Forest Ecology and Management 354 (2015) 291–299

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Growth potential of different species and genotypes for biomass production in short rotation in Mediterranean environments

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ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form 25 May 2015
Accepted 28 May 2015
Available online 13 June 2015

Keywords:
Populus deltoides
Populus x canadensis
Salix matsudana x Salix spp.
Robinia pseudoacacia
Platanus x hispanica
Biomass production
$G \times E$ interaction
IWUE
SRC

ABSTRACT

The sustainable production of lignocellulosic biomass in Short Rotation Coppice (SRC) in the context of bioeconomic development in Europe demands an ever greater understanding of the plant material. Different species and, in some cases, different genotypes (*Populus deltoides* 'Baldo', *Populus x canadensis*: 'Orion', 'Oudenberg', 'Ballottino' and 'I-214'; *Robinia pseudoacacia* 'Nyirsegi', *Salix matsudana x Salix* spp. 'Levante' and *Platanus x hispanica* 'Girona') were tested at four contrasting Mediterranean locations to determine the biomass yield after three years. Besides production, genotypic stability is a key factor in furthering our understanding of the plant material, with important implications for the management of plantations as well as for breeding. To study this factor, several stability models were compared (additive mixed model, Shukla's stability variance model, Finlay–Wilkinson and Eberhart–Russell models) and differences in the response capacity of the material were evaluated in the different environments. This evaluation of genotypic stability, based on the measurement of variances, was complemented by an analysis of the mean genotypic value and the variability in genotype productivity. Intrinsic water use efficiency was also evaluated as it is an important trait of plant material destined for use in Mediterranean conditions. *S. matsudana x Salix* spp. 'Levante' exhibited the highest production and showed an intermediate reactivity (stability) as well as high intrinsic water use efficiency under the conditions in which it was tested. *P. x canadensis* 'Orion' also displayed a good overall performance and was highly sensitive to improving environmental conditions. Conversely, *R. pseudoacacia* and *P. x hispanica* presented yields well below the average as well as low responsiveness to improved environmental conditions. Our findings will contribute to a better understanding of plant material, enabling improved recommendations for plantations the Mediterranean area, including more precise large scale predictions. Furthermore, the information provided will be of particular value in future breeding programs.

1. Introduction

The sustainable production of biomass is seen as a strategic alternative which contributes to the momentum of the bioeconomy in Europe (EC, 2012). Moreover, it can contribute to the generation of a wide range of products including those associated with bioenergy. In this context, under the current climate change scenario, the EU is stimulating the use of clean, renewable energy, with lignocellulosic biomass being a highly promising alternative (EU, 2009).

The Short Rotation Coppice system (SRC) is one of the most effective ways to produce lignocellulosic biomass (Makeschin, 1999). In fact, SRC is a highly suitable option for biomass supply. It offers sustainable production which is particularly interesting from a logistical perspective since it tends to be localized (both in time and space), in contrast to the supply of biomass from woodlands, which is not generally linked to energy production objectives. Hence, to a large extent, these two sources are considered complementary. Much research has been focused on determining the suitability of *Salicaceae* for SRC both in Europe (Weih, 2004) and the USA (Volka et al., 2006). Poplar hybrids (*Populus* spp.) are well adapted to a wide range of environmental conditions; they grow rapidly at high densities and are suitable for coppice cultivation (Tullus et al., 2009). Under optimal environmental

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http://dx.doi.org/10.1016/j.foreco.2015.05.038
0378-1127/Published by Elsevier B.V.

conditions, yields have reached values between 20 and 25 Mg dry matter (DM) ha^{-1} $year^{-1}$ in the Mediterranean (Italy) (Mareschi et al., 2005). In Spain, the potential production at national level is estimated at around 15.3 Mg DM ha^{-1} $year^{-1}$, for standard-management plantations covering a wide range of scenarios (Pérez-Cruzado et al., 2013). Willow is another species of the *Salicaceae* family which is widely used in SRC, especially in Northern Europe (Kuzovkina et al., 2008). It has rarely been used in the Mediterranean area due to its low potential for timber and also because it is more susceptible to water stress than poplar (Johnson et al., 2002), which makes it more suited to temperate climatic conditions.

There are a number of other species that could potentially be highly productive under Mediterranean climatic conditions. *Robinia pseudoacacia* L. and *Platanus x hispanica* Mill. ex Münchh are both well adapted to water limitations (Grunewald et al., 2009; Ripoll et al., 2009). The different scenarios outlined by the Intergovernmental Panel on Climate Change foresee an increase in summer temperatures and therefore in evapotranspiration, as well as a reduction in rainfall in some instances (IPCC, 2007). Under such conditions, both species are possible alternatives for biomass production but need to be evaluated in Mediterranean environments. *R. pseudoacacia* belongs to the *Leguminosae* family and is a nitrogen-fixing species (Hanover et al., 1991). Biomass production of between 3 and 14 Mg DM ha^{-1} $year^{-1}$ has been cited by Werner et al. (2006) or Grunewald et al. (2009) in Germany. Furthermore, this plant displays considerable resprouting capacity after cutting (Luken et al., 1991). *P. x hispanica*, a species which has been used for wood production in the Mediterranean area, belongs to the *Platanaceae* family and is characterized by high growth rate and high sprouting capacity. The average biomass yield of one of its genitors (*Platanus occidentalis* L.) is reported to be between 5 and 11 Mg DM ha^{-1} $year^{-1}$ (Davis and Trettin, 2006; Cobb et al., 2008).

