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Present and future options for *Miscanthus* propagation and establishment

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ABSTRACT

Several species of the genus *Miscanthus* are characterized by high biomass yields and low input requirements, and there is increasing interest in their commercial use for bioenergy production. However, the lack of inexpensive and effective propagation and establishment techniques is currently limiting the potential of miscanthus as a commercial bioenergy crop. In this review, through an evaluation of previous studies, results of our own field trials, experiments and farmer surveys, we concluded that there are five main approaches that can be used for miscanthus establishment. First is direct rhizome planting which is relatively mature, easily realized and inexpensive (1904–3375.7 € ha^{-1}); therefore it is the method mostly preferred by farmers. However, in the long term, its low dividing efficiency (1:10) will cause a conflict between the demand for and supply of rhizomes for large-scale plantations. Compared to the direct rhizome planting, an increased multiplication ratio (1:30) has been realized using rhizome- or stem-derived plantlets. However, due to higher labour and energy inputs required for the pre-growing of plantlets, their establishment cost reduction potential is limited, with estimated costs of between 4240.8 € ha^{-1} and 4400.8 € ha^{-1}. The seed-setting rate of miscanthus (*Miscanthus sinensis*) is very low (0.0–28.7%) under the climatic conditions of south-west Germany, making commercial seed production difficult. The high multiplication ratio (1:960) and fast bulk-up production potential achieved by micropropagation provide an opportunity to reduce the costs of this currently most expensive establishment method (6320.8 € ha^{-1}). The cheapest method could be direct seed sowing (1508.5 € ha^{-1}) if it will become feasible in future. Additionally, the recently developed CEED technology may become a good alternative, if it is not too expensive. For all the propagation methods considered, new technologies and research efforts are required to reduce the material production costs and simultaneously increase the multiplication ratio.

Contents

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1. Introduction

The perennial rhizomatous grass miscanthus has been identified as a leading candidate energy crop for heat, electricity and transport fuel production under European conditions due to the combination of its high energy yields and low input (fertilizer, pesticides, energy) requirements [1,2]. As a crop with the C4 photosynthetic pathway, miscanthus exhibits a high rate of net photosynthesis and water-use efficiency even under the relatively cold conditions of temperate climates [3,4]. These result in high harvestable biomass yields generally varying from 15 to 20 oven-dry ton (odt) ha^{-1} in temperate regions and up to 44 odt ha^{-1} in southern Europe [5]. High contents of lignin (approx. 25%) and carbohydrates with high calorific value (approx. 38% of cellulose and 24% of hemicelluloses) further contribute to the energetic quality of miscanthus biomass [6]. A deep rooting system and an effective mechanism of nutrient (N, P and K) relocation from aboveground plant parts to belowground rhizomes lead to low nitrogen (N) input requirements [7,8]. *Miscanthus* has very few natural pests and diseases, and usually no pesticide application is necessary [9–11]. Heat and power production from miscanthus biomass exhibits a high energy output/input ratio ranging from 15:1 to 32:1 depending on the farming system [1,12,13]. This ratio is much higher than for the processing of traditional energy crops, such as ethanol production from wheat (9:1) and biodiesel from rapeseed (4:1) [1,14].

However, there are still very few large-scale plantations of miscanthus in the world and the estimated total area in Europe is only 38,300 ha [15]. By the end of 2011, 9,000 ha of miscanthus had been established in the UK and 3,000 ha in Germany for the co-firing of biomass with coal and thermal applications [16,17]. The area of cropland used to grow miscanthus is also increasing in other countries. In 2011, the Biomass Crop Assistance Program (BCAP) projects planted 6,600 ha of miscanthus in the United States [18]. The key bottleneck for large-scale production of miscanthus is the high biomass production costs due mainly to the lack of inexpensive and effective propagation and establishment systems [19-21]. Previous studies [19,22–31] have shown that various plant materials can be used for miscanthus propagation, in particular rhizomes, terminal and nodal buds, seeds, nodal stem cuttings and immature tissues, such as inflorescences and leaves (Fig. 1).

Presently, only one clone, *Miscanthus* × *giganteus* Greef et Deuter, is grown commercially. The main establishment technique for *M.* × *giganteus* is the harvest and direct planting of rhizomes into the field (referred to in the following sections as 'rhizome planting'). The growing of plants from rhizomes in the greenhouse and their subsequent transplanting into the field (referred to in the following sections as 'rhizome-derived plants') has recently been gaining favour in North America and is used by farmers to replace failed plants [32]. *M.* × *giganteus*, as a triploid infertile clone, cannot be directly established via seeds [33]. The results of trials with the fertile species *Miscanthus sinensis* Andersson and *Miscanthus sacchariflorus* Bentham suggest that the two establishment methods of direct sowing of seeds (referred to in the following sections as 'seed sowing') and the transplanting of plantlets grown from seeds in module trays (referred to in the following sections as 'seed-propagated plants') are possible and may be less expensive than rhizome planting [19,34,35]. Another vegetative production method, deriving new plants from nodal stem sections (referred to in the following sections as 'stem-derived plants'), has been proved possible for the establishment of *M.* × *giganteus* and may be feasible for other genotypes, in particular species with stem buds such as *M. sacchariflorus* [24,25,27,30,31]. Micropropagation technologies developed to produce progeny plants from tissues are also available for miscanthus and include regenerating plants from somatic embryos formed in callus culture and direct shoot regeneration with in-vitro tillering from apical rhizome meristems or axillary nodes [29,36,37]. More recently, a propagation system called CEED (Crop, Expansion, Encapsulation and Delivery System) has been developed for *M.* × *giganteus*. In this system encapsulated plant material is put into the soil, from which plants emerge. Commercial *M.* × *giganteus* CEEDs have been provided by New Energy Farms since spring 2014 [38]. Even though there are so many options for propagating miscanthus, nearly all commercially available miscanthus plants are currently produced by the methods of rhizome planting, which is easily achieved and relatively inexpensive, and micropropagation, which provides theoretically unlimited propagation possibilities. However, to support the promising future of miscanthus, more studies need to be conducted to lower establishment failure, increase the reproduction rate and reduce establishment costs by optimising current propagation technologies or exploiting other approaches.

The aims of this study are to provide an overview of the state-of-the-art of miscanthus propagation methods including factors that hamper cost reduction and establishment success and to evaluate the different propagation systems with regard to technologies and costs. For this purpose a literature review was performed, farmers propagating and selling rhizomes were interviewed (Farmers), and field trials (Trials) and greenhouse experiments (Exp) were conducted. Trials and experiments were designed to investigate the factors affecting the establishment and development of rhizome-propagated plants, and to estimate the potential of seed production in south-west Germany.

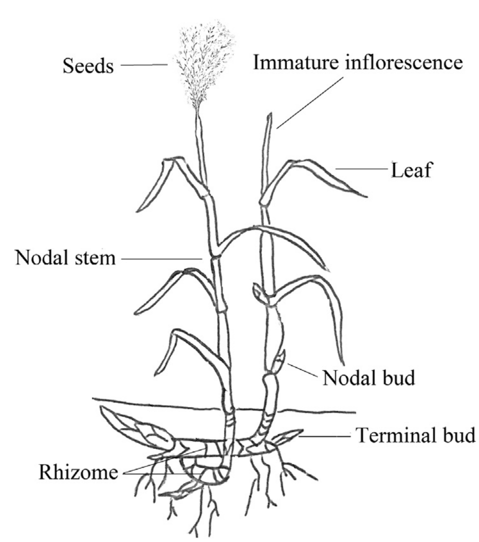

Fig. 1. *Miscanthus* plant parts suitable for propagation.