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A S R

Research paper

Comparing growth rate in a mixed plantation (walnut, poplar and nurse trees) with different planting designs: results from an experimental plantation in northern Italy

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Abstract - Results of a mixed plantation with poplar, walnut and nurse trees established in winter 2003 in Northern Italy, are reported. Main tree species (poplar and walnut) were planted according to a rectangular design (10 x 11m), with different spacings and alternate lines. The experimental trial was carried out to verify the following working hypotheses: (i) possibility to combine main trees with different growth levels (common walnut, hybrid walnut, and different poplar clones) and test two different poplar and walnut spacings (5.0 and 7.4 m) in the same plantation; (ii) opportunity to reduce cultivation's workload, in comparison with poplar monoculture, using mixtures with different poplar clones and N-fixing nurse trees; (iii) verifying the growth pattern of two new poplar clones in comparison with the traditional clones cultivated for different purposes in Italy. The use of different valuable crop trees' mixtures intercropped with nurse trees and shrubs (including N-fixing trees) allows to decrease the cultivation's workload. In fact, a heavy reduction of cultural practices - fertilizers, weed control, irrigation and pesticides applications (-61%) are the main concurrent, supplementary benefits. The best growth performances (DBH and tree height), associated with the higher competition towards walnuts, were recorded with the new clones Lena and Neva in comparison with the I214 and Villafranca. The closer spacing (5 m between poplar and walnut trees) was found to be unsuited to get merchantable poplars sized 30 cm without developing a heavy competition towards walnut trees. The wider spacing (7.4 m) resulted vice versa suitable to get poplar trees sized as requested by veneer factories and to maintain an acceptable competitive level with walnut. Within this plantation design, a shorter rotation (8 yrs) is needed for Lena and Neva clones in comparison with I214 and Villafranca (10 yrs). Walnut intercropped with poplar showed cone-shaped crowns, light branching and a good stem quality in comparison with walnut grown in pure plantations. This model of mixed plantation can become an interesting optional choice to walnut's and poplar's monoculture with notable advantages both for farm economics, landscape quality and environment preservation.

Keywords - common walnut, hybrid walnut, mixed plantation, poplar clones, sustainable tree farming

Introduction

Poplar cultivation is the main internal source for timber industry, producing about 50% of the whole roundwood volume (Facciotto et al. 2003) in Italy. Since the early nineties, poplar cultivation is suffering a heavy reduction from 90,000 to 61,381 hectares (Gasparini e Tabacchi 2011, Coaloa et al. 2012) due to several factors: (i) the weak farmers' contractual position when selling a poplar plantation, (ii) the lack of any industry planning useful for programming planting investments, (iii) the wider use by poplar industry of semi-finished timber products imported from other European and extra-European countries, (iv) the increasing production costs, i.e. petrol, pesticides, fertilizers, etc. (Nervo et al. 2007). This condition enhanced research efforts for the innovation of poplar cultivation systems towards less energy-consuming plantations (Coaloa and Vietto 2005) or plantations able to produce, within the same rotation, larger-sized trees, along with reducing production's costs (Buresti and Mori 2006).

Another tree species, traditionally cultivated in Italy for valuable timber production, is common walnut (*Juglans regia* L.). In the past, this species was generally cultivated as a single tree or in linear plantations, intercropped to agricultural crops, both for nuts and timber production (Minotta 1990, 1992). More recently, this twofold production has been replaced by specialized pure plantations for timber production, using a square spacing of 5 to 6 m, or walnut seed orchards (Giannini and Mercurio 1997).

Over the last decades in Europe, under the financial support of EU rules 2080/92 and of Rural Development Plan, many mixed plantations were established with walnut and other valuable broad-leaved and nurse trees (Becquey 1997, Becquey and Vidal 2006, Buresti and Mori 2006, Kelty 2006, Tani et al. 2006, Clark et al. 2008, Mohni et al. 2009). Recently in Italy, France, and North America, mixed

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plantations with walnut and poplar clones have been tested both in plantation forestry (Zsuffa et al. 1977, Buresti et al. 2008a, Vidal e Becquey 2008a, Paquette et al. 2008) and in agro-forestry systems (Balandier and Dupraz 1999, Rivest et al. 2010). These experiences pointed out the opportunity of testing the simultaneous cultivation of both species, characterized by different rotations (short poplar, medium-long walnut).

In this type of plantation, named in Italy *polycyclical plantation* (after Buresti et al. 2008b and Buresti and Mori 2012), the main crop trees with the same rotation are spaced at a definitive distance, to reach the merchantable size requested by industry within a shorter cycle. The reciprocal distance between main walnut and poplar trees must allow each tree to complete its rotation without the establishment of any heavy interspecific competition. Furthermore, when interplanting distance is correct, a positive competition can arise and the fast growing tree species can influence in a beneficial way the shape of lower growth and shade tolerant trees because of their low-covering crown (Schütz 2001, Pommerening and Murphy 2004, Kelty 2006, Buresti et al. 2008a, Buresti et al. 2008b, Vidal and Becquey 2008a).

