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Genotype × environment interaction and growth stability of several elm clones resistant to Dutch elm disease

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ABSTRACT

Conventionally hybrid elm clones obtained within breeding programs for Dutch elm disease (DED) resistance were selected to meet requirements for use as ornamentals. However, it has been long and commonly observed that these clones may show hybrid vigour and enhanced growth. Nowadays DED resistant hybrid elm clones, which have been released to the market or are under evaluation for an upcoming release, are numerous enough to be considered for timber production or short rotation coppice (SRC). But experimental testing of the growth performances of these clones in different environments is still lacking. In this paper, growth and stability of performance of 24 DED resistant hybrid elm clones planted at three experimental sites with contrasting environmental conditions in Italy were studied. Height and diameter were measured yearly from 2001 to 2009, and the mean yearly increments after plant establishment were calculated. The study revealed a general good growth performance of the majority of the clones with mean height increments above 1 m/year, and an excellent growth performance of some genotypes. Analysis of variance showed significant effects of clone, site and clone × site interaction, for both height and diameter increments. Stability analysis of diameter and height increments was performed by using two parametric (CV% and W^2) and two non-parametric (Hühn's $S_i^{(1)}$ and $S_i^{(2)}$) indexes. According to all indexes, two clones showed superior and stable growth. These clones may be suitable for planting in a range of environments. In addition, several other clones had high growth in general or at a particular site. The results support our belief that these elm clones could be successfully used for timber and biomass production, and provide new knowledge for an informed choice of the most suitable genotypes.

1. Introduction

Elm (*Ulmus* L.) has been used since prehistoric times for food, medicine, fiber, fodder for cattle, timber for construction, firewood. In the Mediterranean Basin, from ancient Roman times (Columella, ≈60 C.E.) to the mid-20th century, elms were used as a living support for grapevine. In the last three centuries, these trees, which are fast-growing, able to adapt to various and difficult soil conditions, resistant to pruning, root damage and to city conditions in general, have also been widely used as ornamentals to adorn avenues and gardens through the Northern Hemisphere. However, during the last century, elm populations suffered major losses, with near-total disappearance of adult trees in some areas of the world as a result of two epidemics of Dutch Elm Disease (DED), one of the most infamous diseases ever known in plant pathology, caused by the Ascomycete *Ophiostoma ulmi* s.l. Since the appearance of the disease at the beginning of the last century, breeding programmes for DED resistance were set up by different research institutions in several European and North American countries.

Although decades of breeding have shown that it is possible to slowly accumulate resistance in second or third generation clones of purely European elms (Heybroek, pers. comm.), complete DED resistance was not found in European nor in American native elms, but individuals highly resistant to DED have nevertheless been identified (Townsend et al., 2005). Therefore Asian DED-resistant elm species have generally been crossed to native elms to speed up the selection of resistant trees. A base of native elms with desirable characters was bred with Asian elms species that, besides a fair level of DED resistance, showed the ability to adapt to a range of climatic conditions and environments. This artificial base broadening of the genetic resources, or "incorporation" (Simmonds, 1993), was planned in order to satisfy all traditional elm uses, so taking into account not only DED resistance, but also fast growth, tree silhouette, leaf and bark colour, leaf shape and dimensions. The resulting progeny was expected to combine DED resistance of Asian

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species with superior growth, ornamental value and environmental adaptability of European elms.

The elm-breeding program carried out in Italy at the Institute of Plant Protection – CNR during the last 40 years aimed to develop elm selections specific to the Mediterranean environment. The need for genotypes adapted to Mediterranean conditions was evident from the poor performance of the Dutch elm clones in the hot and dry areas of Central Italy, and the opportunity to breed better adapted hybrids was offered by the favourable adaptation in Italy of the Siberian elm (*Ulmus pumila* L.), a species that does not thrive in Central Europe and the Netherlands (Mittempergher and Santini, 2004). For this reason a base of valuable individuals of native elms were bred with several accessions of the Siberian elm and other Asian elm species that proved to easily acclimate to different conditions in the Mediterranean region. As a result, four resistant hybrid elms have been patented and released to the market (Santini et al., 2002, 2007). Moreover, many experimentally tested DED resistant elm hybrids of different parentage (Santini et al., 2008) are under evaluation to be released in the next future.

Nowadays DED resistant hybrid elm clones, already released to the market or ready for an upcoming release, are numerous enough to consider their use not only as ornamentals, but also for timber production or short rotation coppice (SRC). However, the growth performances of these clones and their reaction to different environmental conditions have not been experimentally tested.

Environment operates on phenotypes as an "agent of development", shaping the expression of traits (Hodgins-Davis and Townsend, 2009). Hence a step of crucial importance in the evaluation of clones, is the assessment of genotype × environment (G × E) interactions, i.e. the relative impact of differential environmental changes on phenotypes (Isik and Kleinschmit, 2003). The assessment of G × E interaction will, therefore, help to define the range of sites over which a selection of clonal stock can be profitably planted and the environmental conditions under which a certain selection expresses its best yield. To assess the stability of growth performance of the selected clones would be useful and advisable. Clones are expected to provide a more sensitive mean to detect G × E interactions and to evaluate genotypic stability compared to families and provenances, because there is no genetic effect between ramets of the same ortet and non-additive genetic effects between clones are large (Yu and Pulkkinen, 2003).

The objective of this study was to assess growth and performance stability of 24 DED resistant elm clones planted in three contrasting environments in Italy. This kind of information is essential to use these clones for wood or biomass production. In order to identify superior clones that are fast growers in multiple environmental conditions and, on the other hand, to assess which clones are more suitable for a particular environment, several stability analysis procedures were applied.

