DIAMETER DISTRIBUTION AND STOOL BIOMASS PARTITIONING IN A NATIVE BLACK POPLAR POPULATION AND IN A SELECTED HYBRID POPLAR CLONE UNDER SHORT ROTATION FORESTRY

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Poplars (*Populus* spp.) are widely used in short rotation forestry (SRF) where plantations are characterized by high stool and shoot density. At the end of the first rotation coppice (2010-2012), one native *P. nigra* provenance from southern Italy ("Ripiti" stream, Campania region) and one selected hybrid *P. xgenerosa* "Hoogvorst" clone were examined to describe stand structure and determine the dry biomass yield. Living shoots diameter distribution was analyzed with the two-parameter Weibull probability density function (PDF). Aboveground woody volume was estimated according to general formula and equivalent dry biomass was obtained via woody basal density. According to their heights the shoots were classified as dominant, intermediate and suppressed and dry biomass was estimated for each class. Using a two-parameter Weibull PDF it was possible to soundly describe diameter distributions of the two selected *Populus* species. Moreover, a different biomass partitioning pattern between the two species was observed in our experimental SRFs: black poplar allocated biomass between dominant and intermediate shoots, while in hybrid poplar this occurred mainly on dominant shoots. The observed partitioning pattern, which is most likely due to a contrasting (i.e. natural and man-made) selection history of the two species, might affect the biomass physical characteristics of wood and SRF plantation management.

Keywords: bioenergy crop, Weibull PDF, native black poplar, hybrids poplar clone, biomass partitioning.
Parole chiave: coltivazioni energetiche, funzione densità di probabilità Weibull, pioppo nero autoctono, pioppo ibrido, ripartizione biomassa.

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1. Introduction

Selected hybrid clones of the genus *Populus* are commonly utilized in short rotation forestry (SRF) crops of temperate and Mediterranean regions of Europe (Hoffmann-Schiell *et al.*, 1999; Van de Walle *et al.*, 2007; Pannacci *et al.*, 2009; Paris *et al.*, 2011). These crops are high density plantations with rotations shorter than 20 years (Mitchell and Ford-Robertson, 1992). Suitability of poplars to biomass production are related to their (i) high productivity level (ii), fast shoot growth and (iii) high resprouting ability (Ceulemans *et al.*, 1992). In recent years, there has been an increasing interest in poplars productivity and coppice growth models (Ceulemans *et al.*, 1996). Despite this, only few studies have attempted to investigate shoot diameter distribution and aboveground biomass partitioning between shoots (Laureysens *et al.*, 2003; Sandoval *et al.*, 2012).
According to Newton (2007), stand structure can be referred to distribution of tree sizes within a stand. Over the past two decades probability density function (PDF) has been emphasized as a suitable tool for diameter distribution modelling (Knoebell and Burkhart, 1991; Pretzsch, 2009). Many PDFs have been used to modelize tree diameter distribution, but mainly *Weibull* PDF has shown satisfactory results (Nord-Larsen and Cao, 2006; Carretero and Alvarez, 2013) due to its flexibility and adaptability to different distribution types. Several studies have estimated poplar biomass production under different growth conditions (among others Di Matteo *et al.*, 2010), and its partitioning among stem, branches and roots (Scarascia-Mugnozza *et al.*, 1997), whereas information about stool biomass partitioning are still insufficient. Throughout this paper, the term stool biomass partitioning will refer to distribution of dry weight between shoots within stool. Shoot stems are not uniform in size, although the even-aged stands show a narrow size range. Indeed, as the trees grow their number declines as a result of increased competition for resources and size differentiation occurs. The relationships between the individuals of a tree community are described by social categories and crown classes, according to their height and position (Oliver and Larson, 1996; Pretzsch, 2009).
Biomass production of SRF coppice stands depends on the number of alive shoots and their sizes (Laureysens *et al.*, 2005). Therefore, shoot size frequency distribution is essential to describe coppice stand structure whereas stool biomass partitioning according to crown classes permits to describe poplars biomass allocation patterns. Although extensive research has been carried out on

