AGFORWARD
Agroforestry for Europe

System Report:
Trees for Timber with Arable Crops in Italy

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1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2, Deliverable 4.10: "Detailed system description of case study agroforestry systems". The detailed system description includes the key inputs, flows, and outputs of the key ecosystem services of the studied system. It covers the agroecology of the site (climate, soil), the components (tree species, crop system, management system) and key ecosystem services (provisioning, regulating and cultural) and the associated economic values. The data included in this report will also inform the modelling activities which help to address Objective 3.

2 Background

Poplar hybrids and species has been intensively managed in Italy for timber production usually in monoculture plantations, but sometimes in intercropping systems where crops are grown between recently established trees, and in linear plantations along field edges, drainage canals and streams (Eichhorn et al. 2006). In Italy, poplar cultivation in all of the above cultivation models is currently declining due to a stagnating domestic timber market (Facciotto et al. 2015). Global and regional environmental concerns such as the need to reduce atmospheric carbon dioxide levels, control soil erosion, secure alternative energy sources, and restore areas using phytoremediation could provide new opportunities for poplar silvoarable systems and linear plantations (Dalla Valle 2011; Correale et al. 2011; Veneto Agricoltura 2002; Bianconi et al. 2011). Furthermore, the Common Agricultural Policy of the European Union provides opportunities to support the establishment and management of timber trees in agriculture areas to help reverse the decline of trees outside forest. The new Rural Development Plans (RDP) (2014-20) for Italy are currently under evaluation, and hopefully stronger support for agroforestry will be provided, both with direct measures for establishing new agroforestry systems, and also with the inclusion of agroforestry systems in the Ecological Focus Area of the (Pisanelli et al., 2014). Financial support for establishing agroforestry on arable land was first introduced at the European level for the 2007-2013 RDP through measure 222. However the opportunity for farmers to implement the support was limited to only some countries, and the total area of established with EU financial support in the EU27 was only about 627 ha. In Italy, 9 ha of agroforestry were established with the measure 222, all of them at the Casaria farm in the Veneto region. The farm covers a total surface of about 65 ha, with about 9 ha covered by an agroforestry system established in 2013, planting poplar and oak tree species along field edges and ditches.

3 System description

A general description of timber trees with arable crops in Italy is provided in Table 1. A description of the specific experimental system is provided in Table 2. In the experimental system: oaks and poplar trees are planted in the border of the fields and along ditches. The distance between the tree rows is about 35 m. Within the rows, there is a poplar tree every 10 m, alternated with an oak (*Quercus robur*). The relative sizes of the species are shown in Figure 1.

Table 1. General description of the system

General description of system	
Name of group	Trees for timber intercropped with cereals in Italy
Contact	Cristina Dalla Valle, Pierluigi Paris
Work-package	4: Agroforestry for Arable Farmers
Associated WP	None
Geographical extent	Modern systems of timber trees intercropped with crops are very rare in Italy. According to the knowledge of the authors the research area is limited to about 10 ha.
Estimated area	No reliable official statistics are available for modern intercropping systems. For traditional linear plantations along field edges, just local regional statistics are available, often not homogeneous as time series, such the ones for Lombardia Region, reporting wood production from linear plantations, without stratification amongst tree species (e.g. *Populus, Platanus, and Salix*). The last census in Lombardia (year 2000) reports 21,459 km of linear plantations (15.18 m ha^{-1}), producing annually 180.000 m^3 of timber.
Typical soil types	Alluvial soils
Description	Poplar hybrids and species have been intensively managed in Italy for timber production mostly in monoculture plantations, but often in intercropping systems (intercropping of arable crops in between young tree rows) and in linear plantations along field edges, drainage canals and streams. Poplar cultivation, in all the above cultivation models, is currently declining for stagnating domestic timber markets. Regional and global environment concerns such as reducing climate change, soil erosion and providing bioenergy could open new opportunities for poplar silvoarable systems and linear plantations, combining local bioenergy and food production with environmental benefits.
Tree species	Poplar hybrids (*Populus x canadensis*)
Tree products	Timber (plywood, pallets, wooden fruit boxes); from pruning and harvesting sub products: wood chip for particle boards, heating/cooling; power production; wood biomass can be used for bioethanol production
Crop species	Corn (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum vulgare*), soybean (*Glycine max*), sunflower (*Helianthus annuus*), alfalfa (*Medicago sativa*), clovers (*Trifolium* spp.); sugar beet (*Beta vulgaris*)
Crop products	Food, biomass for biogas and bioethanol, fodder. Time of harvest is crop dependent
Animal species	Game (rare)
Animal products	Game for hunting
Other provisioning services	Possibility of using tree leaves as fodder
Regulating services	The trees can provide a microclimate with reduced temperature fluctuations. The trees can promote nutrient cycling and be used for phytoremediation as

	buffer strips along ditches, canals etc. The trees will increase both above-ground carbon storage.
Habitat services and biodiversity	During the first years after tree establishment, weed management is required to prevent weeds from competing with the trees and invading the crop areas. Tree rows can be planted also with accompanying woody species (shrubs, slow growing trees) creating habitat diversifications for wild animals and plants
Cultural services	Planting trees in agricultural fields may change employment requirements for farms, but also at local level.
Key references	See end of report

