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Growth dynamics of 'Imola' poplar clone (*Populus ×canadensis Mönch*) under different cultivation inputs

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Abstract - The influence of environmental drivers and management strategies on crops growth is a focal point to deal with the potential impact of the climate changes on forest yields. The main aim of this study was to evaluate the effect of irrigation and fertilization on growth dynamics of 'Imola' clone, an elite poplar crossed from *Populus deltoides* Bartr. and *Populus nigra* L. for short rotation coppice purposes. Using a split-plot design with three replications, two treatments were applied (irrigation and fertilization) with two levels each one: 'no' and 'yes'; 4 theses were considered: irrigation-only (IRR), fertilization-only (FRT) the irrigation with fertilization (IRF) and control (CRT). At the end of the first 5-year cycle the average yield, in dry matter, was 36.8 Mg ha^{-1} for non-irrigated plots and 80.8 Mg ha^{-1} for irrigated plots. While no statistical evidence was detectable for fertilization treatment, a Linear Mixed Model analysis applied to data highlighted the Summer (June-August) as key season for the irrigation of trees. Conversely, interaction between irrigation and fertilization negatively affected growth in the same period. Overall, this trial demonstrated a low impact of fertilization on growth dynamics. Water availability was confirmed as the most important factor for poplar growth, in such site, focusing on the importance of studying alternative, less impacting methods to irrigate such crops.

Keywords - poplar production, climate, cultivation, planted forests, growth dynamics.

Introduction

The environmental factors strongly affect the spatial distribution and structural composition of forest systems, guiding the selection of ecotypes more adapted to local conditions (Zalesny et al. 2009, Buermann et al. 2016, Pecchi et al. 2019). The growth rate of planted forests is highly related to environmental stresses, including climatic fluctuations and soil characteristics. Even if external inputs (e.g. fertilization, irrigation, etc.) can influence the resistance of trees to environmental pressure, a high amount of energy is required to improve the quality and the yield of the productions properly (Njakou-Djomo et al. 2015). Irrigation and fertilization are the most energy-demanding external inputs in agriculture and planted forestry, with water availability often recognized as the first factor directly affected by climate change (Arnell 1999, Bernacchi and VanLoocke 2015, Schlaepfer et al. 2016). Similarly, the chemical contribution furnished with phytosanitary treatments and synthetic fertilizers requires high dispensing of raw materials and energy (Wood and Cowie 2004, Facciotto et al. 2010). Moreover, these additives are often inadequate or used inappropriately causing nitrate and pollutants losses through leaching (Ceotto et al. 2018), with subsequent risk of groundwater contamination (Balasus et al. 2012) and high greenhouse gas emissions (GHG). Planted forests and their environment are acknowledged as very important for landscape protection, carbon sequestration (Lal 2004, Lal 2005, Meyfang et al. 2017) and timber production (Balatinecz et al. 2001). Their supply for raw materials for energy production such as bioenergy, heat or bio-ethanol production (Sims et al. 2010, Rosso et al. 2013, Guo et al. 2015, Bacenetti et al. 2016), timber (new eco-construction sector based on wood and biodegradable materials for buildings) (Ramage et al. 2017), paper (Cerrillo 2000), packaging, transports, new chemicals products like bio-plastics (Nörnberg et al. 2014) colors and glues is globally acknowledged. In such framework, even if some studies underline a correlation between aboveground biomass and nitrogen (N) content in wood (Paris et al. 2015), recent studies have shown a poor effect of nitrogen soil spreading on poplar (*Populus* spp.) growth, especially in areas suitable for its cultivation, where this element does not represent a limiting factor (Georgiadis et al. 2017a, Dimitriou and Mola-Yudego 2017, Amichev and Van Rees 2018). In this regard, careful evaluation is mandatory in order to achieve an optimiza-

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Table 1 - Main soil physical and chemical characteristics of experimental trial. N = nitrogen, C = carbon.