hybrids poplar plantations, only few studies describe the native *P. nigra* for short-rotation crops (Benetka *et al*., 2002).
The aim of this study is to investigate the stand structure and differences of biomass production under extensively managed short rotation coppice between *P. nigra* (native population ranged in the southern part of its natural distribution; Campania region, Cilento, "Ripiti" stream) and selected *Populus* clone (*P. xgenerosa* "Hoogvorst"). We assume that, by analyzing shoot diameter distribution and stool biomass allocation between shoots it would be possible to define the differences in size structure and related biomass of stools of the two selected poplar species, at the end of the first rotation coppice; these information might in turn be useful to support management of SRF.

2. Material and methods

2.1 Study area and management regime

The study site is located in the Regional Experimental Farm "Improsta" (Latitude 40° 33' 33.21'' N; Longitude 14° 50' 15,60'' E, 21 m a.s.l.) in the Campania Region, Southern Italy. Soil is characterized by a deep (80-100 cm) clay loam with low N-levels and organic matter concentrated in the upper layers.
Meteorological data from a nearby weather station, 3 km distant from the study site (Battipaglia,72 m a.s.l.), indicate a Mediterranean humid-type climate characterized, during the period of the present study (2010-2012), by a mean yearly temperature of 17.8 °C, mean annual cumulated precipitations of 1101.4 mm, and a summer drought period from June to September (14.7% of mean annual precipitations) with the highest mean monthly temperature in July (27 °C).
In April 2007 SRF plantations of different native and selected poplars were established on 3.04 ha. Cuttings were collected in a riparian native *P. nigra* population from different trees originated by seeds (gender undefined), while a hybrid "Hoogvorst" clone came from a nursery. The unrooted cuttings were first water-soaked for 48 hours and then planted mechanically in a single-row layout with 3.0 m inter-row and 0.5 m within rows distances, obtaining the density of 6,667 cuttings per hectare. After the 3-years cutting cycle (winter 2009), all trees were stumped back to 5 cm above ground level by cut and chips harvesting system to promote the single stool to become multi-stemmed.

2.2 Stool and shoot measurements

At the end of the first multi-stemmed rotation (2010-2012), following a systematic sampling criteria, ten stools located in the middle row of both *Populus* SRF plantations were chosen to measure shoot collar diameter (digital Vernier calliper) up to 5 cm above soil level and total shoot height (telescopic pole).
For the two poplars shoot form factor data were collected on three harvested shoot, classified according to their crown position related to maximum height. *Suppressed* crown layer includes shoots with height <50%, *intermediate* layer shoots between 50% and 70% and *dominant* layer shoots between 80% and 100% of the maximum height of stool. Stem volume of individual shoots, previously separated from branches, was determined by using section method following the *Huber* formula.
The corresponding oven-dry branches biomass was determined by leaving the fresh wood material in oven and dried at 65 °C for several days, until the weight of the dried material remained constant. Wood basal density (wood dry weight for fresh volume unit) was determined on proximal, medial and distal stem samples of the two *Populus*. The fresh volume of each sampled stem was determined by water immersion. Wood basal density of distal sample and its inverse formula, was therefore used for dry biomass-volume conversion of branches and calculation of absolute form factor including branches. In order to estimate the volume of SRF stands V was estimated by the following equation (La Marca, 2004):

$$V = G \cdot H_m \cdot F_m$$

where total basal area G is the actual density of plantation after first coppicing, H_m is the mean regressed height of quadratic mean diameter and F_m is the mean absolute form factor of shoots. Finally, coppice stand volume per hectare was converted in dry biomass via wood basal density.

