# Lessons learnt:
# 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, which focuses on "Trees for timber with arable crops in Italy" contributes to the second objective. In turn the report will form part of Deliverable 4.11: "Lessons learnt from innovations related to agroforestry for arable farmers". Similar reports are available for agroforestry of high nature and cultural value, agroforestry with high-value trees, and agroforestry for livestock systems.

# 2 Background

Poplar hybrids and species have been intensively managed in Italy for timber production. Although they are usually managed as monoculture plantations, they are also sometimes established as intercropping systems and linear plantations along field edges, drainage canals and streams (Eichhorn et al. 2006). In the majority of site conditions in Italy, water availability is the most limiting factor affecting poplar growth rates due to their hydrophilic behaviour, which requires constant soil moisture throughout the growing season (Paris et al. 2018; 2015; 2011; Sabatti et al. 2014). 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). Intercropping poplar trees with arable crops is recognized as a form of "smart agriculture" due to the efficient use of site resources (light, nutrients and water) by trees and crops. Additionally, global and regional environmental concerns in relation to carbon dioxide mitigation, soil erosion, use of alternative energy sources, and land restoration using phytoremediation could provide new opportunities for poplar silvoarable systems (Dalla Valle 2011; Correale et al. 2011; Veneto Agricoltura 2002; Bianconi et al. 2011). The Common Agricultural Policy for Rural Development 2014-2020 currently supports the establishment of agroforestry systems in Europe, with direct grants encouraging tree inter-planting with arable crops. The total area of new agroforestry systems established with EU financial support in the EU27 was only about 627 ha (Pisanelli et al. 2014). In Italy, 9 ha of agroforestry were established with the Measure 2.2.2. 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 alley cropping system established in 2013, planting poplar and oak tree species along field edges and ditches. Collaboration between research institution and farming stakeholders for testing alley-cropping systems in Italy was undertaken in Casaria farm within the AGFORWARD project. A meeting was initially organized with stakeholders (Pisanelli et al. 2014) followed by a research and development protocol (Dalla Valle and Paris 2015) and a first detailed system description of a case study system (Paris et al. 2016).

The four main hypotheses related tree-crop productive performances and environmental benefits of alley cropping systems were tested:

i) Tree growth rates in alley cropping systems could be lower than in plantation conditions due to possible intercrops competition for soil water and nutrients;
ii) Tree stem forms, strongly affecting timber quality, could be negatively affected by low planting tree density in alley cropping systems;
iii) Once trees are growing, their shading can decrease intercrops yield, reducing the profitability in comparison to alternative land-use systems;
iv) Competitive or synergic use of soil water and nutrients, between tree and crop components, must be balanced (e.g. soil moisture competition by intercrops towards young trees) to enhance environmental benefits (e.g. reduction of nitrogen leaching due to tree root systems deeper that intercrops).

## 3 Activities

During the AGFORWARD project, four main activities were carried out in the silvoarable system:

1. Measurement of tree growth rates, and stem forms, which were assessed by a fast and non-destructive index of stem straightness (by Barrett and Mullin 1968, re-adapted by Mwase et al. 2008);
2. Measurement of yield and quality of intercrops at progressive distances from tree-rows;
3. Tree shade assessment on intercrops using digital hemispherical photographs;
4. Eco-physiological measurements of the tree-crop interactions by stable isotopes analysis of soil and plant carbon, oxygen and nitrogen.

Table 1. Specific description of the studied alley cropping system of Casaria Farm, Municipality of Masi, Po-Venetian Plain, Italy

| Specific description of site | |
|---|---|
| Area | 65 ha of which 9 ha are managed as alley cropping system, intercropping poplar and oaks established in 2013 |
| Coordinates | 45°08’24.87”N, 11°30’25.61”E |
| Site contact | Cristina Dalla Valle (VenetoAgricoltura); Pierluigi Paris (CNR-IBAF) |
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Example photograph

Figure 1. The alley cropping system at Casaria Farm in summer 2014, one year after tree planting, with durum wheat intercropping

Figure 2. The alley cropping system at Casaria Farm in late July 2016, with the hybrid poplar-oak rows intercropped with soybean

| 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.

