Cent. Eur. J. Biol. • 5(4) • 2010 • 522–530
DOI: 10.2478/s11535-010-0028-y

VERSITA

Central European Journal of **Biology**

Identification of the main site factors and management intensity affecting the establishment of Short-Rotation-Coppices (SRC) in Northern Italy through Stepwise regression analysis

Research Article

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Received 9 November 2009; Accepted 17 February 2010

Abstract: Data collected from 183 poplar and 102 willow SRC experimental plots, located in Central-North Italy, were subjected to stepwise regression analysis to acquire information on the environmental factors affecting plant survival and productivity in the first two-year rotation cycle. Nine *Populus ×canadensis* Mönch, eight *P. deltoids* Bartr. clones and four hybrids of *Salix matsudana* Koidz were included in analysis. Independent variables were: annual and seasonal water availability (rainfall and irrigation), annual mean air temperature, soil texture, pH, N and organic matter content, planting density and management intensity. Dependent variables were: a) mean annual yield during the first two-year rotation cycle in tons per hectare per year of dry matter (Odt·ha^{-1}·y^{-1}); b) plant survival at the end of the second year from planting (%). Water availability resulted the main variable driving plant survival and biomass production in both poplar and willow clones. Water availability appeared to be the principal factor affecting the establishment of poplar and willow energy plantations in the Po valley. Possible variations in the rainfall regime consequent to climate changes could seriously influence land suitability to SRC. Experimental data also indicate that choice of planting density may increase the biomass yield during the first two-year especially with *P. deltoides* clones.

Keywords: *Biomass production • Poplar • Willow • Short rotation coppice • Soil texture • Climate factors • Soil nutrient contents*

1. Introduction

Biomass from short rotation coppice (SRC) is one of the possible alternatives to fossil fuels in Europe. Poplar and willow SRC plantations can produce large amounts of dry matter in a relatively short time (e.g. 1-2 years) maintaining their yield capacity throughout many years [1].

During the last 5 years about 6000 hectares of energy plantations (Short-Rotation-Coppices, SRC) have been established in Italy, mainly in the Po valley, where biomass thermoelectric power plants are under construction, and the Regional Programs for Rural Development included a series of financial incentives to support the establishment and maintenance of SRC. The planted species were those recommended for the North and Central Italy by the National guidelines for energy plantations [2,3] namely poplars (*Populus*

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spp.) followed by willows (*Salix* spp.) and black locust (*Robinia pseudoacacia*). However, the productivity of these plantations appeared much variable, ranging from 3-4 to 15-20 oven dry $t \cdot ha^{-1} \cdot year^{-1}$ ($Odt \cdot ha^{-1} \cdot y^{-1}$) in the first rotation cycle also with the same poplar and willow clones [4,5]. A high variability is reported for poplar and willow SRC in other European Countries [6,7]. Even if research initiatives concerning clone/provenance selection for biomass production have been successfully implemented in Italy [8-10] and in Europe [11-13], this wide variability suggests that the importance of factors different from the genetic characteristics of the planting material has been underestimated such as site characteristics that influence tree growth by the local climate and soil. Management regime may be crucial for attaining high yields [1]. Therefore, it is necessary to deepen the knowledge concerning the ability of adaptation of poplar and willow clones to the different environmental conditions and cultural techniques (manuring and irrigation) in order to select generalist clones with elevated biomass production across the country and specialist clones with exceptional biomass production at specific location. This is important especially for bioenergy plantations [14].

The rapid establishment of the plantations favors the economic return of the investments while a great uncertainty regarding productivity remains and obstacle to economic evaluations as well as the estimation of the actual profitability of the investments. Therefore, for a reliable planning of energy plantations in Italy, deeper information on site and cultivation factors affecting the productivity of the selected species/clones are still needed.

The aim of this paper is to provide information on the main features of the site as well as the management intensity that affect tree survival and biomass production in the first 2-year rotation cycle of SRC plantations based on observations of 183 poplar and 102 willow SRC experimental plots primarily located in the Northern Italy.

