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Impact of rhizome quality on Miscanthus establishment in claypan soil landscapes

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ABSTRACT

Thousands of eroded-soil hectares in the U.S. Midwest have been planted to *Miscanthus* × *giganteus* as an industrial or bioenergy crop in recent years, but few studies on factors affecting crop establishment have been performed on these soils. The objective of this study was to quantify how both rhizome quality and depth of soil from the surface to the first argillic horizon (or depth to claypan (DTC[1])) affected *M.* × *giganteus* establishment. Rhizome quality (i.e., mass, length, diameter, viable buds, score), emergence, growth, and winter survival were measured on rhizomes planted in 2013 at Columbia and 2014 at Centralia, Missouri on clay loam soils with a range of DTC. Rhizome emergence and early tillering slightly increased as DTC increased, but these effects on growth diminished as the season progressed. Rhizome emergence and growth were more influenced by some metrics of rhizome quality; the odds of a rhizome emerging increased by 25 and 40% with each 1 cm and 1 bud increase in rhizome length and active bud count, respectively. Furthermore, late tiller counts, basal circumference, and end-of-season biomass increased as rhizome length and mass increased. Winter survival could not be estimated as well as emergence, but the odds of survival across sites increased by 5% with each 1 cm increase in rhizome length. When DTC was categorized as soil erosion class or landscape position, only the backslope at Centralia caused greater *M.* × *giganteus* growth than other positions. These findings demonstrate the resiliency of *M.* × *giganteus* for early growth and establishment on even the most degraded parts of the claypan soil landscape and indicate that propagating larger rhizomes will improve establishment.

1. Introduction

Degraded soils, in traditional agricultural settings, are often typified as being less productive, and consequently, economically marginal. In addition, they are environmentally vulnerable, being more subject to erosion and topsoil loss than other soils (Scrivner et al., 1985; Kitchen et al., 1999; USDA-NRCS, 2006). One U.S. Midwest soil especially vulnerable to degradation is the Major Land Resource Area 113 Central Claypan Area (USDA-NRCS, 2006). Found throughout much of northeastern and central Missouri and central and southern Illinois, claypan soils are characteristically dense, compact, and contain a slowly permeable subsoil layer high in montmorillonitic clay referred to as the claypan. Due to their high clay content (often 500–650 g kg^{-1}) they generally maintain moisture well but have low plant-available water and limited or slow water infiltration. Erosion on these soils has been accelerated by decades of tillage-dependent grain cropping systems with relatively low productivity that provide no soil cover for 5 to 6 months each year (Massey et al., 2008). Consequently, claypan soils have low and sometimes negative profitability due to low grain yields (Massey et al., 2008). The challenges on these soils have motivated farmers to consider other crop options.

Miscanthus × *giganteus* is an emerging bioenergy and industrial crop that has high biomass production and high potential to remediate environmental problems associated with degraded soils (Lee and T.M. Isenhart, 2000; Bullard, 2001; Heaton et al., 2008; Thomas et al., 2014). Although best management practices of

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[1] DTC—depth to claypan or argillic horizon.

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M. × *giganteus* have been studied for many areas in both the United States and Europe (Miguez et al., 2008; Xue et al., 2015), its production in the United States is limited. However, in 2012 the USDA implemented a national program through the Farm Service Agency called the Biomass Crop Assistance Program (BCAP[3]) to provide financial assistance to growers seeking to establish and produce biomass feedstocks (USDA-Farm Service Agency, 2012). The program includes four project areas within the southern edge of the Midwest Corn (*Zea mays* L.) Belt. Of these, three were funded by the USDA through the former Missouri Farmers Association Oil Biomass (Columbia, Missouri) in 2012 to assist growers in establishing over 5,000 ha of *M.* × *giganteus* in central and southwestern Missouri, and in northeastern Arkansas. Within these three BCAP project areas, *M.* × *giganteus* was planted following cropland, pasture, and conservation reserve program land on soils that had historically experienced notable degradation and diminished grain crop productivity (Scrivner et al., 1985; Kitchen et al., 1999; USDA-NRCS, 2006).

A particular challenge experienced during the establishment of *M.* × *giganteus* in these three BCAP areas was poor rhizome emergence and growth accompanied with significant winterkill, which likely was caused by extreme weather conditions (i.e., spring downpours followed by historic droughts) and inadequate weed control. Poor emergence, growth, and winter survival resulted in crop failure in some fields and the need to replant. Replanting of rhizomes is expensive; planting material costs alone range between US $1,240 to 2,700 ha^{-1} compared to <$740 ha^{-1} for switchgrass (*Panicum virgatum* L.) (Khanna et al., 2008; Anderson et al., 2015; Xue et al., 2015; personal communication with Renew Biomass). Planting costs are even higher for other methods of *M.* × *giganteus* propagation (i.e., rhizome-derived plants, stem nodal cuttings, or micropropogation) (Xue et al., 2015). The exception to these high costs might be sowing seed, as a new *M.* × *giganteus* cultivar that produces viable seed has been developed (Sacks et al., 2013; Anderson et al., 2015), but is not commercially available. Because propagation techniques are difficult and costly (Christian and Haase, 2001), improved knowledge of factors affecting *M.* × *giganteus* establishment on degraded soils is critical for successful large-scale production.