A further benefit arising from this type of plantation is economical, by allowing a better distribution of income, poplar being harvested within 8-10 years and walnut within 20-30 years (Vidal and Becquey 2008b).

Results obtained in a poplar and walnut *polycyclical plantation*, aged 9 years, are here reported. The plantation has been carried out to verify the following hypotheses:

1) opportunity to get poplars sized 30 cm DBH testing two different distances from walnut (5 and 7.4 m) without heavy interspecific competition;
2) possibility of poplar cultivation at lower costs as compared with the traditional technique, reducing tending operations, using more than one poplar clone and mixtures with N-fixing trees;
3) test poplar clones different from the I214 traditionally planted in Italy, to verify their own productivity and ability to be competitive on the wood market;
4) opportunity of harvesting additional valuable trees established as nurse trees.

Materials and Methods

Site description and plantation management

Planting operations started in February 2003 in a flood plain of the Oglio river in the Mantua Province (San Matteo alle Chiaviche). The area is characterized by a good site-index, deep, silty-sandy and moderately alkaline soils, subjected to periodical flooding. A sub-continental climate with cold winters and hot wet summers characterizes the area (mean annual temperature 13.6° C., mean annual precipitation 790 mm with maximum in autumn and minimum in winter; mean rainfall reaches 145 mm in summer with a dry period of one month only).

This mixed plantation, extended over 14 hectares, is characterized by the following main crop trees: four poplar clones (Lena, Neva, I214 e Villafranca), common walnut (*Juglans regia* L.) and hybrid walnut (*Juglans x intermedia* MJ209) (Tab. 1). The common walnut's trees have been planted initially in pairs, each tree being located at 1 m, in order to select shortly the best tree of each couple. In this way, the chance to get a good quality tree in the expected position increases (Buresti et al. 2001, 2003). Walnut and poplar main trees are planted according to a rectangular design (10 x 11 m) using alternate lines. In all, 90 poplars, 45 hybrid walnuts, and 45 common walnut couples were planted per hectare. The plantation is divided into two areas, depending on the planting design adopted (A and B). Each area is divided in monoclonal plots of about 1.5 hectare for each clone. In design A, walnut trees (both hybrid and common walnuts) are set in a row with poplar at 5 m. In design B, walnut trees are staggered to poplars by 7.4 m. Nurse trees were black alder (*Alnus glutinosa* (L.) Gaertn.) and hazel (*Corylus avellana* L.); along with these other four valuable nurse trees were introduced, i.e. narrow-leaved ash (*Fraxinus angustifolia* L.), wild service tree (*Sorbus torminalis* (L.) Cranz.), English oak (*Quercus robur* L.), and pear (*Pyrus*

Table 1 - Main characteristics of poplar clones. Modified from Facciotto et al. (2003).

Clone	origin	main characteristics
Lena	Populus deltoides Bartr.	higher productivity in comparison with I214; resistance to leaf diseases (rusts and aphids); sensitive to wind; high shrinkage and nervousness in comparison with I214.
Neva	Hybrid Populus X canadensis Monch	sensitive to spring defoliation and rusts; resistance to bronzing; bark necrosis and brown spots; higher productivity in comparison with I214; sensitive to wind
I 214	Hybrid Populus X canadensis Monch	resistance to spring defoliation; virus and brown spots; green wood density lower to Lena and Neva; resistance to wind; easy to prune
Villafranca	Populus alba L. clone	resistance to main diseases (rusts. spring defoliation. bronzing. viruses and aphids); hard to prune; slower growth in comparison with I214

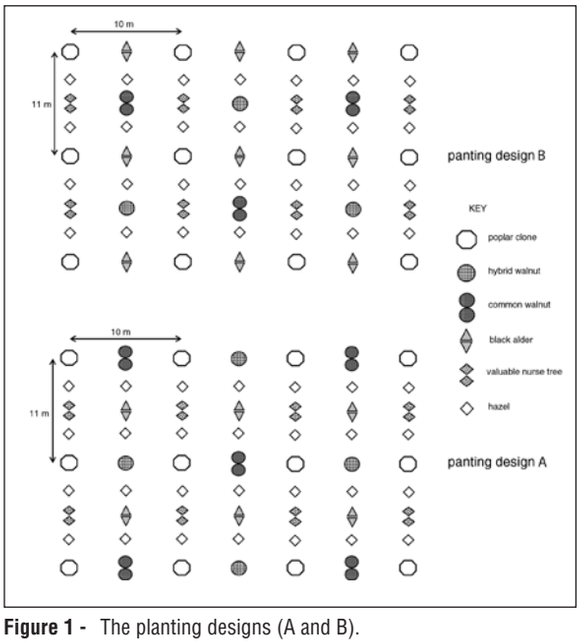

Figure 1 - The planting designs (A and B).

pyraster Burgsd.) (Fig.1). Valuable nurse trees, in addition to their own tending role, act as sort of insurance for the final outcome of the plantation, because they are able to replace any main crop tree in case of death, damage or if they do not achieve the expected development (Buresti and Mori 2004). Consequently, the valuable nurse trees must be subjected, at least for 4 to 6 years (pruning phase), to the same tending operations as the main crop trees (especially pruning).

