OMENZ

Optimising Miscanthus Establishment for Net Zero

PROJECT OMENZ

Biomass Feedstocks Innovation Programme: Phase 2 Final Report

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Executive Summary

Project OMENZ (Optimising Miscanthus Establishment through improved Mechanisation and data capture to meet Net Zero Targets) was established to address the challenge of scaling up Miscanthus planting, overcoming technical hurdles associated with planting large areas of Miscanthus to boost biomass production in the UK. As highlighted in the Climate Change Committee's 2020 report to the government, perennial biomass crops will play a pivotal role in achieving net zero by 2050. To reach this ambitious goal, the report recommended planting 750,000 hectares of perennial biomass crops by 2050.

Miscanthus, a second-generation biomass crop, harbours a large potential for meeting the UK government's net-zero targets for 2050. At present, the area dedicated to the cultivation of Miscanthus in the UK was estimated in 2023 to be at around 9,000 hectares [3]. (The figures refer to England but in Wales and Scotland there is practically no Miscanthus at all.). With an anticipated planting requirement stated by the UK Biomass Strategy in 2023 [15] of between 17,000 hectares per year for biomass crops from 2030 onwards, there is a clear necessity to bring plantings costs for growers down, increase establishment success and augment the available planting capacity.

Project OMENZ, led by TV and comprising a consortium of academic and industrial partners, seeks to enhance existing technologies to enable Miscanthus planting on a scale and price not possible with current methods. Phase 1 of the project identified several barriers to scaling up Miscanthus establishment. Phase 2 has addressed many of these challenges using a range of technologies, biological treatments, and improved quality assurance procedures, now standardised as commercial practices based on a deeper understanding of the crop's biology.

By integrating data from the currently existing supply chain built over the course of more than a decade, the OMENZ team has gained valuable insights into the long-term performance of the crop and has worked to optimise the Miscanthus biomass supply chain, benefiting both growers and end-users. The dissemination of progress has also raised awareness of Miscanthus, helping to recruit growers for the necessary land use expansion.
The OMENZ project has provided the necessary tools to rapidly scale up Miscanthus planting, ensuring a sustainable biomass supply while supporting the UK’s net-zero ambitions.

Graphical Abstract

Abbreviations

OMENZ	…………	Optimising Miscanthus Establishment through improved mechanisation and data capture to meet Net Zero targets
CCC	…………	Climate Change Committee
CU	…………	Cranfield University
EG	…………	Energene Seed Ltd
DEFRA	…………	Department for Environment, Food & Rural Affairs
DESZN	…………	Department for Energy Security and Net Zero
GNT	…………	Genotype
LJMU	…………	Liverpool John Moore University
PGR	…………	Plant growth regulators
QA/QC	…………	Quality Assurance/Quality Control
RMD	…………	Root mass density
TJSS	…………	TJSS Ltd (Formerly Salmac Ltd)
SWV	…………	Soil water volume
TV	…………	Terravesta Farms Ltd/Terravesta
UK-ATC	…………	UK Agri-Tech Centre
UoL	…………	University of Lincoln
YT	…………	Ystumtec Ltd

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1. Background

1.1. Company Information

TV is the leading Miscanthus supply chain company, based in the UK, that helps growers to establish new Miscanthus crops and provide long term, end-user backed contracts to ensure profitability for their biomass. TV currently has over 200 contracted growers in its supply chain in the UK and has supported many more to establish Miscanthus crops over its 10 years of operation. TV has a contracted area of over 5,000 ha of Miscanthus including a range of aged crops, from newly planted to many over 20 years old. TV actively recruits new growers to help expand the Miscanthus biomass supply within the UK and is in the process of expanding to EU countries and the rest of the world. TV’s team provides expert advice throughout the Miscanthus supply chain to help growers get the most out of their crop. Each year, TV is increasing the hectarage of established Miscanthus cropping.

TV supplies two dedicated straw burning power plants with biomass and works with various industries to develop new regional markets to reduce haulage distances and increase growers' returns. The demand on TV for biomass far outstrips its ability to supply, and therefore any increased hectarage will be utilised to meet industry needs.

TV operates two nurseries, one produce rhizomes and to produce seeds, both located in friendly climates to optimise yields and reduce costs.
TV holds regular farm walks with existing growers to demonstrate the benefits of growing Miscanthus. These events are the most effective way of communicating with hands-on and conservative farmers.

TV has invested heavily into research to bring several novel Miscanthus cultivars to near market deployment, with trials of the world’s first commercial seed based Miscanthus hybrids showing promising results and now being tested in commercial settings in several countries (see Table 15). TV's hybrids can help provide biomass for a variety of end uses, for example Bia 10 with stronger stems more suitable for building materials, Brontes 14 with higher sugar content for biochemical applications and Boreas 5b which promises to be more suitable for anaerobic digestion than existing varieties.

These new cultivars provide the ability to scale up the production to meet the growing demand for Miscanthus crops and provide the first opportunity to match Miscanthus biomass composition to specific end markets delivering a higher quality of biomass.

TV utilises modern technologies and innovations to optimise its supply chain. TV has developed the *Harvest Hub*, an online platform to allow growers to report their crop yields, allowing TV's team to deliver biomass from grower to end-user efficiently. TV has begun to use drone technology to monitor and measure crops to develop a more stable and sustainable supply chain in recent years. With growing access to remote sensing data, TV is looking at how its operation can utilise these new technologies to efficiently scale up its planting while still delivering a high establishment quality.

1.2. Project Background

Project OMENZ was launched to enhance the successful establishment of Miscanthus in the United Kingdom. As a second-generation biomass crop, Miscanthus is expected to play a critical role in achieving the UK government's target of net-zero emissions by 2050. Due to its capacity to thrive on low-productivity land while providing ecosystem services, Miscanthus offers a sustainable solution for carbon sequestration, with a net storage potential of 2.35 tonnes of CO_2 equivalent per hectare per year, accounting for emissions associated with planting, cultivation, and transport [14]. This makes Miscanthus a highly viable option for supporting the UK's decarbonization efforts without reliance on government backed annual payment schemes.

With an estimated 17,000 to 23,000 hectares of land available annually for biomass crop cultivation (Source: UK Climate Change Committee), there is a growing demand for the expansion of Miscanthus planting. Furthermore, increasing domestic production is an economic necessity, as it supports the development of short-range, full-cycle biomass supply chains benefiting local communities. However, to meet this rising demand, innovation is essential to enhance establishment rates and enable the large-scale planting of thousands of hectares per year, thereby ensuring a sufficient and sustainable biomass supply.

The current planting capability is constrained by labour-intensive approaches, which limit the rate of crop planting within a given season. This restricts the amount of biomass added to the UK supply and hinders innovations in downstream processing. New potential growers face challenges due to the labour-intensive establishment and monitoring processes, leading to high establishment costs. Therefore, innovation is urgently needed to increase planting capacity, allowing more hectares to be established within the season, ultimately resulting in greater biomass production.

During Phase 1, the OMENZ project examined the entire Miscanthus establishment process and identified several barriers to scaling up its establishment. The project's findings suggest that improvements in key areas such as germplasm production and pre-treatment, automated crop surveys, and enhanced land preparation could significantly increase the efficiency and quality of Miscanthus establishment. By utilizing various technologies, including automation, machine learning, and biological treatments, the project delivers a vastly improved method for establishing Miscanthus.

2. Project Overview

2.1. Aims & Objectives

The aim of the project was to develop innovative planting technologies and approaches to scale up the establishment of Miscanthus, a biomass crop which is critical to meeting the UK government's 2050 net zero targets.

Although Miscanthus had been grown commercially prior to this project, existing planting methods were considered insufficient to meet growing demand. The second phase of the project aimed to build on Phase 1 of the OMENZ initiative, which identified key barriers to effective crop establishment, including challenges in seed production, planting efficiency, rhizome quality assurance, land preparation and monitoring.

Phase 2 of the project focused on overcoming these barriers through a combination of technological advances, including automation, machine learning and biological treatments. Key innovations identified as being of critical importance included research to improve seed quality and viability, further automate planting methods, increase rhizome production and quality control through mechanised processes, and optimise land preparation techniques such as strip tillage. In addition, planting material pre-treatment methods, including temperature and hormone treatments, were identified as potential quick wins to improve germination and establishment rates. Monitoring and evaluation are also a critical component, with the potential use of AI-driven image analysis and real-time field data collection helping to track establishment success and identify areas for improvement.

The overall objective of Phase 2 was to develop a fully operational and qualified production, cultivation and monitoring system for the financial benefit of the entire Miscanthus value chain, with the expectation of commercial deployment within five years. The structure of the OMENZ project was therefore divided into four thematically related work packages, the fifth being project management. The four Action Work Packages and their objectives have been defined with very broad ambitions, with the intention to approach the topic from different angles and with different methods, leading to commercially applicable results and practical insights.

WP1 **Plant Material Physiology** Identify quick wins to be trialled based on plant physiology

- What environmental factors favour root development
- In what way is root development connected to yield
- How to enhance root development
- How to improve seeds and seed yields on the crossing block

WP2 **Planting Material** Identify faster and easier Quality Control, innovation in QC process

- What are the crucial parameters for grading seeds/rhizomes
- What are the cut-off limits of these parameters
- How to monitor and assure these from nursery to field
- What can be automated during production and how to do it

WP3 **Planting & Preparation** Determine optimal soil planting conditions; land prep techniques; test and validate new equipment (strip-tiller); planting of trial field

- What parameters may be influenced by the planting protocol
- Is there machinery available and how well does it perform
- How to select the right field and predict establishment success

WP4 Monitoring Continue development of monitoring equipment and software

- How to measure establishment success remotely
- How to predict yield from plant count
- How to evaluate if fields are less than perfect fields early on

2.2. Project Plan

The project schedule, including the full list of deliverables, has been detailed in the Gantt chart provide with this report.

3. Lot 1 Technical Requirements

3.1. Design & Development of Innovation

1) Seed Production / Planting (WP1) – now TRL 7 from TRL 4
To improve seed quality, considerations were made based on known, but currently unexploited, aspects of plant physiology. The new seed assessment process was developed to reduce the skill level required. Phase 2 also demonstrated whether the pre-treatment identified as effective during Phase 1, could be implemented in the next stage of seed-based planting material production, as well as during the planting process.

2) Miscanthus Rhizome Processing System (WP 2) – now TRL 5 from TRL 1
Phase 1 identified planting material costs as a significant barrier to the widespread adoption of Miscanthus cultivation. To address this challenge, in phase 2 various automation strategies were evaluated within the Miscanthus rhizome production process. This approach aims to enhance affordability for farmers, facilitate broader adoption, and ensure greater consistency in rhizome quality, thereby improving establishment rates. Manual processes, including washing, break-up, selection, and final splitting, were assessed for potential automation to increase efficiency and standardization.

3) Rhizome Quality Assurance & Improved Production (WP2) – now TRL 6 from TRL 4
Work has been conducted to define and implement an effective method for QA for the production chain of Miscanthus rhizomes. Phase 1 revealed that rhizome quality control and assurance are crucial for ensuring good crop establishment, which is essential for increasing land-based biomass feedstock. Phase 1 also identified issues such as the lack of standardized quality control and uniformity in the production chain, which could hinder further automation efforts. Ensuring rhizome quality is critical to achieving good germination and establishment, while physical uniformity will enable more automation options in the future to address anticipated

labour shortages. Phase 2 set clear standards for the size, weight and shape of rhizomes to be preferred (“ginger”), those that perform at an acceptable level ("creeping" and "root ball") and those to be avoided ("insignificant mass" and "stem" rhizomes). There is also now a clear indication of the age at which rhizomes perform best, when to avoid harvesting at all and when rhizomes are still acceptable but start to decline in germination rate. The previous industry standard of "more buds is better" is now quantified with a lower limit and there is clearly an upper limit beyond which "more" is no longer "better". A clear window has been defined within which rhizomes need to be processed after lifting. The optimum storage temperature for keeping rhizomes fresh before delivery and the best watering regime before planting have also been identified.

4) Better Understanding of Miscanthus Development (WP1) – now TRL 7 from TRL 4

To identify "quick wins" in exploiting Miscanthus physiology, the focus would be on gaining a better understanding of various aspects of its physical development. This was achieved through controlled field observations and examining Miscanthus responses to various treatments.

5) Planting Innovation

Land preparation innovation (WP2, WP3) – now TRL 7 from TRL 6

This investigation particularly focused on the land preparation methods identified in Phase 1, with the aim of trialling and testing these methods in Phase 2. The effectiveness of these methods on different land types, as well as the additional maintenance costs, were also assessed.

Material pre-treatment (WP1, WP3) – now TRL 5 from TRL 1

Phase 1 showed that temperature and specific hormone pre-treatments may have positive effects on rhizome germination. These findings have laid the groundwork for further innovation in Phase 2, where pre-treatment of rhizomes with higher temperatures, PGRs, and the addition of endophytic microbes were investigated to identify the most effective combination. Similarly, some pre-treatments, considering physical differences, were also applied in Phase 2 for seed-based hybrids. Other assessment criteria included the establishment and long-term fitness of both above and below ground biomass.

Planting and Monitoring (WP4) – now TRL 5-6 from TRL 3

Phase 1 trials showed that monitoring establishment is a key tool. To build on these findings, commercial field-scale rhizome and seed-based hybrid planting trials were planned as part of the project to demonstrate these learnings. This included improvements to rhizome planting methods and establishment monitoring (further detailed in the AI image analysis section) as demonstrated in Phase 2.

Phase 2 placed particular focus on below ground investigations to help understand: (i) the different behaviours among various GNTs; (ii) the effects of different environmental conditions on underground biomass and the subsequent above-ground yield; (iii) the importance of below ground biomass in sequestering carbon; and (iv) how these findings can provide feedback to other innovations, ensuring their feasible application on a large commercial scale.

6) AI Image Analysis (WP4) – now TRL 7 from TRL 1
During Phase 1, an image recognition AI capable of distinguishing Miscanthus plants from weeds and soil was developed. Further innovations were undertaken in Phase 2, including the development of a plant counter and the training and refinement of the AI to adapt to varying photo conditions and land types. Additionally, multispectral analysis methods, similar to those used in other agricultural sectors (e.g. maize), were trialled.

7) The Requirement Matrix (WP1, WP2, WP3, WP4) – now TRL 5 from TRL 3
This was a joint effort by all Project OMENZ participants. During Phase 1, the Requirement Matrix was developed to define the necessary parameters for decision-making, considering current practices and identifying the data that must be collected ahead of planting to determine land suitability and any required amendments. In Phase 2, further refinements were made to the matrix, incorporating data collected throughout the project. The Requirement Matrix aims to simplify decision-making, leading to improved efficiency.

3.2. Demonstration & Results

1) Seeds production/planting
During this project, the seed production process was defined in detail, and different seed grades were identified. New seed grading methods developed by EG and TV in 2021, along with the 2021 harvest protocol, significantly increased seed quality and viability (D1.071). This resulted in a germination rate above 85%, reducing the need from three seeds per cell to two seeds per cell in plug plant production. The new 2021 seed harvest protocol and grading also enabled better management of lower-quality seeds. Seed-based hybrids harvested in 2022 were compared with those harvested in 2021 after one year of dormancy, showing no significant differences (D1.0721). Subsequent trials, including cutting and partial cutting treatments, were found to potentially increase seed production (D1.073).

The project also enabled close observation of seed maturity over three years, allowing for improvements in the seed production protocol and monitoring methods. This led to discoveries, such as, the effects of climate on seed maturity and speed, which helped better manage the harvest window (D1.0621, D1.0631, D2.101, D2.102, D2.103, D2.104, D2.105, D2.106).

Additionally, efforts were made to explore the use of PGR and other growth conditions to observe seed-based hybrid underground material development (D1.092, D1.0931, D1.1022, D1.123). One of the more important findings from the PGR perspective was the confirmation that commercially used PGRs primarily influence rhizome development not only during the nursery stage of plug production but also after two years of field experiments. These efforts provided clear indications of the types of land most suitable for seed-based hybrid underground biomass development, which have further completed the decision matrix being developed in this project.

There were also some interesting observations regarding seed production. For instance, in WP1 (D1.1021), the goal was to determine if additional treatments could improve germination. However, given the improvements delivering high germination rate from the 2021 seed production, it was difficult to observe any improvement (except in cases of suppression, where D1.112 found that high doses of Ethephon slightly reduced the germination rate, root and stem length) (Table 7, 8, 9). Therefore, seeds with lower germination ability from previous harvests were tested instead. The most significant improvements observed over the control were with gibberellic acid (GA) treatment. While commercial products like Liquid Ice or Elixir were less effective and proved to be more economical to apply. However, these treatments did not show any other physiological benefits on post-germination.

Another observation is the timing of the parental flowers need to be synchronised for the seeds to be fertilised. Therefore, an effort was made to try increasing seed production by controlling flowering. Three treatments were investigated – fully cut the plant at one point during summer, crop the top down to 1.5m at one point in summer, and the use of a PGR (MicroPull™) treatment. It was found that by cropping the top down to 1.5m, more panicles and seeds per panicle were produced (Figure 2). The PGR treatment also produced significantly higher germination rates than that without PGR.

In terms of subsequent seed-plug production, evidence has shown that with GNT 43, 3 seeds sown for each plug produced more biomass volume for the plug (D1.123, D1.094). The same effect did not appear on GNT 3 possibly because GNT 43 had higher germination rate than GNT3. Thus, it is likely worth keeping multiple seeds sown for each plug, as it would be more important to have a plug-plant than having a larger plant (D2.13).

On assessing the seed harvesting process and protocol (D2.106), the lessons learned from the 2023 harvest were applied in 2024, with a significant focus on increasing the monitoring of seed development and flower readiness. The 2024 harvest started a week earlier than in 2023 to avoid seed loss due to adverse weather conditions.

2) Miscanthus rhizome processing system

The development of an automated rhizome processing system significantly reduces costs at the Miscanthus nursery by minimizing manual labour, improving processing efficiency, and reducing waste. The automation of separation, washing, and transport decreases the reliance on human intervention, which lowers labour costs and increases throughput. Additionally, optimizing rhizome break-up ensures better planting material with minimal loss, leading to higher crop establishment rates and reducing the need for additional planting efforts. These factors contribute to overall cost savings and improved nursery productivity. The detailed design (Figure 1)., functioning and performance of the separator are described in detail in Deliverable 2.291.