Depth	N	C	C/N	pH	Sand	Silt	Clay
cm	%	%		(water)	$g\cdot kg^{-1}$	$g\cdot kg^{-1}$	$g\cdot kg^{-1}$
0-15	0.07	0.69	10.0	7.8	580	365	55
15-34	0.08	0.83	9.8	7.9	570	385	45
34-55	0.05	0.56	10.2	7.8	540	400	60

tion of this practice, based on the evaluation of the real necessities of plantations as well as on the poplar biology and physiology concerning its N uptake methods on (i.e. from leaves more than soil).

Poplar tree species are recognized as important patch of the forests mosaic, covering approximately 87 million of hectares worldwide (2% of forest area) mainly as natural populations (FAO 2016). Poplar cultivation is often characterized by high energetic inputs and relatively high environmental costs, especially due to chemicals treatments (against pests and diseases), fertilization and irrigation (Bergante et al. 2010). In the Mediterranean area, many planted forests were established with different *Populus* spp. tree species for timber and bioenergy production, including natural species such as *P. alba*, *P. nigra*, *P. deltoides* exported from the areas of origin (North America, Europe and Central Asia) and their artificial hybrids like *P. ×canadensis* Mönch *(P. deltoides × P. nigra)*. The selection of genotypes was performed in order to develop more productive clones, marketed in many areas of the world that naturally, or with human intervention, could be suitable for their cultivation.

In the topic of genetic improvement, some new poplar genotypes were selected in the last years as more productive and pest- and disease-resistant, able to grow with limited external inputs, unfortunately maintaining high water demands (Coaloa et al. 2016, González-González et al. 2017).

In this paper the growth dynamics of a new hybrid clone (*P. ×canadensis* Mönch) named 'Imola', characterized by fast growth, resistance to main poplar diseases and good rooting, survival and sprouting ability (Facciotto et al. 2011) has been studied under known (and variable) climatic conditions and controlled cultural inputs. The main goal of the research was to investigate the relationship between the most important climatic and cultural factors and the growth and yield of 'Imola' in Northern Italy (Piedmont).

Materials and methods

Study site: climatic regimes, poplar genotype and soil preparation

The study has been carried out in the framework of the SUSCACE Project (Pari 2011) in a field trial of the CREA experimental farm 'Mezzi', located near the Po river (45°08'10"N, 8°30'44'E) in Casale Monferrato. The climate is sub-continental, with hot and dry summer, rainy autumns and temperate winter. The average total annual rain is about 700-800 mm (average of 30 years of measurements in 'Mezzi' farm; see section 'Experimental design' for information about equipment), the vegetative period is April-October. Soils of the farm are generally sandy or sandy-loam with variable gravel content. Soil sampling at three separate depths (0-15, 15-34, 34-55 cm) were performed in the first month of plantation and analysis showed a sub-optimal soil for poplar cultivation with sandy-silt texture and a low gravel content, well oxygenated and deep; the main physical and chemical characteristics are shown in Table 1. However, the water availability is low and rescue irrigations are necessary during the summer season. In this area the 'Imola' clone has been planted for biomass production following the 5-year Short Rotation Coppice (SRC) model; this cultivation model is suitable for biomass but also for raw material production (wood for packaging, pulp for paper, Oriented Strand Board panels).

Before the establishment, soil was prepared through ploughing (30 cm deep), arrowing and with chemical weed control, following the model described by Bergante and Facciotto (2015). In March 2009, one-year old unrooted poles of clone 'Imola', 3-4 m long, were planted 80 cm deep in auger-drilled holes at 3×3 m spacing with a square design, corresponding to a density on 1111 trees per hectare (trees ha^{-1}). The poles were produced in a nursery of the experimental farm 'Mezzi'.

Experimental design

To evaluate the growth of trees properly, daily climatic data were collected during the five years of test with a data recording system (Silidata AD2, Ecodata DMCS32) located in 'Mezzi' farm, 1 km far from the trial. The meteorological data collected are reported in Table 2 and were utilized for the estimation of water balance showed in Figure 1. An aridity period (water stress) was detected and averagely present, in the area of the trial, between June and August. In addition, a water surplus was detectable (blue bars in Spring and Autumn), due to the high amount of rain and to the limited evapotranspiration.