In this plantation, the operations have been considerably reduced when compared with traditional monoclonal poplar plantations by:

1. Reduction of both fertilizers using N-fixing nurse trees, and pesticides using multi-clonal mixed plantations. These plantations allowed the reduction of spreading disease risk by poplar leaf rust (*Melampsora* spp.) or poplar leaf and shoot blight (*Venturia populina* (Vuill.) Fabric.), as already verified in other areas intensively cultivated with poplars (Coaloa and Vietto 2005).
2. Stimulation of poplar radial growth, with consequent reduction of the rotation, by planting more spaced trees that develop longer and well-lighted crowns over the whole cycle.

Over the first two years, only one treatment against wood insects' poplar-and-willow borer (*Cryptorrhynchus lapathi*) was performed; in the following two years a localized treatment to control longhorn beetle (*Saperda carcharis* L.) was carried out in the outside strips (about 20 m) to prevent the diffusion of this insect from neighbouring traditional poplar plantations. Weed control was carried out by polyethylene mulching and using both chemical and mechanical weeding during the first four years. On average two mechanical weeding and one chemical weeding per year were carried out.

No use of fertilizers or irrigations was made, whereas neighbouring traditional I214 plantations are managed intensively with one initial fertilization, 3-5 pesticide treatments per year and periodical emergency irrigations.

Selection of best trees between walnut's couples was accomplished at age 5 when trees differences in vigour and shape were already evident. Pruning of main trees and of valuable nurse trees was carried out up to the age of 6, i.e. when the farmer decided to promote walnut trees because of the good stem quality and clear boles at least up to 3 meters. Poplars were pruned up to 5.5 meters.

Field survey and data analysis

DBH surveys were performed yearly between the age of 4 and 9 (2006 to 2011). In the pruning phase (2006-2007) a sample of walnut and poplar clones only (at least 30 trees per species, clone and spacing) were considered. Since 2008, when the pruning ended, a complete survey of walnut and poplar DBH was made. Total tree and clear bole height of walnut and poplar clones were measured at ages 6 and 9 (2008 and 2011); in 2011 only 50% of poplar heights were measured. In 2011 an individual stem quality evaluation was carried out for walnut trees, ranking stems per quality classes, from A (veneer) to D (firewood) using the method set up for tree farming plantations proposed by Nosenzo et al. (2008) that assigns a quality class, valuing length, trunk axiality, knots presence and other defects. Only DBHs were measured on valuable nurse trees in 2008 and 2009.

First, the normality of distributions was evaluated by mean of Kolmogorof-Smirnov's test, then data were processed with the analysis of variance (ANOVA) comparing separately poplar clones, common walnut and hybrid walnut, but considering both planting designs (A and B). The comparison of means was performed by the Tukey's Test (HSD), with a significance of 0.05 (Statistica 2005). The walnut's distribution per stem quality classes was compared by χ^2 Pearson's test. The performances of valuable nurse trees and walnut trees were evaluated by comparing mean DBH at 2009 (age 7).

A comparison between traditional poplar plantation (Colaoa and Vietto 2005) and this new type of poplar and walnut plantation was carried out comparing the presence (1)/ absence (0) of cultural practices undertaken during the poplar rotation (10 years).

Results

Poplar

Stem diameter - Poplar clones showed differ-

ent growth rates at the age of 7-8 (years 2009-10) Lena and Neva clones reached the commercial size (DBH=30 cm), whilst I214 and Villafranca clones reached the same size 1 or 2 years later (Fig. 2). In 2011, the ANOVA of DBH showed significant differences among the clones and blocks (designs) ranging from 38.0, 36.1, 31.5 and 30.1 cm respectively for Lena, Neva, I214 and Villafranca (Tab. 2).

DBH increments keep high, i.e. 3-4 cm $yr^{1.}$ In 2009, Lena pointed out significant higher increments as compared with all clones in both designs, differences that decreased in the following years. Less productive clones showed more steady increments while a heavy DBH increment reduction was highlighted in Lena and, to a lesser extent, in Neva. In the last two years the I214 clone showed higher DBH increments (Fig. 3).