The laser cutting process failed to meet its intended objective due to the high variability in rhizome morphology. However, the rhizome separation mechanism demonstrated effectiveness beyond initial projections, providing a viable alternative to the laser cutting system. This mechanical separation approach offers a significantly simplified solution, likely more compatible with agricultural environments.

1*. Design -* The rhizome processing system consists of several key components designed to streamline the handling of Miscanthus rhizome (D2.16). (i) It employs fingered rollers running at varied speeds to break apart rhizome mats. (ii) The water bath utilizes an off-the-shelf cattle trough for washing, aided by a debris management system. (iii) The conveyors use wire "ladder" belts to transport rhizome while allowing water and debris to fall through. (iv) Spray bars assist in removing residual sand and grit. (v) A control system, running on an embedded PC, integrates inverters, microcontrollers, and safety overrides to manage the various components. The initially developed (vi) imaging and (vii) laser-cutting system was deprecated due to performance limitations.

2. *Rationale of design -* The separator ensures effective mechanical separation of rhizome clumps without requiring human sorting. The water bath removes soil and debris (D2.23), addressing phytosanitary requirements for rhizome movements across borders. The conveyors (D2.21) enable smooth transport, reducing blockages and wear. Spray bars (D2.22) enhance cleaning efficiency by directing water at optimal angles. The control system automates synchronization, while safety features ensure reliable operation. The deprecation of the imaging and laser-cutting system (D2.24, D2.33)) resulted from inadequate cutting precision and throughput limitations due to the impossibility to guarantee formal specifications of rhizome pieces (Figure 3).

3. Processing sequences - The processing sequence follows a logical flow: separation, washing, cutting, quality assessment, and packing. Rhizomes enter the separator, where being broken into smaller pieces and dropped into the water bath for cleaning. The cleaned rhizomes move via conveyors to spray bars for additional washing. Initially, an automated cutting and quality assessment system was planned, but due to its limitations, manual intervention is now considered. The final cleaned and processed rhizomes are then packed for planting.

4. *Assessment of processing options* - Two major options for scaling up the system were considered: continuous processing versus batch processing. Continuous processing, as initially tested, offers a steady throughput but can result in inconsistent rhizome size distribution. Batch processing, where rhizome remains in the separator until achieving the target size, may provide more uniform outputs and reduce unnecessary processing. The water bath design could incorporate either a large-volume sump to allow debris collection over time or a high-flow water system, which requires more energy but reduces manual cleaning. The conveyor system proved robust and effective, requiring little modification. The imaging system, while promising, was deemed impractical, leading to the reconsideration of manual quality assessment and cutting as a feasible alternative.

5. Abandoned Processing Steps - The imaging system developed for this project utilized a commercially available imaging device in conjunction with a suite of custom-designed software components. This imaging device could capture co-registered images across the near-infrared, visible light, and range spectra, facilitating the identification of rhizome segments suitable for planting. The software, primarily developed in Python, was executed on a central computing unit responsible for managing the entire system's operation (D2.29, D2.291, D2.35, D2.351).

Following the imaging stage, a laser cutting system was implemented to process the identified rhizome segments, with the objective of fully automating their preparation and eliminating manual labour. However, the cutting technology did not achieve the required level of effectiveness and was ultimately deemed unsuitable for processing the rhizomes. Consequently, the imaging system was also deprecated, as its primary function was to support the now-obsolete cutting process.

6. Recommendations for future developments - A future system should prioritize optimizations that maximize throughput while reducing manual labour. Development efforts should focus on enhancing the rhizome separator to improve the break-up process, potentially integrating a batch-processing mode for increased efficiency. The water bath should be equipped with an automated debris removal system to streamline operations. Given the complexity of automating manual cutting and quality assessment, their retention in the near term is recommended. Further automation refinements should concentrate on improving conveyor synchronization and enhancing debris filtration systems.

3) Rhizome quality assurance and improved production

Throughout this project, various experts examined production at the rhizome nursery to identify areas for improvement. During the first QA visit in 2023, a supply chain assessor confirmed that the nursery's QA process for selecting processed material could effectively eliminate less desirable material (D3.042, D3.0431). However, a subsequent visit by Miscanthus physiologists (D2.0422) revealed that the production facility had generated many first-year rhizomes with fewer buds per rhizome, resulting in lower survival rates. Assessments were also conducted to identify different types of rhizomes with the best establishment rates based on their physiology and bud count.

Although it may be difficult to control the amount of the rhizomes, two improvement measures were identified to be implemented in the next production season. First, it was discovered that there were very small materials in the bag that could not be counted in as rhizomes. The nursery was then asked to exclude these smaller materials from the bags as the people manning the planters do not have sufficient time to select between living and dead rhizome pieces during planting. Secondly, tapes that are marked at the appropriate length have been made available to operators to provide a quick reference to eliminate those rhizomes exceeding 15 cm in length. Larger rhizomes are ideal for establishing, but can hinder the planting process, which can result in missed planting opportunities.

Significant differences in quality control were observed between the 2023 and 2024 planting seasons. In 2023, it was found that the quality control of rhizomes upon arrival in the UK was highly variable and substandard, particularly in cold storage control, which caused less desirable planting material (D3.0611, D2.052). There were concerns regarding the quality of cold storage, inadequate monitoring, and a lack of documentation to identify issues during transportation and storage. To address these concerns, a checklist and better-controlled cold storage containers were used in 2024. The time gap between rhizome delivery and planting was reduced by arranging for rhizomes to be delivered on the morning of planting, reducing the time spent between cold storage and planting. This approach also resulted in reduced sprouting of rhizomes.

Regarding rhizome production, YT has developed an image recognition software, which can distinguish between rhizome and root, to allow the decision-making algorithm to determine the cutting point (D2.27, D2.28). While the implementation of the actual cutting might require a finalization beyond this project and has been deprecated due to technical difficulties it is a step forward in fully automated planting rhizome production.

4) Better Understanding of Miscanthus Development

Root engine study – the differences in mean RMD value between soil types and plant age in 2023 were investigated and post-hoc analysis was determined on log-transformed data. The results showed there was significant differences in root distribution across different soil textures and plant ages. Plants grown in medium sandy loams had significantly higher RMDs compared to those grown in clay or clay loam soils. Additionally, older plants (2 years old) exhibited significantly higher RMDs than younger plants (1 year old) (Figure 4).
In other words, the lighter land would encourage rhizome and the associated root mass to grow more, thus potentially boosting the carbon sequestered (D1.142).

Moreover, spatial interpolation figures also indicated a wide branching root system in medium sandy loams, which could allow plants to access nutrients and resources from a larger area thus maximizing plant vigour. In contrast, clay and clay loams were characterized by a tighter and more restricted root architecture, which could potentially negatively affect biomass productivity.

However, studies of the third-year plants indicated that the underground material growth in the lighter sandy soil would slow down. This meant the underground biomass would eventually grow to certain size given enough time regardless the soil type (D1.143). Although heavier clay type soil would restrict the underground biomass growth rate, it was better than the lighter sandy soil by retaining more moisture. Also, sandy type soil was more likely to be susceptible to compaction and therefore, might require subsoiling.

Rhizome soluble carbohydrate study – rhizome sugar (carbohydrate) content was investigated and quantified by means of HPLC-ELSD in context of the size of the ‘root engine’ as a viable indicator of biomass yield. First year analysis was done on sampled rhizome and roots from 18 sites covering 3 representative land types. Clay Loam soils in general were associated with higher amounts of all sugars, as compared to Clay and Medium sandy loams. MSLs were associated with significantly higher amounts of sucrose thus also total sugars as compared to Clay (Table 1). Sugar content was not linked to RMD (D1.142). There was, however, a weak significant positive correlation (Figure 5) between root/rhizome sugar content and soil compaction levels measured as penetration resistance (PR) (D1.161).

High compaction levels can restrict root elongation and is often associated with physical changes to shapes of roots and rhizomes by compression and by forcing root/rhizome elongation through restricted pore spaces. It is possible to hypothesise that excessive pressure on rhizome may contribute to higher concentrations of sugars in dry weight as compared to rhizomes, which are allowed to grow unrestricted.

Root carbohydrate analysis demonstrated that soil texture and the interaction between soil texture and plant age were key factors in determining root/rhizome sugar content. Furthermore, rhizome sugar content was linked to soil compaction levels. Clay hindered the sugar deposit into the rhizome most severely (D1.151). However, such a difference would not be observed in subsequent stages of the crop development. The first year of growing season is crucial for the re-emergence of second year crop that eventually became long-term yield. It was also observed that there was a general trend, for carbohydrate-sucrose to be the most abundant non-structural carbohydrate in Miscanthus rhizomes, followed by the fructose and glucose. Consequently, as with other rhizome-based crops where yield is related to rhizome CHO, it was anticipated that Miscanthus rhizome CHO would directly impact biomass yield.

Association study – the significant factors that influence establishment and other physiology development were identified in the first year in the Mesocosm experiment (D3.013b) (Table 2).

In the first growing season (2023), it was found that the number of rhizome buds ("eyes") and their interaction with rhizome weight were the most significant factors influencing the emergence success of Miscanthus. On the other hand, flood treatment and soil type were the most significant factors affecting final plant height, with both flooded mesocosms and sandy soil resulting in notably greater plant heights. These findings highlight the importance of multiple factors in the successful establishment of Miscanthus.

The findings of first year growing would be taken into consideration with other data from temperature and humidity sensors, root growth, time series growth, dry weight and overwinter survival data in subsequent stages or years of the experiment. The second plot trial, on the other hand, showed that SWV had a strong positive effect on emergence, mean height and to a lesser extent tiller number. (Table 3, D3.025).

For the second-year trial, the data for emergence indicated a significant difference between open and closed plots. The analyses indicated no significant difference between mean tiller number for the open and covered treatments, however a significant difference has been found between mean heights, with covered plots averaging 60cm in height versus 80cm for open areas. The analysis for the two plot trials provides some significant indications of the effects of rhizome size and climate on Miscanthus establishment. Firstly, given the weight range for the rhizomes used, the first-year results indicate a clear positive effect of rhizome weight on tiller number.

The second plot trial shows that SWV has a strong positive effect on emergence, mean height and to a lesser extent tiller number. Significant difference for tiller number was close to the statistical significance threshold and it should be noted that mean tiller number is exactly 1 higher for open blocks.

On the other hand, observations had been made in assessing the environmental effects on other above-ground physiologies, particularly cover and height. Cover is important to ensure that the area of sunlight is efficiently harvested for carbon conversion, while height is a good indicator of yield (Table 4). It was found that both growth degree days (GDD) and SWV had an interactive effect on cover. In terms of soil chemical properties, sand content and surface bulk density had a positive effect on cover and height respectively. In terms of macronutrients, the interaction between potassium and sand content was shown to have a positive effect on Miscanthus cover, while potassium and increased pH had a negative effect on cover and height. Phosphorus and sand interactions had a positive effect on Miscanthus height. The interactions of potassium and sand and surface bulk density also had a positive effect on height.

Two plot trials were also undertaken at the UoL Riseholm campus. The first trial in 2023 was undertaken to determine the differences with Miscanthus rhizome size on emergence and early development. It was found that the chi-square statistic p-value was not significant for emergence between groups (Table 5). While the t tests indicated a significant difference between mean tiller number for the large and small rhizome treatments, t test for mean height indicated no significant difference between the two treatments.

The second trial in 2024, which was located to the immediate south of the first-year plot, examined the effect of water availability. Rain shelters were placed over half of the total planted area (Figure 21) to create a randomized soil water gradient across the plot. It was found that the chi-squared test for emergence indicated a significant difference between open and closed plots. While the t tests indicated no significant difference between mean tiller number for the open and covered treatments, t test for mean height indicated a significant difference between the two treatments. On the other hand, flooding and the interaction between those factors had no influence on the difference in the number of tillers between the two seasons (D1.0532).

The findings of the above trials provided vital information to incorporate into the matrix to better understand the crop's needs and how higher-yielding crops can be produced. Furthermore, the observations on the differences in height and cover across various land types could enable growers to consider higher planting densities and set more realistic yield expectations.

The conclusion so far suggested that the quality of the rhizome is one of the key factors in ensuring good establishment and yield. In particular, the rhizome buds (eyes) play a significant role in emergence and show a strong interaction with rhizome mass. Both the root engine and mesocosm experiments concluded that sandy soils increased underground biomass, and the latter experiment also indicated that these soils had a higher potential yield in terms of plant height. To sum up, among the three representative land types, medium sandy loam would provide the best yield for Miscanthus plantations along with adequate level of Mg, K and P.

5) Planting innovations

Land preparation innovation – a strip tiller that was procured in Phase 1 with TV's own budget and was tested (Figure 6). The strip-tiller was initially identified in Phase 1 for light land only, but during Phase 2 it was subjected to testing in heavier land, and it was found to be able to handle clay soils. However, it caused a significant amount of wear and tear on the machine when working with stones in the soil and dust being kicked up towards the planter and the people manning it. Nevertheless, the strip tiller could still be beneficial in reducing tillage on the field and hence reducing carbon release. Additionally, it was found to reduce moisture loss, a benefit that would be more pronounced during dry establishment seasons. The use of protective equipment and shields was identified as a means of mitigating potential health and safety concerns associated with the tiller's operation.

Planting material pre-treatment – temperature pretreatment and the application of the additive (either chemical or microbial, to be coated onto the rhizome surface before planting) were tested at pot and field scale (Table 6).

For temperature treatments, it was found in Phase 1 that prewarming the rhizome to 25° C before planting would improve emergence under laboratory condition. However, soaking at 25°C for a long period would not be commercially viable and it might be better to soak at between 10 and 20°C for between 4 and 24h (Figure 11). A more detail pre-prewarming test was then done to examine the effects of different temperatures and soaking times (D1.021). And the results showed there was a significant positive effect from soaking while the environment the rhizomes were transferred to also had a prominent effect on the optimal temperature with those rhizomes going to the glasshouse improved most by 20°C and those going outside by 10°C.

This was followed by another field trial of the optimal temperature treatments (D1.022). It was found that growth was better for soaked (10°C) rhizome while emergence was best for control (un-soaked) group. Nevertheless, GNT-9 was known to have bad emergence and so overall there was still notable improvement (Figure 7) after soaking at 20^{o}C.

Chemical PGRs were applied to rhizomes, using a starch-based medium to ensure prolonged and direct rhizome contact, and tested in a large pot trial (D1.011) and then in a field trial (D1.0121). The treatments were Auxin, Ethrel C (aka Ethephon), Gibberelic Acid (GA), Indole-3-Acetic Acid (IAA), Indole-3-Butyric Acid (IBA), Naphthalene Acetic Acid (NAA), Thiourea, a starch-coated control, and a bare rhizome control (no paste). Pot trial results showed that the emergence was not significantly affected while Ethrel, Thiourea, IAA and Auxin treatments led to higher emergence. And in general, PGRs had a significant effect on rhizome growth, in particularly GA and Ethrel had the most rhizome growth. However, there was no overall significant effect on biomass production.

Four PRGs, Ethrel, IAA, NAA and Thiourea, were selected through ranking five of the traits' measured in the pot experiment as the treatments for field trial. Unfortunately, extensive regional field flooding delayed planting, resulting in a short

growing season and reduced plant growth which resulted in very poor overwintering success (D1.0122) (Figure 8, Figure 9).
It was found that the only significant effect was the genotypic differences between GNT-9 and Athena. Interestingly, the no-paste control performed better in the field implied that starch coating might not be a good application method for PGRs.

The effect of a range of commercially available microbial inoculants on the early development of rhizome planted Miscanthus was then tested in Phase 2 (D1.0311). Six microbial inoculants (Elixir, Liquid ice, Micropull, Rhizotonic, Super rootz, Mammoth), Seasum Max (a bio-stimulant) and a standard NPK fertiliser were applied to the rhizome using a starch coating method to keep the microbial inoculant in proximity during early growth. Results showed there was no significant effect on emergence nor growth rate while Seasum Max ranked the highest in most measurements. There were some signs of negative effects on emergence from Elixir, though growth rate was improved by the Elixir, Liquid ice and Micropull. While the other three inoculants produced a higher percentage of starting buds producing tillers (Figure 10).

Different microbial inoculant treatments were then tested at field scale (D1.0321, D1.0322) using a split-plot design, following results from earlier pot trials (D1.0312). Treatments were applied both as starch coatings and as microbial inoculant soaks, as previous experiments (D1.011, D1.0312) had shown some negative effects from starch coatings alone. The selected treatments were Seasum Max, Liquid Ice, Ceres Micropull, Super Rootz, and a control group with and without starch coating.

Planting in June provided good conditions, with >80% emergence of Athena rhizomes. Emergence time was significantly improved by soaking as a delivery method. Interestingly, unsoaked rhizomes (commercial standard practice) had the highest percentage emergence but emerged more slowly than most soaking treatments. Among the soaking, Liquid Ice slightly improved plant height, while starch-coated treatments, particularly SEASUM MAX and Super Rootz, slowed emergence. Soaking while mostly positive did result in fewer tillers than starch paste or 'Dry' treatments, possibly because soaking softens the buds, making them more prone to damage during planting.

Although the field's active microbial system may have reduced inoculant effects, the modest tillering benefits observed in earlier trials (D1.0312) suggest potential for improvement. Refining the delivery method and dosing of microbial inoculants could enhance their effectiveness in field conditions

Three currently available delivery methods, capsulation, hydro-gel coating and direct spray before planting, on potential chemical or microbe treatment were also investigated (D2.061). It was found that the most effective method would be direct spraying as such equipment are already available and there is no need to develop capsulation or gelling process.

Planting and Monitoring – the use of alternative planting methods other than the existing modified potato planter was explored (D2.071). It was found that an automatic rhizome planter from a North American company might offer a promising result. The unit cost half a million US dollars while development cost and the business model were unknown. Considering these and the fact that USA planters were planting more but smaller rhizomes, it seemed the current planting method with the potato planter was the most cost effective to TV.

Analysis of the data obtained from the planting monitors installed on the existing planters yielded several noteworthy findings (D4.044, D4.045, D4.046) (Fig. 12). Primarily, it was determined that the efficacy of the detection mechanism would diminish as materials traversed and brought dusk with them, thereby obscuring the infrared detector over time (Figure 12). This effect, however, can be mitigated through regular cleaning of the tube, although this would increase labour requirements. Secondly, the accuracy of the GPS was found to be suboptimal (Figure 13). Nonetheless, it can serve as an indicator of issues, such as the presence of stuck rhizomes, which could be rectified prior to the continuation of the planting process.