Table 2. Description of the specific case study system

Specific description of site	
Area	65 ha of which 15 ha are managed as agroforestry system intercropping poplar and oaks established in 2013
Co-ordinates	45°08’24.87”N, 11°30’25.61”E
Site contact	Cristina Dalla Valle (VenetoAgricoltura); Pierluigi Paris (CNR-IBAF)
Site contact email	cristina.dallavalle@venetoagricoltura.org; piero.paris@ibaf.cnr.it
Example photograph	

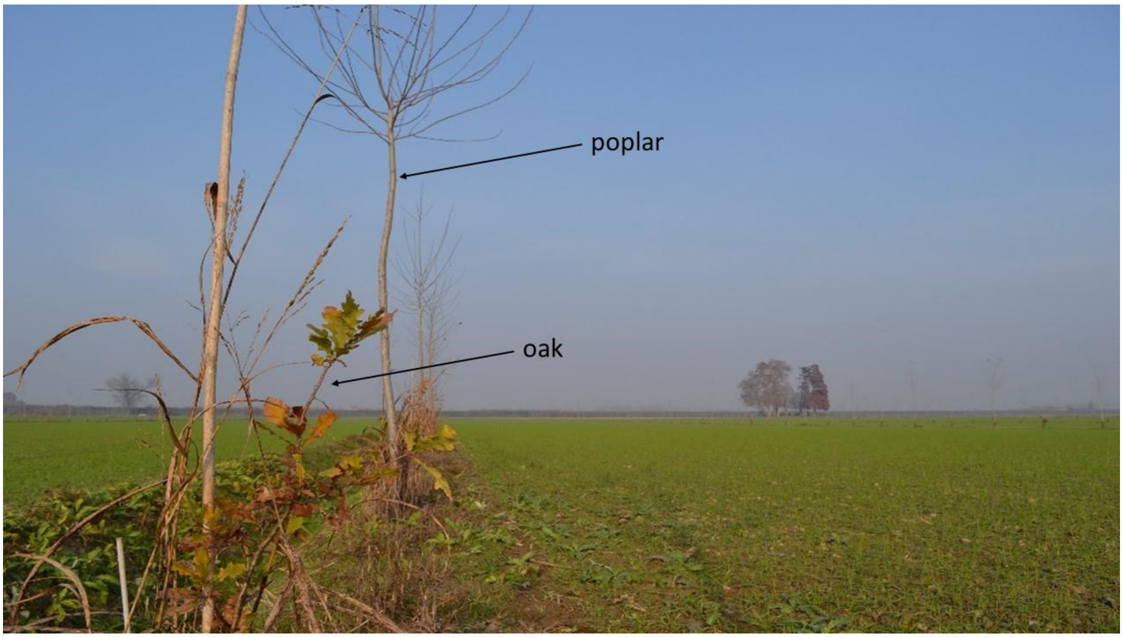

Figure 1. Intercropped oak (*Quercus robur*) and hybrid poplar trees at Casaria Farm (winter 2015-16).

Figure 2. Winter view (December 2015) of the experimental site, with durum wheat as intercrop, in succession to sugar beet. The farm is currently under conversion to organic farming

Map of system

Figure 3. Aerial photograph of Casaria Farm. The yellow line is the border of the agroforestry area. The red lines represent the tree rows alternated with arable areas.

Possible modelling scenarios

Comparison	Technical and economic analysis of timber trees intercropped with arable crops

Climate characteristics	
Mean temperature	14.7°C
Mean annual precipitation	1024 mm
Details of weather station (and data)	Historical data from 2010 to 2014 http://www.arpa.veneto.it/arpavinforma/bollettini/dati-storici
Soil type	
Soil type	WRB (1998): Calcari-fluvic cambisols USDA (1998): Oxyaquic haplustepts, mixed, mesic
Soil depth	approx. 2 m (until groundwater level)
Soil texture	coarse-loamy
Additional soil characteristics	Alluvial soil, formed by sands and lime, from very to extremely calcareous. Loamy texture in surface and coarse in substrate. Good drainage, moderately high permeability and very deep aquifer. Chart of Veneto soils- cartographic unit: BR2.2 http://www.arpa.veneto.it/suolo/htm/carte_web.asp
Aspect	Flat
Tree characteristics	
Species and variety	Hybrid Poplar I-214 (*Populus x euramericana (Dode) Guiner*) and pedunculate oak (*Quercus robur L.*)
Date of planting	Spring 2013
Intra-row spacing	5 m with alternate planting of poplar and oak
Inter-row spacing	35 m (approximately)
Tree protection	Shelters (+ guard pole for oak)
Typical wood yield	On average (with large variability) 90-100 Mg DM per ha of total woody biomass, with 400 trees ha^{-1} and a rotation cycle of 10 years. The total woody biomass is proportionally allocated among: plywood (40-50%), pallets and wooden fruit boxes (30-40%) and biomass for bioenergy or particle boards (20%) (Mercurio and Minotta 2000)
Annual increase in tree biomass	9-10 Mg dry matter ha^{-1} year^{-1} (Mercurio and Minotta, 2000)
Crop/understorey characteristics	
Species	Winter wheat (*Triticum durum*), Sugar beet (*Beta vulgaris*), barley (*Hordeum vulgare*), maize (*Zea mays*), alfalfa (*Medicago sativa*)
Management	Conventional arable crop management with ploughing and herbicide spraying to reduce weeds. The farm is currently in conversion to organic farming, and since the year 2016 the use of chemical inputs is strongly restricted.
Fertiliser, pesticide, machinery and labour management	
Fertiliser	Assumed that this is not modified by tree hedgerows.
Pesticides	Regular spraying of crops during the year to control weeds and pests
Machinery	Tractor access in crop alleys to allow soil preparation and spray application
Labour	Trees: yearly pruning. Crops: no additional labour requirements. Tree intra-row: weeds are yearly mechanically mowed along with vegetation in ditches
Fencing	Not required
Financial and economic characteristics	
Costs	Planting and maintenance costs for tree species and sugar beet at the study site have been collected and analysed for the modelling workshop of the AGFORWARD project in Lisbon, February 2016

