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Research paper

Physiological adaptability of Poplar clones selected for bioenergy purposes under non-irrigated and suboptimal site conditions: A case study in Central Italy

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A B S T R A C T

New Poplar clones for biomass production are currently under evaluation in Italy to be cultivated in Mediterranean site conditions, where the evapotranspirative demand is not balanced by rainfall supply. The study aims to evaluate the dynamic responses of leaf gas exchanges, budding, foliar morphology and yield in three modern hybrids Poplar clones (AF2, AF6 and Monviso) under non-irrigated and suboptimal site conditions in a Short Rotation Forestry plantation of Central Italy. During the drought season, the stomatal closure was gradual in AF2 and AF6 but rapid in Monviso. These traits were associated with the best yields (expressed as dry matter) in AF2 (8.74 Mg ha^{-1} $year^{-1}$) and AF6 (6.53 Mg ha^{-1} $year^{-1}$) compared to Monviso (5.72 Mg ha^{-1} $year^{-1}$). Monviso was advised as sensitive clone to summer drought even if it has showed higher photosynthetic potential traits such as earlier budding and maximum leaf area. AF2 and AF6 were advised as tolerant and moderately-tolerant clones to summer drought as they maintained higher and relatively-higher stomatal conductance (*gs*) values over a growing season, summer photosynthetic assimilation rates (*A*) and intrinsic water-use efficiency (A/gs ratio) compared to Monviso, respectively. We pointed out the occurrence of main physiological processes (budding, maximum and minimum *gs*, maximum leaf area) to highlight the key-periods leading the growth under these site conditions by identifying the air temperature thresholds and precipitation patterns along a growing season. We provided recommendations to Italian Poplar practitioners for cultivations of these clones in Mediterranean areas affected by summer drought.

1. Introduction

Management of agroforestry-based bioenergy production represents part of the portfolio of current technologies under investigations to mitigate changing climatic conditions. The latest European forecasts indicate that biomass demand will grow by 2020 of almost 50% (http://www.risiinfo.com/ebiomass), thus increasing the policy pressure on the biomass sector, which may represent a very significant and sustainable contribution. For instance, a recent European directive (2009/28/EC) has established that by 2020 at least 20% of primary energy consumption should come from renewable sources [1,2]. That is why recently in Europe the surfaces of Short Rotation Forestry (SRF) for bioenergy purposes have notably increased, in parallel with the use of rapidly growing broadleaved species [3,4]. More specifically, the Italian SRF crops consisting in about 7000 ha [2,5], mostly established in the Northern regions along the Pò valley, where climatic and soil conditions are favorable for the cultivation of Poplars. However, more recently also agricultural areas of Central Italy have become attractive for farmers and land managers for SRF cultivation, particularly because they represent a viable economic alternative to the typical agricultural crops such as tobacco and wheat.

The genus *Populus* spans from Europe to North America and Asia. Due to its broad range, ability of spontaneous and controlled intra- and interspecific hybridization enabled the development of a large number of subspecies and transient forms, i.e. simple and

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complex hybrids. Yet, since Poplars are characterized by fast growth and easy vegetative propagation [6], there is a growing interest in fast-growing hybrid Poplar clones cultivated in SRF plantations for reaching more than expected biomass amount in facing the increased bioenergy demand from public and private sector. This interest is being also reinforced by the rapid and continuous growth rate and high yield potential attributable to SRF plantations. Poplar species (*Populus* spp.), are in Italy well-adapted and are the most common used in SRF plantations [2,5,7]. In addition, Poplar, together with Willow (*Salix spp.*) and Robinia *spp*., are the three crops recommended for Central-Northern Italy to be cultivated for bioenergy purposes [8]. However, particular attention paid nowadays to the performance of modern Poplar hybrid clones growing in sub-optimal site conditions of Central and Southern Italy [5,9–12]. Although, they are mainly cultivated in favorable environmental conditions [5,13], they may be severely affected by summer drought when planted outside their environmental optimum, with negative implications on survival and growth. This condition occurs when the evapotranspirative demand is not balanced by rainfall supply. In that site conditions, this implies a dual-concern for reduced productivity and higher mortality of these crops, on the one hand focused on the severe drought periods affecting these areas due to evidences that Poplars are among woody plants the most drought susceptible and because their productivity is associated with large water requirements [14]. On the other hand, the establishment and maintenance of SRF requires considerable investments for irrigation and fertilization, especially in sub-optimal site conditions.