6) AI image analysis

This area of research had been progressing in a highly satisfactory manner during Phase 2. An AI model was produced through TV's investment in CU (CU) 's own development program, which was running parallel to Phase 1. The AI model was integrated into the OMENZ program due to its unique capacity to differentiate between individual Miscanthus plants and weeds using drone-captured images. This provided the foundation for the subsequent development of an automated establishment process for Miscanthus, utilising RGB image recognition from drone images. To refine the prototype, it was necessary to train and optimise the AI using a wider range of image collection cases, specifically from different soil textures and with various crop growth stages of Miscanthus establishment.
Further developments were made during Phase 2 based on the base program of the AI model in the following three areas:

Ground/Field contrast – The TV drone image database (which contained 159 unique fields with 51 growers across England) was referenced for the optimisation of the AI model across a wide range of landscapes. Utilising CU's LandIS soil information, the soil texture, along with other soil properties such as pH and soil organic carbon, for each field were estimated based on the Soil Survey of England and Wales (UK) using the well-known soil textural triangle (Figure 14). This analysis revealed that most of the Miscanthus plantations are in clay, clay loam and sandy clay loam/sandy loam (sandy) soil.

An independent validation of the performance of the AI model was also conducted (D4.012), in which the counts of plants from the sample interpretations were plotted against the prediction for both the original (phase 1) and refined (phase 2) AI models. The results (Figure 15) demonstrated that the refined model had identified a wider range of Miscanthus plants. The refined model demonstrated a superior performance in comparison to the original model (developed in Phase 1), enhancing its reliability and precision in identifying Miscanthus in a more extensive range of fields within operational contexts.

Miscanthus *developmental stages* – additional UAV imagery data was collected at differing growth stages and locations to evaluate the AI model with respect to plant growth stage and timing, as well as operational parameters such as image spectral content and resolution (D4.023). The data were collected by gathering images of (i) fully green Miscanthus (t1), (ii) partially senesced Miscanthus (t2), and (iii) fully senesced Miscanthus in early 2024 (t3) (Figure 16). The AI model demonstrated consistent performance, with optimal performance observed in t1 and t2, as compared to t3. The optimal time for image acquisition was determined to be at the conclusion of the growing season, as indicated by the initial onset of senescence. The potential benefits of utilising a Multi-Spectral Imaging (MSI) camera to capture 4-band multispectral data in conjunction with the RGB data were also considered (Table 10).

The findings indicated that there was minimal discrepancy between the utilisation of RGB and MSI cameras, thereby suggesting that there was no discernible advantage in employing MSI data for plant counting (D4.024). The data from both RGB (Figure 17) and MSI (Figure 18) yielded comparable estimates of plant numbers during all three periods (t1, t2 and t3), as evidenced by the plant count data versus the reference count data. This finding supports the use of RGB cameras, given that MSI-equipped drones are more expensive to acquire and the spatial resolution of MSI is lower than that of RGB, resulting in longer flight plans at lower altitudes and higher operational costs. However, it should be noted that MSI spectral bands are utilised in the calculation of vegetation indices, which are instrumental in biomass prediction.

Plant count and yield estimates - The development of automated plant density maps of Miscanthus (Figure 20) has been achieved for the first time (D4.0421). This novel product facilitates the estimation of the mean plant density in year 1 by TV, and the measurement of whether poor or replanted areas of crop have sufficiently recovered in year 2 to meet specification. The integration of an AI-based Miscanthus identification model with MSI images facilitated the calculation of the Normalised Difference Vegetation Index (NDVI). It was demonstrated that the area-weighted NDVI of a Miscanthus field could be utilised to predict the total potential biomass at the conclusion of the year 1 (emergence) growing season.

Early estimates of Miscanthus dry biomass (yield) in year 2 were made using MSI drone remote sensing calibrated using ground observations (D4.043), up to 5 months before harvest. However, it is crucial to note that the final biomass, which is scheduled to be available in March or April 2025, is essential for correcting for any harvest losses. This has enabled the prediction of marketable yield in future projections.

7) The Requirement Matrix

The requirement matrix has undergone a process of continuous refinement, drawing upon the framework established in Phase 1 of the project. Further considerations were made to assess the necessary information to be obtained in this phase (see Figure 19 and Table 14). This functioned to enhance the matrix architecture and enabled the necessary information to be collected, which would be used within the decision-making process for better requirement data flow. The additional information that might be considered are:

Cropping history site survey - Cropping history is an important indication of the most suitable type of land for planting. The effects of different arable crops on various land types may necessitate amendments or recommendations regarding the selection of suitable GNTs. Conducting site surveys is instrumental in optimising land usage, thereby ensuring maximum biomass yield.

Recommended plant density based on plant selection/variety information – It is recommended that the most suitable rhizome GNTs and their planting density be determined based on information pertaining to soil type and environmental characteristics.

Establishment consideration for economic analysis: The prediction of the yield in advance, or the time required to achieve full yield, is possible by counting the plant density of the field.

This matrix has demonstrated its efficacy in the indication of the yield and establishment of Miscanthus plantations. This is of significance in the determination of the economic cost of production and subsequent transport costs to end users. Furthermore, it is imperative for growers to consider in the first instance whether their land would be suitable for biomass production, in order to ensure the economic sustainability of the operation.

3.3. Contribution of Innovation to Sustainable UK Biomass Supply

The enhanced comprehension of diverse Miscanthus GNTs, encompassing TV's prominent variety Athena (TV1), has further facilitated the process of decision-making concerning GNT selection. Furthermore, the insights derived from this project have led to substantial advancements in the selection and production maintenance of planting material during the crop's lifecycle. These enhancements are poised to guarantee the quality of planting material and ensure the sustainability of production levels throughout the entire lifecycle of the crop. Furthermore, the findings on carbohydrate deployment in the root and rhizome, along with other environmental factors, have been integrated into current operational practices.

The employment of a strip-tiller has been demonstrated to be advantageous for planting operations, particularly in arid conditions, due to its ability to retain moisture and minimise water loss resulting from ploughing activities. While the strip-tiller was unable to overcome the impact of a protracted drought, it demonstrated potential in enhancing establishment when compared to conventional ploughing methods which release more moisture from the soil.

Improved establishment is pivotal for sustainable biomass production, as successful establishment in the first year exerts an outsized influence on subsequent years' yields. This has in some situations led TV to postpone planting from one year to the next because of unfavourable environmental conditions, in the knowledge that in terms of the overall financial impact on the grower, the loss of one earlier crop would be well compensated by the cumulative effect of an increased annual yield over the course of 15 or more years. Better establishment, close to projected values has led to a more accurate estimation of overall biomass production, which in turn reduces under-delivery on the yield plan and increases grower confidence, who thus are more willing to release more land for biomass cultivation. Furthermore, the success of establishment monitoring through image software analysis allows for remote yield estimation and disease detection, thus reducing the labour and resources needed for on-site assessment. It was only with accurate plant density counts from drone images that it was possible to calculate with confidence the impact that a sub-optimal establishment would have over the life of the crop and, as a result, quantitatively support the decision to postpone planting in some situations to the next season for better environmental conditions.

The utilisation of the rhizome counter exhibited a favourable impact on the operator of the planter. However, its efficacy of the developed solution appeared to diminish following a designated period of planting because of sensor degradation through the accumulation of dust. Additionally, it demonstrated an inability to establish precise synchrony with GPS, consequently resulting in the failure to record all instances of mis-planting. Notwithstanding, the counter possessed an indication function within the tractor hub, potentially prompting the operator to enhance their level of attentiveness or alerting the tractor driver to excessive velocity. Meanwhile, large professional machine manufacturers are now offering similar and more sophisticated solutions, the benefits of which are better understood and appreciated by TV as a result of the research in this area. Their solutions solve the encountered shortcomings and thus will be installed on our next generation of planters.

3.4. Key Successes

A significant barrier to the cultivation of Miscanthus has been the cost and complexity of producing planting material, primarily rhizomes, which require careful handling and quality control to ensure successful establishment. The OMENZ project has pioneered advances in rhizome processing and quality assurance (QA), driving down rhizome production costs, reducing plant losses and optimising planting methods for better yields. In addition, novel biological treatments and pre-planting techniques have been introduced to improve germination rates, ensuring a higher return on investment for growers.

The project has leveraged technology to streamline monitoring and management, using AI-powered image analysis and automated planting assessments to provide farmers with real-time insights into crop performance. Knowing early on if establishment has been successful is essential for growers to intervene in time and address establishment issues before they become unfixable due to the perennial nature of Miscanthus and its tendency to outgrow younger, smaller and weaker plants planted later.

OMENZ integrates data-driven decision-making into the supply chain, enabling growers to optimise land use, minimise input costs, and maximise biomass yield. The introduction of mechanised and precision planting techniques has reduced labour dependency, rendering Miscanthus a more attractive long-term investment for farmers.

The project's contributions are threefold: firstly, it assists in achieving the UK's renewable energy objectives, secondly, it ensures that farmers derive benefits from a more profitable and sustainable agricultural model, thirdly. it contributes to unlock the full potential of Miscanthus as a viable biomass solution with uses beyond energy generation.

A more profound comprehension of the physiological characteristics of Miscanthus has been a particularly significant accomplishment in this respect. This knowledge has directly informed rhizome production and the necessary quality control measures. The comprehension of the divergent behaviours exhibited by the crop, influenced by both environmental factors and genetics, provides invaluable insights for the selection of suitable planting conditions and/or crop varieties to achieve optimal results.

Previous studies have demonstrated a paucity of understanding regarding the influence of environmental factors on the physiology of Miscanthus plants. This has resulted in speculation without the support of empirical evidence. However, the results of this project have now provided a clear direction for investigating establishment issues and identifying effective remedies. Insights such as the "root engine" behaviour under various soil conditions and environmental factors have clarified expectations for establishment and growth rates, enabling better predictions of yield potential and the development of appropriate mitigation strategies. A recurrent observation across diverse methodologies is that the carbohydrate content of roots and rhizomes in first-year rhizomes accumulates more slowly. It is noteworthy that clay loam and medium sandy loam soils offer more favourable conditions for carbohydrate accumulation during the initial year. This observation potentially provides a rationale for the impediment of re-emergence from first-year rhizomes, particularly in clay soils, as previously documented. However, it is noteworthy that subsequent sampling reveals a tendency for these differences to diminish over time. This finding underscores the vital role of first-year establishment in ensuring successful crop development.

It has been determined that the practice of irrigating rhizomes in storage prior to planting is not only an inefficient use of water, but also a significant source of wastewater. Previous methods involved the application of water to rhizome pallet stacks to maintain moisture levels, resulting in substantial water wastage and labour expenditure. However, this project has demonstrated that when adequately packaged and covered, rhizomes in storage can maintain optimal moisture levels for over three weeks. This finding has two key implications. Firstly, TV can eliminate the need for water usage and wastewater generation. Secondly, the elimination of the need to water rhizomes reduces operational demands, as it avoids the need to open the storage facility, move pallets and re-cool the container afterwards. This not only saves energy but also minimises the rhizomes' exposure to external temperatures, preserving the quality of planting material while improving energy efficiency.

It is important to note that, while the utilisation of refrigerated containers necessitates a slightly greater investment of time during the loading process and the deployment of additional personnel on certain days, it has resulted in a substantial reduction in energy expenditures. The energy consumption is significantly reduced by cooling a smaller space as opposed to an entire warehouse, consequently leading to a reduction in emissions.

During the project, TV successfully trialled a strip-tiller that had been acquired in Phase 1. The trial revealed that soil tilled using the strip-tilling method demonstrated enhanced emergence, particularly in dry weather conditions. This is attributable to the enhanced water conservation achieved during the tilling process. If adopted as a standard practice, strip-tilling could reduce soil movement, thereby minimising potential carbon release associated with conventional tilling. However, it should be noted that this method also generates dust during planting, which poses a significant health and safety concern. It is therefore recommended that individuals positioned at the back of the planter wear masks for protection.

Visits from the UoL and LJMU to our rhizome nursery have yielded valuable outcomes in the assessment of our QA processes. The UoL confirmed the efficiency of certain aspects of the QA process, while LJMU identified areas for improvement based on physiological insights. Despite the challenges posed by practical constraints, several "quick wins" have been identified. These include addressing issues such as rhizomes being too long, small rhizomes that would have failed QC being included in bags, and the elimination of first-year rhizomes from production. It is noteworthy that the exclusion of first-year rhizomes from production for the UK market has led to a substantial reduction in the incidence of rhizomes sprouting prior to planting, thereby enhancing the overall quality of the rhizome.

In summary, the completed studies on rhizome physiology and environmental influences, together with data collected and made available by TV operations, provided the basic dataset from which the decision matrix could be developed. A significant proportion of these elements had never been investigated on such a scale, making the data evaluated in this project statistically significant in identifying the optimal characteristics of planting material under different environmental conditions.

3.5. Persistent Barriers

The war in Ukraine has had a significant impact on the global agricultural sector, particularly regarding the price of crops such as wheat. This has led to a temporary increase in the profitability of wheat cultivation on less favourable land. Consequently, many potential growers in the UK have shifted their focus during the planting seasons of the years 2022-2025 away from perennial biomass crops, as these traditional annual crops require less initial investment and generate swift although short term returns. Furthermore, the escalating cost of fertilisers has had a detrimental effect on the financial viability of small-scale growers, thereby reducing their capacity to invest in new, upfront-investment-heavy crops. In times of financial hardship, farmers tend to adhere to their established agricultural practices.

Moreover, the United Kingdom's exit from the European Union has had a disruptive effect on the import and export activities of businesses operating within the European Economic Area. TV, which imports rhizomes from the EU, has seen navigating the constantly changing import system and associated requirements become a year-by-year challenge. In the middle of the 2024 planting season, when imports required rapid customs clearance to keep planting material fresh and healthy, the previous customs system, called the *Procedure for Electronic Application for Certificates from the Horticultural Marketing Inspectorate* (PEACH), was replaced with a new system called the *Import of Products, Animals, Food and Feed System* (IPAFFS), which did not include the commodity code for Miscanthus when it was introduced and did not for the following six months. Imports were therefore made under a generic code, which meant that each individual lorry had to be fully inspected, delaying imports and resulting in weaker rhizomes. The very same new procedure has not only caused delays and thus more expensive haulage costs but also increased overall administrative costs.

In addition, the current newly introduced agricultural schemes replacing the former EU CAP system do not encourage farmers to move to net-zero perennial biomass crops. Indeed, the schemes have crowded out simple but effective long-term private sector solutions (investment in perennial biomass crops) for low quality or flood-prone land in favour of schemes requiring annual payments from the government (see Annex A1).

3.6. Impact of Innovation on GHG Emissions

The innovations generated by this project provide both direct environmental benefits and trade-offs.
In terms of reducing greenhouse gas (GHG) emissions, Miscanthus has been reported to sequester up to 2.35 tonnes of CO_2 per hectare per year [11]. In addition, Miscanthus cultivation produces only one fifth of the N_2O emissions compared to annual crops [14]. In addition to GHG reduction, Miscanthus offers several other environmental benefits (Table 13), including reducing soil erosion and nutrient leaching, maintaining consistent yields under flood conditions, phytoremediation, nutrient recycling, providing shelter for grazing animals, improving biodiversity on arable land, and improving soil health (Table 14).

Increasing Miscanthus plantations through improved establishment has an positive environmental impact as outlined. In addition, several of the project's innovations, such as strip-tilling, are known to reduce soil disturbance and CO2 emissions. Improved rhizome quality has reduced the number of rhizomes transported for planting, contributing to 'carbon savings', a key performance indicator in TV's carbon report. In addition, TV has already partnered with water companies and the Game & Wildlife Conservation Trust to assess the impact of Miscanthus on water quality and biodiversity respectively. These collaborations will further highlight the benefits beyond the scope of this project and provide essential parameters for measurement.

There is a trade-off with Miscanthus cultivation that needs to be addressed, particularly in relation to the use of arable land for biomass production, which is part of the wider food versus fuel debate. This project's research has shown that Miscanthus will still need to be grown on arable land. However, the majority of Miscanthus cultivation is expected to take place on less productive or 'marginal' land. Even if only ~10% of English arable land is considered to have the lowest production potential, this amounts to almost 1 million hectares - still a challenging target to meet over the next 30 years. Concerns have been raised about the potential for Miscanthus to overtake arable land. However, the lower market value of Miscanthus compared to food crops means that it is unlikely to compete with food crops for prime agricultural land.

Finally, an environmental issue was identified in Phase 1 of the project - the use of plastic-based film in the early stages of seed-based hybrid planting. In response, a suitable alternative, a starch-based biodegradable film, was identified and evaluated for use in Phase 2.

3.7. Lessons Learned

During this project, several observations were made that were not anticipated during the planning process. Here is a summary of the main lessons learned:

1. **Harvest Timing for Seed Production**:

The timing of the seed harvest is critical for both quality and quantity. Close monitoring of weather conditions is essential to optimise the harvest. The more mature the seed, the better the germination rate. To minimise losses, harvesting must take place within a short period of time to maximise both collection and individual seed quality.

2. **Simplicity in Solutions**:

The experience with the rhizome separator prototype highlighted that a simple solution can often be the most effective. The machine's ease of use received positive feedback from nursery staff, demonstrating that innovations need to align with the practical needs of those working on the ground to ensure successful implementation.

3. **Understanding Miscanthus Physiology**:

The project has generated important information on Miscanthus physiology and successful establishment. Understanding the critical factors affecting rhizome establishment, even in non-ideal environments, is essential. In addition, identifying key aspects of quality control in rhizome production and the supply chain is crucial.

4. **Monitoring Rhizome Transport and Storage**:

The importance of monitoring rhizome transport and storage was emphasised. Based on the findings of this project, a new handling and storage protocol has been developed and is currently in use, with plans for further refinement in the future.

5. **Environmental Influences on Development**:

Observations from the project have shown that environmental factors have a significant impact on Miscanthus development. Heavier soils may inhibit early seedling and rhizome development in the early stages, although growth may catch up over time. In addition, heavier soils have potential benefits for water retention, leading to more stable production in the long term.

