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Changes in duration of rhizome cold storage and manipulation of the growing environment to promote field establishment of *Miscanthus giganteus*

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ABSTRACT

Miscanthus biomass yield can be limited by poor rhizome establishment and this is linked to rhizome age and storage conditions prior to planting. To avoid poor establishment, best practice recommends field planting directly after rhizome division. Operations avoiding rhizome storage, and utilising favourable climatic conditions at planting, may be climatologically and logistically challenging when large areas are planted at high rhizome densities. Our aim is to evaluate storage regimes to maintain rhizome viability and maximise establishment when planted under optimal conditions. To achieve this we have compared differences in site pre-planting management (level of soil cultivation) strategies, along with post-planting treatments (irrigation and soil mulching with compost), against differences in storage regime (temperature) and duration. The results from a rhizome establishment bioassay showed viability at lifting in early March was high, while cold storage of rhizomes had no negative influence on viability and growth. There were no negative impacts of storage temperature on rhizome mineral or carbohydrate concentrations. Increases in air temperature enhanced rhizome and culm final biomass and rate of establishment. Application of irrigation, or compost mulch, to field rhizome plantings improved establishment increasing soil moisture levels in early May through August. In conclusion, cold storage of rhizomes is achievable and effective in maintaining rhizome viability and can be used to extend the planting time. Soil moisture and application of supplementary irrigation was important during establishment. Also important was the avoidance of weed competition. Achieving the most appropriate conditions for optimal establishment will be critical in regions where spring/summer rainfall is restrictive.

1. Introduction

Miscanthus is a perennial, rhizomatous, C_4 grass of subtropical East Asian origin, the stems of which can be harvested annually. It can attain high yields (10–49 t ha^{-1} $year^{-1}$) and high rates of net photosynthesis even under cooler European conditions [1–6] see data within [7]. This level of cold tolerance operates *via* the activity of pyruvate P_i dikinase (PPDK), a known C_4 photosynthesis limiting enzyme [8]. The energy ratio of *Miscanthus* (1:32) is greater than that of any other agricultural crop, including short rotation willow [9]. *Miscanthus* has a high calorific value ∼20 MJ kg^{-1} dwt [10] with the energy value of 20 t dwt equivalent to 12 t of coal [11]. Combined with a low energy production input requirement

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(~0.2 MJ MJ^{-1}) and a high fuel energy production per unit land area (~203 GJ ha^{-1}) for biological fuels [12].

Once established *Miscanthus* takes 3–5 years (site dependent) to attain optimal leaf area index (LAI) and maximisation of shoot biomass [4,13]. Planting density experiments indicate that at 4 plants m^{-2}, around 35 shoots can be produced with a height of ~1.8 m with a maximum LAI of 5.5, intercepting 94% of the incident radiation [15]. These production levels can be maintained at commercially acceptable yields for at least 10–15 years [14, 16]. As a perennial *Miscanthus* recycles rhizome stored minerals and carbohydrates during spring growth [17] it has a low nutrient requirement [14,15] to achieve high yields [18,19]. Water availability also influences productivity and yield variation [10,20] and without it nitrogen application benefits are not realised [3]. Soil moisture is a key determinant in modelling *Miscanthus* productivity along with ET and soil type [7]. *Miscanthus* nutrient and water use efficiencies are known to be partially linked to root biomass and its depth within the soil [7,21,22].

A key component in the establishment of a renewable energy supply chain involving *Miscanthus* is ensuring vegetative crop establishment is as effective and as economical as conventional seed crop establishment [4,26]. This generally cannot be achieved, except with the less productive *Miscanthus sinensis* [23], because higher yielding cultivars are sterile hybrids. While rhizome production is slow and potentially costly, when attempting to maxmise early yields by planting rhizome at densities between 10 k to 40 k ha^{-1} [24]. To achieve best practice requires field planting directly after rhizome division, avoiding storage, and utilising favourable rhizome replanting climatic conditions.