Currently, applied research in this topic is focused to maximize lignocellulosic production and minimize production costs by yield comparative trials among different clones or species, and studying relationships with breeding, physiology, nutrition, silviculture, pest management, harvesting methods, social and economic issues and industrial transformation. This was done by evaluating clonal field performance to identify superior clones and match them with sites on which they will perform best. More recently, great attention has been drawn at evaluating the ecophysiological performance, such as leaf gas exchanges and water-use efficiency (WUE) to detect genotypes consuming less water and are photosynthetically more efficient [15–20]. This is based on the assumption that the success of agroforestry and biomass plantations in sub-optimal site conditions would depend by clones that combine high productivity with drought tolerance traits. That is why recently particular expectations are addressed on leaf gas exchanges responses of selected clones which should maximize C gain while minimizing water loss, and avoiding potentially damaging effects of drought-induced stress. Thus, clones that do not exhibit such ecophysiological characteristics were selected against. However, few studies in Southern Mediterranean regions or other similar environments have evaluated the sustainability of these crops from a physiological point of view, especially in elucidating whether Poplar genotypes are physiologically adapted to Mediterranean environments affected by drought.

The study aims at evaluating the dynamic responses of seasonal stomatal conductance (gs), summer net photosynthesis (A), intrinsic water-use efficiency (iWUE), and budburst phenology in three Poplar clones grown on a non-irrigated SRF in suboptimal site conditions of Central Italy. These clones are selections or crosses of *Populus canadensis*, *Populus generosa* and *Populus nigra* some of which may not be species native or not adapted to the Mediterranean climatic conditions. An additional aim is to individuate in that site conditions the temperature thresholds and precipitation patterns characterizing the occurrence of main physiological processes leading to growth such as buds burst, stomatal conductance variations and maximum leaf area. The study rationale is to select Poplar genotypes for bioenergy production to be cultivated in Mediterranean areas affected by drought. We hypothesized that the most efficient clones will have during drought periods either higher stomatal conductance and net photosynthesis, or more gradual reduction in leaf gas exchanges, maintaining higher *A* while *gs* declines, i.e. higher iWUE. We expected significant genotypic variation in the studied parameters and in their response to varying environmental parameters.

2. Materials and methods

2.1. Study site

We conducted the experiment within the farm of the Agricultural Engineering Research Unit of the Council for Agricultural Research and Economics (CRA-ING), 30 km east of Rome (Monterotondo; 42°06′ N, 12°37′ E). The climate is typically Mediterranean with summer drought and cold winter (average temperature of last ten years was 15.3 °C), and the climatic conditions are outside the limits for optimal climatic conditions for hybrids Poplar cultivation in Italy, i.e. mean potential evapotranspiration (PET) of the last ten years was 1010 mm and Aridity Index of 0.62 (for detailed climate descriptions see Ref. [2]). Mean annual rainfall of the last eight years was 821.2 mm, about 42.5% occurred from October to January and mean drought period was 4 months. The soil is a clay-loamy soil with low level of organic matter, nitrogen and phosphorus (Table 1).

2.2. Plant material and study design

We tested three hybrid Poplar clones on a flat experimental field site. The tested clones are: 'Monviso' [(*P.* X *generosa* Henry) X *P. nigra* L.] and 'AF2' (*P.* X *canadensis*), temporarily registered in the Italian Registry of Forestry Clones only for biomass production and indicated to possess very high (Monviso) and high (AF2) tolerance to Poplar rust (http://www.alasiafrancovivai.com), and clone 'AF6' [(*P.* X *generosa*) X *P. nigra*] indicated as sufficiently tolerant to Poplar rust (http://www.alasiafrancovivai.com).

At February 2005, dormant hardwood cuttings (280 mm long and maximum diameter of 28 mm) were planted at 2.8 × 0.5 m spacing with overall crop density of 7140 cuttings ha^{-1}. Each clone was replicated 6 times on elemental plots (18 plots totally) with unit surface area of 67.2 m^2. All plots were adjacent to each other, without border plants around them. Apart an emergency-irrigation (1400 m^3) carried out at the time of planting (July 2005) to promote a better taking root of cuttings, the plantation has not longer been irrigated. At the end of the first vegetative season the cut-back was carried out. The plantation was harvested two-times during 2007 and 2010 years when the plantation had reached a growing stage of R3S2 (roots aged 3 and stems aged 2) and R6S3 (roots aged 6 and

Table 1
Soil physical properties and chemical characteristics (0–40 cm depth) at the study site.

Sand (%)	43
Silt (%)	25
Clay (%)	32
Soil Texture (USDA)	Clay loam
pH (H_2O)	6.8
Electrical conductivity (mS)	0.072
Organic Matter (g Kg^{-1})	1.64
Organic Carbon (g Kg^{-1})	0.95
Total N (g Kg^{-1})	0.097
P (mg Kg^{-1})	9
K (mg Kg^{-1})	137
C/N	9.81
Cation exchanges capacity (cmol Kg^{-1})	24.44