Tree height - The ANOVA of height is significant for both years (2008 and 2011) pointing out, in 2011, a superior height growth of Lena and Neva clones that reached on average 24.4 m and 24.2 m respectively, in comparison with 20.8 m and 18.2 m of the I214 and Villafranca clones (Tab. 3). At the age of 9 all poplar clones had built up green and efficient, up to 12-18 m long, crowns in comparison with poplars cultivated as usual, where crowns are narrow and shorter because of their progressive elevation due to the heavy competition (poplar stem density = 277 tree ha^{-1}).

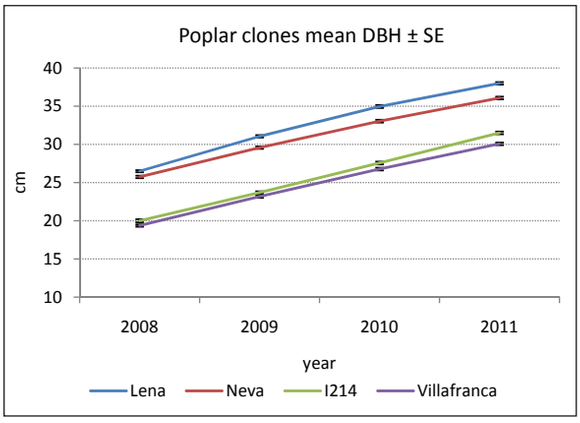

Figure 2 - Poplar clones DBH growth trend ± SE.

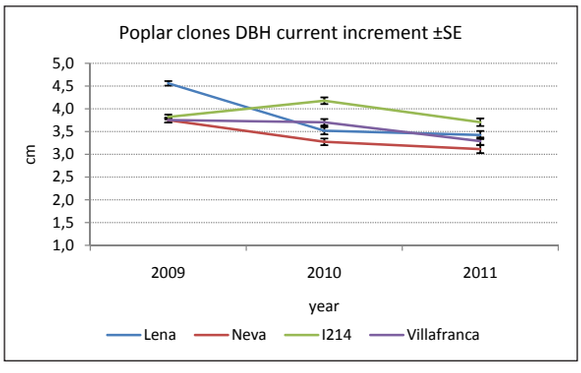

Figure 3 - Poplar clones DBH current increment ± SE.

Table 2 - ANOVA of poplar clones DBH 2011 (9 yrs).

Poplar clone	DBH (cm)	±SD (cm)	HSD	
Lena	38.0	2.2	a	
Neva	36.1	2.7	b	
I214	31.5	3.0	c	
Villafranca	30.1	2.1	d	
ANOVA	df	MS	F	P value
Clone	3	2559.1	516.4	*0.0000*
design (block)	1	896.2	180.8	*0.0000*
clone x design	3	65.9	13.3	*0.0000*
error	716	5.0		

Walnut

Stem diameter - Data analysis pointed out significant differences for walnut DBH grown with different spacings, it being lower in design A compared to B. Significant variations in DBH were also found for both walnuts originated by the different intercropped poplar clones (Fig. 4 and 5). Hybrid walnut reached on average lower DBH (13.2 cm and 13.7 cm) when intercropped with Lena and Neva in comparison with I214 and Villafranca intercropping (14.9 cm and 15.4 cm) in 2011 (age of 9). Common walnut reached 12.6 and 12.9 cm when intercropped with Lena and Neva and 13.1 and 13.6 cm when intercropped with I214 and Villafranca (Tab. 4).

A reduction of DBH increment was observed for both walnuts and designs within all the intercropped poplar clones in the last years. Since 2010, significant differences among intercropping and designs were found for both walnuts. A mean reduction of DBH increment from 1.6 to 0.6 cm in Lena and from 1.5 to 0.7 cm in Neva intercropping was observed for hybrid walnut over 2009-2011, whilst a lower DBH variation of annual increment was detected with the less productive clones: from 1.9 to 1.2 cm in I214 and from 2.0 to 1.1 cm in Villafranca intercropping (Fig. 6). In common walnut DBH increment variations were less significant and only walnut intercropped with I214 in design B was significantly different. A mean reduction of common walnut DBH increment from 1.7 to 0.9 cm in Lena and from 1.8 to 1.1 cm in Neva intercropping was observed along the full observation period; whilst a DBH increment variation from 2.0 to 1.3 cm and from 1.9 to 1.2 cm was recorded, respectively in I214 and Villafranca intercropping (Fig. 7). The trend of DBH increment highlights the different specific growth pattern of both walnuts. Hybrid walnut has an early more sustained growth followed by a progressive reduction due to poplar competition, up to a radial (DBH) growth lower than common walnut (Fig. 8).

Tree height - The ANOVA showed significant differences in height with common walnut for both intercropping types in 2008 and 2011, and for planting design in 2011 only. In hybrid walnut significant differences in height were noticed for the different

Table 3 - ANOVA of poplar clones tree height 2008 - 2011 (6-9 yrs).