Table 2 - Periodic values of climatic factors, cultural inputs and diameter daily increment of trees in the period of measures for each year. Temp: temperature in °C, average of the period; Rain: total rainfall in mm of the period; Irrig: water supply in mm through irrigation; Tot. wat: total of water received through rain and irrigation; RH: relative air humidity, average percentage of the period; Rad: total sol global radiation in MJ m^{-2}, of the period; Inc: diameter increment in mm, during the period of observation and minimum and maximum values of the period.

Year	Period of measures	Temp °C	Rain mm	Irrig mm	Tot wat mm	RH %	Rad MJ m^{-2}	Inc mm day^{-1}
2009	19 May- 08 Sept	23.5	163.6	627.9	705.9	73.5	2253.3	0.07 0-0.48
2010	17 May- 01 Nov	20.9	257.4	208.5	465.9	80.3	2592.5	0.07 0-0.40
2011	28 Mar- 03 Nov	19.5	311.3	525.0	836.3	72.0	3386.0	0.04 0-0.21
2012	04 Mar- 01 Nov	21.1	306.4	566.0	872.4	73.9	2841.7	0.04 0-0.14
2013	13 May- 12 Sept	22.3	221.0	1010.0	1231.0	75.9	2565.2	0.03 0-0.14

In the poplar stand a split plot design with three randomized blocks was organized: each block was split in half, and irrigation was allocated at random to one half of the block. Each irrigation plot was split into two subplots, and fertilization was allocated at random to one of the subplots. As a result, two treatments were applied (irrigation and fertilization) with two levels each one: 'no' and 'yes'; 4 theses were considered: irrigation-only (IRR), fertilization-only (FRT), irrigation with fertilization (IRF) and control (CRT). Each experimental unit (subplot) contained 35 trees (7 rows of 5 trees). Where provided, the irrigation was performed through aboveground drip irrigation system; water was furnished to trees with the aim to avoid any drought stress. The amount of water supplied per intervention is reported in Table 2. Where provided, fertilization was manually distributed each Spring, with a nitrogen slow release fertilizer [Entec 26(+32)] with a dose of 60 kg ha^{-1} of N (Bergante and Facciotto 2015), based on the amount indicated for poplar cultivation in traditional stand during first years by the cultivation protocols (ENCC 1994). For the purpose of this paper we consider the data collected during first cycle, corresponding to first five years of growth. A sample of three trees for each plot (9 per thesis) was measured approximately every 15 days from May to October every year. Measures started after complete leaf distension and continued until the close of the vegetative season. The survival rate (Surv%) and diameter at breast height (DBH) in centimeter were recorded periodically during the five years of growth. To maximize measurement accuracy, the height of diameter measurement was reported with a circle painted on the stem, while the 1.5 m tape and the operator were kept identical for all the years. At the end of vegetative season of each year, all the living trees were measured to estimate the aboveground woody dry matter yield (Mg ha^{-1}) following the method firstly reported by Vervijst and Telenius (1999) and utilizing two different regression equations: one for first year of growth, obtained from Facciotto et al. (2005) and one for years from 2 to 5; this last equation derives from data obtained in SRC stands established in the areas of Western Po Valley and it's reported by Facciotto et al. (2019). During every year we collected, for each period between one measure and the successive, the following environmental and cultural data: average daily temperature in °C measured at 1.5 m from the soil (average of the period), rain in mm (total of the period), relative air humidity (average of the period), solar global radiation in MJ m^{-2} (total of the period divided by number of days), irrigation amount in mm per time, fertilization amount in Kg of N per plot. Irrigation and rain amounts were added to calculate the total water availability, and this was divided by the number of days (mm day^{-1} of water available). We also collected data of the groundwater depth in two wells (one in North and one in South of the trial) with monthly cadence, but, due to its depth (from 4 to 6 m) we didn't consider it useful because during five years poplars aren't able to reach it.

