I-214 and Permanent Polycyclic Tree farms

Relationships among diameter, productive area per plant and rotation cycle length

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di Paolo Mori, Enrico Buresti Lattes

The knowledge of the relationship between plants and, more specifically, with the area needed by each crown to reach a given diameter in a given time frame is crucial to correctly design permanent polycyclic tree farms. This study is focused on poplar clone I-214, one of the most used in poplar plantations not only in Italy but also abroad.

Italy has had a long solid culture in growing poplar (*Populus spp*) plantations, and the majority of poplar growers follows traditional agronomic practices. Currently, the productive area provided to each poplar plant ranges between 25 m^2 (planting scheme 5 x 5 m, which is now falling into disuse) to 42 m^2 (planting scheme 6 x 7 m), even though the most frequent scheme is 6 x 6 m, 36 m^2 for each poplar. The productive objective of such plantations is a bole suitable to rotary cut veneer, thus, with a mean diameter of 30 cm to be reached in a rotation ranging from 9 to 12 years according to site fertility and cultivation intensity (usually in 10 yrs., AA. VV., 2000).

Traditional practices are widely applied by poplar growers despite the fact that in the last 3-4 decades the production cost has increased without a corresponding proportional rise of the price of poplar rotary cut veneer. Consequently, in the last 20 years, innovative experiments focused on designing, managing and growing polycyclic plantations, which consist of different productive cycles in the same plot of land (Buresti Lattes *et al*. 2014, Mori 2015), have been started. The use of poplar in the studied productive cycles has been included, testing different clones and assigning to each poplar a productive area between 45 and 110 m^2 (Table 1). The poplar grown in polycyclic plantation was able to reach a diameter significantly higher than the plants grown in traditional plantation (Castro *et al*. 2013, Buresti Lattes *et al.* 2015). Nevertheless, in most cases, the productive area assigned to each plant could not be selected according to an experimental hypothesis. Actually, RDP (Rural Development Programme) financial measures to sustain tree farming in Italy have been regulating species maximum density, and, thus, this has reduced the possible range of distances among poplars.

The knowledge of the relationship among crown area (net productive area), gross productive area to be assigned to each plant[1)], diameter at breast height (DBH), and the

***1)** In polycyclic plantations the gross productive area could include a tree with a dual role and/or an accessory tree.*

needed time to reach a given DBH is a necessary condition that has to be satisfied before designing a polycyclic plantation.

In polycyclic plantations poplar clones, in particular the clone "I-2014", are frequently used as main tree and/or as a dual role tree (Buresti Lattes and Mori 2016, Buresti Lattes *at al.* 2014). Nevertheless, leaving back the traditional cultural practices, the availability of detailed information is scarce, in particular about which is the gross productive area for I-214 effective in reaching the goal in terms of diameter growth in the shortest time as possible.

In this framework, we carried out a study focused on I-2014, one of the most commonly planted in tree framing in Italy and abroad, with the aim to investigate the relationship between net and gross productive area with diameter and the time needed to reach it.

Materials

The study included 957 I-214 plants, age range between 1 and 9 yrs., which were located in 5 sites in Po Valley in Northern Italy (in two regions: Veneto and Lombardia). The choice of merging information from two regions in the same study, despite both of them in the flatland of Po Valley, was based on the need of analyzing data coming from different conditions in terms of soil, planting scheme, and management: the only common condition was a gross productive area larger than the traditional ones. Data related to 692 plants were collected by Giulia Olivotto in her thesis (Olivotto 2016), while the others 265 poplar were measured by personnel of AALSEA Association (Sustainable Tree Farming to Economy and Environment) during the yearly activity of plantations monitoring. Study sites location is showed in Figure 1.

Methods

All data were collected in winter. In each plantation, the age and the area available for the crown of the I-214 plants were recorded. The poplars belonging to the same plantation were measured in different years, thus, at different age, with the aim of including as continuously as possible different growth stages. Plants of the same age but coming from different sites were included to highlight differences due to sampled environmental conditions.