Several interacting factors affect the successful propagation and establishment of *M.* × *giganteus*. Among others, these include soil properties and conditions, weather conditions before and after propagation, rhizome characteristics, and weed control (Heaton et al., 2004; Pyter et al., 2010). Several studies have investigated how many of these factors affect establishment of *M.* × *giganteus*. Results from many of these studies were recently reviewed and summarized along with surveys of seven miscanthus producers in Canada and Europe (Xue et al., 2015). This synthesis of research and experience identified rhizomes between 5 and 15 cm in length, 60 to 75 g in weight, or with at least three active buds as 'best' options for successful establishment (Xue et al., 2015). However, results among studies on *M.* × *giganteus* establishment show highly variable establishment efficiencies as a function of rhizome characteristics and soil and weather conditions. For example, emergence rates of propagated rhizomes have ranged from 8 to 100% and winter survival rates from 34 to 98% (Huisman and Kortleve, 1994; Christian and Haase, 2001; Christian et al., 2009; Pyter et al., 2009, 2010; Boersma and Heaton, 2014). Therefore, more knowledge is needed about how soil conditions, rhizome or other propagation material characteristics, and weather conditions influence *M.* × *giganteus* establishment, especially on degraded soils.

The objectives of this study were to quantify how both rhizome characteristics or quality (i.e., mass, length, diameter, active buds, score) and DTC affect first-year *M.* × *giganteus* emergence, growth (i.e., tiller count, basal circumference, end-of-season biomass), and winter survival. The context of the investigation was to simulate rhizome and soil conditions representative of production-scale *M.* × *giganteus* plantings found in the central Missouri and northern Arkansas BCAP project areas.

2. Materials and methods

2.1. Site descriptions

Two studies were conducted to accomplish the objectives of this investigation. The first during 2013–2014 was conducted at the University of Missouri South Farm located near Columbia, Missouri USA on a study site known as the Soil Productivity Assessment for Renewable Energy and Conservation (38°54′N, 92°16′W), and the second during 2014–2015 at a long-term USDA-Agricultural Research Service study site near Centralia, Missouri USA (39°13′N, 92°7′W). Both sites are within Major Land Resource Area 113 called the Central Claypan Area (USDA-NRCS, 2006) with predominately Mexico silt loam soil (fine, smectitic, mesic Aeric Vertic Epiaqualf).

2.2. Columbia, 2013

The research site at Columbia was a subset of plots (16 of 176) from a larger experiment that was established in 1982 (Gantzer et al., 1987; Thompson et al., 1991, 1992). The subset used included four replications of four soil erosion classes arranged in a completely randomized design. Each plot was 5.5 m wide × 9.4 m long (0.0049 ha). The erosion class treatments were initially created in 1982 by moving soil with land-leveling tractors to represent various erosional phases or DTC typically observed on a claypan soil landscape. In 2009, these soil erosion classes were redefined using DTC as follows:

(A) <5 cm of topsoil (severely eroded).
(B) 5–20 cm of topsoil (moderately eroded).
(C) 20–30 cm of topsoil depth (slightly eroded).
(D) >30 cm of topsoil depth (non-eroded or depositional).

Depth to claypan was measured using apparent electrical conductivity (EC_a[2]) values from a DUALEM–2S (Dualem Inc., Milton, ON, Canada) sensor mounted on a trailer and pulled behind an all-terrain vehicle. Three east-west transects of soil EC_a were obtained on all plots. On the same day as the EC_a survey, three 1.2-m deep soil samples from each plot were taken using a hydraulic coring machine (Giddings Machine Co., Windsor, Colorado, USA). The DTC was measured on each soil sample as the depth from the surface to the beginning of the argillic horizon. The soil EC_a at these sample locations was linearly correlated to the measured DTC to develop a calibration equation to convert all soil EC_a values to DTC, similar to procedures outlined in Kitchen et al. (1999) and Sudduth et al. (2010).

The prior cropping history of the 16 plots used in this investigation was corn and soybean (*Glycine max* [L.]) during 1982–1993, fallow with native grasses, legumes, and weeds during 1994–2008, switchgrass from 2009 to 2011, and failed *M.* × *giganteus* in 2012 attributed to excessively hot and dry weather conditions during the summer. In 2013, the present study was initiated by tilling the plots in the spring to provide a weed-free seedbed and planting *M.* × *giganteus* rhizomes by hand on 10 June 2013. Rhizomes were planted to a depth of 10 cm in six rows per plot with 76 cm spac-

[3] BCAP— Biomass Crop Assistance Program.

[2] EC_a— apparent electrical conductivity.