2.3 *Models and data analysis*

Two-parameters *Weibull* PDF used to characterize the diameter distribution of the coppice stand has the following form:

$$f(d \| \alpha, \beta) = \beta \cdot \alpha^{-\beta} \cdot d^{\beta-1} \cdot e^{-\left(\frac{d}{\alpha}\right)^{\beta}};$$

$$\beta > 0, \alpha > 0, 0 < d < \infty,$$

where α is the scale, β is the shape parameter and d the shoot collar diameter, measured at 5 cm above the soil level. As its name suggests, β describes the shape of *Weibull* PDF. This parameter is the key of flexibility of the distribution, because it permits to cover most of the shapes of diameter distribution (Nord-Larsen and Cao, 2006). Weibull function parameters were estimated for both poplars adopting the maximum likelihood (MLE) method (Zarnoch and Dell, 1985; Cao, 2004). One sample Kolmogorov-Smirnov (D_{ks}) statistic test (Zar, 2010) was performed at 0.05 α level. Critical value for this test was referred to cut-off value (CV) used for determining if statistic D_{ks} is significant at a specified level. Finally, the accuracy of Weibull function was assessed according to the root mean square error (RMSE). Means of shoot density and dry biomass production of the two *Populus* SRFs were compared by a Student's test for independent groups. Aboveground biomass partitioning among shoot crown classes was analyzed by one-way ANOVA. Newman-Keuls (N-K) multiple range test was applied to detect differences in biomass production among classes. All tests were considered significant when p-value was <0.05. Data management and statistical analysis were carried out using *STATISTICA* 6.0 (STATSOFT INC., 2001).

3. Results

Two-parameters *Weibull* PDF of live shoot diameters (*d*) at the end of the first rotation coppice are reported in Figure 1. Based on one-sample goodness of *Kolmogorov-Smirnov* fit test, *d* came from a two-parameters *Weibull* PDF ($p < 0.05$), for both poplars.
For both poplars the scale α and shape β parameters and statistics of fit are shown in Table 1. Parameters were estimated with more exactitude as shown by its standard error (ES), which in turn was affected by the difference of one order of magnitude in the number of live shoots per stump between the two poplars (see also below).
The shoot size distribution of hybrid "Hoogvorst" clone was negatively skewed (*Skewness* = -0.71 ±0.39) and left tailed, while black poplar "Ripiti" population showed a right tail with positive skew (*Skewness* 1.62 ±0.17). Moreover, the kurtosis of the distributions ranged from platikurtic (*Kurtosis* = 0.92 ±0.76) to leptokurtic (4.17±0.34) for "Hoogvorst" and "Ripiti", respectively.
Aboveground cumulated three years woody dry biomass (stem + branches) production did not show significant differences between the two poplars ("Hoogvorst" 20.12 Mg ha^{-1} and "Ripiti" 18.92 Mg ha^{-1}; t = 0.248, df =19, p = 0.86). Statistically significant difference was revealed, instead, for the number of shoots per stump ("Hoogvorst" 11,067 shoots ha^{-1} and "Ripiti" 113,729 shoots ha^{-1}; t = -5.329, df = 19, p = 0.000). The distribution of aboveground dry biomass according to crown classes (Fig. 2) indicates significant differences among strata within each species. "Hoogvorst" hybrid clone accounted for 96.32% of biomass in dominant shoots, while black poplar "Ripiti" for 65.19% and 31.39% in dominant and intermediate shoots, respectively.
In *P. nigra* "Ripiti" population branches biomass fraction accounted respectively for about 28.89% and 9.29% of dominant and intermediate shoot biomass, while the "Hoogvorst" hybrid clone showed about 18.22% of branches biomass only on dominant shoots. In both cases, branches biomass of suppressed shoots accounted for less than 1% of total shoot biomass.

