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Research paper

Productivity, stand dynamics and the selection effect in a mixed willow clone short rotation coppice plantation

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ABSTRACT

Short Rotation Coppice (SRC) is a promising method of biomass production for energy purposes, but there have been concerns about the low diversity of these stands, including the risk for pest outbreaks. Mixing different clones has been advised as a way to tackle this problem and improve yields through positive diversity effects. Recent research into the relationship between biodiversity and ecosystem functioning supports these recommendations, but also raises worries about mechanisms that may confound results, such as a selection effect due to dominant clones outcompeting weaker ones. However, the few available studies on diversity effects in SRC plantations did not allow the disentangling of the mechanisms at play.

We used data from an experimental SRC site, which incorporated three Swedish *Salix* clones in a row-based mixing design. Productivity was expected to be greater in mixtures and we attempted to elucidate whether this was due to a complementarity or a selection effect. We found that complementarity effects were generally larger than selection effects, yet the total diversity effect on yield was not significant. Leaf surface temperature measurements indicated that drought stress was unlikely to be the factor underlying this distorted diversity productivity relationship. We also found that a less-productive clone (Gudrun) had a different stem biomass distribution when in monoculture, which may have repercussions for the quality of the harvested product and points at a so far less recognized potential benefit of mixing.

1. Introduction

The use of woody biomass for energy production has been a mainstay throughout the history of human civilization and only in recent, industrial times its importance has plummeted in favor of fossil fuels [1,2]. Questions concerning the continuity of the supply of these fossil carbon stocks [3,4] and the impact on the environment of their liberation has led to renewed interest in alternative sources of energy [5], including woody biomass [6]. The recent interest in developed countries for dedicated production systems of woody biomass for energy can be linked to these concerns [7].

Short Rotation Coppice (SRC) is a silvicultural system developed for efficient production of woody biomass. Fast-growing woody species are planted in high density, harvested in short cycles of 2–5 years and replaced when productivity starts to decrease. SRC incorporates some of the agricultural developments of the 20th century, such as science-based breeding of varieties, mechanized field management and the (limited) use of agro-chemicals [7]. Management of SRC sites is extensive when compared to other cultivation systems for energy production, which often operate in cycles of one year or less. Fertilization is less important as relatively few nutrients are removed with the biomass, which is harvested after leaves are shed [8]. The only important management

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intervention during growth is weeding in the first year after planting, sometimes using herbicides [9,10]. In addition to the relatively low intensity of management, SRC systems possess greater structural diversity than annual crops, resulting in a generally greater associated (functional) biodiversity [11–13]. SRC can also provide other ecosystem services next to biomass production, such as phytoremediation [11].

Despite the successful trials of SRC that have been undertaken across the globe [12,14,15], some issues still threaten its ecological and economical sustainability. One of these is the low diversity of these cultures, in particular because often genetically identical high-yielding clones are used [7]. A lack of diversity results in increased pest pressure in agricultural systems [16,17], which typically operate at a temporal scale of less than one year. SRC systems have longer harvest cycles and individual plants are intended to last up to seven such cycles [9], which increases the risk and associated costs of devastating disturbances such as pests or droughts. It is also not as easy or desirable – ecologically or financially – to treat woody (energy) crops with pesticides.

Recent research suggests that introducing mixtures of genetically distinct clones in SRC could be an effective measure to address these risks. The past two decades, evidence has been found in multiple ecosystems of a positive relationship between (genetic) diversity and ecosystem functions such as productivity [18–20]. This field of research is now known as *Biodiversity and Ecosystem Functioning* (BEF). Several mechanisms were proposed to explain these results, including facilitation, complementarity and the selection effect. Facilitation is the interaction between species where at least one species benefits and neither of them is harmed by the presence of the other [21]. Complementarity allows more diverse systems to make more efficient use of resources, as long as the niches of some of their species differ sufficiently [22]. Finally, the selection effect may occur because the probability of dominant species being present increases as the number of species present increases [23–26].