6. **Rhizome Counter Effectiveness**:

The rhizome counter has proved useful for estimating planting coverage, although it requires regular maintenance. However, its integration with drone imagery has not yet been feasible, despite its potential benefits.

7. **Improvements in Image AI Counter**:

The Image AI Counter has undergone significant improvements during this project. It is now able to differentiate between crops planted in different soil types across the UK and to detect crops at different stages of growth. This enhanced capability allows for a longer image acquisition period while maintaining accurate counts.

8. **Cost Considerations and Future Development**:

The additional costs of implementing these innovations must be considered, as some require further development and investment. Nevertheless, the project has successfully moved the technology in the right direction to increase biomass production.

4. Commercialisation Plans

The combined demand for agricultural biomass in the United Kingdom and the European Union is currently valued at approximately £17 billion, with projections indicating an increase to £29 billion by 2050. Of this total, two-thirds is expected to be allocated to energy generation (electricity, heat, and transportation fuel), while the remaining one-third—representing the fastest-growing segment—will be dedicated to the production of bio-based materials [7]. The latter market also has the largest intrinsic CO2 storage potential (i.e. building products) without the need for post-combustion CO2 capture.

To prevent a supply-demand imbalance, which could result in a shortfall of 40–70% of total demand [5], it is imperative to identify additional supply opportunities to traditional difficult to scale biomass sources. Biomass is currently sourced from forestry (60%), agricultural residues and dedicated biomass crops (25%) and recycling and waste (15%) (EEA,2023).

With increasing attention being paid to biomass for its environmental credentials, particularly perennial biomass crops, Miscanthus has come under the spotlight. The current market for Miscanthus is primarily focused on power generation, with annual demand in England in excess of 150,000 tonnes of Miscanthus feedstock and the potential to quadruple consumption (according to TV's surveys of UK medium sized renewable energy operators of around 50 MW).

Beyond power generation, several industries have expressed interest in using Miscanthus as a feedstock, with requests for 1,000,000 tonnes of Miscanthus biomass received by TV in 2024 alone. These come from very diverse industrial sectors such pulp & paper, food packaging, biofuels, biochemicals, pharmaceuticals, construction material and various uses of biochar. However, the limited availability of supply due to the low uptake of Miscanthus and perennial biomass crops remains a significant barrier. This limited availability of feedstock also hinders innovation in the applications of Miscanthus biomass.

One of the main challenges is the perennial nature of the crop, which involves significant up-front costs and delayed returns for growers. Improving planting efficiency and establishment success can help alleviate some of these burdens, potentially enabling growers to achieve returns more quickly.

Although there are other suppliers of Miscanthus in the UK, TV is uniquely positioned by offering the TV Assured Biomass (TAB) contract, which guarantees the sale of the Miscanthus grown. This provides a distinct advantage in accessing and maintaining the Miscanthus supply chain (as detailed in Section 5.5), while offering competitive planting costs and income security for growers.

For those farms that meet one or more of the following criteria: (i) farms with low yielding fields (soil or climate or water table related), (ii) issues of succession and farms with old or missing machinery and equipment Miscanthus can offer a financial lifeline [6].

In most cases, Miscanthus is an economically viable long-term solution to difficult problems. When compared to the UK staple crops wheat and barley, Miscanthus wins financially hands down in all scenarios with the expectation of the best yielding wheat fields [6]. However, the perennial nature of the crop means that farmers have to take into account considerations other than pure economics. 20 years or more of crop life can span two generations of farmers and lead to succession discussions within the farming family. Such a long-term commitment raises important opportunity cost considerations, such as whether successive governments will change energy policy, whether the nearest renewable energy plant will be operational in 10 years' time, or whether more financially attractive opportunities may arise in the short term (as happened recently with SFI).
The high initial up-front investment requires either a strong capital position of the farm, which is rare, or new borrowing is required. The delayed break-even point, with no cash income for the first two years, is another barrier for some growers. All this suggests that, because of the long-term commitment and opportunity costs, perennial crops need to offer not only more secure but also higher returns than other short-term crops or farming options.

Nevertheless, the business case is strong, as shown in the table below which provides a summary of the main financial indicators for farming on low-, mid- and high-yielding fields as well as net margins achievable with current UK farming schemes. Additionally, this research project has increased its attractiveness with better yields and earlier commercially viable harvests through better establishment methods and more vigorous planting material.

Wheat (feed, winter)	**low**	**mid**	**high**
Tot output	1,513	1,770	2,036
Variable costs	698	698	698
Gross margin	815	1,072	1,338
Net margin £	**350**	**607**	**873**

Barley (feed)	**low**	**mid**	**high**
Tot output	1,259	1,443	1,653
Variable costs	596	596	596
Gross margin	663	847	1,058
Net margin £	**198**	**382**	**593**

Miscanthus	**low**	**mid**	**high**
Tot output	855	1,069	1,283
Variable costs	0	0	0
Gross margin	855	1,069	1,283
Net margin £	**420**	**634**	**848**

SFI and CS actions 2024, Net margin £	
Flower rich Margins	**677**
Winter Bird Food	**544**
Legume Fallow (CS)	**439**
Low Input Grass	**151**
Legume Fallows (SFI)	**443**
Winter Cover	**29**
Summer Catch	**63**

To strengthen the market position and encourage greater participation in biomass cultivation across the UK, this project has introduced several innovations to enhance the supply chain. The routes to actualization, along with the expected impacts and potential benefits, are outlined in the following sections.

1. Harvest Timing of Seed and Improved Quality/Quantity

Monitoring seed harvest at the optimal time can significantly enhance both the quality and quantity of the yield. Additionally, a key insight from the project has highlighted an alternative deployment method to plug planting, which has been the only method for deploying seed-based hybrids so far.

Plug planting, while effective, incurs high costs, primarily due to the expense of raising plant plugs and transporting them. A 2022 assessment revealed that the cost per hectare for plug planting ranges between £1,083 and £1,773.35, compared to £1,070 for rhizomes. Transport inefficiencies arise from the need to ship trays of plant plugs, which limits the number of planting materials per shipment. If seeds could be deployed via direct sowing—like to grass seed planting—it would shift the focus to producing seeds more economically while also simplifying transport and storage logistics.

During the September 2024 in-person meeting at LJMU, a method of direct sowing was demonstrated to result in successful seed germination. This method has the potential to disrupt current planting practices. Eliminating the need for plug raising could significantly reduce planting costs, thereby addressing one of the major barriers for growers.

Given that financial returns typically begin only after the first or second year, reducing upfront investment costs would make planting Miscanthus considerably more attractive.

Findings from the project revealed that the current crossing block has the potential to produce up to 23 kg of seeds per hectare. Assuming a 90% viability rate (a conservative estimate), at least 20 kg of viable seed could be harvested per hectare. With a thousand-seed weight (TSW) of less than 0.4 g, this quantity could support the planting of approximately 700 hectares at four seeds per plant or 286 hectares at ten seeds per plant—representing a 10 to 35 times greater multiplication capacity compared to rhizomes.

In addition to lower production costs, seeds offer easier and more cost-effective transport and storage, with fewer physical and administrative requirements. While further research and investment are needed to commercialize this approach, the potential for cost reduction and improved efficiency is significant. These advancements could make Miscanthus cultivation more accessible to growers.

Efforts are also underway to secure innovation funding through grant awards in collaboration with LJMU to support the further development and eventual commercial deployment of this promising approach. Favourable policies and incentives will be essential in driving adoption and realizing the benefits of these innovations.

2. Rhizomes Will Always Have a Place in Planting

Certain licensed rhizome GNTs have unique physiological characteristics that make them well suited for specific applications (e.g. production of "fluffier" chipped biomass, drought tolerant plants, etc.). As a result, innovations such as a rhizome separator would significantly improve the production of planting rhizomes. Unfortunately, due to time constraints, it was not possible to develop an optimal prototype during this project. However, with an additional investment TV could complete a prototype ready for commercial testing. Once developed, the prototype could be adapted for deployment at minimal additional cost.

Although it is too early to quantify the cost savings from this innovation, it has shown great potential for improving efficiency. In fact, the machine offers several notable advantages:

- **Increased production rates:** By automating the most labour-intensive part of the production process, the machine allows for greater daily output.
- **Enhanced working conditions:** The separator includes a washdown system that could significantly reduce dust levels, thereby improving the work environment for staff.
- **Shortened rhizome production time:** This enables the farm to shift to other production activities or planting preparations more quickly, optimizing the use of available labour.

Further investment is required to make this innovation commercially viable. TV, in collaboration with some project partners (LJMU and YT), plans to seek additional funding to complete this work.

As a versatile piece of machinery, the rhizome separator has global applicability for any nursery seeking to pre-separate rhizomes before cutting, making it an asset for improving efficiency in rhizome production.

3. Miscanthus Behaviour and Environmental Cues

Understanding the behaviour of Miscanthus and its response to environmental cues has led to significant improvements in planting strategies, increasing the likelihood of successful establishment. In one planting year, due to a very dry spell immediately after planting, several fields had to be replanted, resulting in an increase in planting costs (replanting/new planting) on top of the following year's costs. Reducing the need for replanting not only improves cash flow for the grower but also contributes to earlier biomass availability for industrial users.

The results of this project also suggest that not every planting requires the use of a strip-tiller for successful establishment. While strip-tilling improves success rates in certain scenarios - particularly when dry weather is expected after planting - its use adds to establishment costs. However, depending on soil type, strip-tilling can reduce overall establishment costs by eliminating or reducing the need for intensive pre-ploughing. Ultimately, the decision to use a strip-tiller rests with the grower. While these insights may not directly generate revenue, they are invaluable in improving operational efficiency and minimising the costs associated with crop failure. Incorporating these learnings into standard operating procedures prevents unnecessary expenditure and prepares TV with a scalable deployment model ready for testing in new territories, including the UK, EU and beyond.

Additionally, future collaboration opportunities with partners such UoL could enable deeper investigation into the environmental effects on Miscanthus behaviour. Connections formed with TJSS during this project may also provide access to machinery trials that leverage these findings.

4. Cold Room Rental vs. Refrigerated Containers

Previously, the cost of renting a cold store to store rhizomes was many times higher than the new storage method developed during this project, which used refrigerated containers as an alternative. This method also improved the quality of the rhizomes during storage. The use of refrigerated containers has delivered better results at a lower cost to the company and is a scalable solution as these containers are readily available worldwide.

Although refrigerated containers require a bit more active management, the benefits - both in terms of cost reduction and quality improvement - are clear. As a result, this method of storage has already been incorporated into the project's operating protocols.

5. Monitoring Systems

Monitoring plays a critical role in planting, establishment, and storage. Although the cost of these systems can increase the cost of planting, they are essential to maximise the likelihood of success.

Planting Monitoring: The prototype planting monitor has demonstrated its potential to ensure adequate planting across fields. It identifies potential problems during planting and verifies that the correct amount of rhizome is planted, providing assurance of material sufficiency. Whilst further refinement may be required for use on every planter, the concept has been proven to work in the field. The next step is to secure funding to manufacture these counters for installation on additional planters.

Cold Storage Monitoring: Maintaining consistent cold storage conditions was critical to preserving the freshness and vigour of planting materials. Failures in 2023 in some projects were largely attributed to inadequate cold storage that failed to maintain stable temperatures. Disposable temperature monitors, costing less than £11 each, can be used effectively in cold storage and during transport. For example, monitoring a single shipment would require 3 monitors at a total cost of £33. This equates to less than £1 per hectare, a negligible price increase when considering the total cost of planting.

AI Counter for Drone Photos: Although the AI counter costs about £100/ha, this cost is justified to resolve disputes over establishment quality. In addition, a second-year drone count can more accurately reflect final establishment, allowing for better yield predictions and logistics planning. Drone service providers typically take orders in February, so planning ahead to January will help streamline the process. Continuous monitoring throughout the supply chain is essential to achieve efficiency and ensure success. Equally important is knowing when to forgo tools in order to reduce costs. Effective use of monitoring systems lies in selecting appropriate technologies, while recognising their limitations. Although some of these innovations are transferable to other crops, many are either adapted technologies or specifically developed for Miscanthus. Therefore, their benefits are expected to be most relevant to Miscanthus cultivation.

6. Supply Chain Considerations (Other Potential Products)

A reliable supply chain is crucial, as Prof Tim Volk pointed out at the Biomass Connect event in November 2024. Over the past decade, TV has successfully developed and maintained a robust supply chain, and innovations from this project have further strengthened it. Recent investment by DESNZ has already contributed to improved planting success within the supply chain. Further investment is both welcome and necessary to enhance existing innovations and expand the chain's capabilities.

7. Other Considerations

- **Incentives:** In 2023, a factsheet was published to guide growers on cultivating Miscanthus while meeting the criteria for SFI payments. By fulfilling the required conditions, growers are eligible to receive up to £264 per hectare in incentives [6]. This resource, available online, has been shared with both current and prospective growers to assist them in claiming applicable incentives.

- **Grower Recruitment:** Collaboration with farmer purchasing groups and TV's renewable energy plant customer is underway to recruit new growers and expand biomass production. Close partnerships help strengthen the supply chain by fostering engagement with the largest biomass consumer. Purchasing group's extensive network is utilized to introduce growers to Miscanthus cultivation and provide reassurance about the crop's strong market demand.
- **Market Product Development:** Although not directly part of this project, work with other organizations continues to prototype Miscanthus for use in construction materials. Early-stage funding bids are also being pursued in partnership with Sheffield Hallam University to advance the development of Miscanthus-based materials for broader applications. Previous product developments include biodegradable film, insulation and soundproofing boards, animal bedding, and domestic fuel products.

8. Products Opportunities Beyond Current Model

There are ongoing discussions about using Miscanthus as a feedstock for the following:

Tissue Paper - Contact has been made with a European company specializing in the use of alternative biomass for tissue paper production. The company is exploring the potential benefits of non-wood feedstock in there.

According to World Atlas [12], a single tree can produce approximately 200 rolls of tissue paper. Data from Weavers Way Co-op [13] suggests that global consumption of tissue paper results in the deforestation of around 27,000 trees annually. A fast-growing alternative like Miscanthus offers a more sustainable feedstock option.

Currently, bamboo is used as the primary material, but its management requires careful attention. Miscanthus, which belongs to the same phylogenetic family as bamboo, is being considered as a promising alternative due to its similar properties.

Fibre Board Production - A collaborator from the CHCx3 project, funded by InnovateUK, has worked with Natural Building System to develop a prototype of Miscanthus fibreboard. While further refinement is needed for it to become load-bearing and water resistant, the production engineer has expressed confidence in its potential. This early-stage research has demonstrated significant market value.

Animal Bedding (TV Equine): TV previously produced a brand of equine bedding that gained significant popularity. Animal bedding has a higher value than its use as fuel, and the production process for Miscanthus-based bedding has been well-defined. TV is assisting several farmers to establish a local supply chain. The product was well-received and demonstrated strong market potential. Miscanthus bedding also offers a sustainable alternative to traditional options like wood shavings. Similar applications are observed in Australia, where local scientists grow Miscanthus for use as chicken or cattle bedding, as well as in Wales for cattle farms.

Biodegradable Film and food packaging: During the European BBI-JU GRACE project (2017–2022), industrial partners experimented with Miscanthus for producing biodegradable plastics, including agricultural film. Although the process showed mixed results, it confirmed that Miscanthus could be used to create biodegradable films. Further improvements in process efficiency are required. The film produced has been successfully used in seed-based hybrid trial planting, achieving positive results in establishment. As plant-based plastics gain popularity in sustainability-conscious markets, biomass feedstock such as Miscanthus is expected to be a top consideration for future developments.

Insulation/Soundproofing: During the European BBI-JU GRACE project (2017–2022), industrial partners developed an indirect method of using Miscanthus to produce insulation and sound-reduction boards. These products are both functional and aesthetically appealing.

Summary

Significant strides have been made in optimizing Miscanthus planting and supply chain management. Key cost-reduction strategies, including direct sowing, cold storage choices, and the use of advanced planting and monitoring technologies, position the company for future success. These innovations reduce expenses through improved establishment success and operational efficiency in the planting supply chain.

Additionally, innovation in planting and establishment has only added an estimated 2% to planting costs (D2.082), which is lower than the UK inflation rate of 2.5% (Office for National Statistics) during 2024 [9].

Next steps include securing further investment to refine and scale these innovations, particularly in prototype development for rhizome planting and AI-driven yield prediction. With strong incentives, market development, and an expanding network of growers, the company is well-positioned for continued growth and commercialization in the biomass sector.

Participation in the NZIP accelerator program has provided valuable insights into market needs, opportunity analysis, district heating, and investment networks. The program has also supported the development of an investment pitch, which is crucial for the company's future growth.

5. Secondary Project Benefits

5.1. Dissemination Activities

- A list of dissemination activities has been undertaken (Table 11, Table 12).

5.2. IP Generated

This project produced several deliverables with associated IP, much of which is already being used in TV's day-to-day operations, supply chain agreements, nurseries and various protocols. Some deliverables raised important questions that were beyond the scope of this project or could not be fully answered within the 3rd year project period. These either require further development within TV or may be the subject of new grant applications. The TRL mentioned in the following table is the level reached at the end of the project.

Topic	**Description**	**Current use**	**Notes**	**TRL**
Planting material processing system	design of the washing, break-up, selection machinery; 2 versions available: batch system and continuous flow	Not in use	Requires further grant	5
Miscanthus seed production	seed production, harvest, grading and seed to plug protocols	Fully applied to nursery operations	seed-to-plug protocol ready for commercialisation	7
Environmental influences on establishment	Soil physico-chemical properties' influences on rhizome development and establishment success	Criteria matrix for field selection and yield prediction	TRL level will grow as more years pass since establishment	7
Rhizome QC and selection system	Temperature priming / chemical pretreatments, better understanding of rhizome physiology	QC protocol, selection process criteria Pretreatment protocol	 Requires TV internal industrialization	8 5
Production of rhizomes	End-to-end quality control process: rhizome quality assurance protocol, storage & planting protocol	Fully applied to nursery operations	TRL level will grow as more years pass	6, 7
Remote monitoring	AI based plant count and yield prediction based on drone imagery of 1st & 2nd year fields	Use on fields with known problems	follow-on project required to add new genotypes and later growth stages and to lower costs with satellite images.	6, 5

5.3 Job Creation

Project OMENZ has contributed significantly to job creation and skill development in the biomass sector. The following details outline the positions filled, training opportunities offered, and ongoing commitments to employment generated by the project.

