miscomar+

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In this Issue:

From Project Coordinator

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Dear Readers,

Welcome to the 2nd MISCOMAR+ Newsletter. As we near completion of our project we would like to tell you about some of our more recent activities, as well as some of our early findings (comprehensive coverage will follow in open access publications and project reports).

As a quick reminder/summary, the MISCOMAR+ project (2020-2023) followed on from MISCOMAR (2016-2019). The aim of both projects was to evaluate the potential of *Miscanthus* hybrids on marginal and contaminated land (MaCL) and to answer questions multiple research questions, such as: 1) how does growth on MaCL influence downstream valorisation options? 2) which hybrids best tolerate MaCL conditions? 3) does *Miscanthus* cultivation integrate into existing farming systems, and does it benefit crops after the reversion of land to arable practices? 4) how do hybrids differ in their responses (i.e., uptake vs exclusion) to heavy metal contamination? 5) how does *Miscanthus* cultivation on different MaCL sites influence soil health?

MISCOMAR+ industrial and academic partners comprise *Miscanthus* breeders, agronomists, physiologists, biomass fractionation experts, remediation specialists, and conversion engineers in the UK, Germany, and Poland, and includes test sites of former intensively farmed and now nutrient depleted and waterlogged land in Lincolnshire (UK), high stone content soils in Unterer Lindenhof (Germany), heavy metal contaminated arable land in Bytom (Poland), and a lignite mine near Cottbus (Germany).

Both MISCOMAR and MISCOMAR+ projects explored soil health and structure, diverse valorisation options, and evaluated different *Miscanthus* hybrids and agronomies on land that is challenging for varied reasons.

In MISCOMAR we identified hybrids that performed well on the different sites but found that initial crop establishment was key and so in MISCOMAR+ we sought to identify practices that improved crop establishment. These practices didn't turn out as we expected! But you can read more about that in Poland, **here** (with the full publication **here**).

The follow-on MISCOMAR+ project very importantly allowed a longer-term assessment of yield and soil quality changes from the trials established in the first project in 2016. We've therefore been busy taking end of project soil cores (Figure 1) to investigate soil health (including carbon) changes after 7 years of *Miscanthus* cultivation. You can read more about preliminary results from the German soil core data **here**.

As part of evaluating valorisation options for *Miscanthus*, in MISCOMAR+ we explored *Miscanthus* pulp utilized in paper making (see **here**), and in gasification (see (**newsletter #1**). Regarding the latter, we also investigated the recovery of metals from *Miscanthus* char where *Miscanthus* had been grown on the metal-contaminated site in Poland. This has helped inform our understanding of the potential of this process for the circular economy. You can read about it **here.**

We hope you enjoy this issue of our newsletter and will check back with us for news of publications and reports. Please contact us if you would like to stay informed on these communications or are interested in future research collaborations.

Figure 1. Soil coring to 1 metre depth at the MISCOMAR+ Miscanthus trial site in Lincolnshire, UK

The effect of different agrotechnical treatments on the establishment of *Miscanthus* hybrids in soil contaminated with heavy metals


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The challenges of climate change (i.e., increased temperatures and drought) and human-induced pollution (i.e., through mining and metal smelting activities) can impact plant establishment. For *Miscanthus*, optimising establishment can substantially increase yields, and survival through the first winter can be radically improved by ensuring sufficient carbohydrate reserves are deposited in the underground rhizome following the first growing season. The success of establishment depends on factors such as the hybrid chosen, cultivation method (i.e. ploughing vs strip tilling), and both climatic and soil conditions (including the presence of any contaminants). Agrotechnical treatments can also be used to increase plant survival rate. These include the application of biochar and photodegradable plastic mulch, which can provide a solution for soils polluted with heavy metals. It was hypothesised that plastic mulch could help initial plant survival by protecting young plants from frosts and decreasing soil water evaporation, while biochar could absorb the bioavailable fraction of metals, decreasing toxicity to the plants, as well as provide other benefits ascribed to biochar, such as promoting water and nutrient availability to the plant. We investigated the application of plastic mulch and biochar individually and in combination in the planting phase for two *Miscanthus* hybrids planted with the rhizome method (TV1) and seedling plugs (GNT43) on soils contaminated with lead, cadmium, and zinc at the IETU site in Bytom near Katowice (Poland).

Figure 1. General view of newly established Miscanthus field using rhizomes (TV1) and seed based hybrids (GNT43).