2. Experimental Procedures

Plantations considered in the present study belong to 11 different experimental trials established in the years from 1996 to 2005 at six sites (Table 1) located in the Po valley (C.M.; C.P.; CAV; G.B. and LOM) and central Italy (Pisa). The C.M. site included 4 experimental trials. The C.P., CAV and G.B. sites included 1 experimental trial each, while both LOM and PISA sites included 2 experiments. All the plantations are in flat areas on deep, alluvial and former agricultural soils. Poplar and willow clones introduced in the trials were selected by the CRA-PLF (former Poplar Research Institute) of Casale Monferrato (Italy).

Two groups of poplar clones from different origins were included in this research (Table 2) and namely (a) *P. ×canadensis* Mönch hybrids: 'I 214', 'BL Costanzo', 'Cima' , 'Luisa Avanzo', 'Lambro', 'Orion', '83.039.009', '83.039.018', '83.148.020'; (b) *P. deltoides* Bartr. genotypes 'Lux', 'Dvina', 'Lena', 'Oglio', 'Baldo', '80-020', '84-078', '85-037'. The following willow clones derived from free pollination of *S. matsudana* Koidz. isolated trees (*S. matsudana* × *?*) were included in the study: 'S78-003', 'Drago', 'Levante', 'S76-008'.

The fields were ploughed to 30 or 40 cm depth and harrowed before planting. Poplar and willow unrooted cuttings, 20 cm long, with diameter between 15 and 23 mm, were used. Planting was carried out with semi-automatic mechanical planters or by hand according to the dimensions of the plantation. Planting density ranged from 5747 to 10000 $plants \cdot ha^{-1}$.

In all studied plots, post-planting residual herbicides (Pendimethalin and Metolachlor) were applied to prevent germination of annual weeds for 30-40 days after planting. In the first year of planting, three or four disc harrowings were carried out between the lines during the summer. During the second year cultivation practices were reduced; only weed control was done by disc harrowing in late spring.

Cultural practices applied on experimental trials are showed in Table 3. Poplar and willow clones were arranged in plots with 2-8 replications for each plantation.

Locality		Latitude	Longitude	Elevation m a.s.l	Soil Texture
Casale Monferrato	(C.M.)	45° 08' N	08° 27' E	116	Sandy-loam
Caramagna Piemonte	(C.P.)	44° 47' N	07° 44' E	262	Sandy-loam
Lombriasco	(LOM)	44° 51'-N	07° 38' E	240	Silty-loam
Cavallermaggiore	(CAV)	44° 43' N	07° 41' E	285	Sandy-loam
Gazzo Bigarello	(G.B.)	45° 11' N	10° 54' E	23	Clay
Pisa	(PISA)	43° 43' N	10° 24' E	9	Loam

Table 1. Geographical coordinates, elevation and soil texture at the experimental sites.

Nr.	Site	Planting year	Planting density plants ha^{-1}	Rep. n .	Nr. of plant per experimental plot	Species/Clones *P. x canadensis*	*P. deltoides*	*S. matsudana* × ?
1	C.M.	2005	8333	4	48	83.039.018 Orion	85-037	Drago Levante S76-008
2	C.M.	2004	8333	3	100	I-214		Levante
3	C.M	2004	8170	3	100			Levante S76-008
4	C.M.	2002	10000	8	25	I-214 83.039.009 83.039.018 83.141.020 Orion	Oglio 84-078 80-020 85-037 Baldo Lambro Lena Dvina	S78-003 Drago Levante S76-008
5	C. P.	2005	8333	3 3	100	83.039.018 Orion	85-037	Drago Levante S76-008
6	CAV	2005	8333	3	75	83.039.018 Orion	85-037	Drago Levante S76008
7	G.B.	2004	8333	4	100	Orion Lux 85-037	Baldo Drago Levante S76-008	S78-003
8	LOM	2005	8333	3	125	83.141.020		S76-008
9	LOM	2004	5747	3	100	I-214 Orion	84-078 Baldo 85-037	S78-003 Drago Levante S76-008
10	PISA	1994	5714	2	1000	BL-Costanzo Cima Luisa Avanzo	Lux	
11	PISA	1994	7142	2	1000	BL-Costanzo Cima Luisa Avanzo	Lux	

Table 2. Planting year, density, number of replication (Rep. n), plot dimension and species/clones in the experimental plantations.