Poplar clone	h2008 (m)	±SD (m)	HSD		h2011 (m)	±SD (m)	HSD	
Lena	17.43	1.43	a		24.38	2.06	a	
Neva	16.80	1.21	b		23.16	1.35	a	
I214	14.09	1.49	c		20.75	1.30	b	
Villafranca	12.13	0.99	d		18.23	2.00	c	
ANOVA	df	MS	F	P value	df	MS	F	P value
clone	3	1111.5	780.50	*0.0000*	3	798.6	285.58	*0.0000*
design (block)	1	114.5	80.40	*0.0000*	1	4.1	1.48	0.2242
clone x design	3	26.3	18.50	*0.0000*	3	25.2	9.02	*0.0000*
	726	1.4			357	2.8		

intercroppings in 2008 and 2011, and for planting design in 2011 only.

The best performances of common walnut at the end of 2011 were measured in the design B with Lena and Neva intercropping (13.7 and 14.4 m) while the worst results were found in design A with I214 (11.2 m) and Villafranca (11.6 m) (Tab 5). In 2011, the best performances of hybrid walnut were recorded in design B with Lena and Neva intercropping (14.9 and 14.5 m) and the worst results were achieved in design A with I214 (13.2 m) and Villafranca (12.8 m) (Tab. 6).

Stem quality - The quality of hybrid walnut showed to be significant superior ($\chi^2 = 31.2$ $p<0.001$) as compared with common walnut. The 72% of hybrid trees belong to classes A and B, suitable for veneer and first quality saw-timber production, while only 53% of common walnut trees reached the same category (Tab.7). Stem pruning was carried out up to the height of 3 m. Over this height, crowns were left to grow free. The percentage of trees suitable to produce valuable assortments could increase for both walnut species at higher plantation ages, because defects due to knots and small stem curves could be overestimated in trees aged 9 years.

Valuable nurse trees

Close to the end of the pruning phase (2009), the owner decided to concentrate operations only on walnut trees showing faster growth and/or fitting the expected stem quality, neglecting valuable nurse trees. Among these, the best DBH growth performance was recorded by narrow-leaved ash followed by pear, oak, and wild service trees. Mean DBH values measured in 2009 in walnuts and valuable nurse trees are reported in Fig. 9.

Cultivation practices

The comparison between cultivation practices undertaken in the two plantation types (pure and polycyclical) during the poplar rotation are showed in Tab. 8 and 9. In the mixed walnut-poplar plantation, the absence of any irrigation and fertilization, a heavy reduction of the use of pesticides (-90%) and of mechanical weed control (-60%) was recorded. On the other hand, the chemical weed control along walnut lines, the selection between walnut couples, and the increase of pruning (+25%), were necessary in this new type of plantation.

Discussion

At the age of 9 (2011), Lena and Neva clones reached notable diameters (34.7 to 38.4 cm) but showed already evidence of an incremental reduction, whilst the I214 and Villafranca maintained a more regular growth course with lower DBH (29.1 to 33.3 cm). These growth patterns highlight on one side the early establishment of intraspecific competition within the fastest growing clones, especially Lena, and on the other side, the delayed occurrence of the same condition within the less productive clones (I214 and Villafranca).

The year 2009 showed to be the right time for

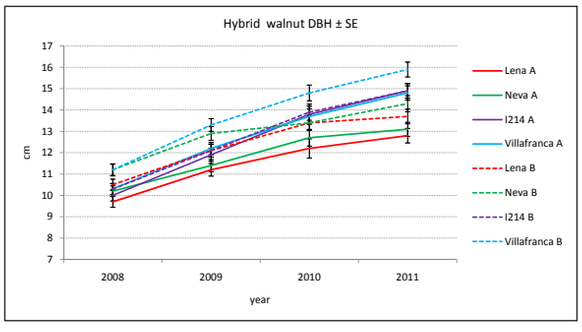

Figure 4 - Hybrid walnut DBH growth trend ± SE per intercropping and design.

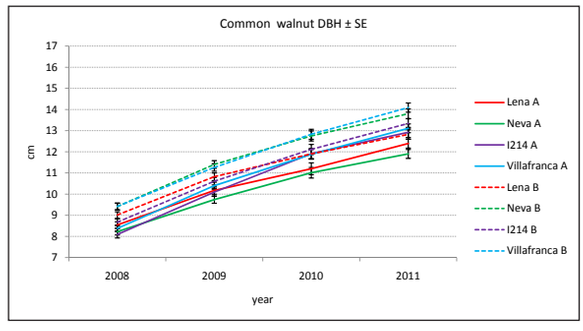

Figure 5 - Common walnut DBH growth trend ± SE per intercropping and design.