The survival rate of the *Miscanthus* hybrids studied was strongly hybrid-dependent and was additionally influenced by the respective planting technique. TV1 rhizomes had a survival rate of about 60% and were characterised by weaker growth (height and number of stems) compared to the seed based GNT43, where the survival rate was over 90% in the control treatment. For both hybrids, the most effective treatment was the control. In this experiment therefore, the agrotechniques used to improve establishment had the opposite effect. Of all treatments, the greatest plant losses occurred in the combined biochar and plastic mulch treatment, regardless of hybrid. We believe this was due to the planting time being too late, which meant that high temperatures and low precipitation caused significant stress to the plants. Hypothesis about blackness of the biochar and in consequence rising soil temperature seems not be realistic, low amount of biochar was added and no significant changes in soil structure were made.

Regarding metal uptake in harvested biomass, TV1 showed no difference in element concentration between treatments after the first growing season, while significantly higher concentrations of Pb and Cd were found in GNT43 compared to the control, regardless of treatment. In contrast to the published literature with uncontaminated soils, the separate or joint application of biochar and plastic mulch neither increased the survival rate nor reduced the accumulation of toxic metals during establishment on contaminated soils.

Nevertheless, *Miscanthus*, especially GNT43, once established, grows very well with low offtakes, and in the absence of alternatives, these marginal contaminated areas should be expanded with *Miscanthus* hybrids. Further research is needed with different approaches to support the establishment of *Miscanthus* hybrids in the first year after planting on difficult soils, i.e. soils contaminated with heavy metals. Agronomic developments for various marginal contaminated soils in different countries need further commercial development.

For more details, see the published project articles - Krzyżak, J., Rusinowski, S., Sitko, K., Szada-Borzyszkowska, A., Stec, R., Jensen, E., Clifton-Brown J., Kiesel A., Lewin E., Pogrzeba, M. (2023). The Effect of Different Agrotechnical Treatments on the Establishment of Miscanthus Hybrids in Soil Contaminated with Trace Metals. Plants, 12(1), 98.

Figure 2. Aerial view of Miscanthus plantation at the end of the first growing season, showing differences in plant growth. The best plant cover and growth are for GNT43 in control treatment, the empty field is mostly for TV1, regardless of the treatment used

Figure 3. Differences in growth of GNT43 (left) and TV1 (right) during the first growing season on heavy metal contaminated soil in Bytom, Poland

Miscanthus cultivation and utilization improves environmental aspects



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Soil health

Miscanthus is generally known as a beneficial crop for soil health due to its perennial nature and the formation of an intensive mulch layer from leaf litter. However, little is known about the performance of *Miscanthus* to improve soil health on marginal and contaminated land and for different biomass utilization pathways (e.g., anaerobic digestion or combustion).

To assess this, soil core samples were taken at three sites: denuded arable land (UK), marginal, shallow, and stony arable soil (Germany), and heavy metal contaminated (Poland). At each site, novel *Miscanthus* hybrids have been cultivated for more than 7 years under two different harvest regimes, a **green harvest** in October for anaerobic digestion and a **brown harvest** in early spring for combustion or gasification.

To maximize methane yield when using *Miscanthus* biomass for anaerobic digestion, a green harvest is performed in the autumn at peak biomass, when leaves are generally still on the stems and overall biomass digestibility is higher. The harvest for combustion or thermochemical gasification is typically delayed to early spring to reduce moisture content and the leaf:stem ratio as the former contains higher concentrations of ash and other elements. Post-winter harvests not only improve biomass quality for combustion (ash, potassium, and chloride cause slagging/corrosion), they also optimize nutrient recycling in the plant, promoting sustainability. Green harvested *Miscanthus* for anaerobic digestion may require recycling of nutrients via the application of digestate, a co-product of anaerobic digestion used for fertilization.

Due to the offtake of leaves in green harvesting regimes, the mulch layer of such fields can be substantially reduced than mulch layers where *Miscanthus* is harvested in early spring. We hypothesised that the soil carbon sequestration in green-harvested fields would be lower than that in brown-harvested fields.

While the analysis of soil organic carbon content is ongoing, initial nutrient analyses indicate that harvesting *Miscanthus* green indeed results in higher nutrient offtakes. For the site in Germany, this level of nutrient offtake has so far not affected the nutrient status of the soil, although the nutrient status at this site is very high due to continuous organic fertilization application in past decades. All results related to soil health will become available at the project's completion and will be made publicly available.