Site Nr.	Ploughing	Establishment Harrowing (n)	Basic fertilization	Chemical weed* control (n)	Mechanical weed control (n) I year	II year	Pest control (n) I year	II year	Irrigation (mm) I year	II year	Fertilization
1	30 cm dept.	1	manure (50 t·ha^{-1})	1	3	2	4	1	60	60	-
2	30 cm dept	1	manure (50 t·ha^{-1})	1	3	1	5	5	150	120	-
3	30 cm dept.	1	manure (50 t·ha^{-1})	1	3	1	5	5	150	120	-
4	30 cm dept	2	manure (60 t·ha^{-1})	1	4	2	2	2	42	366	-
5	40 cm dept.	1	-	1	3	2	1	-	80	80	-
6	40 cm dept.	1	-	1	3	3	2	2	80	80	-
7	30 cm dept.	1	-	1	3	2	1	1	80	80	-
8	40 cm dept	1	-	1	3	2	1	1	-	-	-
9	40 cm dept.	1	-	1	4	2	2	1	-	-	-
10	30 cm dept.	2	8.24.24 (450 kg·ha^{-1})	1	4	1	-	-	-	-	urea 100 kg·ha^{-1}
11	30 cm dept.	2	8.24.24 (450 kg·ha^{-1})	1	4	1	-	-	120	120	urea 100 kg·ha^{-1}

Table 3. List of the most important cultural practices that were applied in the experimental trials: number of operation and material utilized.

**Pendimethalin (800 g·ha^{-1}) and Metolachlor (1700 g·ha^{-1})*

Rotation length was 2 years. Table 2 reports planting year and density as well as the number of replication, number of plants included in each experimental plots and the species/clones at each site.

Soil and climate data, as well as plant survival and biomass production, were estimated at each site. Soil analyses were performed on bulk-samples collected at the depth of 25-30 cm. The number of sub-samples varied in each site according to the expected soil heterogeneity. The measured parameters were texture, pH (in H_2O), Kjeldahl N and organic C content using the Lotti method [15].

Meteorological data were recorded from weather stations located at the planting site or in other representative areas. Meteorological parameters considered in the study were mean annual air temperature, annual rainfall and rainfall during the growing season (from April to September). These parameters were determined for the first and second year after planting.

The cultivation parameters included in the analysis were: planting density (tree ha^{-1}), fertilization and irrigation. Quantities of water (mm) received with irrigation during first and second years were introduced in the analysis added to rainfall. Fertilization was considered a dummy variable.

Biomass production was estimated using the method proposed in "Mensurational variables Protocol" [16] and Verwijst & Telenius, 1999 [17]. To obtain the dry weight, the samples (stem and branches without leaves) were oven dried at 103±2°C to constant weight. These data were used to define the relationship: $Y= aX^b$ [18] following the method reported by Verwijst and Telenius [17] where Y is the shoot dry weight (in grams) and X is the stem diameter (in mm) at 1.30 m. Clone productivity was estimated by averaging the replications included in each plantation. Measures were repeated at the end of the first and second year from planting. Predictor variables included in the analysis were chosen according to literature [19-22]; data ranges

