screening of biomasses available and applicable in growing media. The materials were divided into:

- cultivated biomass like wood chips from willow or forest, grass fibre from elephant grass or meadows
- residual materials from other productions such as cereal straw, hay, grass fibres from protein extraction, solid digestates (from anaerobic digestion, e.g. of animal manure), and insect frass.

Assessed by dry matter (DM) content, the biggest amount of material was available from straw. About 41 % of straw after cereal and rapeseed production is currently left in the fields to decompose. Applied in growing media, the quality varies with cereal species, is lowest for rye, and depends on soil type and amount of rainfall. A water content > 15 % will initiate biological activity where straw will be transformed to flakes. This degradation waives the use for bioenergy, but the variations in straw quality was not higher than for other potential biomasses. Straw could be applied for carbon storage on the field or for heating, but the prices are too low to compete the price for growing media.

The quality of wood chips from willow and forest is relatively stable but affected by the content of bark, which again depends on the age of the tree at cutting, and further on the tree species and season of harvest. Willow is normally cut every third year and must at least be cut every tenth year. When cut before the third-year water content may be too high and affect the quality negatively. Wet storage conditions may in the same way affect quality negatively. Some forest wood chips are prepared for paper production without bark and consequently containing lesser plant nutrients. The price of wood chips competes to use for energy purposes, forest wood chips normally with higher price than willow wood chips. Denmark imports wood chips. The willow wood chip production is stable and modest.

The quality of grass from meadows or the cultivated elephant grass (miscanthus) varies according to the frequency of harvests and harvest season. Miscanthus and grass fibre from protein extraction are currently only available in small amounts, but protein extraction is expected to become more common in future. The price is expected to follow other feed products.

Fibres from animal manure separated before or after anaerobic digestion is an upcoming technique where the price and potential application for other purposes is yet unknown.

Insect frass, which is a mix of insect residues, excrements and feed leftovers, are only available in small amounts. The future amount, price and potential will depend on legal frames and criteria. If sanitation is required before application in growing media, costs will rise significantly (Ugilt Larsen & Hinge, 2019).

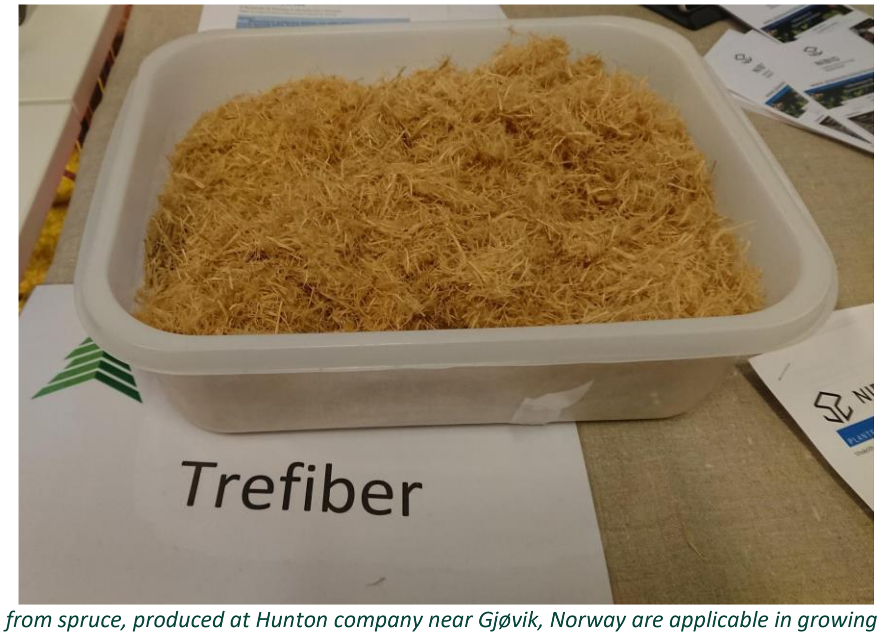
4.2 Woody materials in growing media

Woody materials processed to other products than paper and applied to growing media are presented in the following three sections.

4.2.1 Forest industry residues: ashes, bark and fibre

Norwegian forest industry initiated a project in 2017, called "Innovativ resirkulering av sidestrømmer av bark og bioaske for å erstatte ikke-fornybare produkter" (ReBio)(in English: "Innovative recycling of residual materials of bark and woody ashes to replace non-renewable resources") (Horn 2020).

The aim was to find best praxis for handling residual materials from forest industry to obtain best quality in replacement or reduction of peat in growing media. An initial step was to compost bark were proceeded with wood fibre from spruce (Picture 6), in addition to wood ash and biochar from pine wood from spruce and pine. This was quite challenging, because the thermophilic stage was difficult to achieve properly, and the resulting material had too high content of bacteria. Instead, the studies.