4 Description of design

Intercrop alleys are alternated with tree rows with a distance of about 35 m. Tree rows are oriented in a north-south direction along field edges and drainage ditches. Tree rows are 400-450 m long, and poplars are planted at approximately 10 m intervals, alternated with oak (*Quercus robur*). As shown in Figure 7 only the poplars are visible over the arable crops. The primary goal of the research is to measure yield differences between alley cropping and conventional agricultural systems. The treatment are described in Table 3.

Table 3. Description of treatments

Treatment A/B	Treatment C
Alley cropping	Reference Crop
Tree: Poplar and oak	No trees
Crop: crops rotation	Crops rotation

4.1 Tree species

Tree establishment took place in winter 2013, using unrooted two year old rods for poplar and two years old seedlings for oak. Trees were planted by hand, in rows parallel to the existing ditches. Trees were provided with shelters to protect them from wild animal browsing. Oaks were also provided with a guardian pole. Poplar trees are pruned annually by hand. The tree intra-row is weeded annually, with mechanical mowing, along with the vegetation growing in the ditches.

4.2 Crop species

The crop alleys in between the tree rows are planted with conventional crops common in Italy such as maize (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum vulgare*), soybean (*Glycine max*), sunflower (*Helianthus annuus*), alfalfa (*Medicago sativa*), clovers (*Trifolium* spp.), and sugar beet (*Beta vulgaris*). Since the year 2015-16, the farm is in conversion to organic farming.

Up to the year 2015, crop management has been carried out with the usual mixture of ploughing and herbicide spraying to keep down weeds and pests, and applying chemical fertilizers according to crop requirements. All farm operations use conventional machinery and seek to minimise hand labour. The farm has an irrigation system which is used in dry conditions.

5 Measurements

5.1 Measurements taken during the year 2015

During 2015, observations were restricted to Treatments A and B, because the farmer had decided to use the two fields for the reference crop (see Figure 4) for crops different to the one used in the silvoarable field, where sugar beet was grown between the poplar trees. The list of measurements taken in the study period are listed in Table 4. Three transects were created in the silvoarable field. The position and dimensions of the three transects are shown in Figure 4. Each transect was delimited by two adjacent poplar tree rows, each row with 5 trees.

Table 4. List of measurements taken in the year 2015

Treatment A: Alley cropping trees (Poplar and oak)	Treatment B: Alley cropping crop
July 2015: Soil moisture July 2015: Soil and plant water stable isotopes July 2015: Hemispherical photos Dec. 2015: Tree height, DBH, branching height Dec. 2015: Stem form	July 2015: Soil moisture July 2015: Soil and plant water stable isotopes July 2015: Hemispherical photos Sept. 2015: Sugar beet production

Meteorological data was recorded for 2004-2015

Figure 4. Sampling transects (in black) for Treatments A and B at *Casaria* Farm. Each transect is delimitated by two adjacent poplar rows with 5 trees per row, and within the transect sugar beet was manually harvested in 3 sampling plots (in yellow): one plot at the alley centre, and two plots on the alley edges, close to the tree row. The yellow and numbered markers indicate the sampling positions for stable isotopes study.

5.2 Climate data

Local climatic data were obtained by a recording station managed by the Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (ARPAV) (www.arpa.veneto.it). The weather station is located in the Municipality of Masi, at a distance of 4.2 km (south direction, 194°) from the study area. Another weather station, managed by the farm, is also available on the study site, but its data are currently not available. The weather data of the *Masi* station are available on a daily basis for air temperature (minimum, maximum and average), air humidity, precipitation, solar radiation, wind direction and speed.

Table 5 shows the data of the average temperature, precipitation and solar radiation on a monthly basis. For the year 2015, the data for November and December were not available when writing the report. On average, the months of the growing season of sugar beet were warmer and drier in comparison to the 10-years average data of the period.

Table 5. Meteorological data of the study area at Masi station by ARPA Veneto (www.arpa.veneto.it). Standard errors of the mean are indicated in brackets. *data not available when writing the report.