Independent Variable		*P. ×canadensis*		*P. deltoides*		*S. matsudana × ?*	
		Range	Mean	Range	Mean	Range	Mean
Climate							
WATER1	annual rainfall + irrig. (mm) in the 1st year	647-1068	824	620-1068	863	606-1068	755
WATER2	annual rainfall + irrig. (mm) in the 2nd year	614-860	754	693-860	774	613-860	712
SWATER1	cumulative rainfall + irrig. (mm) in the 1st growing season	316-612	473	305-612	471	305-612	431
SWATER2	cumulative rainfall + irrig. (mm) in the 2nd growing season	305-533	454	377-533	459	377-533	452
CUMANNW	cumulative annual rainfall + irrig.(mm) of 1st and 2nd year	1311-1928	1578	1311-1928	1636	1253-1545	1466
CUMSEAW	cumulative rainfall + irrig. (mm) of 1st and 2nd growing season	701-1145	905	701-1145	930	701-1145	883
ANNTEMP1	mean annual temperature (°C) of the first year from planting	12.5-15.5	13.4	12.5-15.5	13.1	12.5-13.2	12.7
ANNTEMP2	mean annual temperature (°C) of the second year from planting	12.5-14.7	13.5	12.5-14.7	13.1	12.5-13.4	12.9
Soil characteristics							
SAND %	percent sand	21-87	59	21-87	58	21-87	59
SILT %	percent silt	9-53	28	9-53	26	9-53	25
CLAY %	percent clay	3-41	14	3-41	17	3-41	16
pH	soil pH value	5.6-8.0	7.1	5.6-8.0	7.3	5.6-8.0	7.2
TOT N	total soil Nitrogen (g/kg)	0.1-1.0	0.4	01-1.0	0.4	0.1-1.0	0.5
OC%	percent organic carbon	0.6-5.8	2.1	0.6-5.8	2.6	0.6-5.8	2.8
Management							
PLD	planting density (plants ha^{-1})	5714-10000	8046	5714-10000	8338	5747-10000	8172
FERT	fertilization (0= non fertilized, 1= fertilized)	0-1		0-1		0-1	

Table 4. Range and mean values of environmental and management factors measured in the experimental plantations.

Nr	Clone	*P. ×canadensis*		Clone	*P. deltoides*		Clone	*S. matsudana × ?*	
		Survival (%)	yield (odt·ha^{-1}·yr.$^{-1}$)		Survival (%)	yield (odt·ha^{-1}·yr.$^{-1}$)		Survival (%)	yield (odt·ha^{-1}·yr.$^{-1}$)
1	83.039.018	80	5.50	85-037	23	3.70	Drago	53	6.20
	Orion	85	7.95				Levante	62	8.00
							S76-008	63	4.65
2	I-214	86	3.45				Levante	83	4.70
3							Levante	89	6.45
							S76-008	91	6.70
4	I-214	89	8.35	Oglio	68	14.05	S78-003	97	14.75
	83.039.009	95	10.15	84-078	81	13.90	Drago	93	19.15
	83.039.018	96	10.30	80-020	62	10.85	Levante	98	14.80
	83.141.020	94	12.65	85-037	84	16.10	S76-008	98	11.00
	Orion	96	16.95	Baldo	81	17.45			
				Lambro	63	9.50			
				Lena	81	14.20			
				Dvina	69	11.75			
5	83.039.018	95	8.35	85-037	69	7.80	Drago	95	10.30
	Orion	99	10.85				Levante	92	13.45
							S76-008	98	13.70
6	83.039.018	83	5.55	85-037	55	5.45	Drago	96	10.55
	Orion	89	8.65				Levante	86	9.50
							S76-008	85	11.10
7	Orion	100	3.30	Baldo	100	5.90	S78-003	97	2.90
				Lux	85	4.30	Drago	89	0.30
				85-037	98	4.00	Levante	90	1.15
							S76-008	95	1.85
8	83.141.020	66	1.25				S76-008	94	3.50
9	I-214	96	4.35	84-078	90	6.00	S78-003	98	3.65
	Orion	96	4.46	Baldo	92	4.75	Drago	97	6.60
				85-037	92	5.45	Levante	92	7.50
							S76-008	99	5.25
10	BL-Costanzo	60	3.25	Lux	84	7.05			
	Cima	90	4.55						
	Luisa Avanzo	98	5.55						
11	BL-Costanzo	81	4.45	Lux	90	7.10			
	Cima	97	5.70						
	Luisa Avanzo	97	6.25						
	Mean	88.3	7.01		78.0	8.84		89.2	7.91
	S.D.	11.6	3.61		18.5	4.60		12.2	4.83