On each I-214 plant, the following variables were measured: circumference at breast height; 2 crown radii aligned with the plantation row; 2 crown radii perpendicular to the plantation row. Table 1 shows the main information about age, measured plants per age, and

Data collection year	Plantation	Age (yrs)	Measured plants (n.)	Distance within the row (m)	Distance between the rows (m)	Gross productive area per plant (m^2)
2016	Gazzo Veronese (LIFE+ InBioWood)	1	61	6	12	72
2016	Gazzo Veronese (LIFE+ InBioWood)	2	47	6	10	60
2016	Gazzo Veronese (LIFE+ InBioWood)	2	44	5	9	45
2016	Gazzo Veronese (LIFE+ InBioWood)	3	47	6	10	60
2016	Gazzo Veronese (LIFE+ InBioWood)	3	45	5	9	45
2015	Villa Bartolomea (AALSEA)	3	45	6,2	18	111,6
2016	Villa Bartolomea (AALSEA)	4	92	6,2	18	111,6
2014	San Matteo delle Chiaviche (Corte Buvoli) - (AALSEA)	4	62	6	18	108
2014	Viadana (AALSEA)	4	35	5,5	20	110
2016	San Matteo delle Chiaviche (Corte Buvoli) - (AALSEA)	5	40	6	18	108
2017	Villa Bartolomea (AALSEA)	5	89	6,2	18	111,6
2016	Viadana (AALSEA)	5	35	5,5	20	110
2016	Viadana (AALSEA)	6	79	5,5	20	110
2016	Viadana (AALSEA)	7	79	5,5	20	110
2016	Ponte sull'Oglio (AALSEA)	8	79	4,5	13,5	60,75
2016	Ponte sull'Oglio (AALSEA)	9	79	4,5	13,5	60,75

Table 1 - Data collection year, age, and gross productive area of I-214 plants in the polycyclic plantations experimental sites. In brackets the research unit in charge of assessing the evolution of the plantation.

Figure 1 - Detail of the regions of northern Italy and geographical position of the polycyclic plantations included in this study.

designed gross productive area.

Data were analyzed with the aim of relating:

- DBH with crown area;
- age with DBH.

A regression analysis was performed for both relationships, and the best performing equation was used; the coefficient of determination (R^2) and Standard Deviation for both diameter and age classes were calculated.

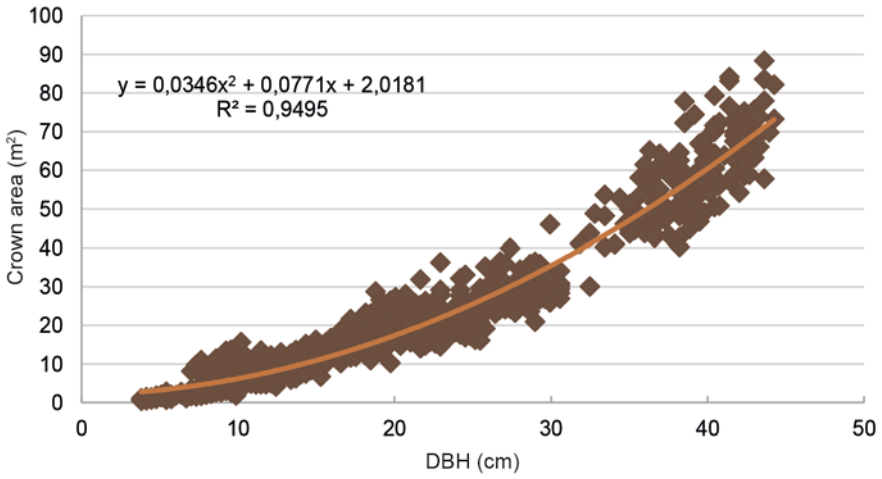
Results

Collected data resulted in total 5752. The statistic (or random) error varied according to age class, and the values of r% both for diameter and crown area per age class are shown in Table 2. Regression analysis highlighted a positive relationship between crown area and DBH (Graph 1); the equation that better described the data set (957 combinations of diameter and crown area values) was a second degree polynomial with a R^2 = 0.9495, which pointed out a strict relationship between the two variables.