Month	Mean temperature (°C)			Precipitation (mm)			Global solar radiation (MJ m^{-2})		
	1994-2014		2015	1994-2014		2015	1994-2014		2015
Jan	2.5	(0.39)	3.6	47.5	(8.1)	22.6	128	(7)	166
Feb	4.2	(0.36)	5.5	44.5	(8.1)	116.2	219	(9)	217
Mar	8.6	(0.31)	9.4	51.3	(11.6)	77.8	393	(14)	421
Apr	13.1	(0.29)	13.6	74.6	(9.0)	43.4	503	(16)	572
may	18.1	(0.24)	18.8	69.0	(7.7)	68.0	653	(21)	624
Jun	21.9	(0.27)	23.0	62.5	(9.3)	83.6	716	(9)	742
Jul	23.8	(0.23)	26.8	48.5	(10.7)	23.6	760	(14)	788
Aug	23.2	(0.34)	24.0	60.7	(8.0)	37.6	648	(9)	607
Sep	18.4	(0.29)	18.8	70.1	(7.2)	21.2	460	(9)	446
Oct	13.5	(0.26)	13.5	83.9	(12.2)	105.0	279	(10)	272
Nov	8.2	(0.36)	*	76.6	(8.5)	*	145	(7)	*
Dec	3.4	(0.34)	*	58.6	(8.0)	*	111	(6)	*
Mean	13.4	(0.19)							
Total				737.3	(43.7)		4550	(286	

5.3 Measurements on tree component

Measurement of poplar tree growth was undertaken on 9 July 2015, during the growing season, and on 1 December 2015, at the end of the growing season. These measurements were taken twice during the growing season, in order to have some initial indication on the season growth rate. Measurement of tree diameter at 1.30 m above soil level were done with a calliper (precision: ± 0.1 mm). Total tree height and the branching height (the height of the first branch on the stem from the soil level) were measured with an extendible height pole (precision ± 10 cm). Stem form index was assessed visually using an index of stem straightness according to Barrett and Mullin (1968), re-adapted by Mwase et al. (2008) (Figure 5). The point of DBH measurement along the tree stem was permanently marked.

Index of stem straightness:
1 = completely vertical and straight
2 = roughly vertical and straight
3 = roughly vertical, 1–2 bends
4 = not vertical, 1–2 bends
5 = not vertical and greater than two bends
6 = very crooked (not vertical and greater than three bends)
By Barrett and Mullin (1968), re-adapted by Mwase et al. (2008)

Figure 5. November 2015. Growth and stem form measurement, with the Index of stem straightness, of poplar trees at the end of the year. Durum wheat has been sown for the coming growing season of 2016.

5.4 Measurements on crop component

Within each transect, sugar beet was harvested in three rectangular plots with a dimension of 3 x 2.7 m (Figure 6). One sugar beet plot was in the centre of the crop alley, the other two plots were positioned with the external border at a distance of two meters from the tree row. Evaluation of the sugar beet production was performed on 3 September 2015, the day before the harvest of the crop.

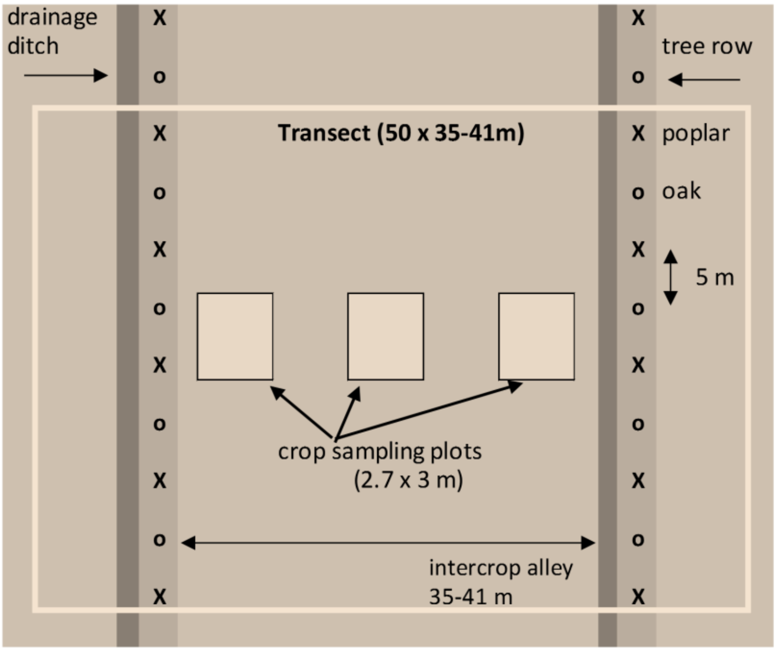

Figure 6. Schematic lay-out of the transect along the crop alleys and poplar rows.

The taproots were manually lift in each plot and weighted in the field with a portable scale (precision $\pm$ 0.01 kg). Root sub-samples were used for the determination of the moisture content of the fresh taproot yield (TRFY, in Mg ha^{-1}) and sugar content (SC, in %). The last parameter was determined in the field with a portable reflectometer. Moisture content was assessed by the determination of the fresh weight of the subsample in the field, immediately after root excavation, with a portable scale (precision $\pm$ 1 g) and reweighing the subsample after drying it into the stove at 80°C to constant weight.