Job Positions - One Sales Team Leader, three Post-Doctoral Scientists, one Field Technician, one Senior Developer were created for the project. One Innovation Associate and one Project Manager was also recruited to provide additional support to the project. Two other temporary and two permanent position were also created. Six other placement positions were also created.

Training Opportunities - Funding for a PhD student program was secured by LJMU to contribute to the project without incurring additional costs. A collaborative student project at CU, funded by TV and Waterboard, was facilitated. In addition, one visiting MSc student and one PhD student were involved in the project without incurring extra costs. Two undergraduate students were employed for summer work for the projects.

5.4. New Partnerships

In the fourth quarter, an innovative UK company founded in 2018 and specialising in drone field surveys, thrived through its collaboration with TV on the OMENZ project. This partnership has provided this supplier with invaluable access to key industry partners and resources, paving the way for the development of groundbreaking services for the British farming sector. These advancements hold the potential to transform crop monitoring. Additionally, this support has been instrumental in strengthening the young company's financial position as it prepares for upcoming UK legislation that will shape other areas of its services.

TV has also secured long-term agreements with two new nursery partners, integrating newly developed protocols for seed and rhizome production, as well as quality assurance. With enhanced monitoring, the quality of planting material has significantly improved, reinforcing a strong partnership built on shared goals of excellence and evidence-based decision-making.

In line with this vision, new collaborations have been established in transport, storage solutions, handling, seed cleaning and grading, and germination testing. Each of these partnerships is based on the technical expertise and knowledge gained from this project. Overall, the entire value chain has been reviewed, improved and given more objective parameters to measure the success of the collaboration.

The project's success is further reflected in the development of superior seeds and increased yields for the crossing blocks, leading to additional partnerships and agreements built upon the innovative parameters developed by the various project contributors.

5.5. Supply Chain Development

Throughout the project, the supply chain has been refined by testing various new approaches to handling of planting material. Notably, a more resilient supply chain has been established by optimizing nursery material selection, utilizing hauliers for transport, and implementing improved cold storage and handling protocols. Specific successes have been identified, such as effective storage in nurseries, along with areas for improvement, as outlined in earlier sections. These enhancements have resulted in reduced costs and improved the quality of rhizomes delivered.

6. Project Management

6.1. Project Structure & Scheduling

The project was organized into five work packages, with the deliverables for each outlined in a Gantt chart that was reviewed regularly. Reviews were conducted weekly between TV and UKATC and monthly with the consortium. An updated Gantt chart was provided as a separate file alongside the quarterly and final reports.

Throughout the project, personnel from each partner organization were assigned to support various tasks (details provided in Section 5.3), either to offer additional assistance or to replace team members no longer involved. Existing recruitment processes were employed to effectively manage personnel changes and minimize disruptions to the project's progress.

6.2. Key Risks & Mitigations

A detailed risk register was created at the start of the project and reviewed regularly by the consortium. Updates to individual risks and the overall project risk were documented and reported on a monthly and quarterly basis. The final project risk register is included as a separate file accompanying this final report.

Key Risks:

- Adverse weather conditions during spring/summer 2023 affected planting trials of 2022 and the subsequent harvest in 2023. (R21)
- Concerns raised by growers in initial response to the Biomass Strategy resulted in a risk to ROI to DEZNZ due to challenges recruiting new growers in the initial period post biomass strategy being released. Terravesta alleviated these concerns by actively engaging with growers through dissemination and through analysis of the report.
- COVID-19 regulations and other regulatory changes regarding transportation of plant material generated a project risk. This reduced as the seriousness of COVID-19 infection reduced. (R7, R20)
- Engagement with subcontractor, change in personnel. This was a high risk due to the number of partners on the project but relationships were managed well and maintained. (R2, R29, R33)

6.3. Project Management Lessons Learned

The risk restrictions to the transportation of plant material generated by the Covid-19 pandemic were managed well. Lessons learned from this was that it is important to have appropriate alternative arrangements in place to mitigate the effects and to plan so that risk management can be dealt with proactively.

In the early stages of this project there was some enhanced developments in the project management approach to align with DESNZ’s reporting requirements.

7. Conclusions & Next Steps

The project has largely achieved its objectives by building the necessary capacity to increase annual planting and improving confidence in crop establishment. It has also improved the understanding of Miscanthus physiology, providing insights into how best to handle planting material, which has led to increased establishment success. The knowledge and innovations developed through this project can be used by TV to refine operations and drive further innovation beyond its scope.

Other issues requiring further research and development include methods to make direct drilling viable through seed priming, coating and pelleting. Given the accelerating climate impact of global warming, what techniques or applications are available to further facilitate soil moisture retention.

To further improve the economics of plug planting, research is needed into plug hardening in the nursery, avoiding the use of film to protect the young plug in the field at an early stage.

Methods of improving plug rhizome growth and accelerating plug growth through research into light duration and light spectrum analysis and, last but not least, the development of high speed, fully automated plug planting machinery to achieve the target of 10 hectares of Miscanthus plug planting per day.

References

[1] Amy, C. (2024). The Sustainable Farming Incentive: stats to know. https://defrafarming.blog.gov.uk/2024/05/03/stats-you-need-to-know-about-the-sustainable-farming-incentive/

[2] Climate Change Committee (2020) - Sixth Carbon Budget – Methodology Report. https://www.theccc.org.uk/ wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-Methodology-Report.pdf

[3] Department for Environment Food & Rural Affairs (DEFFA) (2023). Bioenergy crops in England and the UK: 2008-2023 https://www.gov.uk/government/statistics/bioenergy-crops-in-england-and-the-uk-2008-2023/bioenergy-crops-in-england-and-the-uk-2008-2023

[4] Department for Environment Food & Rural Affairs (DEFFA) (2024). Sustainable Farming Incentive action uptake data October 2024 https://www.gov.uk/government/statistics/sustainable-farming-incentive-action-uptake-data-october-2024/sustainable-farming-incentive-action-uptake-data-october-2024

[5] European Environment Agency (EEA) (2023). The EU biomass puzzle

[6] John Nix Pocketbook (2024), Terravesta internal Miscanthus data.

[7] Material Economics. EU biomass use in a net-zero economy

[8] McCalmont, J.P., Hastings, A., McNamara, N.P., Richter, G.M., Robson, P., Donnison, I.S. and Clifton-Brown, J. (2017), Environmental costs and benefits of growing Miscanthus for bioenergy in the UK. GCB Bioenergy, 9: 489-507.

[9] Office for National Statistics. Consumer price inflation, UK: September 2024 https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/consumerpriceinflation/september2024)

[10] Shepherd A, Clifton-Brown J, Kam J, Buckby S, Hastings A. Commercial experience with Miscanthus crops: Establishment, yields and environmental observations. *GCB Bioenergy*. 2020; 12: 510–523. https://doi.org/10.1111/gcbb.12690

[11] Terravesta. Terravesta Miscanthus: Innovative Solutions for CO2 Capture and Carbon Storage. https://www.terravesta.com/Miscanthus carbon/

[12] World atlas. How Many Trees Does It Take To Make 1 Roll Of Toilet Paper? https://www.worldatlas.com/articles/how-many-trees-does-it-take-to-make-1-roll-of-toilet-paper.htm l

[13] Weavers Way Environment Committee. How Much Toilet Paper Do You Use? https://weaversway.coop/shuttle-online/2017/04/how-much-toilet-paper-do-you-use)

[14] Lask J., Kam., Weik J., Kiesel A., Wagner M., Lewandowski, I. (2021) A simple parametric model for calculating the greenhouse gas emissions of miscanthus cultivation in Europe. GCB Bioenergy

[15] DESNZ - Policy paper Biomass Strategy, August 10th 2023, https://www.gov.uk/government/publications/biomass-strategy

Appendix

A1. Figures and tables

Figure 1 Overview of the fully assembled prototype system as tested.

Figure 2 Cutting plant down to 1.5m in July for more panicles/seeds per panicle

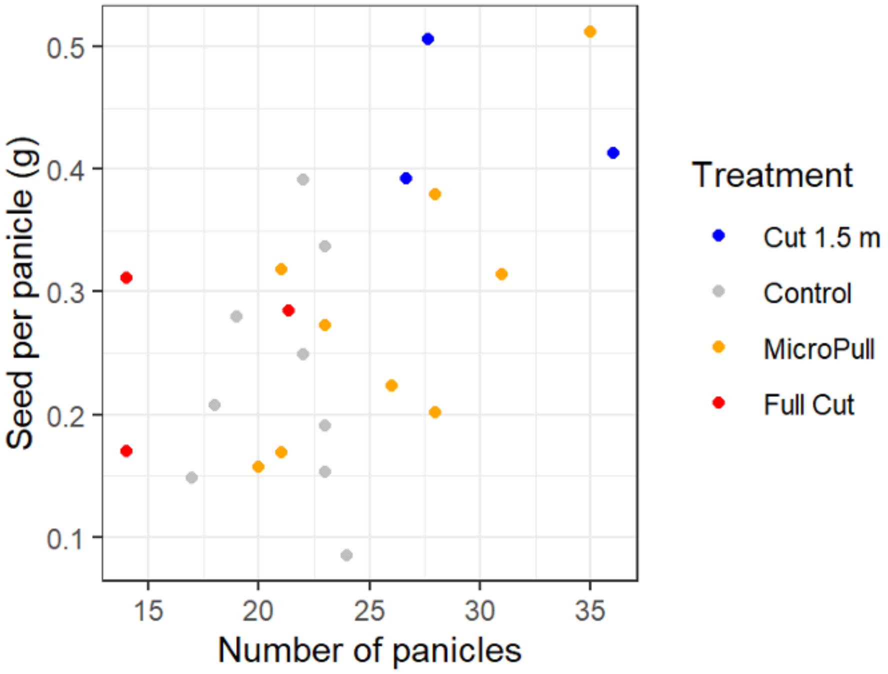
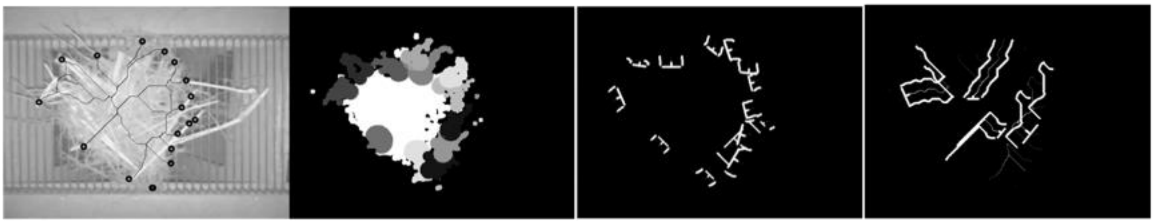


Figure 3 Simulation of cut line on a physical rhizome.



The presence of "root hair" interferes with cut line generation. However, with different filters, these "root hair" can be separated from the bulk of rhizome and cut lines can be generated to remove these "root hair".

Figure 4 Spatial distribution contour maps of RMD for all sampled field categories

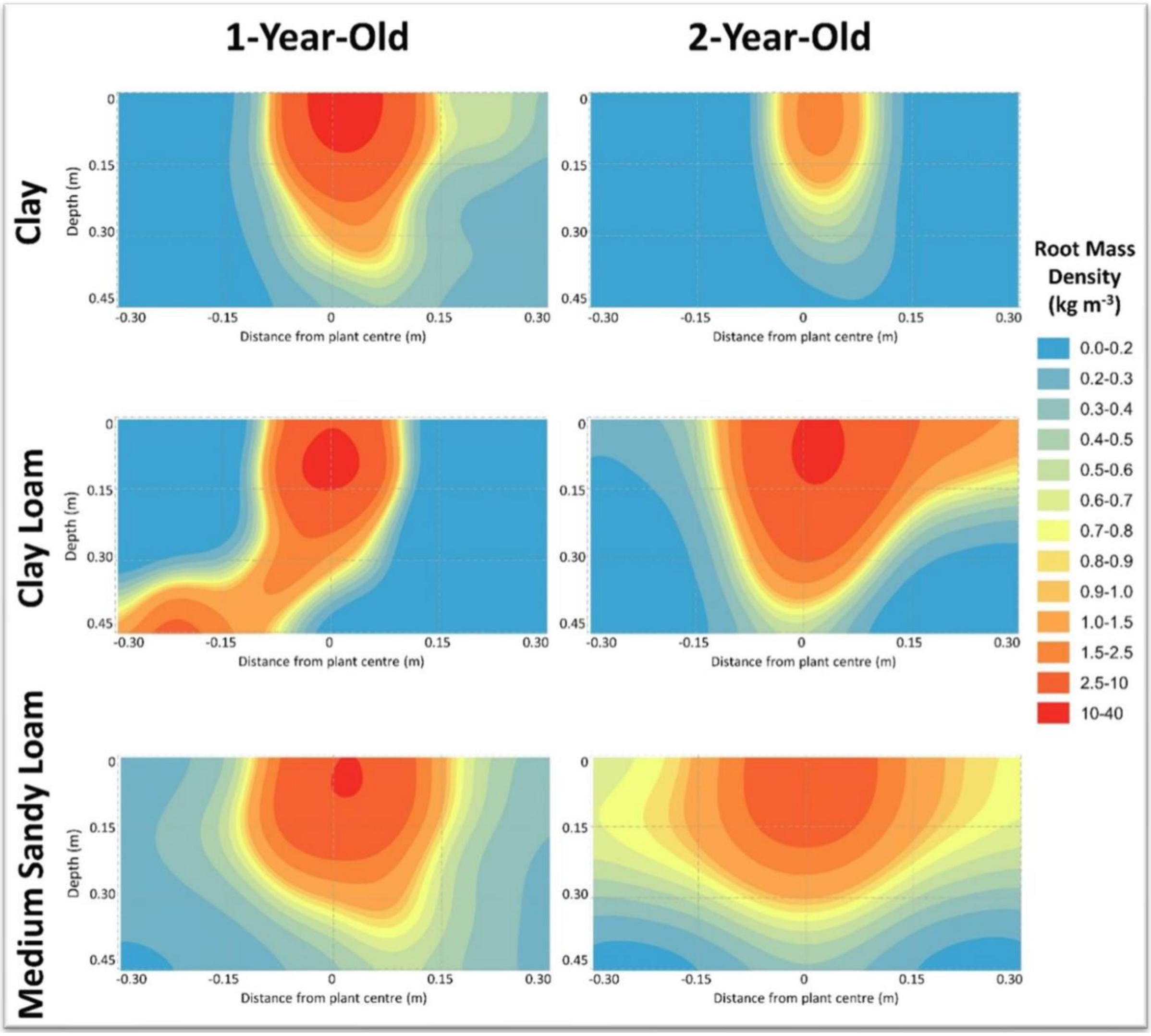


Table 1 Sugar content of Miscanthus *root/rhizome.*

ng g^{-1} DM	**Fructose**	**Glucose**	**Sucrose**	**Total sugars**
Clay	15.8 [a]	7.65 [a]	29.8 [a]	53.2 [a]

Clay loam	21.1 ^{b}	14.1 ^{b}	50.4 ^{b}	85.6 ^{b}
Medium sandy loam	14.3 ^{a}	6.75 ^{a}	51.4 ^{b}	72.4 ^{b}

Values followed by the same letter(s) were not significantly different following One-way ANOVA and post-hoc Fisher LSD Analysis.

Figure 5 Correlation between total sugar content and soil penetration resistance

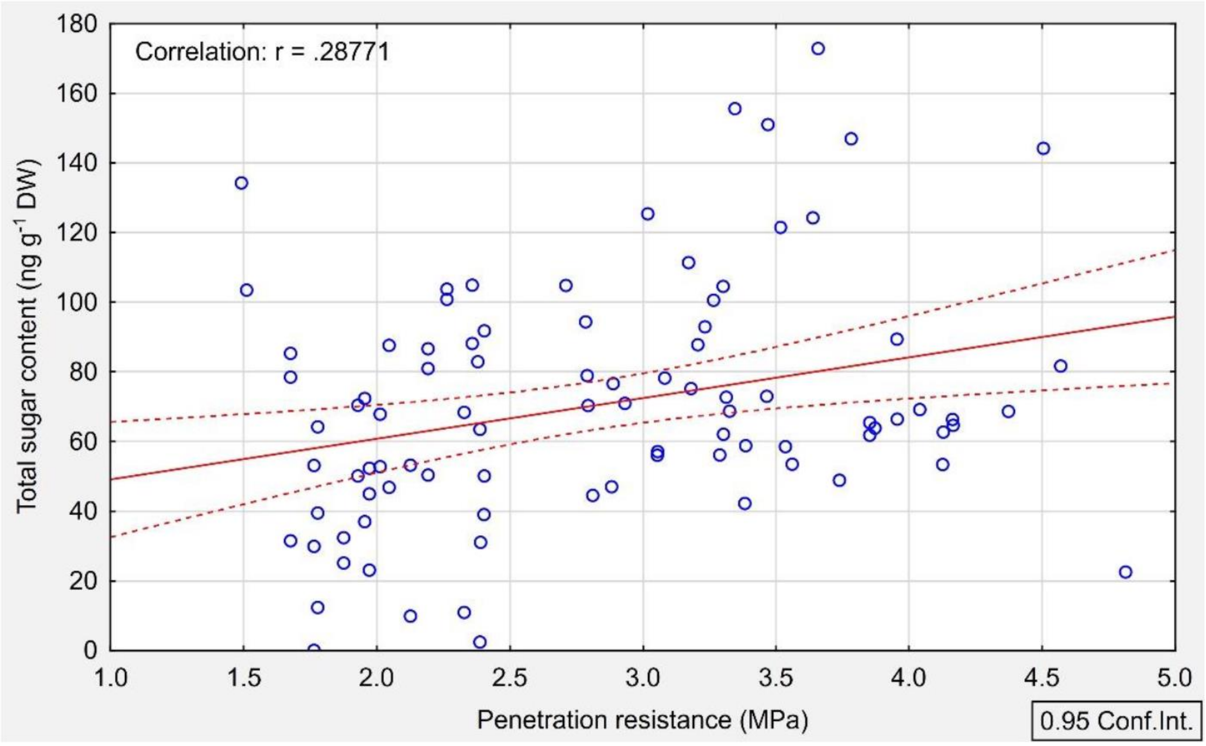


Table 2 Significant factors toward various physiologies.