Environmental performance of paper-based products

During the MISCOMAR+ project, *Miscanthus* biomass has been successfully tested for paper production in collaboration with FIBERS 365 GmbH. In the last couple of months, the environmental, social, and economic sustainability for *Miscanthus* paper products has been assessed. Over-

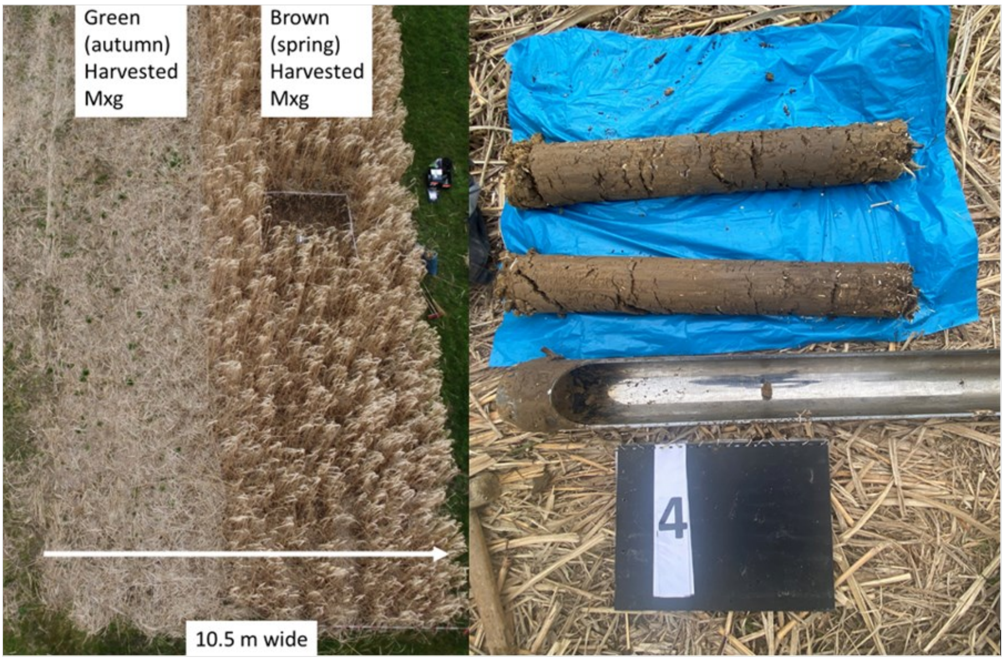

Figure 1. Left: A drone picture shows the green and brown harvest regime just before brown harvest in late spring. Right: Soil cores taken through the plant and in the interrow after extraction on the field in spring 2023. Mxg= Miscanthus x giganteus