4. Discussion and conclusion

The insight of tree diameter distribution aids to make management decision (Cao, 2004), because it describes stand structure accurately (Bullock and Burkart, 2005). Diameter distribution is used to define other important variables such as basal area, volume and biomass of the stand and permits to evaluate the appropriate technologies of SRF harvesting (Petráš *et al.*, 2010). At the end of a third year of first SRF rotation, the current analysis permits us to analytically describe living shoots diameter distribution of hybrids and native poplars by means of a two-parameter Weibull PDF. Our result agrees with those reported by Sandoval *et al.* (2012), which, although using different PDF models, show that shoot diameter distribution under SRF plantation is also well described through Weibull PDF.
The analysis of frequency diameter distributions outlined the existence of shoots size inequality between the two studied species. In fact the native black poplar "Ripiti" showed a frequency diameter distributions left skewed because of high frequency of small suppressed shoots whereas hybrid "Hoogvorst" poplar was right skewed due to high mortality of suppressed shoots; hence cumulative shoot mortality, due to competition and insect predation processes in the starting shoot cohorts of the first rotation, was 72% for "Hoogvorst" clone, while for "Ripiti" it was 37%.
As a result, the black poplar coppice stand was characterized by stools with high number of shoots and low size differentiation, while hybrid poplar showed low number of shoots with high size differentiation. Consequently, the greater contribution to stool dry biomass was made by dominant shoots for hybrid "Hoogvorst" clone, while suppressed shoots remained always numerically lower and showed only a low contribution to stool biomass. In the black poplar "Ripiti" population both intermediate and dominant shoots contribute to dry biomass with preponderance of dominant shoots. The greater shoots have been identified as major contributing components to stool biomass production in SRF plantation of poplar hybrids (Auclair and Bouvarel, 1992; Laureysens *et al.*, 2003).
At the end of first rotation coppice, the aboveground dry biomass ranged from 20.12 Mg ha^{-1} to 18.92 Mg ha^{-1}, equivalent to mean annual increment of 6.71 Mg ha^{-1} yr^{-1} and 6.31 Mg ha^{-1} yr^{-1} for "Hoogvorst" and "Ripiti", respectively. These production levels range within the values found in other poplars SRF plantation studies. Annual yields of 1.3-24 Mg ha^{-1} have been reported for various poplar clones under different growth conditions, i.e. soil, climate and management regime (Niakoudjomo *et al.*, 2015). Moreover, two different coppice stool models can be documented in the present study: *i*) a hybrid "Hoogvorst" poplar clone with dry biomass mainly concentrated on high dominant shoots (80-100% of H_{max}), partitioned on a low number of shoots (2.3 shoots $stump^{-1}$) with low branches biomass. On the other hand, *ii*) black poplar "Ripiti" showed a higher number of low shoots (21 shoots $stump^{-1}$) and biomass was partitioned both on dominant and intermediate shoots. In addition, black poplar allocated biomass near-equally between dominant and intermediate shoots while hybrid poplar clones allocated biomass mainly on dominant shoots.
This different pattern is most likely due to a different selection history which characterizes the two poplars. Man-made selection of hybrids poplar clones is based mainly on the existence of an enhanced heterosis (i.e. hybrid vigor) directed toward high single and straight stem production rather than toward resprouting ability (Laureysens *et al.*, 2003).

Conversely, black poplar is a pioneer species growing along riparian forests characterized by frequent physical disturbances such as flooding (Barsoum, 2000; Corenblit *et al.*, 2013). Therefore, our analysis confirms the high resprouting ability of native black poplar populations and the existence of a weak shoot hierarchy in the following years after disturbance. Considering that sizes and stool biomass partitioning influence harvesting systems and physical traits of biomass, the current analysis suggests that operation cutting should be calibrated according to shoot size and, as a consequence, different for the studied species. In fact dead biomass, due to shoot mortality, was higher in "Hoogvorst" than "Ripiti" and likely affecting biomass quality. Moreover, the higher number of shoots per stool, which characterize native *P. nigra* "Ripiti" population, is linked to their high branches biomass fraction suggesting a high bark fraction in harvested biomass.
Finally, selection criteria of SRF poplar species should take into account the high resprouting ability that characterize different native *P. nigra* populations and their pattern of biomass allocation.