Picture 6: Fibres from spruce, produced at Hunton company near Gjøvik, Norway are applicable in growing media. Photo: Susanne Friis Pedersen

To possibly produce a complete growing media, further applied materials were biochar and wood ash, green waste compost, peat, rockmeal, sand, poultry manure, mineral fertilisers and struvite. For comparison, four commercially available growing media with various amount of peat were applied. The aim was to replace as much peat as possible with wood fibre while maintaining a high-quality growing media which could be applied by hobby gardeners without further fertilisation. The project was followed by former actions to develop a recipe for a commercial growing media called Green Viking Premium soil ("in Norwegian: Green Viking Premium Blomsterjord"). The product has a significantly reduced peat content (Günther, 2020) and includes green waste compost and rock meal as recycled substrates. Further ingredients are not revealed by the producer (Nordic Garden). So far, Norwegian scientists do not recommend a complete phasing out of peat (Haraldsen *et.al.*,2020), but wood fibre replacing peat in growing media makes a better reduction than replacing with woodless compost (Günther, 2020).

In the ReBio project, the four commercial growing media were compared with 26 treatments where freshly made growing media were mixed with spruce fibre, green compost and sand, alone or in combinations, and further ingredients applied were rock meal and biochar from pinewood. The treatments were amended with four different fertilisation regimes, composed of woodash, poultry manure, mineral fertiliser or struvite (Haraldsen *et al.*, 2020). The trial aimed at maintaining an equal fertilisation of N in all treatments. Nine out of 26 treatments were peat-free, combining wood fibre, compost and rock meal or sand. In three replicates, test crops were cultures of carrot (3L pots), tomato (3,5L pots), petunia flower (10 cm high pots) and potato (5L pots). The crops were cultivated over two months in greenhouse with a day temperature of 20 °C and night temperature of 16 °C.

The tomatoes responded more to fertilisation regime than to growing media, but some peat-reduced growing media performed quite well, while two of the commercial products showed weak growth.

The potatoes grown in peat-free growing media gave very low yields as compared with commercial controls.

For carrots, again the peat-free alternatives performed quite poorly, whereas several peat-reduced alternatives gave high yields, comparable with commercial controls.

In petunia, the plants developed very differently in the 30 treatments, but again the peat-free treatments performed poorly whereas several peat-reduced treatments performed good. An extra test round with petunias indicated that petunias responded negatively to biochar in the growing media.

During the cultivation, fungus gnats *Sciaridea* (small, flying insects attracted by moist soil) was a disturbing issue which unfortunately is not uncommon when cultivating in wood based growing media.

It was concluded that some proportion of peat could prevent too wet conditions in the growing media and thereby also prevent fungus gnats. The conclusion of this extensive trial was that none of the 26 treatments were recommended for plant cultivation. Replacement of peat with wood-based materials has to be considered along with an appropriate fertilisation regime. To increase the content of recycled products in growing media, both wood-ash and struvite were applicable in this trial and may be applied in future. For the hobby market 30 % compost in the growing media must be a minimum to replace non-renewable peat (Haraldsen *et.al.*, 2020). Furthermore, they conclude that expanding the proportion of garden waste compost in a growing media to above 30 % will imply a risk of providing too high nutrient concentrations and may also affect storage stability of the growing media when stored in plastic bags where anaerobic conditions easily arise (Haraldsen *et.al.*, 2020).

The ongoing Norwegian project "Nye bærekraftige vekstmedier som erstatning for torv" (New sustainable growing materials to replace peat), SubTech (Grofondet 2021) aims to deliver peat-free growing media applicable for Norwegian protected growing of berries and vegetables, with spruce wood fibre as a main ingredient. In SubTech, Norwegian Institute of Bioeconomy Research (NIBIO) compares growing media made from spruce wood fibre, peat, biochar and microorganisms, aiming at media which can be cheaper and perform better than currently applied peat- og coco coir-based growing media. A former project at NIBIO research station Apelsvoll showed that strawberry cultivation in wood fibre could be performed as successfully as in peat, when liquid mineral fertiliser was applied (Haraldsen *et.al.*, 2020). In a trial with strawberry variety ´Sonata´, two controls of peat with perlite and coco coir (Figure 1: 1,2) were compared with 9 growing media composed of wood fibre of different qualities (Figure 1: 3-11). Two wood fibre materials (9, 10) were amended with humic or fulvic acid, and one (11) with fulvic acid and bacteria, Figure 1 (Woznicki, 2020). Wood fibre from spruce performed best, and plants produced on average close to 500 g of strawberries per plant. With peat, about 470 g per plant was produced. Adddition of humic acid, fulvic acid and bacteria gave quite variable results, and somewhat lower berry yields (350-450 g per plant on average).