Only few studies have been undertaken on clonal mixtures in SRC plantations, mainly in the UK [27] and in Northern Ireland [28,29]. These studies found that clonal mixtures of willow (*Salix* sp.) tended to be more productive [29] and less susceptible to pests [27] than monoculture stands of the clones the mixtures were composed of. These findings might be explained by the mechanisms described in BEF literature [22]. Facilitation could mitigate the impact of pests through *associational resistance*: differences in susceptibility to pests among clones reduce the overall biotic pressure in the plantation, for instance because it takes longer for pests to spread [30]. Complementarity, e.g. through differences in shade tolerance, could increase the system's efficiency of resource use [31]. In the study by McCracken. et al. [29], nested mixtures of five, ten, fifteen and twenty clones were compared with the monocultures of their constituent clones. Relatively poor yields of three out of the five clones that were present in all these mixtures could explain the positive diversity effect they found when comparing the five-way mixture with the three others as a selection effect. Comparisons with monocultures cannot be considered accurate, if some of the clones are virtually eliminated as the mixed treatments age and the high-yielding (dominant) clones quickly fill the gaps left this way – as was observed in the study.

In our study, we aimed at evaluating whether multiclonal SRC plantations had higher productivity, and whether this higher productivity was due to complementarity effects, rather than or in addition to selection effects. We set up an experimental SRC plantation in which the contributions of the different willow clones to the overall yield could be separated. Furthermore, we determined possible other effects of mixing clones by comparing the stand dynamics of mixtures and monocultures. Conventional sampling methods to assess productivity and soil characteristics were complemented with thermal imagery obtained with an Unmanned Aerial Vehicle (UAV) at the end of a long dry period. The thermal maps were used as indirect estimator of transpiration levels and drought stress severity [32] of the different plots.

2. Materials and methods

2.1. Study site

In March 2010, an experimental Short Rotation Coppice (SRC) plantation was established in Zedelgem, Belgium (51°15′ N, 3°13′ E). The study site has a temperate maritime climate with a mean annual rainfall of 855 mm and air temperature of 10.5 °C (1981–2010, KMI Belgium). Four small former agricultural fields with a sandy soil were combined into an area of 2.28 ha. Before planting, the soil of the site was surveyed. The pH (KCl, 4.8) was below the optimal zone for willow, while the K and Mg content were at the lower end. Therefore, the site was treated with dolomitic lime (3 t ha^{-1}) and fertilized with manure (cattle, 23 t ha^{-1}). In the first year after planting, manual weed management was performed three times, based on previous research and management guidelines [9,10]. The site was not cut back after the first growing season, because of the high cost of harvest in the region the site was located.

The site was planted with Swedish willow clone cuttings and saplings of indigenous species. We will focus on the willow clones only, which comprised half of the site. Willow clones have been used in SRC plantations for some time now and breeding stations in Sweden and in the UK have produced varieties with SRC as a specific focus [7]. Swedish clones gave better results than locally-adapted varieties at former SRC experiments in Belgium (Enerpedia.be, in Dutch). The three clones planted at our study site were Tordis, Klara and Gudrun. Gudrun is a clonal variety of *Salix dasyclados*, whereas Tordis is a hybrid of *Salix viminalis* and *Salix schwerinii* clones. Klara is a hybrid with a complex lineage, including clones of *S. viminalis*, *S. dasyclados* and *S. schwerinii*. Gudrun is advertised for its low susceptibility to frost, leaf rust (*Melampsora sp.*) and leaf beetles (*Phratora sp.*), Tordis for its tolerance to dry soils and Klara for its frost tolerance and high yield. More information on these clones (including their full pedigrees if known) can be found in the Willow Varietal Identification Guide from Teagasc, Ireland and AFBI, Northern Ireland [33].

The three clones were planted in a full factorial mixing design, i.e. all seven possible combinations of the three clones were present. All the diversity treatments were replicated, which resulted in fourteen different plots distributed over two blocks (Fig. 1a). The spatial distribution of the plots was decided randomly, although each block contained seven different clone combinations. The mean plot size was 33 m × 12 m. Room was left for one access path between the two blocks and machine-turning strips around them. The Swedish planting scheme was used. This scheme consists of double rows of trees, roughly parallel to the north–south axis at our site, with planting distances of 1.5 m between the double rows and 0.75 m between the two rows of a double row. Within each row, the planting distance between the cuttings was about 60 cm (Fig. 1b). This pattern resulted in a planting density of almost 15.000 cuttings per ha and a total of 6 double rows per plot. Mixing was (double) row-based, so that the double rows in a plot contained only one clone.

2.2. Data collection

In late August–September 2011 and in December 2013, subplots of 6.75 m × 3 m were set up in twelve of the fourteen plots (Fig. 1).