Statistical analysis

All the obtained data (measurement parameters and climate) were included in a statistical model to evaluate the influence of each climatic/cultivation driver on growth of target tree species considering the growth period between two successive measures (about 15 days). In such time-slice the average daily diameter increase and the average daily value of all other factors were calculated (i.e. average daily water or average daily global radiation obtained in each observation period). According to similar studies (Bergante et al. 2010) the influence of environmental factors on *P. ×canadensis*' growth was estimated using the 'Imola' clone as model, due to the typical behavior of the species. In addition, the experimental design was studied to evaluate also the effects of fertilization and irrigation separately and in combination. An *ANOVA* was firstly per-

Table 3 - Season division and codes.

Season	Days (day/month)	Code
Spring	15/03 – 30/04	SP1
	01/05 – 14/06	SP2
Summer	15/06 – 31/07	SU1
	01/08 – 14/09	SU2
Autumn	15/09 – 31/10	AU1
	01/11 – 14/12	AU2

formed to evaluate the growth and yield differences between the thesis using the package ‘agricolae’ (de Mendiburu 2013) of R statistical language (R Core Team 2019) while the graph of Figure 2 was made using the package ‘DescTools’ of R software (Signorell et al. 2018). Then a two steps tree-level linear mixed model (LMM) approach was used to evaluate the influence of each climatic factor or cultural input using ‘lme4’ (Bates et al. 2015) and ‘LmerTest’ (Kuznetsova et al. 2017) packages of R statistical language. In all the models the unique tree identification number (ID) was set as random factor since each rate of growth represents repeated measurements from each tree. Then a LMM was firstly run on the control-only trees and using temperature, rainfall, relative humidity and solar radiation as fixed effects. Such first model (LMM1) was built to evaluate the effect of climate on ‘Imola’ growth. Then a second LMM (LMM2) was performed on all sampled trees without climate as predictors and using just the season and the treatment as fixed effects, including their interactions. Age was included too, in order to deal with growing dimension of trees. With LMM2 the influence of treatments and their timing (when each was applied) was studied. The Seasons were divided in two periods: early=1 and late=2 (e.g. SP1 and SP2 for Spring) according to thresholds reported in Table 3

Authors present a model equation with estimated fixed intercept, model coefficient, random intercept and residual error.

Results

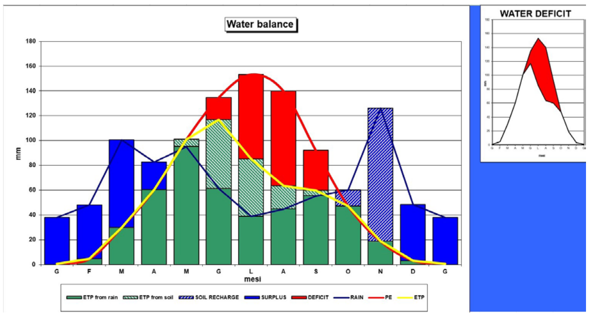

Figure 1 - Hydric balance of the site of trial; average for the period 2009-2013. In red is shown the water deficit period from June to September (for the abbreviations see: Armiraglio et al. 2003).

The Figure 1 represents the calculation of the water balance of the site, extrapolated from environmental data measured during the years of the test, thanks to the spreadsheet developed by Armiraglio et al. (2003). The Figure 1 shows a water deficit in the period from May to September (on the right) and rainy period in Spring and Autumn (dark smoothed line). In these conditions the rains may be able to recharge the water table, which however cannot be reached from the roots on this site. During the spring season, therefore, the water deficit, intensified by strong evapotranspiration (ETP) can affect plant growth if it is not attenuated with targeted irrigations.

The Figure 2 shows the average annual increment of diameters (considered as average of diameter of the trees measured for each plot) measured during vegetative season from plantation time to harvest at the end of 5th year.