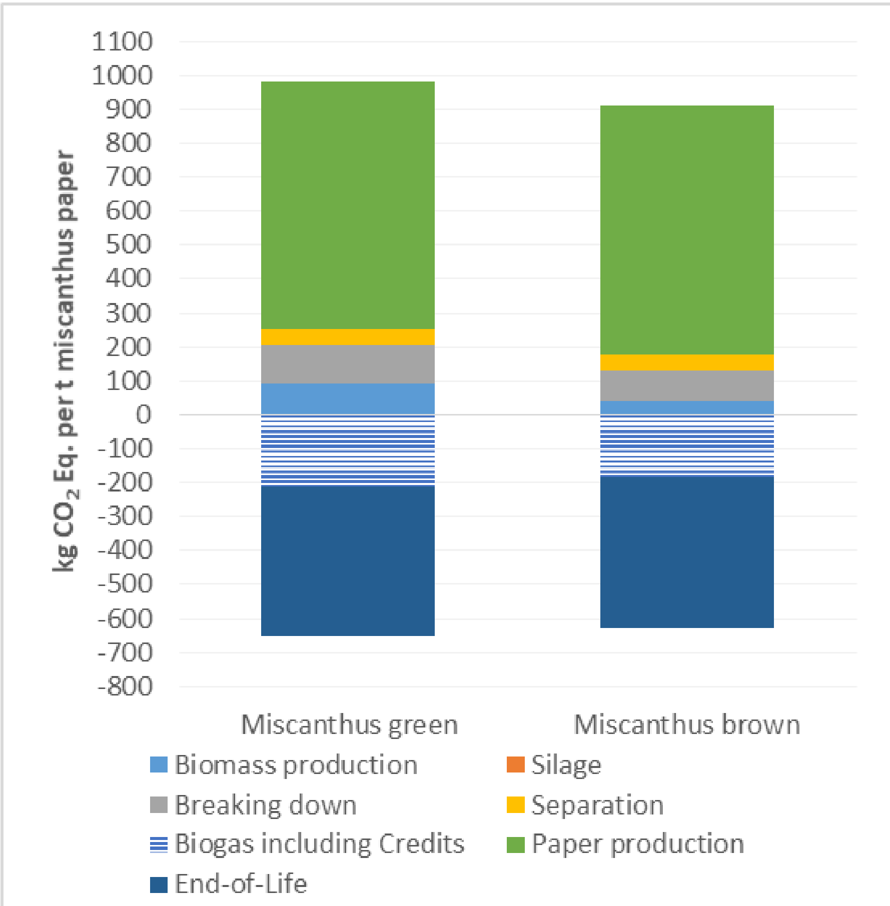

Figure 2. Breakdown of carbon dioxide (CO_2 eq.) emissions equivalent (eq.) for paper derived from green- and brown- (autumn and spring) harvested Miscanthus. Net CO_2-eq. emissions of brown-harvested Miscanthus (286 kg CO_2-eq. t-1) represent a potential CO_2-eq saving of 28 % compared to a paper reference product (400 kg CO_2-eq. t-1, Maga et al., 2021)

all, *Miscanthus* paper products using FIBERS 365 technology can help to significantly improve the sustainability of paper-based products due to a reduced energy and avoided chemical demand during biomass processing and paper production compared to wood-based paper. For this reason, the production of *Miscanthus*-based paper is leading to potential CO_2-eq savings in a range of 17-28% when compared with cellulose cardboard unbleached (net emissions green cut *Miscanthus*: 332.58 kg CO_2-eq/t Paper, net emissions brown cut *Miscanthus*: 286 kg CO2-eq/t, and reference product: 400 kg CO_2-eq/t Paper (Maga et al. 2021)).

Compared to other potential feedstocks (e.g. cup plant), *Miscanthus* offers several

unique advantages including efficient harvest logistics, simple storage as dry biomass, and good fibre qualities. Another advantage of *Miscanthus* compared to woody biomass is that the annual harvest of perennial *Miscanthus* allows true carbon circularity, while wood harvested from trees releases carbon that has accumulated over decades. This is of particular concern where such biomass is used for paper products with a short lifetime. This issue is receiving increased awareness for the paper industry and with the public, making high yielding, annually harvested crops like *Miscanthus* a very attractive feedstock candidate.

Recovery of metals from *Miscanthus* char – a screening using chemical equilibrium models

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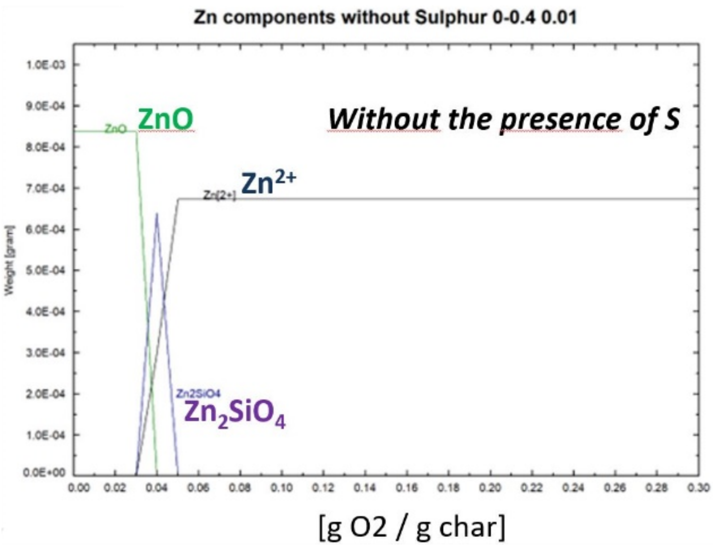
When speaking of biomass as a resource, still not many years ago the main application considered was the generation of energy – heat and/or power. Therefore, plants like poplar, birch and *Miscanthus* were called „energy crops". After preprocessing (e.g., chipping or pelletizing), energy crops were fed into thermal conversion processes, mainly combustion, sometimes gasification. For the latter especially, woody species were used due to their low ash content and less operational problems. The residues, ash in the case of combustion and char in the case of gasification, were either disposed of, or used in the cement production process. With everything being better than disposal, especially ash was generally considered as a process waste stream.

Nowadays, we understand the need to recover and recycle materials, substances, and even elements as part of the circular economy. The recovery of individual elements from "waste" streams released at the end of a chemical process is potentially attractive for multiple reasons: first, these elements could regain their value instead of being a waste; second, we can reduce the need to extract further elements from the planet; and third, the reintroduction of potentially harmful elements back into the environment could be prevented. One of the tasks of the MISCOMAR+ project was dedicated to the last goal. *Miscanthus* grown on land contaminated with heavy metals contained zinc, cadmium and lead, which are all harmful to the environment, and relevant to the circular economy.