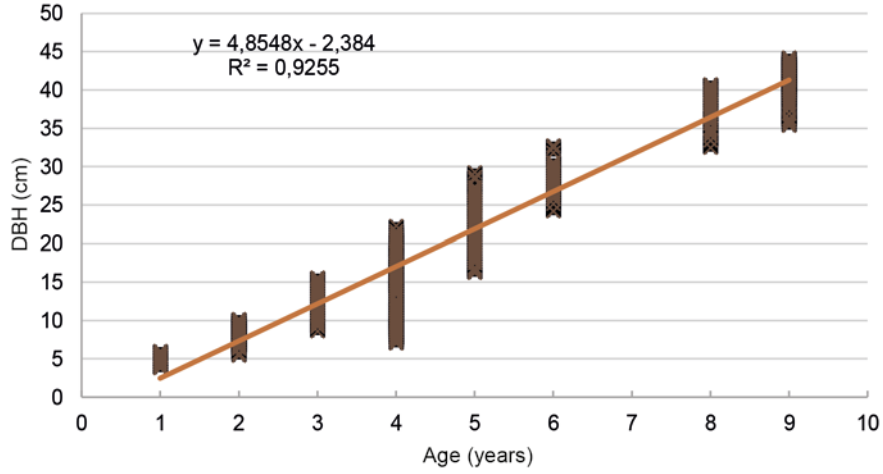
The value of the crown area obtained by the polynomial equation using a DBH of 30 cm is equal to 34.9 m^2, this value is very close to the area assigned to each plant in traditional poplar plantations. The relevant difference between poplars grown with a productive area of 36 m^2 and poplars grown in polycyclic plantations, which rely on a higher productive area, is that, in traditional plantation, the diameter growth rate usually shows a decreasing trend starting at 5-7 years, while in polycyclic plantation the diameter maintains a strong constant growth rate for a longer period.

The relationship between age and DBH in polycyclic plantations (Graph 2), where the crown relies on assigned larger space, supported this result. In this case, the regression equation that better explained the relationship was a straight line (R^2=0.9255). According to the equation, it takes 6.7 years to I-214 plants to overcome 30 cm in diameter, a much shorter period than in traditional plantations (10 years). Moreover, if poplar can grow in polycyclic plantation for 10 years, I-214 plants could reach a higher diameter according to the regression curve, on average 46.2 cm. This result is slightly higher than what observed by Buresti *et al*. (2015) in a polycyclic plantation 11 years old in the area of San Matteo delle Chiaviche (Lombardia region).

Tables 3 and 4 show the values of diameter and crown area per age class obtained by the two equations. Considering that polycyclic plantations are designed to avoid the dramatic decrease of DBH growth rate that usually occurs in traditional plantations due to light competition, in Table 3 we added a column showing the gross productive area to be assigned to each plant. The gross productive area, which is higher than the net area, allows poplar to grow developing a larger, deeper, and better exposed to light crown than in traditional plantations. Tanks to such a higher available space, the decrease in DBH growth rate at age 5-7 can be avoided. The values of gross productive area shown in Table 3 are cautious and based on results coming from two plantations where harvested poplars had not reached the higher growth rate yet. In the first case (Buresti Lattes 2008), assigning to each poplar a gross productive area of 70 m^2, the plants reached a diameter of 34 cm in 7 years. The ratio between crown area and gross productive area was equal to 1.56, thus poplar plants had +56% of gross area than the area occupied by plants with the same diameter growing without any crown competition. In the second case (Buresti *et al.* 2008), plants reached a diameter of 45.2 cm with an available area of 110 m^2.The ratio between net and gross productive area resulted 1.44 (+44%). In both cases, when harvested, the poplars showed still a strong diameter growth rate[2]. Consequently, such data were not useful to define the value of gross productive area necessary to maximize the number of poplars per hectare and, thus, to get a given diameter in the shortest time as possible. We can just state that, to obtain 34 cm diameter,



Graph 1 - Relationship between DBH and crown area of poplar clone I-214 plants.



Graph 2 - Relationship between age and DBH of poplar clone I-214 plants in polycyclic plantations.

Age (years)	Measured plants (N)	DBH (r%)	Crown area (r%)
1	61	3	8,48
2	90	2,95	7,7
3	137	2,3	5,4
4	189	4,01	5,89
5	243	1,53	2,91
6	79	1,38	3,67
8	79	1,19	2,64
9	79	1,25	2,69

Table 2 - Sample size per age classes and statistic (random) error (r%).

***2)** The current annual diameter increment was equal to 4.08 cm (Buresti Lattes 2008) and 3.8 cm (Buresti Lattes et al. 2015) in plant of 7 and 11 years old, respectively.*

a gross productive area 56 % higher than the net productive area did not cause a dramatic decrease in diameter growth rate.

This is true also for the plants that reached a diameter of 45.2 cm that grew in a gross productive area higher +44%.In this last case we could verify that 11 years did not result a physiological limit to provide still a strong diameter growth rate in I-214.

By extrapolating data of the regression curve equation, we could add the last four lines in Table 4; in order to:

- highlight the potential of I-214 clone in terms of physiological limits to provide (1) a strong diameter growth and (2) the relationship between age, crown area, and DBH to be evaluated in future;
- compare our data with the pool data collected by AALSEA in another polycyclic plantation located in San Matteo delle Chiaviche (Mantova province) using a different clone (Neva; Table 5).