| Climate characteristics | |
|---|---|
| Mean temperature | 14.7°C |
| Mean annual precipitation | 1024 mm |
| Details of weather station (and data) | Historical data from 2010 to 2014<br>http://www.arpa.veneto.it/arpavinforma/bollettini/dati-storici |
| **Soil type** | |
| Soil type | WRB (1998): Calcari-fluvic cambisols<br>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.<br>Chart of Veneto soils- cartographic unit: BR2.2<br>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 poplars and oaks |
| 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 | 2014: Durum wheat (*Triticum durum*); 2015: Sugar beet (*Beta vulgaris*); 2016: durum wheat (Nov. 2015-June 2016) and soybean (*Glycine max*) (July-Sept. 2016) |
| Management | In 2014 and 2015, conventional arable crop management with ploughing and herbicide spraying to reduce weeds. Since 2016, the farm is currently in conversion to organic farming, with the use of chemical inputs being 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 (2014-2015) |
| Machinery | Tractor access in crop alleys to allow soil preparation, spray application and crop harvest |
| Labour | Trees: yearly pruning by hand. 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 at the modelling workshop of the AGFORWARD project in Lisbon, February 2016 |

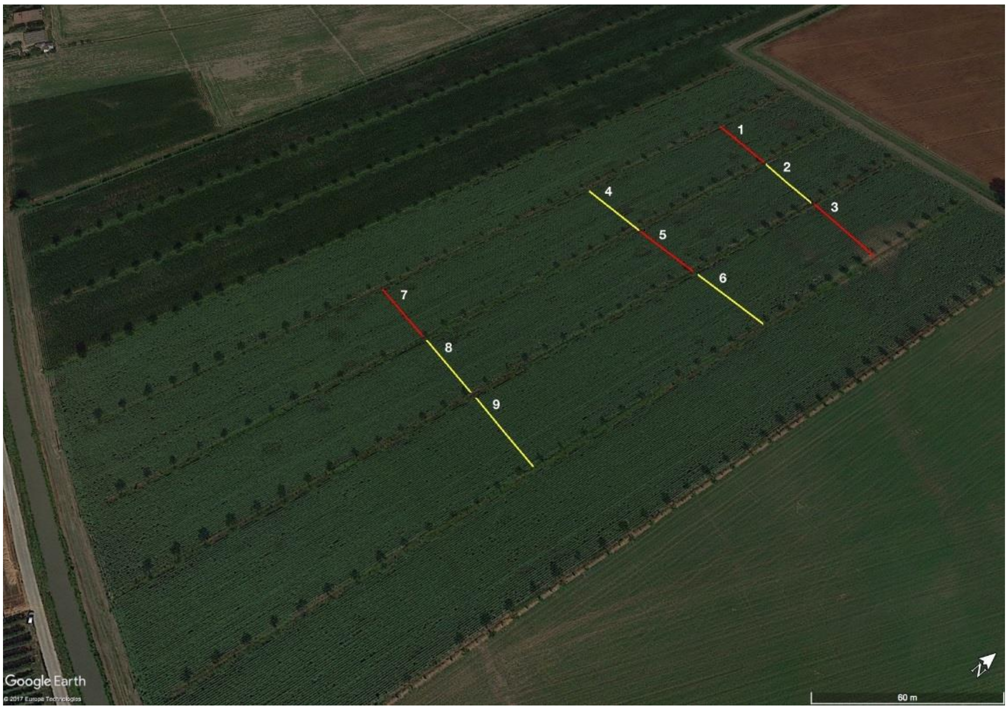



Figure 4. Sampling transects at *Casaria* alley cropping system. Each transect is delimitated by two adjacent poplar - oak rows, with intra-row spacing of 5 m. Intercrop was manually harvested in 3 sampling plots within the transect: one plot at the alley centre, and two plots on the alley edges, close (1.5 m away) to the tree rows. Intercrop sampling was performed along red transects in 2015, and along yellow and red transects in summer 2016.

# 4 Results

## 4.1 Tree growth

The data of tree growth, for hybrid poplar and pedunculate oak are shown in Table 2, after they were intercropped with wheat for the first two growing seasons (2013-2014), with sugar beet in 2015, and with wheat and soybean during 2016. Oak and poplar were planted in the same year. Oak has a much slower growth rate than hybrid poplar (see also Figure 2), as well known since the system establishment.

Timber quality of poplar trees was evaluated using the stem straightness index. The wood quality of the 4 years-old intercropped poplar trees appears to be good with an estimated straightness index close to 2. The value of the 3 is the minimum threshold for producing saw logs.

Table 2. Total height, stem diameter at breast height (DBH) and stem form index in winter 2016 at Casaria Farm, after four growing seasons since tree planting. Means and standard error of means (in parenthesis) are shown.

| 4$^{th}$ year | Total height (m) | DBH (cm) | Stem form index |
|---|---|---|---|
| Poplar | 6.97 (0.15) | 7.27 (0.27) | 2.330 (0.015) |
| Oak | 1.30 (0.07) | | |

Figure 5 shows the comparison of poplar growth rates in Casaria alley cropping system, and standard growth rates of hybrid poplar I214 in timber plantations at different site conditions and rotation lengths. The hybrid poplar trees in the alley cropping plantation initially showed a slow growth that may have been due to competition with the crops or weeds for water and nutrients. It is also possible, that soil around the trees was very compacted. At the time of tree planting, the soil along the tree rows (2 m wide) was left almost unploughed, and the trees were planted by making narrow (3 to 5 cm diameter) and 1 m deep holes where the poplar rods were inserted.