The diameter of trees, in average, increased 2.5 cm per year during the first three years; trees showed a first intraspecific competition behavior starting from the fourth year, when the annual growth has dropped to an average of 1.7 cm during fourth year and 1 cm during fifth year. In all the years the diameter growth showed differences between treatments. All irrigated trees (IRR ad IRF) maintained higher

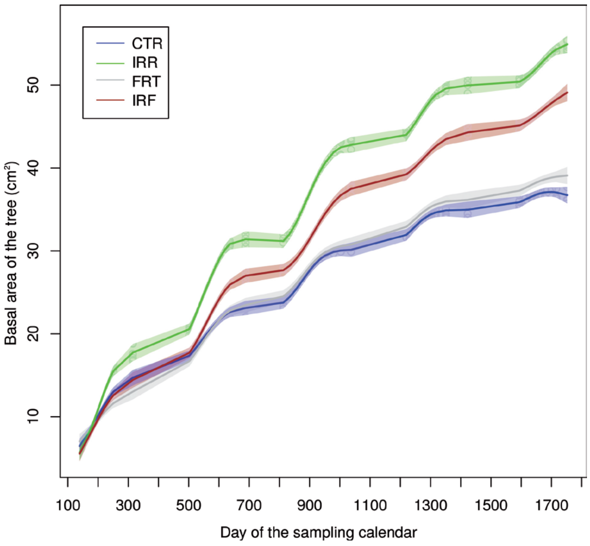

Figure 2 - Growth of diameters at breast height (Dbh) of the trees of each treatment during the five years of measurements. X axis: days of growth (Giulian calendar); y axis: mean basal area (cm²/trees). Shaded area: estimated standard error.

Table 4 - Dry biomass yield (Mg ha^{-1}): mean and ANOVA of total yield at the end of harvest cycle and annual average for each different factor studied.

Irrigation	Fertilization	Code	Total yield d.m. Mg ha^{-1}	Average annual yield d.m. Mg ha^{-1}
No	no	CRT	34.27	6.85
	yes	FRT	39.39	7.88
Yes	no	IRR	85.97	17.19
	yes	IRF	75.96	15.19
Mean main factor:				
Irrigation	yes		80.76	16.15
	no		36.76	7.35
Mean second factor:				
Fertilization	yes		57.67	11.05
	no		60.12	12.02
Overall mean:			58.90	11.78
P value:	IRR		650.7**	
	FRT		0.14 n.s	
	IRR×FRT		1.38 n.s	

Signif. code for p-value: **: p≤0.01; ns p>0.05

annual increments, also during the last year with more high competition among the trees. During first three years the growth rate was more or less constant until to August (SU1) and for all treatments. From the fourth year a different growth is detectable between irrigated and non-irrigated trees. While the irrigated trees continued with steady growth until August, the non-irrigated trees slowed their growth as early as May.

In the Table 4 are reported data of dry biomass yield at the end of first cycle, and the annual average for each treatment. During the first five years ‘Imola’ clone showed a fast growth, with a overall average yield of 58.9 Mg ha^{-1} of dry matter, corresponding to an annual average production of 11.8 Mg ha^{-1} of dry matter. Significant differences were found between irrigated plots, with a mean total yield of 80.8 Mg ha^{-1} and non-irrigated plots with a mean total yield of 36.8 Mg ha^{-1}. There were no effects on growth due to fertilization, indeed, IRF thesis showed a negative effect on the growth with lower biomass production than IRR.

The LMM applied to climatic factors (CTR thesis only) indicated the significant effect of Temperature (Temp., daily average of the period) and relative air humidity (RH, daily percentage average) on trees diameter growth (Tab. 5).

Applying the LMM to cultural inputs in relation to seasonal periods (Tab. 6), we found a significant effect on growth of the seasonal period SP2. The LMM2 underlines also as significant period the autumn (both AU1 and AU2) but with a slight decrease compared to the starting season (negative estimated coefficient). Among the cultural inputs, the Model underlines the significant effect of irrigation during all summer (SU1:IRR and SU2:IRR).