FORSØK 2: SAMMENLIGNING AV ULIKE TREFIBER-BLANDINGER TIL 'SONATA'

1. **Torv + Perlitt** (20%)
2. **Kokos**
3. **Grov trefiber**: 400 g fiber/1 L vann
4. **Våt trefiber**: 1.25 kg fiber + 0.5 L vann
5. **Fin trefiber**: 500 g fiber/1L vann
6. **Løs trefiber**: 400 g fiber/1 L vann
7. **Furu-fiber** fra Klasmann: 2.5 kg/1L vann
8. **Torv/trefiber-miks** fra NORGRO: 1.25 kg/ 1L vann
9. **Grov trefiber + humus-syre**: 400 g fiber/1 L vann + 50 ml HS
10. **Grov trefiber + fulviksyre**: 400 g fiber/1 L vann + 50 ml FS
11. **Grov trefiber + fulviksyre m. bakterier**: *Bacillus subtilis, B. methylotrophicus, B. licheniformis* 400 g fiber/1L vann + 50 ml FS+B

Figure 1. 11 different qualities and mixes of wood fibre for cultivation of strawberry variety ´ Sonata´. Woznicki, 2020.

However, for application in organic growing, liquid organic fertilisers will be required, which may possibly interact with wood fibre products in other ways than mineral fertilisers.

Wood fibre could possibly replace rockwool in conventional production. Rockwool is deposited after use and takes a lot of energy to produce. Wood fibre as growing substrate requires further investigation in watering and nutrient regime to function well in both conventional and organic production (Oldertrøen, 2020).

4.2.2 Animal bedding with woodchips applied as growing media

NORSØK followed a compost barn in Snåsa, Norway, as part of a project focusing on compost. Two growing seasons, 2017 and 2018, were followed. It was a combined stable for suckler cows and a greenhouse. The purpose was to see if the deep litter with wood chips and cow manure could become a suitable growing media for greenhouse cultivation during summer (Friis Pedersen & Ebbesvik 2018).

Picture 7: Compost barn ready for plant cultivation during summertime. Photo: Susanne Friis Pedersen

About 60 cm of woodchips were laid on the floor, before letting the animals inside. To initiate thermophilic process, a compost from deep litter from sheep was mixed into the layer of woodchips. During winter, the bedding was managed by harrowing twice a day to a depth of 25-30 cm. At least once a week dry wood shavings were added on top. Woodchips were produced from local forest materials (spruce and pine), and from the farm's own forest (spruce, salix etc.). The management ensure significant increase in temperature, and the bedding material was tested for cultivation of several plant species cultivation which were planted or established by planting of seeds into the bedding material in May (Picture 7). Plants of squash and hokkaido crops performed nicely in the compost barn during 2017 (Picture 8), and tomatoes also grew well but with some indications of nutrient deficiency.

Picture 8 & 9: Plants of hokkaido (8) and squash (9) performed well in the summer of 2017. Photo: Susanne Friis Pedersen

In the decomposed bedding material, phosphorus values were satisfactory for plant growth, whereas potassium values were too high. The pH recorded in beginning of the growing season was 8.8 and C/N 28. At the end of the season pH was 8.6 and C/N 19 (Friis Pedersen & Ebbesvik 2018).

The following growing season, magnesium sulfate ($MgSO_4$) was added to reduce pH, but no better results than from the previous year was obtained (pH 8.4 in May and 8.8 in September). C/N was 30 in May and 24 in September (Friis Pedersen & Ebbesvik, 2020). An appropriate C/N for cultivation in mature compost is 12 to 15 (van der Wulff *et al.*, 2016)

In spite of a successful growth of some crops and promising Solvita®-tests in both years, the final recommendation for this compost was to let the compost mature for a longer period before cultivation. The compost may serve as soil improvement, but did not qualify to be a suitable growing media (Friis Pedersen & Ebbesvik, 2018; Friis Pedersen & Ebbesvik, 2020).