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Table 1. Summary of parameters and fit statistics of estimated Weibull PDF model for shoot diameters at the end of the first rotation coppice (2010-2012) in "Hoogvorst" and "Ripiti" poplars. Parameters α and β represent respectively the scale and the shape of Weibull PDF. In brackets their standard error. The statistics of fit are Kolmogorov-Smirnov statistic D_{KS}, critical value of test D_α, root mean square error RMSE and *p*-value, respectively.
Tabella 1. Parametri e statistiche della *Weibull* PDF a due parametri al termine del primo ciclo ceduo (2010-2012) dei pioppi "Hoogvorst" e "Ripiti". α e β rappresentano rispettivamente il parametro di scala e il parametro di forma della funzione *Weibulll* PDF. In parentesi sono riportati i valori dell'errore standard. Le statistiche sono il valore del test di Kolmogorov-Smirnov D_{KS}, il valore critico del test D_α, la radice dell'errore quadratico medio RMSE e il livello di significatività *p*, rispettivamente.

Species/clone	*Name*	α	β	D_{KS}	D_α	*RMSE*	*p*
Populus xgenerosa	Hoogvorst	4.48 (±0.19)	3.97 (±0.53)	0.0717	0.218	0.016	0.011
Populus nigra	Ripiti	1.87 (±0.07)	1.96 (±0.09)	0.0810	0.093	0.025	0.012

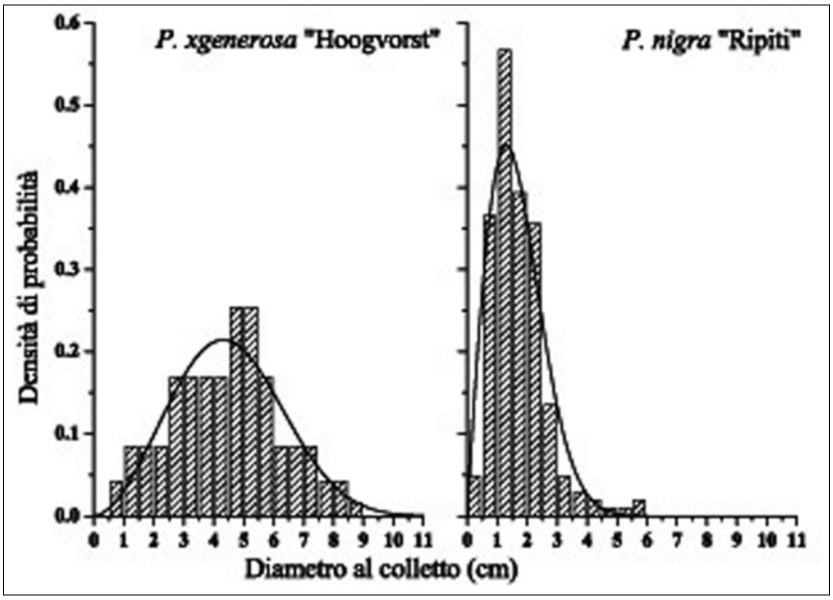

Figure 1. Shoot diameter (0.5 cm size-class) distribution (columns) and two-parameter Weibull PDF (line) for native *Populus nigra* "Ripiti" population and hybrid *Populus xgenerosa* "Hoogvorst" clone at the end of the first rotation coppice (2010-2012).
Figura 1. Distribuzione diametrica dei polloni (colonne, classi diametro 0.5 cm) e funzione *Weibull* a due parametri (linea) di *Populus nigra* "Ripiti" e *Populus xgenerosa* "Hoogvorst" al termine del primo ciclo ceduo (2010-2012).

