POSITION PAPER

Recognize the high potential of paludiculture on rewetted peat soils to mitigate climate change

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1 Introduction

Draining peat soils leads to oxidation of the peat and soil subsidence. In Germany, drained peatlands account for only 7 % of the agricultural land but are responsible for 37 % of the agricultural greenhouse gas (GHG) emissions (GMC, 2018). Rewetting peat soils appears to be a cost efficient GHG mitigation measure (Röder et al., 2015). The ideal situation would be a natural colonisation with peat forming plants after rewetting and a return to a carbon sequestrating system without harvesting. However, the productive function can often not be relinquished and paludiculture, the practice of productive use of wet and rewetted peatlands, should be considered. In paludiculture, harvesting wet crops for food, fodder, fibre and fuel is combined with the provision of vital ecosystem services (Wichtmann et al., 2016). This concept provides production opportunities for the necessary, fundamental change in land use of drained peatlands to a more sustainable, wetter land use, which should benefit both the regional economy and the climate. Peatlands used for paludiculture maintain a productive function under permanently wet, peat preserving conditions. The average groundwater level in the growing season is 20 cm below the soil surface or higher, and the minimum groundwater level is never more than 40 cm below the soil surface (Geurts and Fritz, 2018). This implies that drained grasslands and croplands can be converted into peat moss lawns, reed and cattail plantations, or wet meadows with grass species adapted to a higher soil moisture content. The biomass can be used for a whole range of products and applications, including human consumption and fodder, or wet grasslands can still be used as pastures (e.g. by light dairy cows or water buffaloes).

2 Paludicrops

There are various types of peatland cultivation systems with crops grown under wet conditions, so-called paludicrops. Many of these are ready to be implemented on a larger scale, including on farms. Biomass yields of 15 to 30 t dry matter per ha are potentially possible (Heinz, 2012; Köbbing et al., 2013; Grosshans, 2014), which is comparable to conventional crops. Paludicrops can be used as fodder, as protein

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source, or as raw material for the production of horticultural growing substrates, or alternatively for bio-energy and as a resource for bio-based materials (insulation, building materials, paper, bioplastics). Paludicrops differ in their soil chemical and hydrological requirements, and growers need to adapt to these requirements (Geurts and Fritz, 2018). *Table 1* lists promising paludicrops, their preferred range in water levels, applications for which they are grown (both on-farm and off-farm), existing pilots and large-scale implementation, and to which extent they have potential for carbon and blue crediting systems (see below). Moreover, usage of biomass for bio-based materials will prolong the lifecycle of carbon, as compared to fodder for ruminants where part of the carbon is rapidly emitted again as CH_4 and CO_2.

3 Payments for ecosystem services

There is a large GHG emission reduction potential when rewetting drained and fertilised peat soils, commonly 40 to 60 t CO_2-eq. ha^{-1} a^{-1} for productive and fertilised grasslands. Firstly, CO_2 emissions become lower at higher groundwater levels and approach zero in waterlogged soil. Secondly, emissions of N_2O, a very strong GHG, are reduced as N fertilisation will usually be decreased and N_2, rather than N_2O, will be formed during denitrification when oxygen availability is low in wet conditions (Tiemeyer et al., 2016). In addition to biomass use, the GHG emission reduction creates opportunities for business models based on carbon crediting schemes (e.g. Moorfutures®; Joosten et al., 2015; Günther et al., 2018). The climate mitigation potential is partly counteracted by methane emissions that are largely driven by summer inundation, topsoil chemistry, vegetation type, availability of easily decomposable biomass, and nutrient or carbon input (Couwenberg and Fritz, 2012). Guidelines for low GHG emission (< 10 t CO_2-eq. ha^{-1} a^{-1}) production cycles on rewetted peatlands are available (Tiemeyer et al., 2016; Günther et al., 2017; Geurts and Fritz, 2018). In addition, every hectare of drained peatland that is converted to paludiculture is as effective as taking climate mitigation actions on 10 to 100 ha of mineral soils for food production, which would have led to a lower productivity (e.g. lower use of fertilisers).