5.5 Eco-physiological measurements

In order to study the tree-crop interactions on solar radiation and soil moisture and nutrients, eco-physiological assays were performed on 9 July 2015 comprising hemispherical photos (HP), soil moisture sampling, and collection of soil and plant samples for stable isotope determinations. Hemispherical photos were taken with a Nikon Coolpix camera and fish eye lens at progressive distances from tree rows. The photos were processed using Gap Light Analyser software. On 9 July 2015, the poplar trees were near their maximum leaf area. As required by the specific protocol, the hemispherical photos were taken after sunset under conditions of diffuse solar radiation.

Soil moisture was evaluated via the gravimetric method. Soil samples (ca. 100 g) were immediately weighted in the field with a portable scale (precision $\pm$ 0.1 g), sealed into metal cylinder and moved to the laboratory the next day, and dried into a ventilated stove at 105°C until constant weight, and reweighted for dry weight determination.

Figure 7. July 2015. Poplar trees intercropped with sugar beet. Sampling for soil moisture and soil and plant isotope analysis

5.6 Stable isotopes in soil hydrology, plant water-use efficiency and nitrogen cycle

Stable oxygen isotopes can be used as natural tracers for studying the sources of water and processes of water use by plants. Soil water is usually characterized by complex patterns of isotopic composition ($\delta^{18}O$) along the soil profile. Both climate and hydrology influence the $\delta^{18}O$ values of different water pools resulting in the water table and the waters in the shallow, medium and deep soil layers usually having different isotopic compositions. No isotopic effects occur during water uptake by roots or during xylem transport, so that xylem water $\delta^{18}O$ reflects a weighted average of the different water sources used by the plant. In contrast, leaf water $\delta^{18}O$ is enriched by evaporative effects that occur during transpiration. Oxygen stable isotopes were used for elucidating the strategies of plant water use in pure and mixed systems, based on quantifying the variation in oxygen isotope composition of soil and plant tissue water (Lauteri et al. 2006). We tested the hypothesis that poplar/oak trees may exploit water pools different from those used by the intercrops. Other relevant agro-ecological features of the studied systems are those related to the crop water-use efficiency (WUE) and to N fertilization and cycling. In this respect, C and N stable isotopes analyses can provide important insights in modelling agroforestry systems' efficiency and sustainability.

A sampling campaign took place in the experimental field in July 2015. The sampling concerned three transects as displayed in Figure 4. On each transect, three replicates of soil profiles were sampled close to and in between ditches, respectively. We considered three depths per profile: 20, 40 and 60 cm. Further, we sampled soil from the bottom of each ditch and running water from the main drainage channel in proximity of the field. Poplar twigs and carrots of the sugar beet roots were also sampled. All water samples have been frozen and water analyses are currently in progress using a laboratory cryogenic vacuum line. After extraction, a small amount of water will be analysed by means of IRMS techniques to determine the oxygen isotope composition ($\delta^{18}O$). The results should provide information on the root capability to extract water from different soil layers in order to evaluate the degree of competitive water-use patterns by comparing the performances in trees and crops. Additional information on these patterns should result from additional xylem water extracted from twigs of adult plants of *Platanus orientalis* and *Sequoia sempervirens*, sampled in proximity of the field.

Young, well-expanded and healthy leaves were also collected from both poplar and sugar beet in the experimental field. Leaves were dried and ground. The powder was analysed by means of Isotope-ratio Mass Spectrometry (IRMS) to determine both carbon and nitrogen isotope compositions.

Collection of material for the stable isotope determinations concerned the three transects. On each transect, three replicates of soil profiles (3 depths: 20, 40 and 60 cm) were sampled close to and in between ditches, respectively. Further, we sampled soil from the bottom of each ditch. Flowing water was collected from a drainage channel in proximity to the field. Poplar twigs and the sugar beet roots were also sampled. All these samples have been frozen and water extraction is carried out by using a laboratory cryogenic vacuum line. After extraction, water samples will be analysed by means of IRMS techniques to determine oxygen isotope composition ($\delta^{18}O$). Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope compositions have been determined on leaf samples of poplar and sugar beet.

6 Provisional results

6.1 Sugar beet production

As mentioned in Section 5.3, three plots per transect were harvested manually and the fresh production of the roots were weight immediately after extraction from the soil, using a portable scale (precision 100 g). Data of sugar beet yield and sugar content are shown it Table 6.

Table 6. Sugar beet tap-root yield characteristics in Treatment B during the year 2015 (values in brackets are the standard error of the mean).

Plot	Root fresh yield ($Mg\ ha^{-1}$)	Root dry yield ($Mg\ ha^{-1}$)	Sugar concentration (%)
Alley edge-East	67.9 (3.62) ns	14.4 (0.67)	15.90 (0.249) ns
Alley edge-West	62.2 (3.38)	16.2 (1.19)	15.92 (0.297)
Alley centre	77.9 (3.52)	12.6 (0.9)	15.17 (0.387)
ANOVA P value			
Transect	0.494	0.166	0.007
Plot	0.164	0.324	0.097

An ANOVA was completed using “Transect” and “Sampling plot” as random factors (Figure 6). There was no significant effect of sampling position on fresh and dry yield of sugar beet. Sugar concentration was significantly affected by transect, but not by plot sampling position. These data suggest that, during 2015, the three-year old poplar trees (whose growth is discussed in the next paragraph) neither significantly affected the yield nor sugar concentration of the crop.