Table 4 - DBH 2011 (9 yrs) common and hybrid walnut ANOVA per planting design and intercropped poplar clones.

		Hybrid walnut				Common walnut		
intercropping	design	DBH (cm)	±SD (cm)	HSD		DBH	±SD (cm)	HSD (cm)
Lena	A	12.8	1.9	c		12.39	1.35	de
Neva	A	13.1	2.4	c		11.90	1.03	e
I214	A	14.9	2	ab		12.92	0.86	bcd
Villafranca	A	14.8	2.3	ab		13.11	1.68	bcd
Lena	B	13.7	2.2	bc		12.82	1.25	cd
Neva	B	14.3	2.1	bc		13.80	1.43	ab
I214	B	14.9	2.3	ab		13.34	1.59	abc
Villafranca	B	15.9	2.2	a		14.09	1.65	a
ANOVA	df	MS	F	P value	df	MS	F	P value
design	1	50.93	10.58	*0.0013*	1	70.06	36.31	*0.0000*
intercropping	3	79.69	16.55	*0.0000*	3	14.91	7.73	*0.0001*
intercropping x design	3	5.70	1.18	0.3160	3	9.42	4.88	*0.0025*
error	314	4.81			314	1.93		

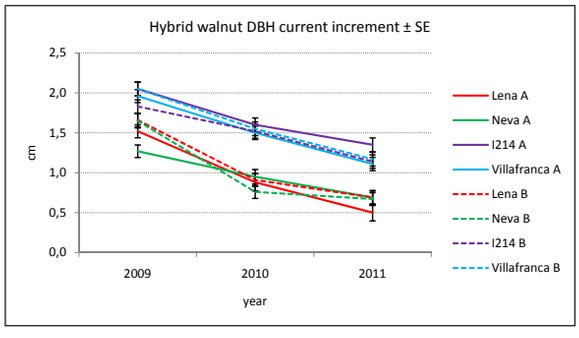

Figure 6 - Hybrid walnut DBH current increment per intercropping and design.

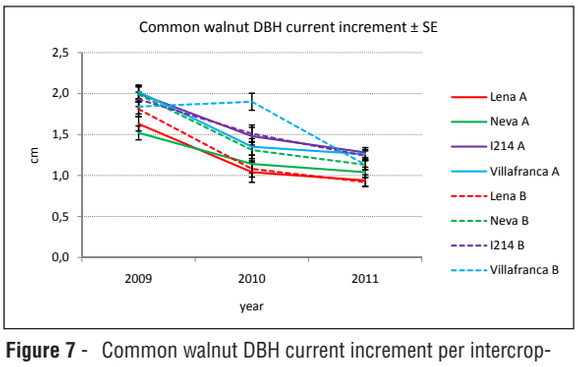

Figure 7 - Common walnut DBH current increment per intercropping and design.

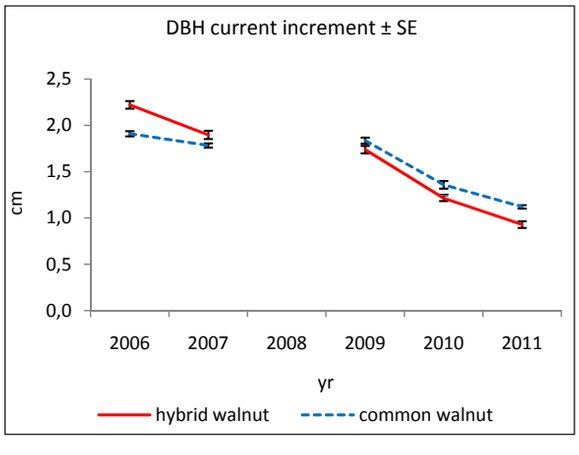

Figure 8 - Comparison between common and hybrid walnut DBH increment.

poplars harvesting, especially for the more productive clones - Lena and Neva - (Facciotto et al. 2003) already sized enough for marketing (DBH ≥30 cm), but adverse concomitant local market conditions didn't make profitable their felling to the farmer. Their maintenance for a longer time affected negatively walnut DBH increment, that is -63% compared with 2009 (hybrid walnut intercropped with Lena), -46% (common walnut) and -36% with the I214 intercropping in both walnuts spp. (Tab. 10). At the end of 2011, walnuts have still long, green functional crowns (12-18 m) and looked able to react to poplars' harvesting as compared with pure walnut plantations undergoing a late thinning, these generally showing a lower reaction (De Meo et al. 1999, Marchino and Ravagni 2007). Despite that, no data exist at now about the incremental DBH reaction of walnut following a period of heavy competition in this type of plantation. This points out the need of using larger poplar-walnut interplanting distances, especially if we are going to use both slower growing clones needing rotations of about 10 years to produce poplars sized more than 40 cm (Buresti and Mori 2013). The basic importance of defining suited planting designs and correct walnut-poplar distances is in this way underlined.