Table 1
Hybrid clones included in the trial and their parentage.

Clone code	Parental species
FL 033	(*U. glabra* × *U. minor*) × *U. pumila*
FL 089	*Ulmus* 'Plantyn' [(*Ulmus glabra* 'Exoniensis' × *Ulmus wallichiana* p39) × (*U. minor* 1 × *U. minor* 28)] × *U. pumila* S.2
FL 094	*Ulmus* 'Plantyn' [(*Ulmus glabra* 'Exoniensis' × *Ulmus wallichiana*) × (*U. minor* 1 × *U. minor* 28)] × *U. pumila* S.15
FL 146	*Ulmus* 'Sapporo Autumn Gold' (*U. pumila* × *U. japonica*) o.p.
FL 214	*Ulmus* 'Sapporo Autumn Gold' (*U. pumila* × *U. japonica*) × *U. wilsoniana*
FL 316	*U. japonica* × *U. pumila*
FL 339	*U. wilsoniana* × *U. pumila*
FL 390	*U. japonica* × *U. pumila*
FL 437	(*U. pumila* × *U. japonica*) o.p.
FL 444	(*U. pumila* × *U. pumila*) × *U. wilsoniana*
FL 452	*U. japonica* × (*U. pumila* × *U. pumila*)
FL 464	(*U. pumila* × *U. pumila*) × *U. chenmoui*
FL 465	(*U. pumila* × *U. pumila*) × *U. chenmoui*
FL 467	(*U. pumila* × *U. pumila*) × *U. chenmoui*
FL 483	*Ulmus* 'Columella' [((*U. glabra* 'Exoniensis' × *U. wallichiana*) × *U. minor*)] o.p.
FL 489	[[((*U. wallichiana* × *U. minor*) × (*U. pumila* × *U. minor*)) o.p.] × (*U. hollandica* 'Vegeta' × *U minor*)] o.p.
FL 493	[[((*U. wallichiana* × *U. minor*) × (*U. pumila* × *U. minor*)) o.p.] × (*U. hollandica* 'Vegeta' × *U minor*)] o.p.
FL 506	(*U. glabra* × *U. minor*) × *U. chenmoui*
FL 509	(*U. glabra* × *U. minor*) × *U. chenmoui*
FL 513	[[((*U. wallichiana* × *U. minor*) × *U. pumila* × *U. minor*)) o.p.] × (*U. hollandica* 'Vegeta' × *U minor*)] o.p.
FL 514	[[((*U. wallichiana* × *U. minor*) × (*U. pumila* × *U. minor*)) o.p.] × (*U. hollandica* 'Vegeta' × *U. minor*)] o.p.
FL 568	*U. pumila* × [(*U. glabra* 'Exoniensis' × *U. wallichiana*) × *U. minor*]
FL 588	*U. pumila* × [(*U. glabra* 'Exoniensis' × *U. wallichiana*) × *U. minor*]
FL 589	*U. pumila* × [(*U. glabra* 'Exoniensis' × *U. wallichiana*) × *U. minor*]

2. Materials and methods

2.1. Plant material and experimental sites

The 24 clones selected for this trial are reported in Table 1. All the clones showed high level of resistance to DED according to a standardized inoculation and assessment protocol described in Santini et al. (2002, 2007, 2008).

The clones were propagated by means of winter cuttings in 1998. Shoots 50–60 cm long were collected from upright branches of the clones in late January and February and stored at 4 °C until they were processed for propagation. Hardwood cuttings 20 cm long and 1–2 cm in diameter, bearing at least three buds were quickly dipped in Exuberone® (Bayer CropScience, France), and placed in a rooting mix of perlite and sand (1:1 by volume). Rooting occurred within 4 weeks. In the following spring the rooted cuttings were potted and grown in the experimental nursery of the Institute for Plant Protection – CNR.

In 2000 the two-years-old rooted cuttings were planted out at 5 m × 5 m spacing in adaptation trials at three sites with contrasting environmental conditions in Italy: (1) The site "Feudozzo" (N 41°45′N, 14°25′E, 960 m asl) is located on the Apennines, on shallow limy soil, in the experimental farm "La Torre di Feudozzo" (AQ), which is managed by the Italian State Forestry Department (Corpo Forestale dello Stato Ufficio Territoriale per la Biodiversità, Castel di Sangro). The site is characterised by a mountain Mediterranean climate with cold and snowy winters and cool summers without drought. Average rainfall is 1520 mm/year with a peak in winter. The yearly average temperature is 9.6 °C. The coldest month is January with an average minimum temperature −2.1 °C. The warmest month is August with an average maximum temperature of 25 °C. (2) The site "Marsiliana" (43°01′N, 10°48′E, 300 m asl) is located on clayey soils rich in iron in the experimental farm "La Marsiliana" (GR), which is managed by the Italian State Forestry Department (Corpo Forestale dello Stato, Ufficio Territoriale per la Biodiversità, Follonica). The site is characterised by a typical Mediterranean climate with mild and moist winters and hot and dry summers. Average rainfall is 760 mm/year, with a peak in autumn. The yearly average temperature is 15.3 °C. The coldest month is January with an average minimum temperature of 2.9 °C. The warmest month is August with an average maximum temperature of 32 °C. (3) The site "Castellaccio" (42°58′N, 12°36′E; 192 m asl) is located in Spello (PG) on reclaimed but clayey soil, in the nursery "Il Castellaccio" (UmbraFlor s.r.l.). It is characterised by a moderately continental climate with hot summers and cold winters with sporadic snowfall. The average rainfall is 815 mm/year distributed on 80 rainy days, with a peak in autumn. The yearly average temperature is 13.8 °C. The coldest month is January with an average minimum temperature of 0 °C.