Table 5. Average of survival (%) and yield (odt·ha^{-1}·y^{-1}) of species/clones at the end of the second year from planting in each site.

and means are shown in Table 4 separately for the considered species/hybrids.

The recorded information was processed through the stepwise regression procedure included in the SPSS 13.0 statistical package using percent plant survival (%) as well as the average biomass production measured at the end of the second year from planting for each clone and experimental trial. The package was utilized to calculate an average annual production (odt·ha^{-1}·y^{-1}) (Table 5) as a dependent variable and the corresponding soil, climate and cultivation data as predictors. For poplar, regression was run separately for the two sets of clones included in the study (*i.e.* clones belonging to *P. ×canadensis* and *P. deltoides* group). The beta standardized coefficient has been taken as representative of the relative weight of predictor variables selected by the stepwise procedure.

3. Results and Discussion

Table 5 reports survival percentages (%) and yields (odt·ha^{-1}·y^{-1}) measured in the experimental plots. *Salix* and *P. ×canadensis* exhibited the higher survival, with a mean of 89.2 and 88.3% respectively, while *P. deltoides* clones reached a mean survival of 78.0%. These data confirm the relatively scarce rooting ability of *P. deltoides* cuttings already stated by Ronald *et al.* [23], and particularly of the “85-037” clone. Rooting ability may be improved by using suitable planting material, sufficient

SPECIES	DEPENDENT VARIABLE	PREDICTORS	BETA STANDARDIZED COEFFICIENT	ADJUSTED R^2	F VALUE OF THE REGRESSION
P. ×canadensis	SURV %	-	-	-	-
	BIOYLD	CUMSEAW	0.750**	0.541	26.96***
P. deltoides	SURV %	CLAY	0.971***	0.682	16.04***
		CUMANNW	0.427*		
	BIOYLD	WATER1	0.561***	0.826	35.67***
		CUMSEAW	0.397*		
S. matsudana ×?	SURV%	-	-	-	-
	BIOYLD	SWATER1	0.787***	0.619	37.41***

Table 6. Results of Stepwise regression analysis for *P. ×canadensis, P. deltoides* and *S. matsudana ×?*.