In addition to climate benefits, paludiculture can reduce nutrients in surface water and reduce flood risks and droughts by acting as temporary water storage areas, and increase biodiversity compared with conventional agriculture. In so-called blue crediting schemes, farmers could be paid for these water management related ecosystem services (Bohlen et al., 2009; Grygoruk et al., 2013). However, these schemes are still in the development stage.

4 Pilot projects

Paludiculture pilots and demonstration sites on a farm-scale already exist in various countries *(Table 1)*. Preliminary results suggest that peat forming paludicrops (e.g. peat moss, reed and alder) grown at groundwater levels 10 cm below the soil surface are the optimal compromise between biomass production, climate mitigation, and peat preservation (Schäfer and Joosten, 2005; Jurasinski et al., 2016; Günther et al., 2017). However, some crops, such as cattail, perform better at water levels 5 to 20 cm above the surface, which may lead to substantial methane emissions in case of adverse circumstances (high carbon input or presence of fresh litter (Couwenberg and Fritz, 2012). Harvesting belowground biomass is not eligible since causing regular soil disturbance conflicts with the preservation of the peat carbon stock as a primary concern of paludiculture. In addition, caution should be taken if using exotic plant species as paludicrops (e.g. wild rice, rice, giant reed, miscanthus), because they may become invasive (Matthews et al., 2015).

5 Opportunities and bottlenecks for implementation

For large-scale implementation of paludiculture, long-term schemes and income security for farmers is required. In this respect, paludicrops need to acquire the general eligibility for agricultural payments in the first and second pillar of the EU's Common Agricultural Policy (CAP) as currently exist for conventional CO_2-intensive crops from drainage-based agriculture (Wichmann, 2018). So far, most paludicrops lack the status of agricultural crops despite centuries of productive use (e.g. reed for thatching, willow for wattle fences). Within the next funding period, any kind of cultivation for food, fibre, or energy on rewetted peat soils should become eligible for direct CAP payments. Furthermore, future public payment schemes need to set a new course by considering the external effects of peatland use, i.e. phasing out any support for drainage-based peatland use, supporting the shift to paludiculture (e.g. investments for planning, planting, special machinery), and paying for reduced GHG emissions and other ecosystem services provided by wet and rewetted peatlands (Wichmann, 2018). Moreover, the application of the 'polluter pays principle' (e.g. used in the Water Framework Directive; Correljé et al., 2007) on drainage-based peatland use may promote CO_2-neutral and economically sustainable production systems on peat such as paludiculture.

An obstacle that still exists is the fact that water management in agricultural areas is usually tailored to serve drainage-based agriculture, which often makes rewetting expensive when surrounding fields are still drained. Furthermore, while special machinery and certain important production chains are already available, the scale of production is currently too small to feed supply chains of e.g. peat moss for bulk growing substrate, and cattail for insulation and building material. As a result, the market for most paludiculture products as raw materials for bioenergy and bio-based materials is not yet functional and business models are still under development.

Next to biomass revenues and harmonised subsidies, ecosystem services should be rewarded and incentives should be developed to stimulate the implementation of paludiculture, including the accounting for reduced GHG emissions (carbon credits), water purification, climate change-related water retention and storage (blue credits), and biodiversity. In the Netherlands, this has already been done for some forms of nature-inclusive agriculture (Runhaar, 2017).

Further steps in implementing paludiculture are being taken in several projects in various European countries (see acknowledgement). Pilot projects are very important to further develop management and harvesting techniques, obtain robust data on environmental benefits (including Life Cycle Analyses (LCA) of land use and associated products), and create markets for products.