6.2 Tree growth and stem form

The data of tree growth are shown in Table 7. The growth of the three-year-old poplar trees in Treatment A was slow; they were intercropped with sugar beet in 2015, and with wheat in 2013 and 2014. During the study year the DBH increment, in the period July-December, was about 0.63 cm, which is low. For example, hybrid poplar trees under Short Rotation Coppice management, with a very high shoot density (ca. 25000 shoot per ha, Paris et al. 2011), can have DBH increments of 1 or 1.5 cm per year on fertile soils (Paris et al. 2015). The slow growth may have been due to competition from the crop or weeds for water and nutrients. It is also possible that the soil around the tree was compacted. The soil along the tree rows (2 m wide) was left almost un-ploughed, just making a deep hole (3-5 cm of diameter) were the poplar rod was inserted.

Table 7. Diameter at breast height, total and branching height and stem form index of poplar trees in Treatment A in the year 2015

Diameter at breast height (mm)			Total height (m)	Branching height(m)	Stem form Index
9 July 2015	1 Dec 2015	Increment			
35.6 (1.4)	43.13	6.3 (0.84)	4.43 (0.12)	2.9 (0.08)	2.33 (0.15)

Timber quality of poplar trees was evaluated using the stem straightness index. The wood quality of the three years old intercropped trees appeared to be good with an estimated straightness index close to 2 (Figure 5). The value of 3 is the minimum threshold for producing saw logs.

6.3 Hemispherical photos

Examples of the hemispherical photos are shown in Figure 8.

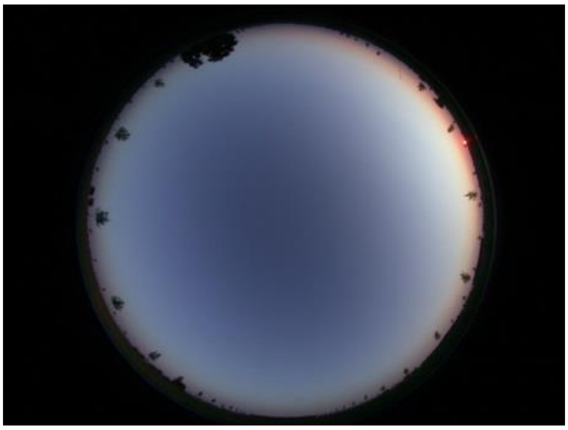

Figure 8. Example of hemispherical photos taken along tree row (left) and at the centre of the crop alley (right).

The proportion of solar radiation (as determined using the hemispherical photographs) as determined using the Gap Light Analyser software (Frazer et al., 2000) are shown in Figure 9. There were significant differences in solar radiation values across the crop alley, with a maximum towards the alley centre. However as the poplar trees are only three-years old, in absolute terms the differences (about 3%) are very limited.

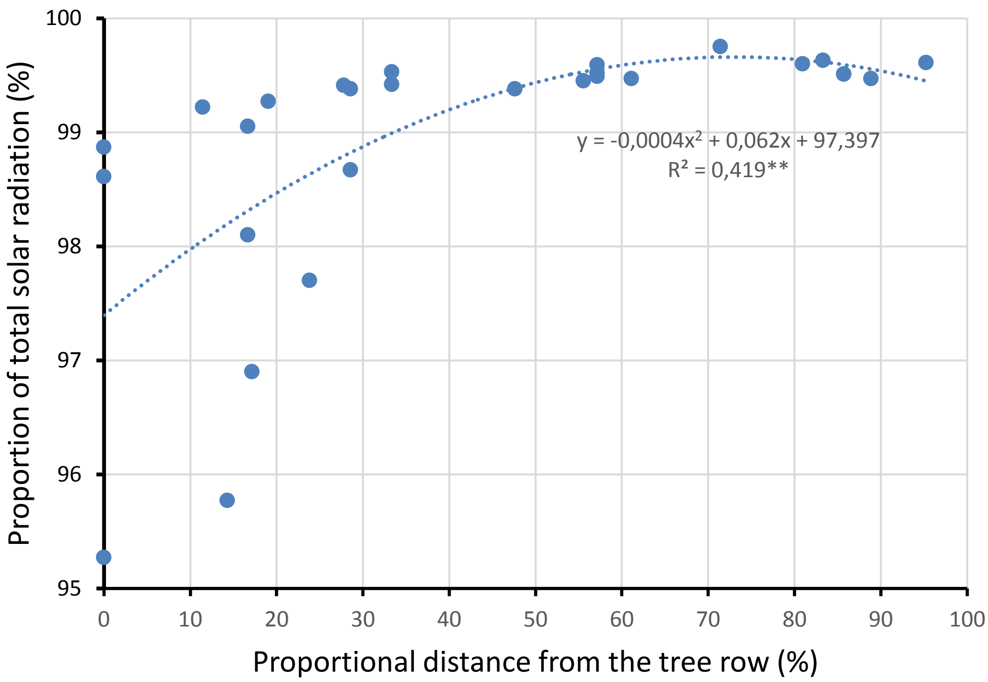

Figure 9. Percentage of total solar radiation transmitted below the poplar canopy (% Trans Tot) along poplar rows (Treat. A) and crop alleys (Treat. B) in July 2015. Measurements were obtained with hemispherical photos taken with a digital camera moved across alleys between poplar rows in the three transects. Each point represents a single observation. Distance from tree row is expressed in percentage: 0%= tree row; 100%: crop alley centre.