Considerations

Thanks to the new polycyclic plantations established by LIFE+ InBioWood (LIFE ENV/IT/000153) and to the others managed by AALSEA, it was possible to pool a great amount of data collected in the provinces of Mantova and Verona to study the relationship among age, diameter, net productive area and rotation length.

Buresti Lattes *et al.* (2015) showed that it is possible to grow trees with 45 cm in diameter and 110 m^2 of productive area[3] in 11 years. This study, focused of 5 plantations in different site conditions, showed that I-214 plants can grow maintaining high diameter increment beyond the 5-7 years if it is provided by a gross productive area higher that the traditional.

Our data could be refined in future; nevertheless, the high R^2 value obtained in this study indicated that it is possible to predict, to a good approximation, the net productive area to obtain a given diameter in a given time. The former parameter, and consequently the rotation, can vary according to soil fertility. Thus, in future, to be more precise, regression curves should be calculated according to soil fertility classes. However, considering the high R^2 values that we obtained and considering the fact that the studied sites are very favourable to poplar cultivation, real cases should not differ so much form the results of this study.

However, there are still some questions to answer in order to refine this new method to produce wood of poplar clone I-214. Thanks to the results of this study, it is possible to relate diameter and productive area, but it is not possible to predict precisely the relationship between net and gross productive area to be assigned in order to maximize the plant number per hectare maintaining at the same time a high diameter growth rate to the end of the rotation cycle. We made an effort to provide a first assessment,

Diameter (cm)	Crown area (net productive area) (m^2)	Gross productive area (+44%) (m^2)	Standard deviation (m^2)	Sample size (n.)
25	25,6	36,9	4,692	197
30	35,5	51,1	4,804	53
35	47,1	67,8	6,349	40
40	60,5	87,1	8,993	98
45	75,6	108,9	7,753	20
50	92,4	133,1		
55	110,9	159,7		
60	131,2	188,9		

Table 3 - Relationship between DBH and crown area, as a result of the polynomial equation of the regression curve. The central column (in red) shows the values of the gross productive area, which were calculated according to a prudential growth increment coefficient of 44% and which were considered enough to reach the corresponding diameter in the shortest time as possible (according to environmental site conditions).

Age (years)	Diameter (cm)	Standard deviation
1	2,5	0,57
2	7,3	1,12
3	12,2	1,67
4	17	3,89
5	21,9	2,68
6	26,7	1,73
8	36,5	1,99
9	41,3	2,28
10	46,2	
11	51	
12	55,9	
13	60,7	

Table 4 - Relationship between plant age and DBH, as a result of the equation of the linear regression. The last four lines (in red) were calculated extrapolating the values by linear regression equation.

Year	Age (years)	Diameter (cm)
2013	10	45,7
2014	11	46,7
2015	12	48,6
2016	13	52,5

Table 5 - DBH of the 105 plants of Neva poplar clone at different ages. To be noticed, the strong negative effect of high temperatures recorded in summer 2003 that led to hypothesize that the physiological limit of Neva has been attained; it highlights also the favourable effect of summer 2016, which showed that 13 years old plant can still be productive (3.9 cm of annual diameter increment)

***3)** In polycyclic plantations other plants, i.e., main trees at mid-long term and/or accessories, can be present at the same time in the same productive area.*

even though we were aware that the values are quite high. Anyway, we could rely only on the results coming from gross productive area values that have been already established by the legislation of Region Lombardia for tree farming (RDP 2007-2013: max 90 poplars per ha, thus, 110 m^2 per plant). This values were 44% higher than the net area needed to obtain 45.5 cm diameter at 11 years, and they were used to calculate the gross productive area in Table 4. As usually occurs, this study provided a useful answer to refine I-214 cultivation but, at the same time, it opened new questions, e.g.: is a gross productive area 44% higher than the net area excessive or adequate? If it is possible to reduce the gross productive area to be assigned to each plant, to what extent is it possible to reduce this value? To 20%? If it is realistic to decrease it to 30% or to 20%, could the cultivation of I-214 in polycyclic plantation lead to a financial balance lower or higher than what obtained following the traditional cultivation method? The answer to these questions will be the future challenge for technicians, researchers and professional involved in designing and managing tree farming and polycyclic plantations.

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Authors: Paolo Mori, *Compagnia delle Foreste. E-mail:* paolomori@compagniadelleforeste.it
Enrico Buresti Lattes, *AALSEA - Associazione Arboricoltura da Legno Sostenibile per l'Economia e l'Ambiente. E-mail:* segreteria@aalsea.it

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