Discussion

The most important traditionally applied cultivation inputs for poplar growth, irrigation and fertilization, seems to be re-evaluated. For poplar cultivation, the N fertilization is often seen as a mandatory practice. However, our results clearly showed a low impact on growth dynamics during first five years. In addition, a sort of “negative effect” in irrigated trees was detectable (Fig. 2 and Tab. 6): the interaction of irrigation and fertilization is underlined as significant factor during the second part of summer (SU2:IRF), indicating a positive effect of water during the hottest part of the year despite fertilization and causing an increased growth rate. This might re-

Table 5 - LMM1 result for influence of climatic factors on the DBH growth of ‘Imola’.

	Estimated coefficient	Std. Error	P. value	
Intercept	8.159e-01	3.941e-01	0.038758	*
Temp	4.191e-02	1.211e-02	0.000567	***
Rain	1.641e-03	1.102e-03	0.137025	ns
RH	-1.237e-02	5.075e-03	0.015009	*
Rad	-3.155e-05	2.803e-04	0.910409	ns

Signif. code for p-value: *: p≤0.05; ***: p≤ 0.001; ns p>0.05.

Table 6 - Result of LMM2 analysis for influence of season (Spring, Summer, Fall) and cultural factors (Irrigation, Fertilization and Irrigation + Fertilization (IF)) on growth of poplar ‘Imola’.

Factor group	Factor	Est. Coeff.	Std Error	P
	Intercept	1.64855	0.12360	<2e-16***
	Age	-0.29285	0.01111	<2e-16***
Season	Spring2	0.31559	0.13607	0.020442*
	Summer1	0.03064	0.12274	0.802912
	Summer2	0.10003	0.12424	0.420776
	Fall1	-0.62129	0.13919	8.35e-06***
	Fall2	-0.65667	0.24823	0.008199**
Treatment	Fert	0.10667	0.16833	0.526421
	Irrig	0.01781	0.16896	0.916072
	IF	0.03167	0.16833	0.850815
Interaction	Spring1 Fert	-0.05000	0.19227	0.794846
	Summer1 Fert	-0.13407	0.17356	0.439881
	Summer2 Fert	-0.31771	0.17552	0.070379
	Fall 1 Fert	-0.11571	0.19680	0.556587
	Fall2 Fert	-0.18000	0.35104	0.608157
	Spring1 Irrig	0.02802	0.19282	0.884455
	Summer1 Irrig	0.47756	0.17417	0.006142**
	Summer2 Irrig	0.68552	0.17612	0.000101***
	Fall1 Irrig	0.23000	0.19750	0.244288
	Fall2 Irrig	0.08219	0.35134	0.815053
	Spring1 IF	-0.14917	0.19227	0.437925
	Summer1 IF	0.25926	0.17356	0.135336
	Summer2 IF	0.48479	0.17552	0.005778**
	Fall 1 IF	0.10881	0.19680	0.580374
	Fall2 IF	0.04833	0.35104	0.890498

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

veal a sort of minimization of the negative effect of fertilization and in particular in the hot and dry periods of summers and in association with irrigation.