**:0.05*
***:0.01*
****:0.001*

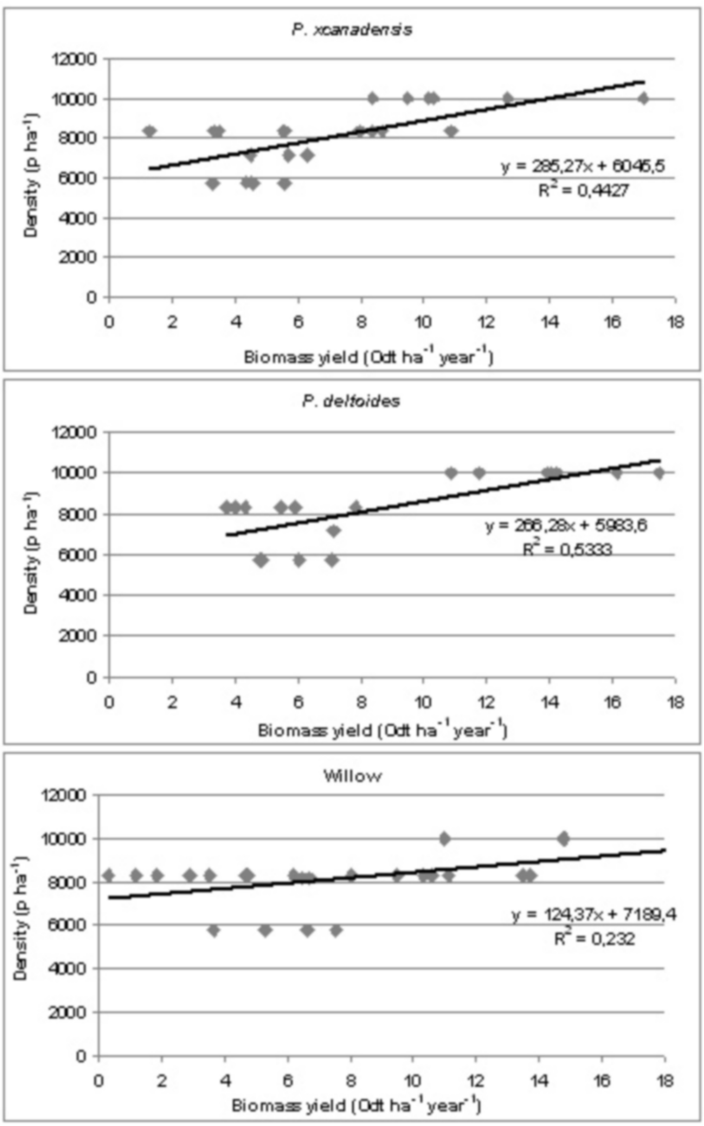

Figure 1. Response of different planting density in terms of biomass productivity for *P. ×canadensis, P. deltoides* and willow.

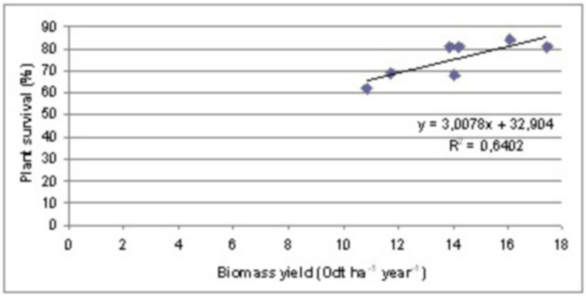

Figure 2. *P. deltoides*: relationship between survival percentage and biomass yield.

hydration, planting in well prepared soil and avoiding weed competition especially in the first 2-3 month of growth. Mean yield was 8.8, 7.9 and 7.0 odt·ha^{-1}·y^{-1} for *P. deltoides*, *Salix* and *P. ×canadensis*, respectively. The highest yield values were found in plantation nr. 4 at Casale Monferrato site with willow clone 'Drago' (19.15 odt ha^{-1} y^{-1}), *P. deltoides* clone 'Baldo' (17.45 odt ha^{-1} y^{-1}) and *P. ×canadensis* clone 'Orion' (16.95 odt·ha^{-1} y^{-1}). Among poplar clones *P. deltoides* 'Baldo' and *P. ×canadensis* 'Orion', recently patented in EU, had the highest mean yields in the most part of the trials. On the other hand, in the present study the above mentioned poplar clones evidenced low yields in plantations nr. 7 and 9 (Table 5). The new poplar clones (*i.e.* 'Baldo', 'Orion', 'Oglio', '84-078', '83.039.018') performed better than the old commercial clones ('I-214', 'BL Costanzo'). The four willow clones produced similar yields in dry biomass compared between them; but, excluding the site n° 7 where they has been damaged from hares and wild rabbits, they produced higher yields compared to the best performing poplar clones. These figures are comparable to those recently reported for SRC with poplar and willow in Northern Europe [24,25], Canada [26] and Italy [27,28].

Tables 6 reports the results of the stepwise regression analyses carried out for *P. ×canadensis*, *P. deltoides* and willow clones. The sum of rainfall and irrigation, expressed as cumulative water availability of the first two years (CUMANNW) appears the main factor driving plant survival in *P. deltoides*. Only one soil characteristic, clay percentage (CLAY%), was also selected as a predictor by stepwise analysis; however, clay content is related to soil water availability.