6.4 Soil moisture

Data of soil moisture were subject to ANOVA using sampling position (crop alley centre and edge; poplar row) and sampling depths as random factors. ANOVA results indicate no significant effect neither for the sampling position ($P \leq 0.06$) and depth ($P \leq 0.566$), nor their interaction ($P \leq 0.697$). However, the sampling position effect did show a trend, with the tree row and alley edge having slightly drier soil in comparison to the alley centre. This may be a result of competition for water between the crop and trees.

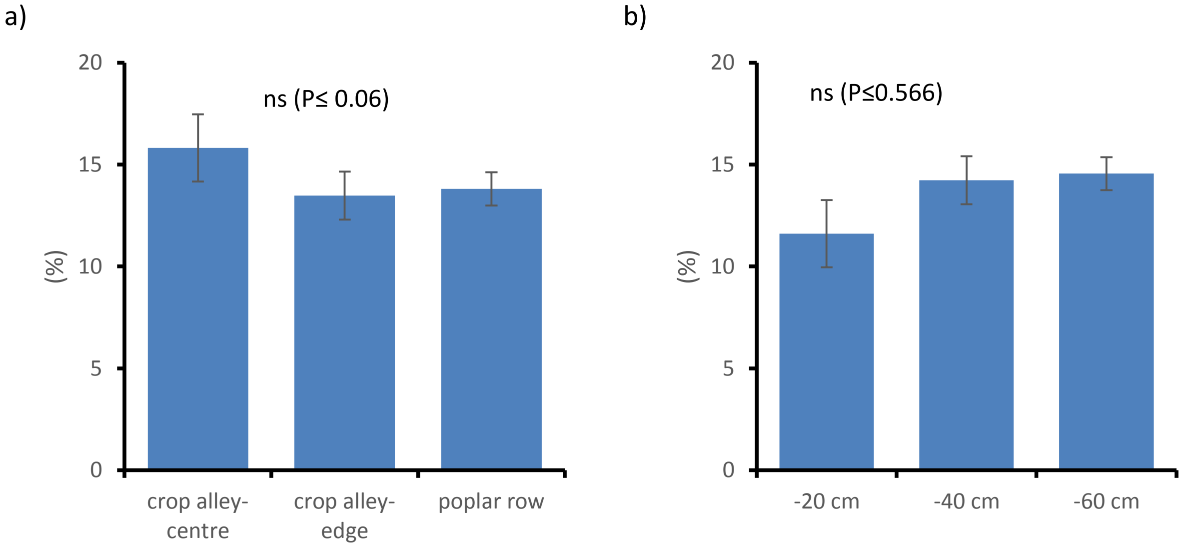

Figure 10. Soil moisture in a) three positions, and b) at three soil depths in treatment A and B on July 2015. Ns= not significant. P= level of probability

6.5 Stable isotopes in soil hydrology, plant water-use efficiency and nitrogen cycle

Results of Nitrogen isotope composition ($\delta^{15}N$) vs carbon isotope composition ($\delta^{13}C$) in poplar and sugar beet leaves are shown in Figure 11. It is worth noting that poplar and sugar beet are clearly separated on both axes. The enriched $\delta^{13}C$ suggests that the sugar beet displays higher intrinsic water-use efficiencies (WUE) than poplar. Such a high difference in WUE between the crop and the tree could be due to the different physiology of the species. The sugar beet also revealed a much higher leaf nitrogen content than poplar. This finding strongly indicates higher WUE because of enhanced photosynthetic capacity in sugar beet, rather than because of a higher stomatal control.

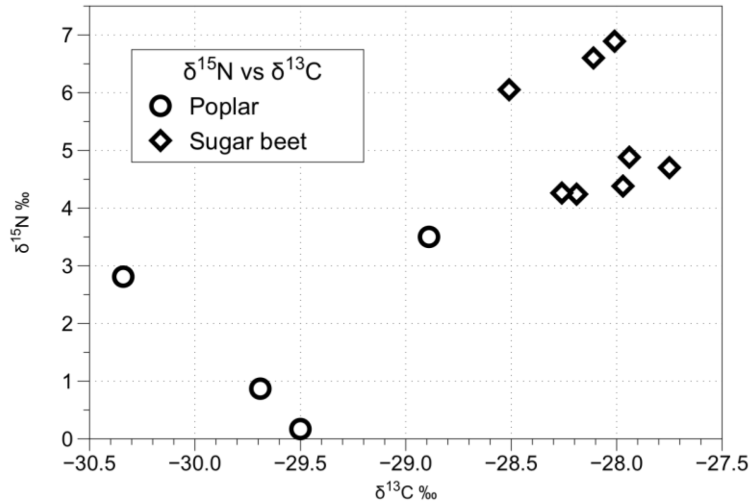

Figure 11. Nitrogen isotope composition ($\delta^{15}N$) vs carbon isotope composition ($\delta^{13}C$) in poplar (circle) and sugar beet (diamond) leaves.