4.2.3 Biochar and composted bark

A Swedish student trial compared different mixes of three substrate-components in a trial covering 32 pots, each containing 3 l. The first substrate component was biochar made of waste from cereal production and municipal green waste (pH 9.3). The second was bark compost originating from pine and spruce pine composted for one year intended for soil improvement (pH 6.2) and the third was peat with no nutrients added (pH 4.5). The mixes were set aiming for a pH between 5.0 and 6.5 and 45-65 % micro pores for outdoor containers and indoor seedlings, 10-20 % macro pores for outdoor containers and 15-25 % for production of seedlings. Three mixtures were tested with proportions by volume of *biochar: bark compost: peat*, being *25: 45: 30; 35: 35: 30;* and *45: 25: 30*. The trial ran for three weeks at 18-20 °C in a greenhouse. During that period, each pot was watered 10 times with 600 ml tap water each time. The substrates were tested for physical and chemical properties once before starting the trial, once after five water applications and once at completion of the trial. The best suited mix for outdoor containers was 45 % biochar + 25 % bark compost + 30 % peat. The physical properties for this mix showed initially 54 % micropores and 20 % macropores and at the end 42 % micropores and 34 % macropores. pH started at 7.1, increasing to 8.5. With addition of biochar, the bulk density and electric conductivity increased. No plants were cultivated in this trial, but for plants adapted to high pH level the biochar: bark compost: peat-mix 45:25:30 was found suitable for short time cultivation both in- and outdoor (Bergquist, 2018).

When cultivation is performed in small volumes N is quickly mineralised and consumed, pH may decrease and substrates are often inclined to shrink. In a Swedish student report (Guinane, 2012), the owners of eight plant nurseries were interviewed about their challenges in general. They used eight different growing media Two were peat-free. One, intended for cuttings, was mixed of composted bark, compost, mont-morillonit-mineral, wood fibre, horngrid and bone meal. The other peat-free growing media was a mix of composted leaves, branches, gras cuts, soil, bark, sand and pig bristles applied as pellets. This mix was made on site, and the grower who used it was motivated to do this because (s)he had experienced that commercial products fluctuated too much in quality. All informants supported implementing alternatives to peat. The student report proposed following substrates for components in growing media: Spent mushroom compost, paper sludge, fibre leftovers from apple juice, spent newspapers, compost, alfalfa and kenaf. Kenaf is synonym to *Hibiscus cannabinus* which is cultivated in USA.

However, none of these materials were recommended to comprise more than 20-50 % of volume in a growing media (Guinane, 2012). Alfalfa is cultivated in Denmark and in southern Sweden and is suitable for growing media after sorting out of big plant parts and composting for 20 days. A recipe for alfalfa treatment in growing media proposed by Kueppert & Everett was referred in Guinane, 2021. An advantage of alfalfa is that it is rich in organic N which is slowly released.

Another Swedish study found that bark and sawdust from conifers and hardwood trees, when mixed with animal manure, straw, miscanthus and hemp and green waste and composted could compose a growing media with acceptable level of shrinking. The maximum shrinking level was set to 10-30 % of volume from initiating the cultivation. Saw dust could be applied if it derived from hardwood and made-up maximum 30 % of the growing media volume. Saw dust was found to increase the pore volume for air,but restrict the water holding capacity. Better water holding capacity could be obtained by replacing sawdust by bark. Biomass from hardwood had generally better characteristics for application in growing media than biomass from conifers. Conifers contains more lignin and resin than hardwood, which delay the release of plant-available N (Hålam, 2015).

4.3 Various composts as growing media

Compost deriving from other than woody plants and paper sludge (woody material well processed) are presented in the following sections where manure as well plays a significant role.

4.3.1 Composted field crops

The Danish research institute ICROFS has conducted a comprehensive series of projects and studies to develop organic growing. To design a growing media for greenhouse vegetables (cucumber and tomato), trials were made to compost wheat straw with grass-clover hay (Dresbøll 2003) in the project “Organic Production of Cucumber and Tomato grown in composted Plant Material from Field Crops”(ORCTOM) during 2001-04 (Anon. 2005). The project aimed at a good quality of growing media while minimizing nitrogen loss and assessing the physical structure of applied substrates before and during the composting process. It was found that by adding only one quarter of the hay at the start and the remaining volume after 3 weeks twice as much N was available in the compost after 8 weeks. The compost could be applied as growing media, but had too high nutrient concentration and the structure was not satisfactory. To test whether this could be improved by mixing it with another plant-based compost, with better structure and lower nutrient concentration, the decomposition of hemp and miscanthus (elephant grass) was compared with decomposition of wheat straw over 8 weeks. Miscanthus and hemp were quite stable and only lost about 10 % of the initial weight over 8 weeks. Hemp (dicot plant type) had a better structure with much more fibre than miscanthus (monocot plant type). Studies by scanning electron microscope revealed that the cell anatomy was highly important for the rate of decomposition and that lignin content alone is not enough to determine decomposition rate of a plant material.   The structural diversity of hemp was most diverse. Plant tissue structure and their anatomic arrangement seemed to be as important for decomposition as the chemical content. After 10 weeks of decomposition of grass-clover material with wheat straw, miscanthus, or hemp the C/N content had degraded from 26 to 15 in wheat straw and miscanthus, and from 16 to 11 in hemp (Dresbøll, 2004, Appendix IV).