The aims reported here are to determine how to optimise field *Miscanthus* rhizome establishment, given the need for rhizome storage to enable large areas to be established economically at high densities. To achieve this a glasshouse 'bioassay' is used to measure rhizome establishment (rooting and culm growth) under varied but controlled environment conditions. The bioassay measures rhizome establishment against the effectiveness of maintaining rhizome viability during cold storage [14] to extend the planting time [1,27]. We hypothesize that rhizome establishment is critically influenced by differences in air temperature and growing media moisture content. Both parameters are known to reduce *Miscanthus* rhizome establishment [25,26]. Our study, using the same material, also evaluates field establishment. Our aim here is to define the period over which rhizome cold storage has no negative influence on field establishment, in combination with different levels of soil cultivation and the addition of irrigation and compost mulch, to conserve soil moisture. Cultivation influences crop establishment, particularly with respect to competition from weeds [26], while supplementary irrigation can improve rhizome establishment, particularly under dry conditions [25,26]. We hypothesise that optimal storage will maintain rhizome viability and ensure effective establishment given optimal planting conditions. To test this we have compared differences in site pre-planting management (level of soil cultivation) strategies along with post-planting treatments (irrigation and soil mulching with compost) against differences in storage regime (temperature) and duration.

2. Materials and methods

2.1. *Plant material and rhizome selection*

Rhizomes of the sterile triploid interspecific hybrid *M. sinensis* '*Giganteus*' (*M. x giganteus*, Greef *et* Deu) were purchased from ADAS (Ely, Cambridgeshire, UK) and were field dug, collected and delivered to East Malling Research (EMR) on the day of field harvesting (23 March).The origins of this material derive from *Miscanthus* selections for high productivity [4]. A total of 25,000 rhizomes were transported from Ely, in pallet sacks (5000 each). The rhizomes were immediately placed into 2 °C cold store and covered with Hessian sacks to minimise further water loss. A lethal temperature for field *M. x giganteus* rhizomes is quoted as −3.4 °C [28]. All the experiments reported here used this single source of rhizomes which were selected visually according to their size and potential viability (visually assessed, having light coloured rhizomes and culm buds showing expansion of scales). Rhizome which appeared dead or had few viable nodal buds (<3), were discarded. Rhizomes were also sorted by size, only the medium size (double the diameter of a small finger) was selected for use in the bioassay, for the field planting medium to large rhizomes were selected, the rest were discarded.

2.2. *Glasshouse experiment - rhizome establishment bioassay*

The experiment was carried out in three temperature controlled glasshouse compartments, each at different, but constant day/night temperature. The set point temperatures were 12, 17, and 22 °C, with the measured average temperatures, over the growing period, being 17, 20 and 25 °C respectively. Each compartment was split longitudinally with one half receiving supplementary radiation, using 5 sodium lights (400 W SONTI), for 6 h day^{-1} (5:30–8:30 and 18:30–21:30).

2.2.1. *Experimental details*

The experiment started on 1 April, when rhizomes had been in storage for 8 days. Three comparable rhizomes were placed at a depth of 8–10 cm in compost (75% peat-based compost and 25% perlite) containing slow release fertilizer (Scotts Osmocote pro–NPK fertiliser 18+9+10 (+2) with magnesium and with trace elements, applied at a rate of 4.4 kg m^{-3} of potting compost), in 7.5 L pots. Half the pots were watered to achieve a moisture content between 0.4 and 0.45 m^3 m^{-3}, (using the organic substrate calibration as determined with SM200 probe, Delta-T Devices, Cambridge, UK). The 'wet treatment' and the other half were watered to achieve a lower moisture content to 0.3–0.35 m^3 m^{-3} the 'dry treatment'. These set points were based on UK best practice guidelines for *Miscanthus* establishment and were intended to achieve optimal and reduced rhizome establishment respectively [11]. Six pots of each moisture treatment were placed into each subcompartment of the glasshouse and randomised (see Experimental design below).

Pots were covered with plastic to restrict evaporation and retain compost moisture. After 1 week, as rhizome culms emerged, the plastic was removed and irrigation supplied to