Over the last decade, much attention has been focused on SRC crops in the Mediterranean, with numerous studies addressing aspects such as the management and suitability of different genetic material as well as the characteristics of the biomass produced (Guidi et al., 2008; Moscatelli et al., 2008). Moreover, due to the rapid growth of these species, considerable production can be achieved in short rotation (around three years), thus facilitating a continuous supply (Nassi O Di Nasso et al., 2010).

Besides the genetic variability of the vegetal material, the environment also exerts an important influence on growth performance. In this regard, different environmental conditions can affect biomass production such as water availability, soil type or latitude among many others. These features, considered as a whole, define different environments. Bradshaw (1965) defined GE interaction as the difference in the response of genotypes to different environments. This interaction weakens the relationship between genotype and phenotype (Romagosa et al., 2009). The combination of genetics and environment ($G \times E$ interaction), expressed in different phenotypes, can strongly influence growth performance (Isik and Kleinschmit, 2003). In a broad sense, the analysis of this interaction, which was once considered a marginal issue is now considered a key issue (Pigliucci, 2005).

From an agronomic perspective, the genotypic stability (Becker and Leon, 1988) is regarded as the cultivar's capacity to perform according to the productive potential of each environment, meaning, without departing from the expected behavior estimated from its average genotypic value. Both approaches are necessary when the aim is to properly address both management and breeding.

In the majority of forest tree species, little is known about these $G \times E$ interactions although a number of studies have addressed this question in specific species, such as patula pine progenies (Kanzler et al., 2003), elm clones (Santini et al., 2010), or poplar clones (Rae et al., 2008; Sixto et al., 2013). The existence of these $G \times E$ interactions makes it difficult to identify which genotypes perform best, although such interactions are not frequently analyzed in tree breeding due to the time, effort and economic investment required. However, by characterizing these interactions, the genotypes with the most stable response under specific environmental conditions can be identified and the most suitable use for the plants determined. Piepho and Van Eeuwijk (2002) refer to a variety of approaches to explore $G \times E$ interaction and to analyze genotypic stability, including mixed-models. Piepho (1998) states that the notion of stability implies that there is a random, unpredictable element in the performance of a genotype, for example, the weather. The greater the random component, the lower the stability of the genotype. However, there is also a predictable element, for example, where a given genotype is known to exhibit favorable behavior in terms of growth and production. Mixed models are particularly suitable for stability analysis, not only because they incorporate random effects, but also because these models allow the variance–covariance structure of the data to be modeled. Most stability measurements can be included in the framework of a mixed-model by modeling variance–covariance structures in which genotypes are fixed and environments are random factors (Denis et al., 1997). Little is known about the effect of the $G \times E$ interaction on biomass production in short rotation coppice, although if this effect could be determined it would lead to greater efficiency in breeding programs (Basford and Cooper, 1998). In this way, the genotype with the highest production in a particular environment can be selected (Rae et al., 2004; Sixto et al., 2013).

Besides knowledge of the genotypic stability of the plant materials, water use efficiency has been highlighted as a useful trait-criterion for yield improvement (Rebetzke et al., 2002) in the context of climate change. This would also be a key factor in breeding programs (Richards, 2006). Intrinsic water use efficiency (IWUE) has been recorded under tight genetic control in different tree species such as *Pinus* (Aranda et al., 2010) or oaks (Ramirez-Valiente et al., 2010) species and has shown high inter-specific variability (Gornall and Guy, 2007).

Forest tree breeding programs to increase biomass production are relatively short term and the resultant selections are often based on a single environment due to, among other reasons, the high cost of experimentation in this field. Characterizing the material in terms of the stability of response may provide valuable information with regard to its possible future use as parent material.

The aim of this study is to evaluate the suitability of different forest tree species (*Populus* spp. *Salix* spp. *R. pseudoacacia* and *P. x hispanica*) and genotypes for use in SRC in Mediterranean environments by (i) comparing their biomass production at the end of the first rotation (productivity), (ii) estimating the relevance of the genotype $*$ environment interaction (stability in biomass performance) and (iii) characterizing the response of the genetic material used in relation to the intrinsic water use efficiency to gain a better understanding of the plant material.

2. Material and methods

2.1. Plant material

Eight varieties belonging to different genera, species or hybrids were used in this study. These were: *Populus deltoides* ('Baldo'), *Populus x canadensis* ('Orion', 'Oudenberg', 'Ballottino' and 'I-214'); *R. pseudoacacia* ('Nyirsegi'), *Salix matsudana x Salix* spp. ('Levante') and *P. x hispanica* ('Girona'). In the case of *Populus* spp. and *Salix* spp. genotypes, we used unrooted cuttings of 20–30 cm in length, taken from year old stems in a stool-bed field. Prior to planting the cuttings were soaked in water for 48 h. In the case