4.3.2 Spent Mushroom Compost

In a student report, Ericson (2021) presented a literature review on spent mushroom compost (SMC) for cultivation in containers, discussing 20 different plant species comprising vegetables and berries, ornamental shrubs, one grass species, one cereal species and one herb. The volume of SMC in Sweden is yearly 10,000 ton from cultivation of mushroom Champignon (*Agaricus bisporus).* The substrates applied in a MC are straw from wheat, and manure from horses and/or hens. The SMC will also include fungal mycelia, lime or gypsum and a topping layer of peat. For each kg harvested mushroom, 5 kg compost is produced (picture 10). The review showed that SMC is applicable for different purpose. When stored for > 15 days after final mushroom harvest it is suitable for cultivation of transplants of tomato, sweet pepper, squash, and lettuce. When applied as a soil amendment, SMC may suppress soilborne pathogens and nematodes and contain slowly released plant nutrients. Disadvantages reported were a high salinity and electrical conductivity, a high pH level (7.4-7.9) and that the material will become more compacted during growing period while the pore volume shrinks (Ericson, 2021).

Picture 10: For each kg mushroom harvested there will be 5 kg Spent Mushroom Compost. Photo: Susanne Friis Pedersen

4.3.3 Paper pulp amended with solid digestate

Forest industry may have residual products such as paper sludge, which may be used as a growing media with respect to physical characteristics. Possibly, this could replace imported peat alternatives such as coco coir. However, such materials which may perform well with respect to physical characteristics, do not contain much plant nutrients. Solid digestate (from biogas production) or composted animal manure may be mixed with paper sludge to provide nutrients and ensure a satisfactory structure of the growing media.

Paper pulp was tested and compared with coco coir and peat in a Norwegian student thesis (Nesse, 2017). The tree main questions were: 1) Is it possible to construct a growing media with similar physical properties to peat? 2) Is paper sludge as good as coco coir with respect to physical properties? 3) Do various nutrient-rich waste products differ with respect to fertilisation effects?

Four materials rich in nutrients were tested in combination with structure-rich paper sludge and coco coir, with a commercial peat product, "Floralux Naturtorv" as a control.

The four nutrient-rich materials were:

1) Cow manure fibre separated from dairy cow slurry delivered by farmer K. Vasdal, Skien and composted over three weeks at 50 °C, in the following abbreviated to "Cow fibre"
2) Cow manure sediment produced from cow slurry after defibrating, treated by vermicomposting over 40 days, delivered by farmer K. Vasdal, Skien. Vermicomposting is a decomposition carried out by earthworms like red wigglers, *Eisenia foetida*.
3) Solid digestate from source-separated organic household waste (HW) composted with about 60% green waste from gardens, produced by Romerike biogas plant on behalf of Oslo municipality (abbreviated RBA)
4) Untreated solid digestate from HW, produced by Hadeland and Ringerike waste company (abbreviated HRA).

Paper sludge was received from FollaCell AS, Follafoss, Norway, and was treated with alkaline solution and washed several times. Coco coir was imported from India.

The nine treatments compared were: 1) Paper sludge 2) 20 % composted solid digestate RBA + 80 % paper sludge 3) 20 % untreated solid digestate HRA + 80 % paper sludge 4) 50 % vermicomposted cow manure solid digestate and 50 % paper sludge 5) 50 % cow fibre compost and 50 % paper sludge 6) 20 % composted solid digestate treated at high temperature HRA and 80 % coco coir 7) 20 % untreated solid digestate treated at low temperature RBA and 80 % coco coir 8) 50 % vermicomposted cow manure solid digestate and 50 % coco coir 8) 50 % cow fibre and 50 % paper sludge and 9) peat as control. All growing media were added calcium carbonate to achieve a pH of 6, and all treatments including the control was amended with mineral fertilisers to achieve a satisfactory content for plant nutrients.

Three litres of each growing media was filled in 3,5 litre pots and tested with cultivation of two crops, tomato and lettuce, in three replicates. The growth period was two months at 21 °C and biomass above and below soil surface were harvested, dried and measured at the completion of the study.