Both walnut trees (common and hybrid) showed a fast DBH growth. Hybrid walnut presented a superior stem quality in accordance with Paris et al. (2003), 72% of stems being suitable for good quality veneer and saw timber production. On the contrary, common walnut had only 53% of stems in the best quality classes (Tab. 7). Despite the worse performance in terms of growth and stem quality, the use of common walnut is more frequent since its timber is more appreciated by the Italian industry and because this species has been traditionally cultivated in Italy since the Roman period. The achievement of a good standard in the trunk quality has been determined by poplar's presence (i.e. fast growing species with low-covering crown) able to nurse, under his light canopy, walnuts characterized by

Table 5 - Tree height 2008 - 2011 (6-9 yrs) common walnut ANOVA per planting design and intercropped poplar clones.

		Common walnut							
intercropping	design	h2008 (cm)	±SD (cm)	HSD		h2011	±SD (cm)	HSD (cm)	
Lena	A	8.26	1.06	a		13.13	1.60	a	
Neva	A	7.89	0.98	a		12.53	1.22	a	
I214	A	7.08	0.64	b		11.20	1.08	b	
Villafranca	A	7.80	1.15	a		11.63	1.50	b	
Lena	B	8.38	1.33	ab		13.71	1.63	a	
Neva	B	8.55	1.55	a		14.42	1.99	a	
I214	B	7.39	1.19	c		12.38	1.91	b	
Villafranca	B	7.74	0.89	bc		12.05	1.30	b	
ANOVA		gdl	MS	F	P value	gdl	MS	F	P value
design		1	4.86	3.86	0.0503	1	80.51	33.62	*0.000*
intercropping		3	16.97	13.48	*0.0000*	3	68.94	28.79	*0.000*
intercropping x design		3	1.70	1.35	0.2571	3	8.97	3.75	0.011
error	281	1.26				306	2.39		

Table 6 - Tree height 2008 - 2011 (6-9 yrs) hybrid walnut ANOVA per planting design and intercropped poplar clones.

		Hybrid walnut							
intercropping	design	h2008 (cm)	±SD (cm)	HSD		h2011	±SD (cm)	HSD (cm)	
Lena	A	8.36	0.97	a		13.57	1.65	a	
Neva	A	8.14	1.40	a		13.69	2.03	a	
I214	A	8.11	0.75	a		13.22	1.44	a	
Villafranca	A	7.88	1.05	a		12.81	1.54	a	
Lena	B	8.57	1.40	ab		14.92	2.18	a	
Neva	B	9.08	1.38	a		14.51	2.03	ab	
I214	B	7.94	1.06	b		14.09	1.67	ab	
Villafranca	B	8.06	0.98	b		13.41	1.28	b	
ANOVA	df	MS	F	P value	df	MS	F	P value	
design		1	4.87	2.97	0.0862	1	65.07	21.1	*0,0000*
intercropping		3	6.01	3.66	*0.0131*	3	20.45	6.63	*0,0002*
intercropping .x design	3	3.15	1.92	0.1274	3	2.06	0.67	0.5722	
error	238	1.64			307	3.08			

Table 7 - Distribution of common and hybrid walnut per stem quality classes and relative χ^2 test.

Stem quality classes	common walnut n	%	hybrid walnut n	%
A	35	10.8	63	19.4
B	137	42.4	170	52.5
C	97	30.0	71	21.9
D	54	16.7	20	6.2
tot	323	100.0	324	100.0

$\chi^2 = 31.19$ p=0.000

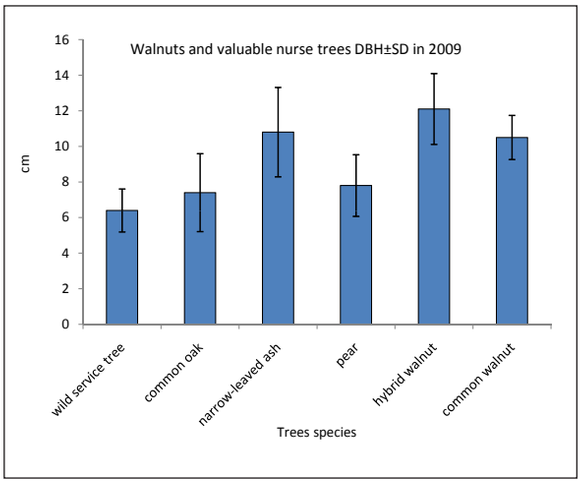

Figure 9 - Comparison among walnuts and valuable nurse trees DBH ±SD at the age of 7 (2009).

slender, cone-shaped crowns and small-sized, easily self-pruned branches (Buresti et al. 2008b). Valuable nurse trees were no longer managed (except the best phenotypes) because of the good walnut performance both in terms of growth and stem quality. That is why their cultivation (pruning) has been abandoned in this trial. In any case, according to Kelty (2006) and Buresti and Mori (2004), they can support an improvement of biodiversity and stability of mixed plantations and their intercropping is a sort of farmer's insurance for the final outcome of the plantation.