In the MISCOMAR+ project an attempt was made to study separation of the above heavy metals from char following gasification of metal contaminated *Miscanthus*. To explore the limits of the leaching process and to simulate the effect of different treatment steps, chemical equilibrium simulations were run using commercial FactSage software. The separation methods considered were: leaching using different solvents (water, acids and bases), employing different concentrations of the solvents, evaluating different treatment sequences, leaching times and temperatures. FactSage uses extensive databases of many chemical compounds and their properties, including different phases (e.g., solid, liquid, aqueous) which, combined with the assumption of chemical equilibrium, allows a quick estimation of what species will be formed upon mixing of different reagents at a certain pressure and temperature. In this way, a relatively quick screening of the final composition and phase distribution can be achieved. The result of such a simulation can be considered as the „ultimate" composition, as the chemical equilibrium implies infinite residence time.

We ran approx. 120 simulations with the elemental composition of biochar ob-



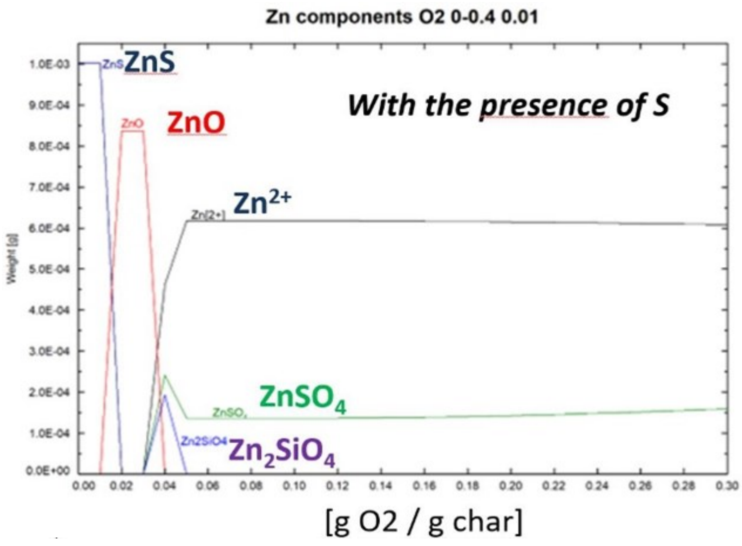


Figure 1a. Phase diagrams of zinc resulting from FactSage simulations illustrating the change of the formed phases as a function of the presence of oxygen, without the presence of sulphur in the system

Figure 1b. Phase diagrams of zinc resulting from FactSage simulations illustrating the change of the formed phases as a function of the presence of oxygen, when sulphur is present

tained during gasification of *Miscanthus* (see newsletter #1) and different leaching agents. The idea was to try to separate different inorganic constituents (e.g., potassium and phosphorus), not only heavy metals.

Simulation results showed that, theoretically, the leaching process could be arranged in such way that respectively potassium, silica, sodium, magnesium, zinc, cadmium, and lead are fully separated as ions in distinctive steps. This result looks very promising. However, our leaching experiments at lab scale showed that the effect of leaching, which was determined by means of an ICP analysis, was different, as the obtained separation efficiencies were significantly lower than predicted. On one hand this was expected, due to kinetic limitations of the real process. Secondly, the input composition will strongly determine the results of the simulations, and e.g., lead (element) and lead-oxide or lead sulfide as input will lead to different simulation results. This requires an analysis of char further than the elemental composition, which at this stage is the main recommendation for the future work in this context, accompanied by the validation via the real leaching / separation experiments. Also, studies with “model char” which would be less complex in composition than the real char could help to validate the modeling approach presented above.

The Miscomar+ field day

The Miscomar+ field day on 5 July 2023 near Cottbus hosted by the company LEAG, showed developments in agronomic treatments for *Miscanthus* which allowed the perennial crop to be successfully established on industrially damaged land associated with the mining of brown coal. The cooperation between the mining company LEAG who hosted the trials and local *Miscanthus* experts Uwe and Carmen Kuehn were supported by the Miscomar+ scientists. LEAG will continue to host the field trials set up under Miscomar+ to evaluate the longer term yield potential and to generate the data required for socio-economic assessments. LEAG actively encourage the expansion of trials through participation in new projects.

Link to the TV programme on Youtube - ”Energiegras für die Lausitz”

Photos. J. Clifton-Brown

Project Facts Sheet

Project acronym:	MISCOMAR+
Project full title:	*Miscanthus* for Contaminated and Marginal Lands PLUS
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Duration of the project:	40 month
Project website:	www.miscomar.eu

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