All tested materials and mixtures had quite satisfactory physical characteristics. 100 % paper sludge had somewhat more air-filled pores (> 150 µm) and slightly less pores able to held plant-available water (3-150 µm) than peat. Addition of nutrient-rich materials decreased the proportion of pores > 150 µm. Chemical characteristics differed between the growing media with highest proportion of plant nutrients in treatments containing solid digestate. A high content of sodium and aluminium especially in paper sludge did affect negatively on plant growth. Whereas treatments which included untreated solid digestate had significant concentrations of ammonium (NH_4^+), peat, paper sludge and treatments with composted materials mostly contained nitrate (NO_3^-). High concentrations of ammonium affect negatively on seed germination and plant growth.

A germination test over 21 days showed that the solid digestate materials could hamper seed germination. Seeds germinated rapidly in coco coir and cow fibre, and quite well in paper sludge and vermicomposted cow manure. In the composted and untreated solid digestate, a crust formed on the soil surface and germination was significantly hampered, especially in the composted digestate. The amount of biomass produced comprised 9.4 g DM per pot for lettuce and 9.1 for tomato in the peat control. Lettuce grew quite well in paper sludge (5.3 g DM/pot), but tomatoes only produced 3.5 g DM/pot in this material. Amended with untreated solid digestate, the yields increased to 7.1 g DM/pot for lettuce and 4.9 for tomato. Vermicomposted manure performed quite well when mixed 50% with coco coir and gave 5.0 g DM/pot for lettuce and 3.3 for tomato. Other treatments performed poorly and gave yields ≤ 3.7 g DM/pot in lettuce and ≤ 1.6 in tomato.

Since the paper sludge functioned quite well with respect to physical characteristics, this material may be quite relevant to apply as an alternative to peat, provided that it can be produced with lower concentrations of sodium. Organic materials applied for fertilisation should be stabilised and not contain too high levels of ammonium.

In another Norwegian master thesis, vermicomposted solid digestate from household waste was mixed with different proportions of nutrient-poor garden compost made from green waste, both produced by Lindum AS (Norwegian waste company). Relevant for this report were two research questions: 1) Can compost based growing media and fertilisation give similar result as peat and mineral fertilisation when cultivating black currant in boxes on a roof? And 2) Is the mix of 70 % garden compost and 30 % vermicomposted solid digestate provided by Lindum the optimal mix for the purpose?

The garden compost was brushwood and grass cuttings composted for 10 months. The vermicomposted solid digestate (VSD) was solid digestate from HW composted with worms in a drum.

Mixtures comprising 15 : 85, 30 : 70 and 60 : 40 of VSD : garden compost were compared as growing media for young plants of black currant established in a rooftop garden system (Gardli 2018). The control treatment was a commercially available growing media made from peat with mineral fertiliser.

Vegetative and generative growth were assessed. Vegetative growth was counted by time of leaf spread in the months of April and May. No significant difference was found but placements in the outer circle of the berry cultivation had slightly later leaf spreading than in the inner circle. This was not correlated to the growing media. No significant difference of generative growth measured by berry weight was found.

The control treatment produced the largest plants after one season, but treatments with 30 and 60 % VSD also gave nicely developed plants, with better root development than found for peat. 15 % VSD+ 85 % garden compost gave poor plant growth and root development (Gardli, 2018).

To mix solid digestate with wood fibre to provide a satisfactory structure in the resulting growing media is also tested in a PhD-thesis at the Norwegian University of Life Sciences (Brodin 2021). Wood fibres from conifers produced for insulation possess good physical characteristics for growing media, contributing to a firm structure, and such material is more homogeneous than wood fibre originating from green waste. A mix of 30% solid digestate and 70 % wood fibre performs equal to peat in several characteristics and has proven to work well as long as the cultivated plants are irrigated from below. Even if a solid digestate is decomposed, a second decomposition phase (composting) must be conducted after mixing digestate and wood fibre to ensure a stable growing media where nitrogen is not captured by microorganisms to become unavailable for plant uptake. Application of nutrient-rich materials may be relevant in this composting process. Mixing 20 % of peat into the digestate-wood fibre growing media facilitates water storage in containers and may be relevant for irrigation from above and for small plant containers (Brodin, 2021).

4.3.4 Well-matured compost as growing media

In a comparison study of selected commercially available growing media approved for certified organic production McKinnon (2017) revealed that the same product (same name from the same producer) performed quite differently between years, and that some products had too much weed seeds. In further tests, some locally produced growing media from materials obtained on site were included. This comprised composts made from horse manure and/or leaves of birch trees.