TABLE 1

Overview of important paludiculture crops and applications, range in water levels, list of important production areas including pilots and potential areas, potential for carbon credits based on estimates of GHG emission reduction (including biomass use for replacing fossil resources), and potential for blue credits based on suitability for water purification (P) and water storage (S): ++ very high potential, + high potential, 0 little potential, - negative effect. Figures based on references in Wichtmann et al. (2016) and Geurts and Fritz (2018).

Crop	Water level (cm +/- soil surface)	Product	Potential for carbon credits	Potential for blue credits	Important production areas including pilots (in ha) and potential areas (in italics)
Cattail *(Typha sp.)*	0 to +20	insulation and building material	+	P + S +	Kamp (D) 30 Zuiderveen (NL) 4 Peel (NL) 1 Bûtefjild (NL) 0.1 *Danube delta (RO)*
		bedding material	+	P + S +	Peel (NL) 1 Zegveld (NL) 0.4
		extraction of protein, fibres, cellulose	0/+	P ++ S +	*Canada*
		feed for pest-controlling predatory mites	0/+	P ++ S +	Zegveld (NL) 0.4
		fodder	-/+	P ++ S +	Peel (NL) 1 ha Zegveld (NL) 0.4
		combustion	-/+	P + S +	Canada > 500
Reed *(Phragmites australis)*	-20 to +20	thatching, insulation and building material	++	P + S ++	UK 6,500 Netherlands 4,500 Mecklenburg-Vorpommern (D) 550 Poland 8,000 Hungary 7,500 Austria 1,500 Denmark, China *Romania 190,000* *Ukraine >100,000*
		paper	++/+	P + S ++	China > 1 million
		extraction of protein, fibres, cellulose	0/+	P +/++ S ++	*Germany*
		combustion/ biogas	-/+	P +/++ S ++	Italy 0.75 Germany *Belarus & Ukraine: large potential areas*
Peat moss *(Sphagnum sp.)*	-15 to -5	high quality substrate in horticulture	++	P + S 0/+	Hankhausen (D) 14 Twist (D) 10 Ilperveld (NL) 8 Canada 8 Finland, Chile
Grasses like reed canary grass *(Phalaris arundinacea)*	-30 to +10	combustion/ biogas	-/+	P 0 S +	Malchin (D) 200 Denmark, Estonia, Belarus
		fodder	0/+	P 0/+ S +	Mecklenburg-Vorpommern (D)
Alder *(Alnus sp.)*	-40 to +5	wood/timber	++	P 0/+ S ++	Mecklenburg-Vorpommern (D) USA

To convince landowners, producers/farmers, and manufacturers, long-term schemes and certificates for CO_2 and other ecosystem services have to be developed and experiences from existing paludiculture pilots in Europe and large-scale implementation in peat-rich regions in the world should be shared. The second pillar of the CAP already provides some incentives for all steps of implementation that can be used and refined (cf. Wichmann, 2018).

6 Conclusions

- Farm carbon footprints benefit largely from raising water levels to the peat surface resulting in substantial GHG emission reduction.
- Small areas of drained peatlands converted to climate mitigation optimised paludiculture can offset the need to take climate mitigation actions on 10 to 100 times larger areas of mineral soils for food production.
- Sustainable wet agriculture can also be economically viable. New business models are being created, which can often be combined with conventional farming (fodder, bedding material, meat/milk with CO_2 certificate), but high quality off-farm applications also exist already.
- Society is responsible for creating essential preconditions for large-scale peatland rewetting and paludiculture, including the provision of the necessary infrastructure and recognition of the sustainability value of paludiculture.
- Techniques and tools for paludiculture are available and under optimal conditions comparable biomass yields and revenues as in conventional agriculture are potentially possible.
- Water level management, nutrient availability, and crop choice are the main determinants for productivity. Other aspects are GHG emission reduction, costs of implementation, and the provision of other ecosystem services.
- CAP funding schemes need to be revised to facilitate sustainable solutions for wet peatland agriculture.
- Well-documented, long-term pilot projects and the generation of LCAs are very important to gain insight into long-term yields and income from paludiculture and are necessary for innovations and further market development.

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