As *P. ×canadensis* and willow are concerned, the statistical procedure did not find any significant relationship among survival and the independent variables, while *P. deltoides* shown a relatively high correlation, with an adj R^2 of 0.682. These results also may be attributed to the already mentioned low rooting potential of *P. deltoides* cuttings that makes this species more sensitive to water availability during the establishment phase [23]. In the first site, the low survival rate of clone 85-037 would be avoided with a sprinkler irrigation (25 mm) immediately after planting.

Water availability during the first two years after planting, expressed as both annual (WATER1) and during the growing season (SWATER1, CUMSEAW), was the main factor influencing biomass production in the first rotation cycle with all the tree species tested in the present study. As already underlined for survivorship, *P. deltoides* clones exhibited a stronger correlation with production, showing an adj R^2 of 0.826, followed by willow (adj R^2 = 0.619) and *P. ×canadensis* clones (adj R^2 = 0.541).

The soil characteristics were not selected as predictors because all the soil considered have a texture adapted to both poplar and willow SRC plantations [22]. On the other hand, it is well known that soil texture and organic matter content may interact with plant growth influencing soil structure and hydrological characteristics. These results are supported by other studies that stressed the importance of water availability for poplar and willow growth in SRC [13,21,29,30].

Some authors reported a correlation between willow production and air temperature using growing degree days [30]. In the present trials, no correlation was found between production and annual mean temperature; nevertheless, Kopp *et al.* [30] reported their results starting from the 4th year, while this work regards only the first two years from planting. No correlation between production and fertilization was found according to Kopp *et al.* [30] and Hofmann-Schielle *et al.* [20]. Fertilization is a difficult factor to evaluate: the effects can depend on quantity of nutrients, soil type, water availability and root development [20].

The response of different planting densities in terms of productivity is shown in Figure 1 for *P. ×canadensis*, *P. deltoides* and willow, respectively. The highest productivities were observed with 10000 plants·ha^{-1} for all the tested species. A marked decrease in biomass yield occurred with *P. deltoides* clones passing from 10000 to 8333 plants·ha^{-1}, while this trend was less pronounced with *P. ×canadensis* and *Salix*. Furthermore, the first poplar species showed a positive correlation between biomass production and plant survival when planted at 10000 plants·ha^{-1} (Figure 2), and productivity was higher at mortality rates equal or less than 20%. This figure confirms the minimum survival of 80% usually recommended by CRA-PLF in Italy for commercial poplar SRC. However it is necessary to stress the fact that, by decreasing the density, the diameter of trees increases and this improves the quality of the biomass: less bark content, less ash content and higher net calorific value.

4. Conclusions

In this study variations in the amount of yearly or seasonal precipitation have proven to be related to similar variations in plant survival and productivity during the first rotation cycle. Therefore, water availability must be considered one of the principal factors affecting the establishment of poplar and willow SRC in the Po valley and central Italy, and irrigation must always be taken into account in these areas to prevent yield losses during the dry years. Furthermore, possible variations in the rainfall regime consequent to climate changes [31,32] could seriously influence land suitability to SRC in the study area.

The results confirm that soil texture also can play a significant role in driving the establishment of plantations. Poplars and willow give the best performances in loamy soils, where the hydrological characteristics are probably close to the optimum for these tree species, according to the National guidelines for energy plantations [2] and others authors [1]. Data collected in the present study also indicate that densities of 10000 plants ha^{-1} may increase the biomass yield during the first 2 year cycle with respect to 8000 plants ha^{-1} especially with *P. deltoides* clones. A minimum survival percentage of 80% is recommendable to avoid yield losses. Further research is underway to verify the effect of site and cultivation factors throughout the whole productive cycle of the plantations.

Acknowledgements

This study was funded by the research project of Italian Ministry of Agriculture 'BIOENERGIE' subproject 'BIOENERLEGNO'.

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