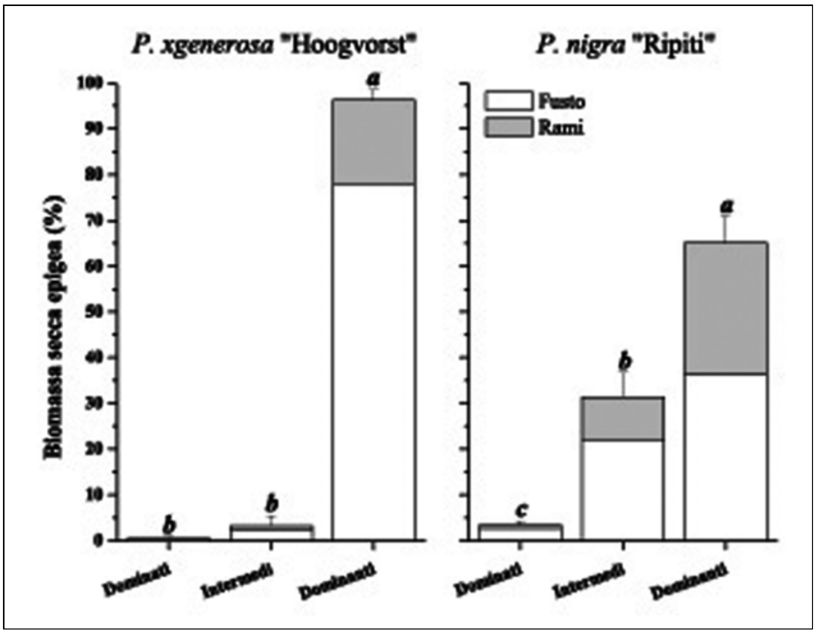

Figure 2. Stool dry biomass (%, mean and standard error) partitioning between shoot crown classes and stem and branches. Dominant (80-100% of H_{max}), intermediate (50-80% of H_{max}), and suppressed (<50% of H_{max}) strata are classified according to maximum height recorded on the stool. Letters indicate significant differences among strata according to Newman-Kuels multiple range test, $p<0.05$.
Figura 2. Ripartizione biomassa secca sulla ceppaia (%, media e errore standard) fra classi dimensionali di polloni e rami e fusto. Gli strati dominanti (100-80% of H_{max}), intermedi (50-80% of H_{max}) e dominati (<50% of H_{max}) sono stati definiti sulla base dell'altezza massima di ogni ceppaia. Le lettere indicano differenze significative tra gli strati secondo il test di confronto multiplo di Newman-Kuels, $p<0.05$.

RIASSUNTO

Distribuzione diametrica e ripartizione della biomassa in un pioppo nero autoctono e in un pioppo ibrido selezionato cresciuti in ceduo a turno breve

I pioppi (*Populus* spp.) sono largamente impiegati in piantagioni ad elevata densità quali sono i cedui a turno breve. Un pioppo nero autoctono (*P. nigra*) dell'Italia meridionale (torrente "*Ripiti*", Campania) e un pioppo ibrido selezionato "*Hoogvorst*" (*P. xgenerosa*) sono stati confrontati,al termine del primo ciclo ceduo (2010-2012), con l'obiettivo di descrivere la struttura dimensionale del soprassuolo e la produzione cumulata di biomassa epigea. La distribuzione diametrica dei polloni sopravvissuti è stata analizzata mediante la funzione densità di probabilità *Weibull* a due parametri. Il volume legnoso epigeo è stato determinato mediante la formula generale e convertito in biomassa secca attraverso i valori di densità basale corrispondenti. I polloni di ogni ceppaia sono stati classificati in funzione dell'altezza massima in dominanti, intermedi e dominati, ed è stata determinata la biomassa secca corrispondente. In entrambe le specie la distribuzione diametrica può essere descritta attraverso una *Weibull* PDF a due parametri, mentre si osserva una differente modalità di ripartizione della biomassa tra il pioppo nero "*Ripiti*" e il pioppo ibrido "*Hoogvorst*". Nel primo caso la biomassa secca è distribuita prevalentemente fra polloni delle classi dominanti e intermedie, nel secondo, invece, è concentrata principalmente sui polloni della classe dominante. Tale differenza è riconducibile a differenti percorsi evolutivi che hanno interessato i due pioppi studiati: uno naturale per il pioppo nero e l'altro operato dall'uomo per il clone ibrido.

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