Concerning N fertilizers, many and conflicting results are reported in literature for poplar (Rennenberg et al. 2010, DesRochers et al. 2006). For instance, Amichev and Van Rees (2018) reported a negative effect on the growth of the high doses of nitrogen spreading, supporting our results if we consider that, in our case, we applied low doses of N but an accumulation effect may have occurred both due to the annual application of a type of fertilizer with slow-N release, and due to possible high levels of nutrients already present in the soil from previous crops (*Medicago sativa* L.). A negative effect of N on poplar trees health and growth was found in the past by Frison (1978) who hypothesized a negative effect of nitrogen associated with high levels of phosphorus. Moscatelli et al. (2008) evaluated the effects of nitrogen fertilization on soil N and C content, with detectable positive results only for short periods and suggesting a slow adaptation of the microbial flora, without particular effects on the production of biomass in the short time. However, a lack of effect on aboveground biomass and a decrease of below ground biomass was also acknowledged by the Authors. Similarly, Dimitriou and Mola-Yudego (2017) analyzed the possible variables affecting the effect of N fertilization on growth, citing among the various possibilities, the age of the plants and the canopy closure, the studied genotype, the soil type and other environmental conditions. Concerning this study, additional data collected on leaves biomass (under publication) showed a lower production of leaf biomass by fertilized plants, suggesting an evident depressive effect on growth. Summarizing and considering the previously reported literature, our result of negative interaction between irrigation and fertilization is difficult to explain and can be due to: *(i)* a different nutrients allocation in roots-shoots tissues; *(ii)* a greater development of weeds that are able to compete with poplar; *(iii)* a higher water and/or energy demand for nutrient absorption and processing; *(iiii)* other unknown negative interactions at metabolism level. Current literature over cited often underlines a sensible effect of fertilizers addition only in poor soils, with water availability and during first three years of growth. In suitable environmental conditions, the most productive clones seem not to benefit in any way from fertilization. Recent studies discovered the presence in foliar tissues of N-fixing bacterial activity also for poplar that could be able to self-supply of necessary N (Doty et al. 2005).

Conversely, the importance of irrigation was confirmed and especially in SU1 and SU2. Overall, this result reinforces the indications that have always been given regarding the role of irrigation in the areas suitable to poplar cultivation. The irrigation has the specific purpose of maintaining or increasing the growth rate of trees. As regard the importance of the availability of water table, poplars are able to reach it if the soil conditions are suitable; the roots system develops depending of genotype, type of material for plantation (cuttings, poles), soil structure, nutrients and humidity (Teobaldelli et al. 2007, Zenone et al. 2008). Young trees in biomass plantation develop an horizontal root system, reaching about a depth of 1.5 m (Friend et al. 1991); considered the deep of our water table (4-6 m) we have hypothesized a lack of connection, however proved by the poor growth of plants not artificially irrigated. However the poplars may not be able to reach the aquifer also for reasons linked to the structure of the soil horizons, in the presence of gravel for example, or of asphyxiated horizons (Frison 1995); in other cases the groundwater can be reachable at certain times of the year, lowering then during periods of maximum water intake. In some areas of Northern Italy, where flow irrigation is carried out, this also has the specific task of keeping the groundwater level constant and available for trees. The greatest poplar wood yields are recorded in these areas. Concerning the importance of climatic drivers, our results are quite different from previous studies that indicated water availability as most important factor for biomass production during first two years of growth (Bergante et al. 2010). Considering that high suitability for poplar cultivation of the area, rainwater availability, during the test period, probably did not represented a limiting factor for growth, although it was limited during the summer seasons (SU1 and SU2). This hypothesis is also corroborated by the fact that the FRT thesis and the control where no additional water was provided, showed a slow but continuous diametric growth and no mortality (Fig.2).

Conclusions

The forestry sector has been acknowledged as a key sector for CO_2 mitigation (absorption, soil translocation and stabilization in the wood), soil and water protection, rural development and agricultural diversification (Dixon 1995, Jose 2009, Paris et al. 2014, AA.VV 2018) in the framework of Kyoto Protocol and 2020 Objectives (European Commission 2010). Water remains the most important environmental and cultural driver for 'Imola' clone and for poplars in general. However, this factor will also probably be one of the most affected by climate change. Significant improvements in this research field will have to be linked to the selection of species and genotypes able to growth and survive in water limited conditions. On the other hand, a wiser application of irrigation and fertilization should be applied, developing low-level cultivation methods (Paris et al. 2018), or improving the knowledge about the timing of application balancing external energetic inputs properly. Further and more detailed studies are needed to clarify which genetic and environmental factors influence the result of fertilization and irrigation to avoid or optimize these practices based on each single situation, considering their high economic and environmental footprint.

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More information can be found at: http://www.gruppo-panacea.it/biomasse/tesi-1.

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