Results highlight that the concurrent cultivation of walnut and poplar species is possible and advisable because of the manifold positive outcomes: reduced environmental impact of the plantation type as compared with traditional poplar monoculture, since the trial pointed out a clear reduction of external inputs in terms of (i) fertilization (-100%), (ii) irrigation (-100%), (iii) use of pesticides (-90%) as compared with the traditional cultivation.

This was possible by using multi-clonal mixed plantations with N-fixing nurse trees that considerably reduce both the spreading of pests and diseases and also the consequent amount of chemical treatments. The use of fertilizers was cut down, too.

All these achievements are quite positive as

Table 8 - Presence (1) or absence (0) of cultural practices in traditional poplar plantations - modified from Colaoa and Vietto (2005).

Traditional poplar plantation	**years of poplar rotation**										
cultural operations	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	**total**
mechanical weed control	1	1	1	1	1	1	1	1	1	1	**10**
irrigation	1	1	1	1	1	1	1	1	1	1	**10**
pesticide	1	1	1	1	1	1	1	1	1	1	**10**
chemical weed control	0	0	0	0	0	0	0	0	0	0	**0**
pruning	1	1	1	0	1	0	0	0	0	0	4
selection double walnut	0	0	0	0	0	0	0	0	0	0	**0**
fertilization	1	1	1	1	0	0	0	0	0	0	**4**
total interventions	**5**	**5**	**5**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**38**

Table 9 - Presence (1) or absence (0) of cultural practices in the studied plantation.

Polyciclical plantation	**years of poplar rotation**										
cultural operations	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	**total**
mechanical weed control	1	1	1	1	0	0	0	0	0	0	**4**
irrigation	0	0	0	0	0	0	0	0	0	0	**0**
pesticides	0	1	0	0	0	0	0	0	0	0	**1**
chemical weed control	1	1	1	1	0	0	0	0	0	0	**4**
pruning	0	1	1	1	1	0	0	0	0	1	**5**
selection double walnut	0	0	0	0	1	0	0	0	0	0	**1**
fertilization	0	0	0	0	0	0	0	0	0	0	**0**
total interventions	**2**	**4**	**3**	**3**	**2**	**0**	**0**	**0**	**0**	**1**	**15**

Table 10 - Reduction of current DBH increments between 2009 and 2011

Intercropped clones	**hybrid walnut DBH increment reduction %**	**common walnut DBH increment reduction %**
Lena	63	46
Neva	53	37
I214	36	36
Villafranca	43	38

compared with the number of cultivation practices needed in a traditional poplar's plantations along the whole poplar rotation (Colaoa and Vietto 2005). Their occurrence was limited to less than one half in the studied plantation. The abatement of these cultivation costs has a notable economic advantage both for farmers and towards the environment.

A limitation to the use of the Lena and Neva clones is nowadays the shortage of market for these clones in Italy, in spite of their significant superior growth, the lower cultivation needs, in comparison with I214, and the suitable mechanical timber characteristics. Unfortunately, the higher shrinkage of timber in these clones decreases the value for veneer production, this determining a difficult marketing. At present, veneer industry fully prefers timber from I214 plantations (Facciotto et al. 2003). According to Vidal and Becquey (2008b), the mixture between poplar and walnut appears to be interesting from the economic point of view too. Further research trials are necessary to value the overall productivity of the two main tree species at the end of walnut rotation and the analytical evaluation of costs.

Conclusive remarks

The recent experimental trials on mixed *polycyclical plantations* (walnut, poplar and nurse trees) highlighted the notable potential of this type of plantation in flood plain areas favourable to the cultivation of both main species, providing interesting productive outcomes as well as ecological-environmental considerations. These mixed plantations, more resistant to external disturbances and less demanding in terms of energetic inputs (fertilization, pesticides, irrigation, etc.) proved to be innovative and more sustainable for poplar and walnut cultivation. It can become an advantage for the farmer, especially within the current unfavourable period for poplar timber marketing and for the quality of flood plain environment.

The experiences with this plantation design are at an early stage and more comparative tests, widespread trials and screening of results are necessary. The goals in progress are: development of suitable cultivation models with wide inter-distances walnut-poplar (≥7.4 m), enough to allow: (i) the early achievement of poplar's cultivation goals before heavy competition with walnut becomes established; (ii) the use of a fast growing species, i.e. poplar to nurse walnut trees provided with slender, conical-shaped crowns, and light branching.

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