In 2018, eight commercial growing media approved for certified organic growing were compared with composts prepared at NORSØK. The commercial growing media contained a significant proportion of peat, and nutrients were supplied by poultry manure, or manure from ruminants or seaweeds. No plant nutrients were added during the test period, where iceberg lettuce, cauliflower and squash, with different nutritional requirements were grown initially in trays and then in pots. Total growing period were 26 days for squash and 40 days for cauliflower and iceberg lettuce. Transplants were visually assessed, and dry weight measured. For cauliflower, which has high nutrient demand, the local compost produced plants of equal quality to some commercial growing media (Picture 11 pot 10). Growing media produced from composted yellow lupine *Lupinus luteus* and flax *Linum usitatissimum,* produced in Denmark (pot 1) and an English product from composted wool and ferns (pot 11), also gave large plants, whereas several commercial growing media from peat, amended with various organic fertilisers, performed quite poorly. The three locally produced contained horse manure composted over 2 years (pot 9), leaves from birch composted over 3 years (pot 8), or a mixture of these materials leaves and manure 1:2 (pot 10). Especially the locally produced leaf compost performed very well but contained a significant amount of viable weed seeds.

Several commercially available products gave small and poorly developed plants, some also of lettuce and squash with less nutrient demand, and were considered completely unsuitable for the purpose, demonstrating the high risk for organic growers relying on purchasing of growing media. (McKinnon, 2018).

Picture 11: Representative plants of cauliflower after 39 days of growing in various growing media; 1= composted lupin + flax, 2-7 = peat with organic manure; 8 = composted leaves, 9 = composted horse manure, 10= composted mix of horse manure and leaves 2:1, 11= composted wool and ferns. Photo: K. McKinnon

A Danish student presented a master thesis about making own organic sowing and potting substrate and how to communicate this knowledge to organic garden growers (Priess Hansen, 2014). The purpose was to make the target group competent to act by providing skills of acting, visions and knowledge. It was an interdisciplinary thesis reviewing scientific literature compared to and explained by practical efforts in the target group and dissemination based on analysis of the target group, considering use of gardening terms and communication guidelines. The project emphasized knowledge to act on replacing peat instead of knowledge about consequences without taking action. Providing experience and skills to the target group a workshop was implemented and five articles published on the webpage run by the Danish *Landsforeningen for Praktisk Økologi* (in English: National Association for English Practical Ecology). The dissemination in the articles where angled "need-to-know" and "how-to-do" omitting everything "nice-to-know".

Priess Hansen (2014) revealed several barriers for organic hobby growers to make their own sowing and potting substrate. Detected barriers were lack of recipe; lack of space; lack of knowledge about pH and plant nutrients; lack of knowledge about raw materials, their properties and availability; and lack of willingness to risk transplants for the garden season.

Focusing on growing media for transplants the physical, chemical, and biological qualities must be stricter because of:

- smaller volume where roots cannot avoid less favourable spots
- the homogeneity and evenness of the substrate is more important for seed and roots in the smaller volume
- the stages from sprouting to first leaves are more sensitive to mineral salts and high pH
- the plant has not yet established symbiosis with mycorrhiza making it more robust.

Compost from green waste has often high pH, which makes it is particularly difficult for species such as carrot, chili, chive, eggplant, leek, and potato to thrive, while Spanish pepper, asparagus and parsley can better stand a high pH. Another practical issue about using composted green waste is that the woody raw material has to be milled early in the process to obtain an even distribution of pores. The continua of airy pores are essential to water retention and thriving of seedlings (Priess Hansen, 2014).

4.4 Paludiculture

Peat farming or "Sphagnum farming" also named "paludiculture" is an upcoming scientific area, which deals with restoration after peat extraction. A search on "Sphagnum farming" in Science Direct shows between 15 to 54 results from 2011 to 2021. The German University at Greifswald provides more information and lists publications in English at their webpage www.sphagnumfarming.net (Haraldsen *et.al.,* 2020). It is included as a living alternative to fossil peat but it is still peat from vulnerable nature areas.

The Swedish foundation Lantbruksforskning cooperates with Hasselfors garden and Swedish University of Agricultural Sciences, SLU, trying to farm peat species like white mosses. The project is named "Vitmossa (*sphagnum*) är framtidens klimatvänliga torvsubstitut i våra trädgårdar" (Eng.: White mosses (*Sphagnum*) are the future climate friendly substitute for peat in our garden sector") (Lantbruksforskningen, 2021).

The faster growing clones of white moss species *Sphagnum palustre* and *S. papillosum* originate from Finland and spores have been randomly spread in the Swedish experiment which covers two ha of land with former peat extraction. The production was initiated in the autumn of 2018. Different watering regimes and application of organic matter like peat and cereal straw are tested. Emission of methane, uptake of carbon dioxide, water quality and growth are measured. The capacity is 25-30 cm growth per year which can be harvested after some years. They mosses will store more carbon than they emit (Kling & Jordan, 2020; Lantbruksforskningen, 2021).