Response	**Variable(s)**	**Effect (t)**	**(df)**	**P**
Emergence (1/0)	Rhizome weight	0.509	51.48595	0.55983
	Eye number	0.587	49.4548	**
	Flood (1/0)	2.699	37.63228	0.98412
	Soil type	-0.02	34.05545	0.69013
	Rhizome weight : soil type	0.402	52.99853	0.3935
	Flood : soil type	0.86	10.14887	0.44497
	Eye number : soil type	-0.795	45.99064	0.82098
	Eye number : flood	-0.228	47.16537	0.79082
	Eye number : rhizome weight	-0.267	48.76339	* 0.02868
	Rhizome weight : flood	-2.255	51.26245	0.61896
Final Height (cm)	Rhizome weight	8.899	29.48728	0.985
	Eye number	-0.019	27.28268	0.2378
	Flood (1/0)	-1.21	24.43018	* 0.0245
	Soil type	2.375	28.63013	* 0.0474
	Rhizome weight : soil type	2.069	29.53306	0.5836
	Flood : soil type	-0.555	27.18736	0.2178
	Soil type : eye number	-1.313	10.3005	0.2535
	Eye number : flood	1.173	22.11097	0.565
	Eye number : rhizome weight	-0.584	22.93805	0.3654
	Rhizome weight : flood	0.921	26.2025	0.4975
Final Culm #	Rhizome weight	-0.45	32	0.65603

	Eye number	-0.473	32	0.63968
	Flood (1/0)	2.035	32	0.05023
	Soil type	-0.187	32	0.85307
	Mesocosm ID	0.931	32	0.35875
	Rhizome weight : soil type	-3.471	32	**
	Flood : Soil type	2.049	32	* 0.04870
	Soil type : eye number	-1.913	32	0.06473
	Eye number : flood	0.222	32	0.82575
	Eye number : rhizome weight	0.075	32	0.94084
	Rhizome weight : flood	-0.45	32	0.65603

The 2023 data considered from the Mesocosm experiment.

Table 3 Emergence rates for large and small rhizomes

Rhizome size class	**Number emerged**	**% emerged**	**p (Chi2)**	**Mean Tiller No**	**P (t test)**	**Mean Height (cm)**	**P (t test)**
Large	42	43.7		3.6		70.3	
Small	18	18.7	NA	2.8	NA	46.5	NA
Large	72	73		6.22		67.23	
Small	64	65	0.22	4.8	0.002	66.04	0.11

Mean values calculated including 0 values for non-emerged plants, with Chi-squared values, mean tiller and height for large and small rhizomes and with significance for t tests.

Table 4 Mean SWV percentage

Treatment	**Mean SWV %**	**% emerged**	**p (Chi^2)**	**Mean Tiller No**	**p (t test)**	**Mean Height (cm)**	**p (t test)**
Covered	0.066	79	0.041	2.79	0.09	59.62	0.038
Open	0.163	96		3.79		80.54	

Obtained from TOMST loggers, emergence rates, mean tiller number and mean height for covered and open treatments

Table 5 Miscanthus *rhizome size differences on emergence*

Response	**Variable(s)**	**Effect (F/t)**	**(df)**	**P**
Cover (%)	GDD_{-6}	-0.212	2.183e+01	0.834
	SWV_A	2.457	3.860e+01	*** 0.0186**
	GDD_{-6} *SWV_A SWV_A GDD_{-6} * SWV_A GDD_{-6} SWV_A GDD_{-6} * SWV_A	2.574	4.387e+01	*** 0.0135**
Height (cm)	GDD_{-6} SWV_A GDD_{-6} * SWV_A GDD_{-6} SWV_A GDD_{-6} * SWV_A	-0.368	17.866	0.717
	SWV_A	-1.925	32.576	0.063
	GDD_{-6} *SWV_A	1.980	37.981	0.055

Cover (%)	Magnesium	-2.152	3.190e+02	* **0.032**
	Phosphorus	1.147	3.217e+02	0.252
	Potassium	-0.049	3.236e+02	0.961
	pH	-0.624	3.245e+02	0.533
	Magnesium * Phosphorus	-0.129	3.197e+02	0.897
	Magnesium * Potassium	1.148	3.202e+02	0.251
	Magnesium * pH	1.958	3.193e+02	0.051
	Phosphorus *Potassium	-0.464	3.181e+02	0.642
	Phosphorus *pH	-0.985	3.213e+02	0.325
	Potassium * pH	-0.345	3.217e+02	0.730
Height (cm)	Magnesium	-1.345	3.176e+02	0.179
	Phosphorus	2.446	3.199e+02	* **0.015**
	Potassium	-1.030	3.220e+02	0.304
	pH	-0.287	3.232e+02	0.774
	Magnesium * Phosphorus	-2.064	3.181e+02	* **0.040**
	Magnesium * Potassium	2.531	3.186e+02	* **0.012**
	Magnesium * pH	1.347	3.178e+02	0.179
	Phosphorus *Potassium	-1.117	3.168e+02	0.265
	Phosphorus *pH	-1.590	3.196e+02	0.113
	Potassium * pH	0.421	3.200e+02	0.674
Cover (%)	Bulk density	0.631	332/2	0.793
	Shear strength (MPa)	0.849	1/0.999	0.526
Height (cm)	Bulk density	0.654	332/2	0.782
Cover (%)	Texture: SALO	3.390	3	* **7.824e-04**
	Texture: CLLO	9.457	3	* **5.967e-19**
	Texture: SASILO SWV_A GDD-$_6$ * SWV_A GDD-$_6$ SWV_A GDD-$_6$ * SWV_A	18.577	3	* **2.545e-53**
	Texture: SICLLO	11.647	3	* **1.609e-26**
Height (cm)	Texture: SALO	15.708	3	* **5.766e-42**
	Texture: CLLO	27.522	3	* **1.123e-87**
	Texture: SASILO	39.131	3	* **2.1259e-126**
	Texture: SICLLO	22.007	3	* **7.82-e67**

Analyses made to consider if significant effect ($P<0.05$) is attributed to the considered variable(s) and their potential interaction(s).

Figure 6 Baselier strip tiller

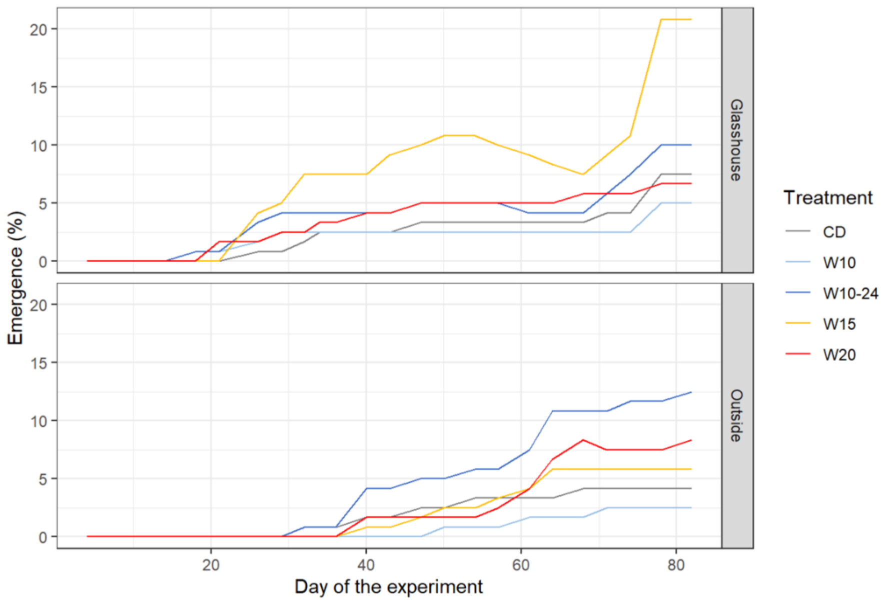
Table 6 Planting material pre-treatment tests with various treatments & strengths

Treatment	Strength	Application	Pot scale	Field scale
Control		Dry	A	A & 9
Control		Soak	A	A
Control		Paste	A	A & 9
Temperature	5°C	Dry	A	
Temperature	5°C	Soak	A & 10	
Temperature	10°C	Soak	9	
Temperature	10°C	Soak	A & 9	
Temperature	10°C	Soak	A & 9 & 10	
Temperature	10°C	Dry	A	A & 9
Temperature	10°C	Soak	A & 9	
Temperature	15°C	Soak	A	
Temperature	15°C	Soak		A
Temperature	20°C	Soak	9	A & 9
Temperature	20°C	Soak	9	
Temperature	20°C	Dry	A	
Temperature	20°C	Soak	A & 9 & 10	
Temperature	20°C	Soak	A & 9	
Temperature	25°C	Soak	10	
Temperature	30°C	Soak	10	
Elixir	x1	Paste	A	
Elixir	x2	Paste	A	
Elixir	x4	Paste	A	
Liquid ice	x1	Paste	A	A
Liquid ice	x1	Soak		A
Liquid ice	x2	Paste	A	
Liquid ice	x4	Paste	A	
Mammoth P	x1	Paste	A	
Mammoth P	x2	Paste	A	
Mammoth P	x4	Paste	A	
Micropull	x1	Paste	A	
Micropull	x2	Paste	A	A
Micropull	x2	Soak		A
Micropull	x4	Paste	A	
NPK	x1	Paste	A	
NPK	x2	Paste	A	

NPK	x4	Paste	A	
Rhizotonik	x1	Paste	A	
Rhizotonik	x2	Paste	A	
Rhizotonik	x4	Paste	A	
Seasum Max	x1	Paste	A	
Seasum Max	x2	Paste	A	
Seasum Max	x4	Paste	A	A & 9
Seasum Max	x4	Soak		A
Super rootz	x1	Paste	A	
Super rootz	x2	Paste	A	A
Super rootz	x2	Soak		A
Super rootz	x4	Paste	A	
Auxin	x1	Paste	A	
Auxin	x2	Paste	A	
Auxin	x4	Paste	A	
Ethephon	x1	Paste	A	A & 9
Ethephon	x2	Paste	A	
Ethephon	x4	Paste	A	
GA	x1	Paste	A	
GA	x2	Paste	A	
GA	x4	Paste	A	
IAA	x1	Paste	A	A
IAA	x2	Paste	A	
IAA	x4	Paste	A	
IBA	x1	Paste	A	
IBA	x2	Paste	A	
IBA	x4	Paste	A	
NAA	x1	Paste	A	
NAA	x2	Paste	A	
NAA	x4	Paste	A	
Thiourea	x1	Paste	A	A
Thiourea	x2	Paste	A	
Thiourea	x4	Paste	A	

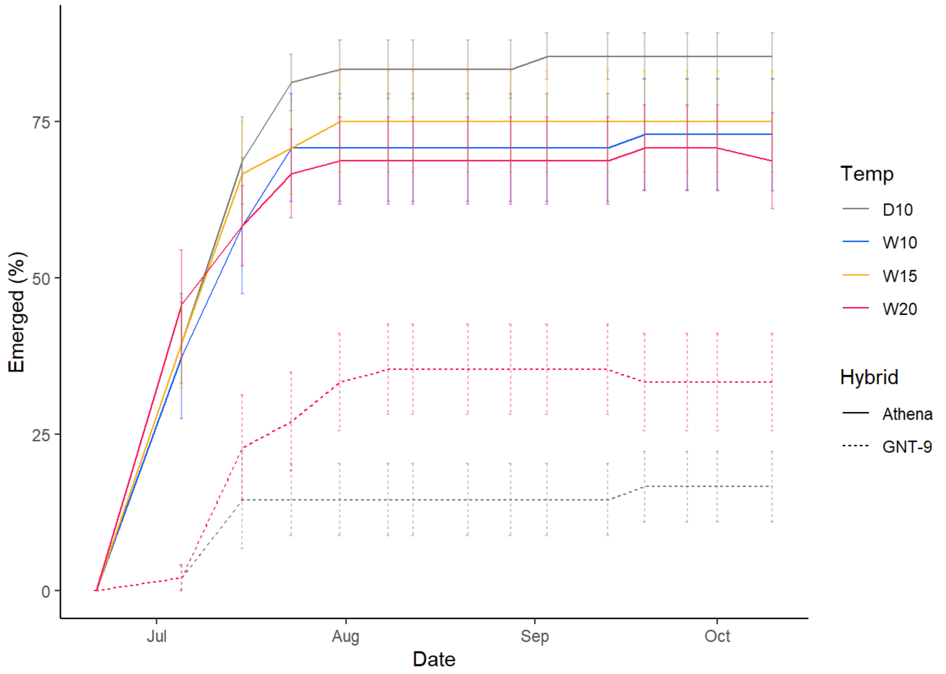
Every rhizome treatment tested at pot and field scale with A as Athena and 9 & 10 representing GNT-9 and GNT-10. Strength shows both a comparison to the recommended construction and the application time if applicable.

Figure 7 Trial of optimal rhizome temperature treatments



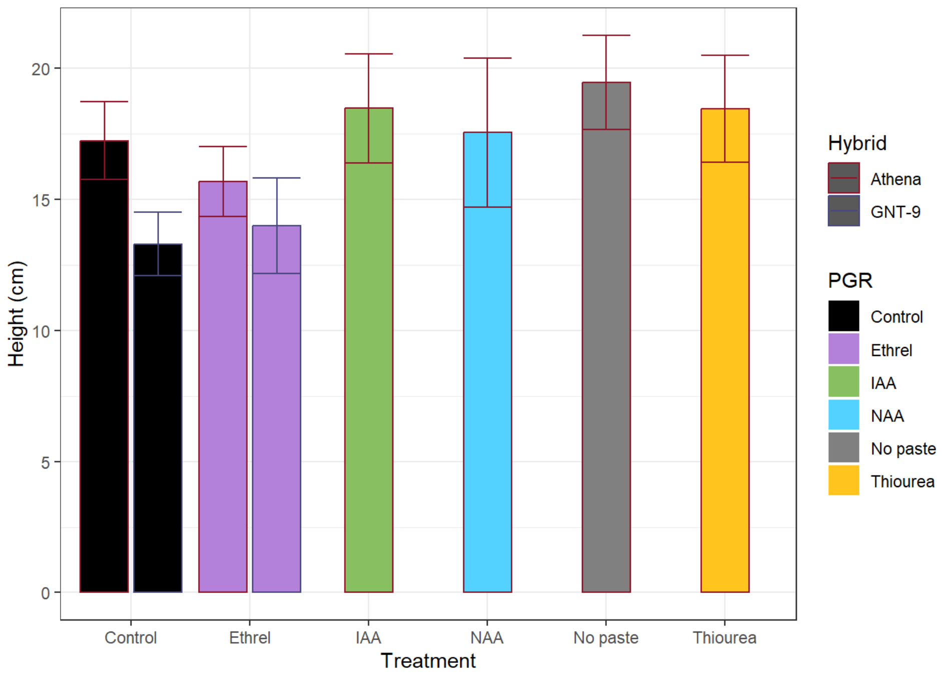
Testing in/out of glasshouse, 3 temperature treatments with an extended 10°C treatment and a control.

Figure 8 Trial 24-hour temperature soaking before planting



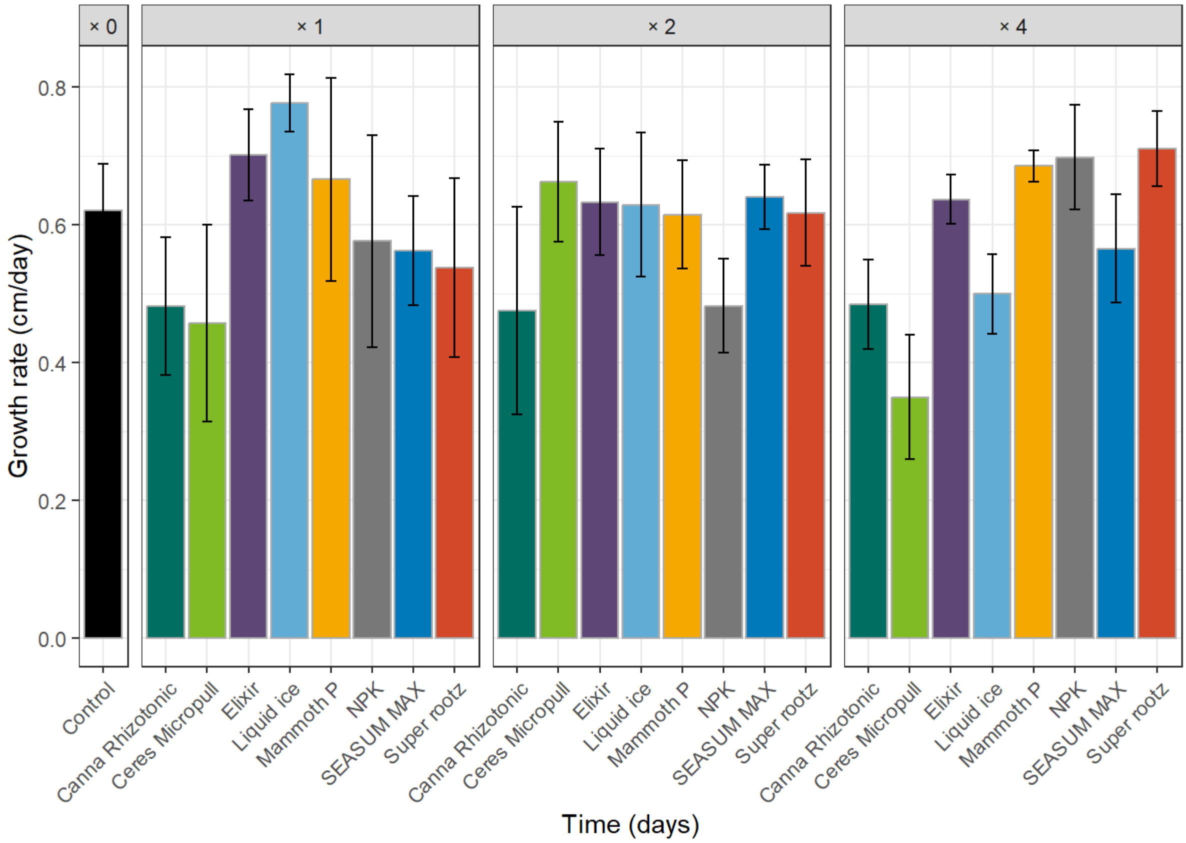
Field emergence in 2024 for rhizomes treated with 24-hour temperature soaking before planting. n = 12

Figure 9 The maximum plant height in the PGR field trial (2023).