On the nitrogen side, enriched values of $\delta^{15}N$ in sugar beet could have been the result of high nitrogen fertilization (about 130 kg N ha^{-1}). The relatively low values of $\delta^{15}N$ measured in poplar could suggest that the tree is utilizing, at least partially, the nitrogen leaching towards the ditches. Indeed, mineral nitrogen is usually characterised by values of $\delta^{15}N$ close to 0‰.

Enriched values in the crop could also be due to several fractionation factors acting in the system. A portion of the nitrogen could be leached after rainfall or irrigation and some could have been incorporated by the soil microorganisms and gradually released to the crop. This latter nitrogen transfer is highly susceptible to cause isotope fractionations. Another hypothesis is that isotope fractionation occurs during the complex nitrogen pathways within the plant itself. It is anticipated that further measurements planned on the root material could provide further information on this relevant issue.

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8 References

Bianconi D, De Paolis M, Agnello AC, Lippi D, Pietrini F, Zacchini M, Polcaro C, Donati E, Paris P, Spina S, Massacci A (2011). Field-scale rhyzoremediation of a contaminated soil with hexachlorocyclohexane (HCH) isomers: the potential of poplars for environmental restoration and economic sustainability. In: Golubev IA (Ed.): Phytoremediation: Processes, Characteristics, and Applications. Nova Science Publisher, Hauppauge. NY. Vol 10 pp.231-ISBN: 978-1-61728-753-4, 2010 Nova Science Publishers, Inc.

Barrett RL, Mullin LJ (1968). A method of assessing stem straightness in tropical pines. Rhodesian Bul For Res No. 4. Rhodesian Forestry Commission.

Correale Santacroce F, Dalla Valle C, Rizzi A (2011). Fasce boscate lungo le arterie viarie. Veneto Agricoltura, Azienda Regionale per i settori Agricolo, Forestale e Agro-Alimentare, Legnaro (Pd).

Dalla Valle C (2011). AGROFORESTAZIONE. Produrre con gli alberi per un'agricoltura differente. Veneto Agricoltura, Azienda Regionale per i settori Agricolo, Forestale e Agro-Alimentare, Legnaro (Pd).

Facciotto G, Minotta G, Paris P, Pelleri F (2015) Tree farming, Agroforestry and the New Green Revolution. A necessary alliance. O Ciancio (Ed.), Proc. II Inter Congress Silviculture, Vol. II: 658-69. Italian Academy of Forest Sciences, Firenze-Italy, 26-28 Nov. 2014

Eichhorn MP, Paris P, Herzog F, Incoll LD, Liagre F, Mantzanas K, Mayus M, Moreno G, Papanastasis VP, Pilbeam DJ, Pisanelli A, Dupraz C (2006). Silvoarable systems in Europe –past, present and future prospects. Agroforestry Systems 67: 29 –50.

Frazer GW, Canham CD, Lertzman KP (2000). Gap light analyzer 2.0. Bull. Ecol. Soc. Am. 81, 191–197.

Lauteri M, Alessio GA, Paris P (2006). Using Oxygen Stable Isotopes to Investigate the Soil-Plant-Atmosphere Hydraulic Continuum in Complex Stand of Walnut. Proceedings of Vth International Walnut Symposium. Malvolti ME, Avanzo D (Eds.). Acta Hort. (ISHS) 705:223-230.

Mercurio R, Minotta G (2000). Arboricoltura da legno. CLUEB Bologna, Italia, ISBN 88-491-1603-9, 203 pp.

Mwase WF, Savill PS, Hemery G (2008). Genetic parameter estimates for growth and form traits in common ash (*Fraxinus excelsior*, L.) in a breeding seedling orchard at Little Wittenham in England. New Forests 36: 225–238.

Paris P, Mareschi L, Sabatti M, Tosi L, Scarascia-Mugnozza G (2015). Nitrogen removal and its determinants in hybrid Populus clones for bioenergy plantations after two biennial rotations in two temperate sites in northern Italy. iForest, Biogeosciences and Forestry 8: 668-676.

Paris P, Mareschi L, Ecosse A, Pisanelli A, Sabatti M, Scarascia Mugnozza G (2011). Comparing hybrid Populus clones for SRF across Northern Italy after two biennial rotations: survival, growth and yield. Biomass and Bioenergy 35:1524-1532.

Pisanelli A, Camilli F, Dalla Valle C, Paris P (2014). Initial Stakeholder Meeting Report Trees for timber intercropped with cereals in Italy. http://www.agforward.eu/index.php/en/trees-for-timber-intercropped-with-cereals-445.html

Pisanelli A, Marandola D, Marongiu S, Paris P, Rosati A, Romano R (2014). The role of Rural Development Policy in supporting agroforestry systems in EU. Book of Abstracts (Palma JHN Ed.) 2nd European Agroforestry Conference, ISBN 978-972-97874-4-7, pages 22-25, European Agroforestry Federation, 4-6 June 2014, Cottbus, Germany.

Veneto Agricoltura (2002). Fasce Tampone Boscate in ambiente agricolo. Veneto Agricoltura, Azienda Regionale per i settori Agricolo, Forestale e Agro-Alimentare, Legnaro (Pd).