The Danish Pindstrup Group is also involved in peat farming as part of restauration project after peat extraction. Vegetative propagating plant material is spread in former peat extraction land south of Aarhus. Keeping a water regime with high humidity is essential to support the growth of peat and avoid other species to take over e.g., *Carex spp.* (Haraldsen *et.al.*, 2020).

5 Final remarks

Peat is still an important input in organic growing in Scandinavia but the awareness of reducing the application by appropriate alternatives is rapidly raising.

Wood material has promising characteristics for replacing peat in growing media. Several industrial (by)products have shown promising physical characteristics, but more work is still required to design completely peat-free alternatives which can compete with peat-based products.

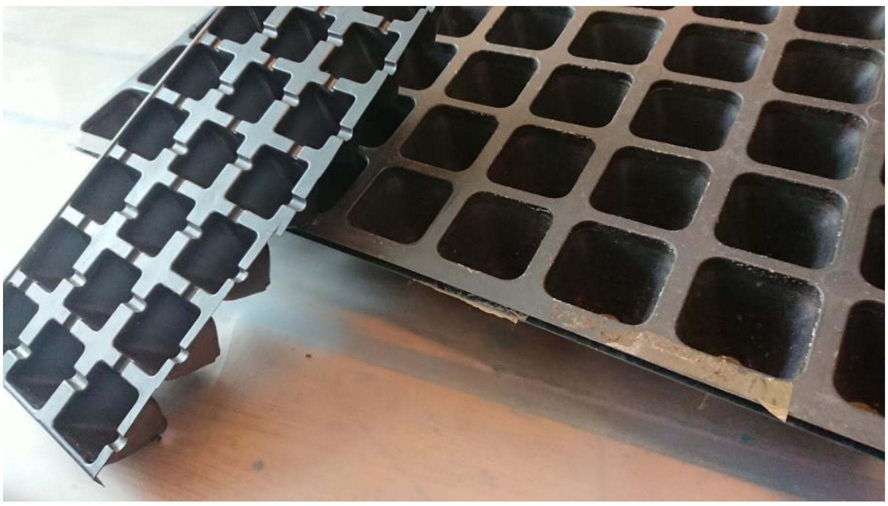
Compost is an important material which may substitute peat, but the challenge is commonly a too high content of nutrients, which may lead to leaching and may also restrict the plant growth. Composting is a cheap technology which can be applied both by private growers and professionals. Compost can be mixed into other materials, e.g. sand, to dilute nutrient concentration and pH and increase the bulk density.

Abandoning plant production in restricted media in organic growing, requesting cultivation directly in the ground of the greenhouse (European Union 2018), may possibly lead to a reduced demand for growing media. On the other side, containerised production is increasing rapidly e.g. of grafted tomatoes, which may counteract this trend.

Farmed peat is an emerging technology which may possibly substitute extraction of wild peat.

The replacement of peat can be eighter completely or partly. In Scandinavia, the only private standard outing a limit to the proportion of peat in growing media is the biodynamic Demeter standard, limiting its use to 75 %. This limit could well be applied in general EU regulations on organic production.

The use of peat during cultivation of transplants can be minimised by clever management. Starting with small pots and a growing media with peat which favours seed germination, plants can then be transferred to larger containers with a peat-reduced or peat-free growing media (Picture 12), as was also recommended by EGTOP (2013).



Picture 12: Downsizing volume of growing media for transplants may consequently downsize the use of peat. Photo: Susanne Friis Pedersen

On the other hand, upsizing the volume of pots and trays may give better homogeneity of compost products due to the trials done by Aurdal (Brodin, 2021).

The market for growing media is divided between private growers and professionals. Private gardeners buy smaller amounts in bags and have less economical risk. The professional market is dependent on a stable quality, bigger volumes and lower prices.

Professional growers often have access to materials which could suit well as a substrate in green composts, and hence should be encouraged to carry out composting with local resources. This may support some change of practise leading into a more sustainable future. Organic producers should be leading such change.

It is important to be specific on which plant cultures each growing medium is appropriate for. An important distinction is the cultivation of transplants, plants in larger containers indoors or outdoors, and further for berries, vegetables and flowers with various cultivation time. The physical quality of growing media for transplants is crucial, and in this category, peat is most difficult to replace. Products designed for specific cultures have to consider the specific nutrient demands and adapt the fertilisers to the demands of the culture.

Testing out locally made growing media characteristics and best management practices may involve organic growers and other stakeholders end encourage more local production of potting soil.

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