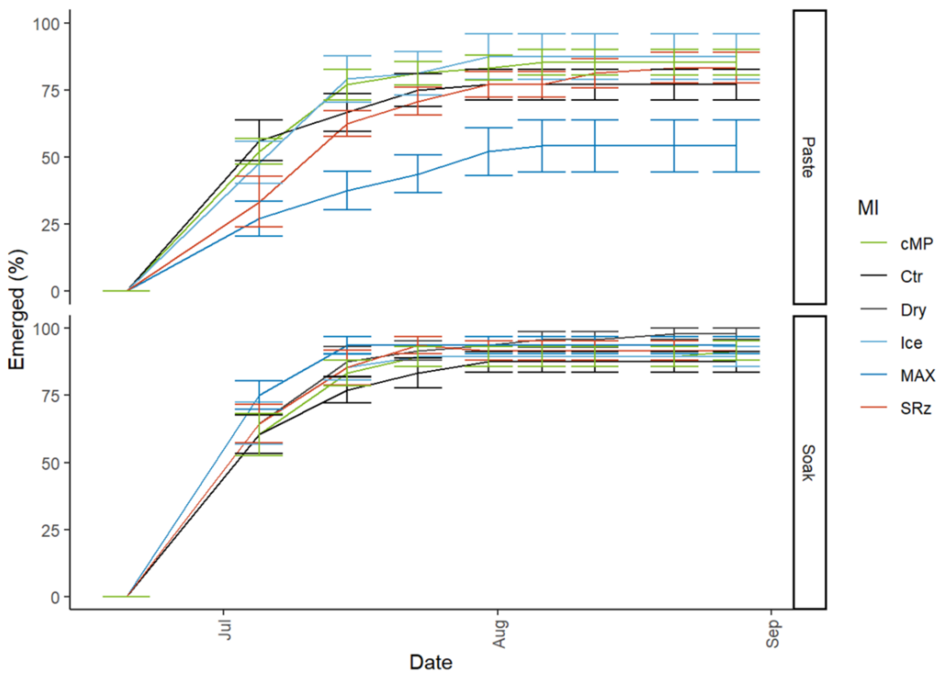
There is an extra column highlighted in grey for GNT-9.

Figure 10 The ligule growth rate in the microbial inoculants pot trial.



Grouped into concentrations with ×4 being four times the strength commonly used in the literature

Figure 11 Microbial inoculants treated Athena rhizomes in the field (2024)



Split into starch paste and 24h soaking.

Table 7 Germination rates for Miscanthus *seeds at day 5 (D5)*

Ethephon application rate	**Mean germination rate (%)**	
	Good seeds D5	**Bad seeds D5**
High	94.3[a]	39.3[b]
Low	100[a]	55.7[c]
Control	97[a]	66[d]

Miscanthus cv. GNT-43 ‘good’ seeds and GNT -14 ‘bad’ seeds were treated with high (1000 µL L-) and low (100 µL L-) rates of ethephon and their germination rate (%) at day 5, compared to the respective controls. Different superscript letters denote significant differences between seed batches (seed quality x treatment)

Table 8 Root length for Miscanthus *seeds at day 5*

Ethephon application rate	**Mean root length (mm)**	
	Good seeds	**Bad seeds**
High	9.6[c]	4.9[d]
Low	19.6[a]	12.5[b]
Control	21.5[a]	12.3[b]

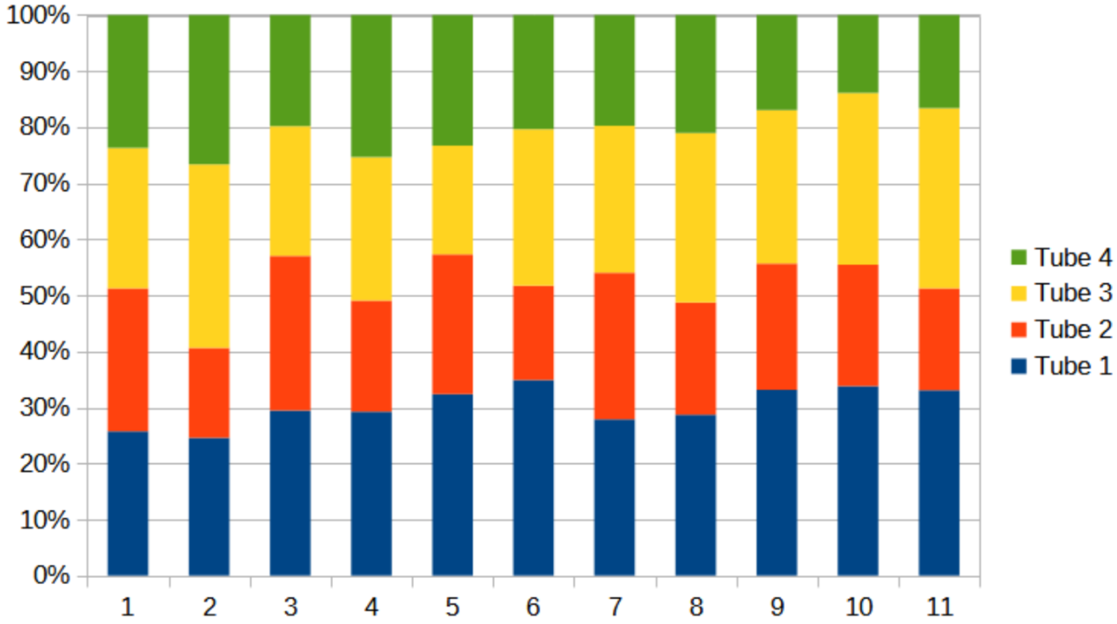
Miscanthus cv. GNT-43 ‘good’ seeds and GNT -14 ‘bad’ seeds were treated with high (1000 µL L-) and low (100 µL L-) rates of ethephon and their germination rate (%) at day 5, compared to the respective controls. Different superscript letters denote significant differences between seed batches (seed quality x treatment)

Table 9 Mean stem length for Miscanthus *seeds.*

Ethephon application rate	**Mean stem length (mm)**	
	Good seeds	**Bad seeds**
High	1.2[c]	0.7[c]
Low	2.3[b]	1.0[c]
Control	7.0[a]	2.1[b]

Miscanthus cv. GNT-43 ‘good’ seeds and GNT -14 ‘bad’ seeds were treated with high (1000 µL L-) and low (100 µL L-) rates of ethephon and their germination rate (%) at day 5, compared to the respective controls. Different superscript letters denote significant differences between seed batches (seed quality x treatment)

Figure 12 12 Bar chart showing the percentage of rhizomes detected in each tube.

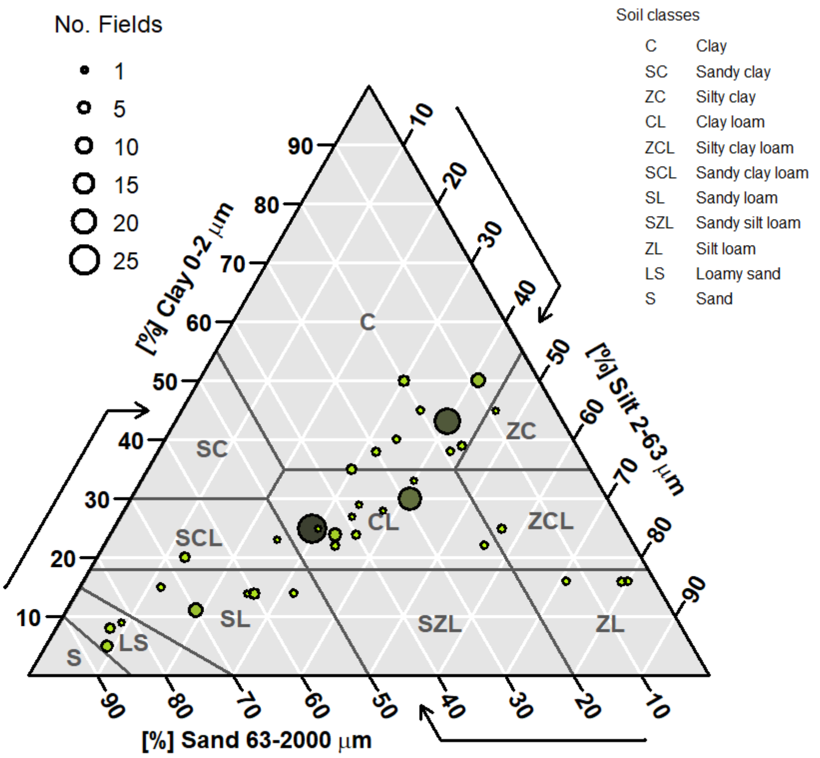


Proportions should be close to equal under normal circumstances. Moving from left to right is the order of data files assessed. Note that the first datafile, corresponding to the first deployment, has very well-matched proportions for the 4 tubes and that variations increase over time, particularly in tubes 2 and 4

Figure 13 Dataset with small but significant position offset from GPS data

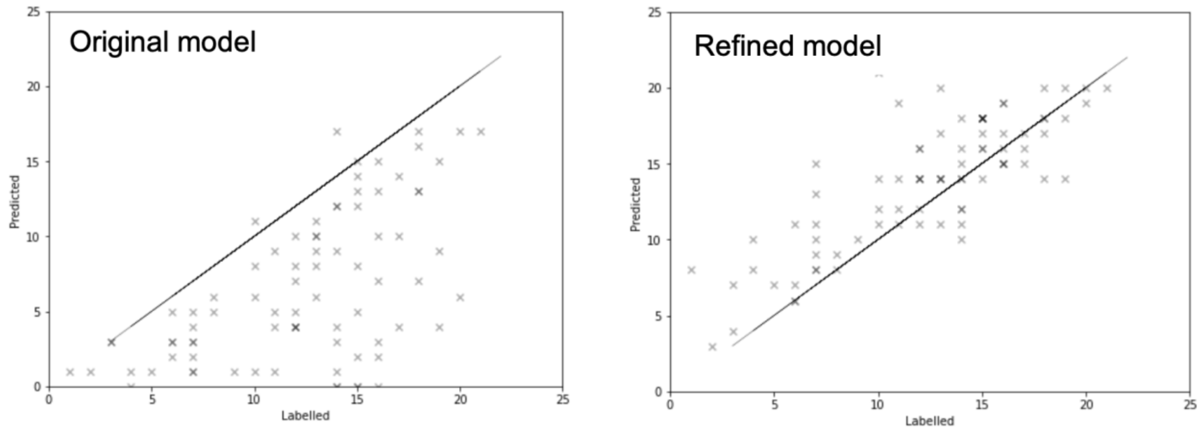
The data appears to be shifted approximately 7 metres to the South East from where would be expected due to the locations of the trees and hedges.

Figure 14 Soil analysis of the Miscanthus plantations



Most are in Clay, Clay Loam and Sandy clay loam/Sandy loam (sandy) soil.

Figure 15 Validation cross plots of plant counts manual labelling vs AI prediction



These are between the *Original* model (Phase 1) and the *Refined* model (Phase 2).

Figure 16 Crop development stages for planned image collection dates

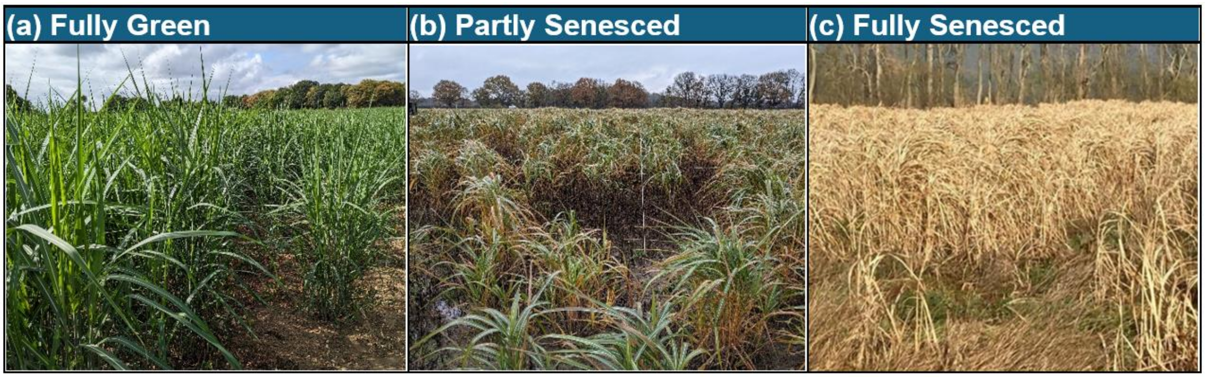


Table 10 The 4 bands of wavelength investigated

Waveband	Centre Wavelength	Bandwidth
Green (G)	560 nm	± 16 nm
Red (R)	650 nm	± 16 nm
Red Edge (RE)	730 nm	± 16 nm
Near infrared (NIR)	860 nm	± 26 nm

Figure 17 RGB validation for plant count over the 3 time periods

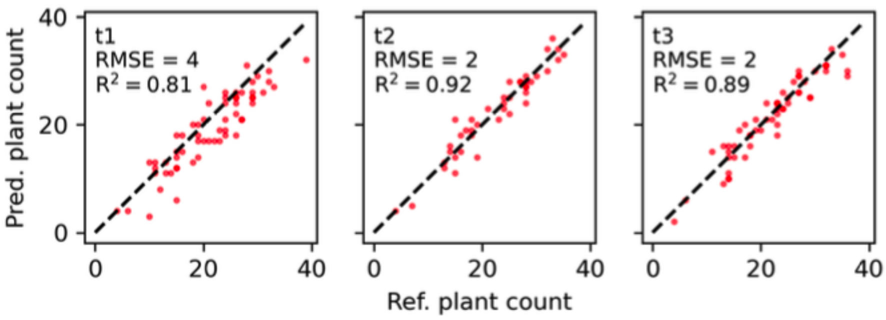


Figure 18 MSI validation for plant count over the 3 time periods

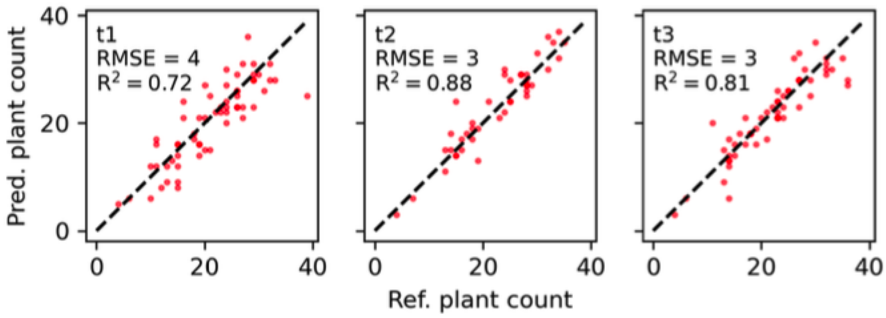


Figure 19 The selection matrix at the beginning of the project

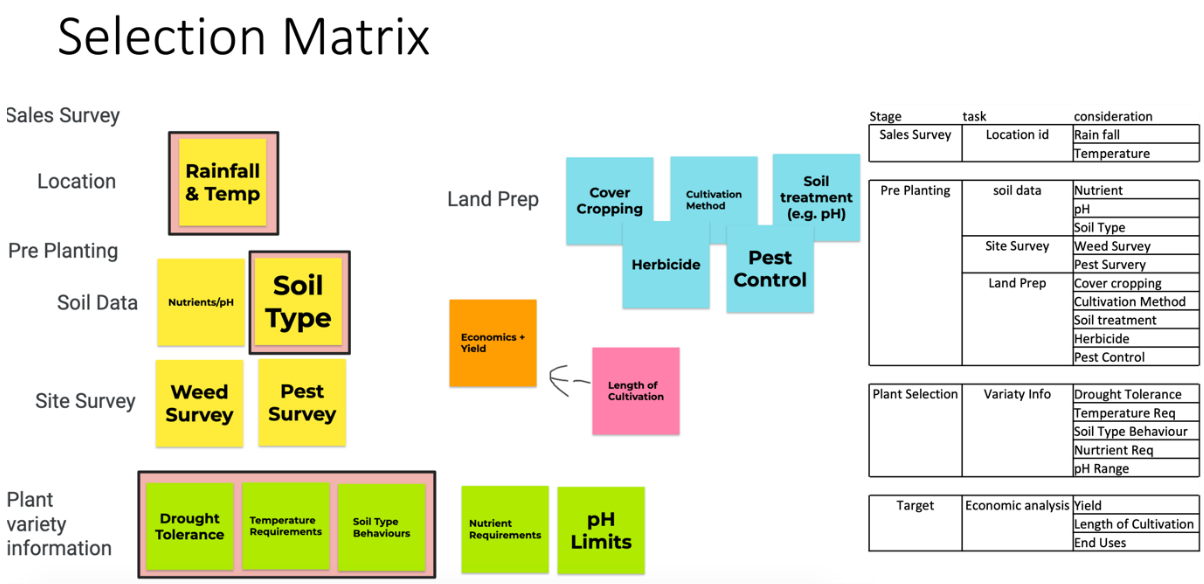
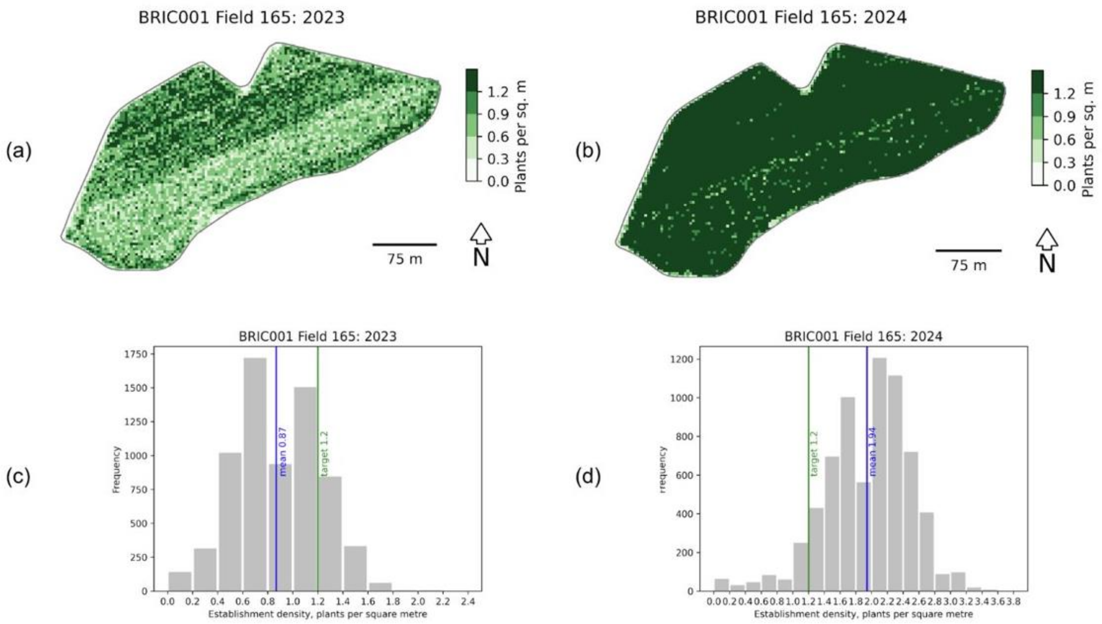


Figure 20 Comparison of AI-assisted plant count data over 2 seasons



The “frequency” value indicated on the y-axis is the frequency of 3*3m squares. The blue line indicates the mean value and the green line the target value of 1.2 plants per square meter.

Figure 21 Rain shelters

Table 11 The dissemination activities record -full

Title of Activity	Activity	Description	Stakeholders engaged	Date
UK government provides £3.3 million in funding to Miscanthus Upscaling project	Online Article	Link	*TV monthly newsletter*	08/08/22
Phase 2 of the OMENZ project, Optimising Miscanthus Establishment through improved mechanisation and data capture to meet Net Zero targets, has been awarded £3.3 million worth of funding	Tweet	Link	*CHAP Tweet*	11/08/22
Using Technology to optimise Miscanthus establishment	Online Article	Link	*CHAP online Blog*	8/22/22
Can grass solve the clean energy crisis?	Online Article	Link	*LJMU*	08/08/22
Our government-funded OMENZ project ramps up with first meeting	Online Article	Link	*TV online article*	26/09/22
Miscanthus *myth busters - CHAP*	Online FAQ	*Online FAQ*	*CHAP audience*	*28/10/22*
CHAP Webinar – Agritech week 2022	Webinar	*Online webinar*	*CHAP audience*	*10/11/22*

NIAB Agritech week	Seminar	*In person*	*NIAB audience*	*11/11/22*
Royal Welsh Winter fare 2022	Fare	Presentation	*Royal Welsh attendance*	28/11/22
Low carbon agricultural show	AgroExpo	*Public engagement*	*Energy provider, growers, DESNZ, academics*	*7-8/2/23*
Future Build Show	BuildExpo	*Public engagement*	*Academics, students, material engineers, architects*	*6-8/3/23*
Biomass Feedstocks Innovation Programme Phase 2	Event	*presentation*	*UK policy*	*15/06/23*
Norfolk Farm Walk	Grower engagement	*Farm walk*	*growers and publics*	*07/09/23*
Yorkshire Farm Walk	Grower engagement	*Farm walk*	*growers and publics*	*21/09/23*
Wood Heat Conference	Conference	*Oral Presentation*	*Public/interest groups/commercial*	*24-25/10/23*
Biomass Connect Farm Walk	Farm Walk	*Presentation of* Miscanthus *and OMENZ Innovation*	*Prospective growers/interest groups/public*	*26/10/23*
Farm Innovation Show NEC	Exhibition	Attendee	*Farming communities*	16/11/23
LCA workshop	Workshop	*Organised by DESNZ and Supergen*	*DESNZ project participants*	*20/02/24*
CHCx3 Biomass Crops Webinar	Seminar	*NiAB*	*Anyone interested*	*02/02/24*
Energy from plants – how hybrids can boost biomass production	Online article	*Published by LJMU*	*Open world*	*01/08/24*
UK researchers boost commercial production of Miscanthus *grass for biomass*	Online article	*Bioenergy Insight*	*Viewer for online journal Bioenergy Insight*	*02/08/24*
Research to boost commercial production of Miscanthus grass for biomass	Online article	*BioEnergy Times*	*Viewer for online journal BioEnergy Times*	02/08/24
Research from LJMU School of Biological and Environmental Sciences is boosting commercial production of Miscanthus grass, a key material for the burgeoning biomass energy sector	Online article	SeedQuest	*Viewer for online journal SeedQuest*	01/08/24
Energy From Plants – How Hybrids Can Boost Biomass Production	Online article	Seed Today	*Viewer for online journal Seed Today*	05/08/24
Energy From Plants – How Hybrids Can Boost Biomass Production	Online article	Renewable Energy Magazine	*Viewer for online journal Renewable Energy Magazine*	05/08/24
UK Researchers Boost Commercial production of Miscanthus Grass for Biomass	Online article	International centre for Sustainable Carbon	*Viewer for International centre for Sustainable Carbon*	16/08/24

Farming Programme 22nd September 2024 (7 am)	Podcast	Online podcast by The Farming Programme	*Local growers and interest group*	22/09/24
Farm walk and Brigg power station tour	Farm walk	Invitation for all interested party to see how Miscanthus is grown and its use for power generation	*Public*	24/09/24
Power station tour, an opportunity to discuss sustainable income stream	Online article	Agronomist & Arable Farmers	*Viewer for Agronomist & arable Farmer*	03/09/24
Farm walk and power station tour looks at long-term benefits of farming Miscanthus	Online article	Farming Online	*Viewers for Farming Online*	03/09/24
Miscanthus farm walk invite	Online article	Crop Production Magazine	*Viewer for Crop Production Magazine*	03/09/24
Farmers invited to Miscanthus farm walk and power plant talk	Online article	Farm Contractor	*Viewer for Farm contractor*	05/09/24
Biomass Connect showcase event	Expo Workshops	Organised by Biomass Connect	*BFIP project participants*	07/10/24 -08/10/24
Cotswold Farm Walk	Expo	Show casing Miscanthus to potential growers	*Potential growers/public interest*	10/10/24
Biomass Connect Bishop Burton	Expo	Explaining commercial Miscanthus in biomass connect	*All interested parties*	9/10/24
British Ecological Society Annual meeting	Conference presentation	Presenting part of the project OMENZ to the conference	*Participants*	10-13/12/24
Biomass and Energy Crops VI	Conference presentation	Oral presentation	*Participants*	1-3/10/24
Miscanthus: Biodiversity benefits beyond energy use | UK ATC	Online article	Online article	*Interested parties, subscribers to UK-ATC*	12/11/24
Miscanthus supply chain & harvest open day	Open Day	Co-hosted by Terravesta & the Centre for High Carbon Capture Cropping	*Participants*	26/02/25

Table 12 The dissemination activities record undertaken - media coverage

Title	Medium	Publisher	Audience	Link	Date
Government grants £3.3m in funding to Miscanthus upscaling project	Newsletter	Agronomist & Arable Farmer	393	Link	10/8/22
Government grants £3.3m in funding to Miscanthus upscaling project	Online Article	Agronomist & Arable Farmer	590	Link	8/8/22
UK government provides £3.3 million in funding to Miscanthus upscaling project	Online Article	Bioenergy Insight	1,480	Link	9/8/22
Government to provide £3.3 million to upscale Miscanthus planting	Online Article	FarmContractor	66	Link	10/8/22

UK government puts £3.3 million into mechanising Miscanthus production	Online Article	The Scottish Farmer	642	Link	10/8/22
Grants awarded to increase biomass crop efficiency	Online Article	Farmers Weekly	3,630	Link	9/8/22
Government provides £3.3m funding to upscale perennial energy crop	Online Article	Farming UK	611	Link	9/8/22
UK Government Provides £3.3 Million in Funding to Miscanthus Upscaling Project	Online Article	Renewable Energy Magazine	456	Link	8/8/22
£3.3m of funding awarded for planting Miscanthus	Online Forum	The Farming Forum	2,440	Link	8/8/22
£3.3m of funding awarded for planting Miscanthus	Online Article	Agriland	1,480	Link	8/8/22
UK govt provides £3.3 million in funding to Miscanthus upscaling project	Online Article	Farming Online	116	Link	8/8/22
UK government provides £3.3M funding for Miscanthus upscaling project	Online Article	The Farming Forum	2440	Link	8/8/22
UK government provides £3.3M funding for Miscanthus upscaling project	Online Article	Crop Production Magazine	555	Link	8/8/22
OMENZ – Optimising Miscanthus Establishment through improved mechanisation and data capture to meet Net Zero targets	Website	CU	Global	Link	17/4/23
October Miscanthus establishment and cultivation event packs a punch	Printed Article	The Farmer Focus	UK	N/A	16/10/23
October Miscanthus establishment and cultivation event packs a punch	Printed Article	The Farmer Focus	UK	N/A	23/10/23
October Miscanthus establishment and cultivation event packs a punch	Printed Article	The Farmers Mart	UK	N/A	1/11/23
Multiple reasons to consider Miscanthus this spring	Printed Article	Agronomist and Arable Farmers	UK	N/A	1/12/23
Kevin Lindegaard, Director of Crops for Energy	Online Article	Energy Now	World	Link	29/11/23
Summer internship at LJMU: Fighting climate change one Miscanthus experiment at a time	Online Article	LJMU	World	Link	1/12/23
Miscanthus farm walk to explore resilient cropping in wet climates	Online Article	Energy Now	World	Link	11/4/24
Event to explore resilient cropping in wet climate	Online Forum	The Farming Forum	World	Link	11/4/24
Event to explore resilient cropping in wet climate	Online Article	Crop Production Magazine	World	Link	11/4/24
Exploring resilient cropping in wet climates: Miscanthus farm walk delves into strategies	Online webpage	Biomass Connect	World	Link	15/5/24
Farm walk explores benefits of Miscanthus	Printed Article	Anglia Farmer	UK	N/A	1/5/24
Farm walk explores benefits of Miscanthus	Printed Article	Midland Farmer	UK	N/A	1/5/24
Energy from plants – how hybrids can boost biomass production	Online article	Published by LJMU	World	Link	1/8/24
UK researchers boost commercial production of Miscanthus grass for biomass	Online article	Bioenergy Insight	World	Link	2/8/24

Research to boost commercial production of Miscanthus grass for biomass	Online article	BioEnergy Times	World	Link	2/8/24
Energy From Plants – How Hybrids Can Boost Biomass Production	Online article	Seed Today	World	Link	5/8/24
Energy From Plants – How Hybrids Can Boost Biomass Production	Online article	Renewable Energy Magazine	World	Link	5/8/24
UK Researchers Boost Commercial production of Miscanthus Grass for Biomass	Online article	International centre for Sustainable Carbon	World	Link	16/8/24
Farming Programme 22nd September 2024 (7 am)	*Podcast*	The Farming Programme	Local growers	Link	22/9/24
Farm walk and Brigg power station tour	Farm walk	Invitation for all interested party to see how Miscanthus is grown and its use for power generation	UK	Link	24/9/24
Power station tour an opportunity to discuss sustainable income stream	*Online article*	Agronomist & Arable Farmers	World	Link	3/9/24
Farm walk and power station tour looks at long-term benefits of farming Miscanthus	*Online article*	Farming Online	World	Link	3/9/24
Miscanthus farm walk invite	*Online article*	Crop Production Magazine	World	Link	3/9/24
Farmers invited to Miscanthus farm walk and power plant talk	*Online article*	Farm Contractor	World	Link	5/9/24
Miscanthus: Biodiversity benefits beyond energy use	*Online article*	UK ATC	NA	Link	12/11/24
New study shows Miscanthus' greater potential for productivity, economic returns	*Online article*	Biomass Magazine	World	Link	30/12/24
Miscanthus recognised as a profitable, long-term resilient option for farmers in study	*Online article*	Farming Online	World	Link	13/2/25

Table 13 Scientific evidence by grouped by environmental benefits

Effects category	**Reference**
Prevent soil erosion nutrient leaching	Thomas, M A, Ahiablame, L M, Engel, B A, & Chaubey, I (2014). 'Modelling Water Quality Impacts of Growing Corn, Switchgrass, and Miscanthus on Marginal Soils'. Journal of Water Resource and Protection, Volume 06, Issue 14, Pages 1352–1368 https://doi.org/10.4236/jwarp.2014.614125
Consistent yield under flood condition	Kam, J, Traynor, D, Clifton-Brown, J C, Purdy, S J, & McCalmont, J P (2020). 'Miscanthus as energy crop and means of mitigating flood'. Advances in Science, Technology and Innovation, Pages 461–462 https://doi.org/10.1007/978-3-030-13068-8_115
Phytoremediation	Barbosa, B., Boléo, S., Sidella, S. *et al.* Phytoremediation of Heavy Metal-Contaminated Soils Using the Perennial Energy Crops Miscanthus spp. and *Arundo donax* L. *Bioenergy. Res.* **8,** 1500–1511 (2015). https://doi.org/10.1007/s12155-015-9688-9
	Fagnano M, Visconti D, Fiorentino N. Agronomic Approaches for Characterization, Remediation, and Monitoring of Contaminated Sites. *Agronomy*. 2020; 10(9):1335. https://doi.org/10.3390/agronomy10091335

Nutrient recycling	Littlejohn, C. P., Hofmann, R. W., & Wratten, S. D. (2019). 'Delivery of multiple ecosystem services in pasture by shelter created from the hybrid sterile bioenergy grass Miscanthus x giganteus.' Scientific Reports, Volume 9, Issue 1. https://doi.org/10.1038/s41598-019-40696-2
	Lask, J, Magenau, E, Ferrarini, A, Kiesel, A, Wagner, M, & Lewandowski, I (2020). 'Perennial rhizomatous grasses: Can they really increase species richness and abundance in arable land? - A meta-analysis.' GCB Bioenergy, Volume 12, Issue 11, Pages 968–978 https://doi.org/10.1111/gcbb.12750
Pasture shelter	Littlejohn, C. P., Hofmann, R. W., & Wratten, S. D. (2019). 'Delivery of multiple ecosystem services in pasture by shelter created from the hybrid sterile bioenergy grass Miscanthus x giganteus.' Scientific Reports, Volume 9, Issue 1. https://doi.org/10.1038/s41598-019-40696-2
Biodiversity on arable land	Lask, J, Magenau, E, Ferrarini, A, Kiesel, A, Wagner, M, & Lewandowski, I (2020). 'Perennial rhizomatous grasses: Can they really increase species richness and abundance in arable land? A meta-analysis.' GCB Bioenergy, Volume 12, Issue 11, Pages 968–978 https://doi.org/10.1111/gcbb.12750
	Squance M. (2021) The Biodiversity of Miscanthus Crop. Terravesta Internal Report
Soil Health	Kam J. (2021) The Benefits of using Miscanthus for Soil Health. Terravesta Internal Report.
GHG reduction	TV Carbon report (https://www.terravesta.com/Miscanthus-carbon/)
	McCalmont JP, Hastings A, McNamara NP, Richter GM, Robson P, Donnison IS, Clifton-Brown J (2017). Environmental costs and benefits of growing Miscanthus for bioenergy in the UK. Global Change Biology Bioenergy. Volume 9, Issue 3, Pages 489-507. https://doi.org/10.1111/gcbb.12294.

Table 14 Updated Matrix requirement in table form

Stage	Task	Evaluation	Input	Output
Sales Survey	Location id	Rainfall	Met Data from last 5 years from the closest station	Monthly Average over 5 years (mm)
		Temperature	Met Data from last 5 years from the closest station	Monthly average over 5 years (degree C)
Pre-planting	Soil data	Nutrient	Soil samples	N, P, K, Mg (mg/kg)
		pH	Soil samples	pH
		Soil Type	Soil samples	Sand/Silk/Clay %
	Site Survey	Weed Survey	Field observation, interview with grower for known weed	species/types
		Pest Survey	Field observation, interview with grower for known pests,	species/types
		Cropping History	Previously grown crop	Prediction of soil condition
	Land Prep	Cover cropping	Location id + Soil Data + Site Survey	Suitability/need of cover crop, species choice
		Cultivation Method	Location id + Soil Data + Site Survey	power harrow, strip till with light/heavy land
		Soil treatment	Location id + Soil Data + Site Survey	Lime and additive (fertiliser)
		Herbicide	Weed Survey	Herbicide type, application
		Pest Control	Pest Survey	Treatment recommendation (chemical/soil adjustment)

Plant Selection	Variety Info	Drought Tolerance	Lit review; Info from breeder(s); Experiment in Phase 2	survival baseline, yield effect
		Temperature Requirement	Lit review; Info from breeder(s); Experiment in Phase 2	Range, yield effect
		Soil Type Behaviour	Lit review; Info from breeder(s); Experiment in Phase 2	Best combination
		Nutrient Requirement	Lit review; Info from breeder(s); Experiment in Phase 2	Range, yield effect
		pH Range	Lit review; Info from breeder(s); Experiment in Phase 2	Range, yield effect
		Planting Density	Model of soil type vs Cultivar; rhizome cost; Future experiments	recommended planting density and GNTs ranking
Target	Econ. analysis	Establishment	Establishment count from Cranfield's developed Miscanthus establishment counter (selectively drone photo second year establishment from poor first year establishment instead of blanket first year photo)	Predicted yield or time-gap for full yield
		Yield	Past and current trial with above info; predictive model and neighbour yield	Predicted yield and economic calculation (potential yield estimation via analyses from drone photo)
		Length of Cultivation	Economic assessment on historic and current sales + yield data	Baseline and incremental economic value simulation result
		End Uses	Collect requirement of end use	Suggest end use based on requirement

Table 15 TV genotypes, availability, TRL and main characteristics

Name	Propagation	Specialty	Availability	TRL
Athena 1	Rhizomes	Northern climates, vigorous, earlier harvest	Available	
Artemis 3		Drought resistant, very big	2029	4
Astraea 9	Rhizomes	Early senescence, many stems	2026	5
Bia 10	Rhizomes	Very drought resistant, woody, covers gaps	2026	5
Brontes 14		High sugar content	2029	4
Boreas 5b		Suitable for anaerobic digestion and liquid fuel	2029	4
Aphrodite 43		Southern climates, vigorous, very tall	Available	8