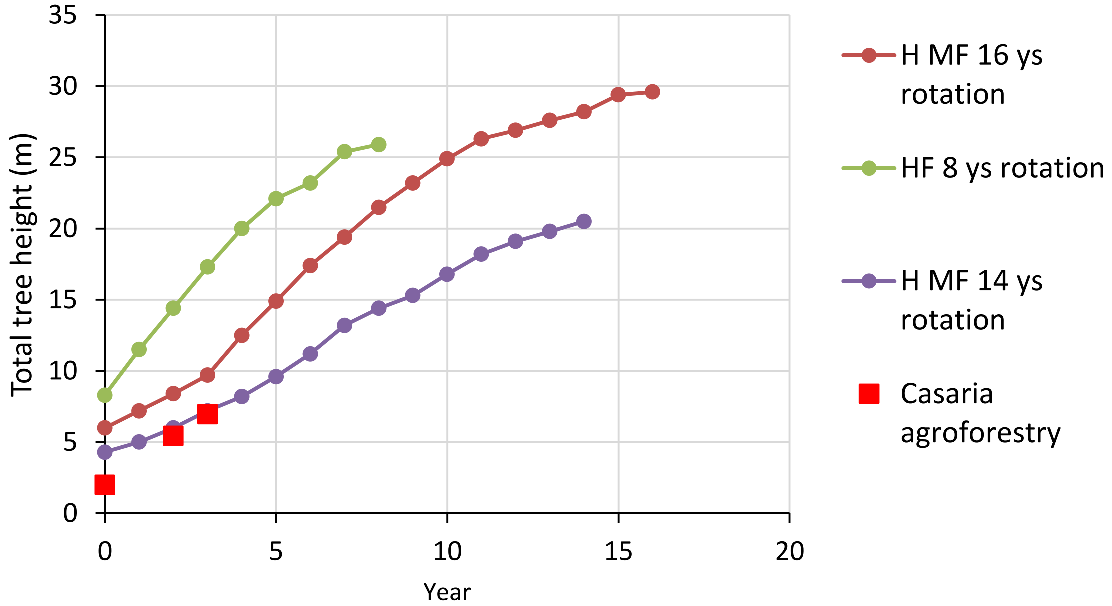



Figure 5. Comparison of poplar growth rates in Casaria alley cropping system (red squares) and standard growth rates of hybrid poplar I-214 in timber plantations at different site conditions and rotation length (H MF = site with high-medium fertility; HF = site of high fertility). The height at year 0 represents the height of rods, above soil surface, used for tree planting. Gianni Facciotto (CREA, Italy) provided standard data for comparison.

After four years, the growth rate of poplar trees in the alley cropping system is comparable to that of the standard condition of a site with a high-medium fertility, with an estimated length of the rotation of 14 years, which is longer than the standard rotation of poplar plantations in the area.

### 4.2 Intercrop yields

Three sampling plots of sugar beet per transect were harvested manually, during summer 2015, and the fresh production of the roots was weighted immediately after extraction from the soil, using a portable scale (precision 100 g). Data of sugar beet yields and sugar contents are shown in Table 3.

Table 3. Sugar beet tap-root yield characteristics during the year 2015 (values in brackets are the standard errors of the means).

| Plot | Root fresh yield (Mg ha$^{-1}$) | Root dry yield (Mg ha$^{-1}$) | Sugar concentration (%) |
|---|---|---|---|
| Alley edge-East | 67.90 (3.62) ns | 14.4 (0.67) | 15.9 (0.249) ns |
| Alley edge-West | 62.20 (3.38) | 12.6 (0.9) | 15.170 (0.387) |
| Alley centre | 77.90 (3.52) | 16.2 (1.2) | 15.920 (0.297) |
| ANOVA P value | | | |
| Transect | 0.494 | 0.166 | **0.007 *** |
| Plot | 0.164 | 0.324 | 0.097 |

The taproots were manually lift in each plot and weighted in the field with a portable scale (precision ± 0.01 kg). Root sub-samples were used for the determination of the moisture content of the fresh taproots (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 ± 1 g) and reweighing the subsample after stove drying at 80°C until constant weight. An ANOVA test was conducted using *Transect* and *Plot* as random factors. 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 did not significantly affect the yield or crop quality of the associated crop. Three plots per transect of durum wheat and three of soybean were harvested manually, respectively in June 2016 for a total of 27 plots and in October 2016 for a total of 27 plots (each one of 1 m$^2$), following the sampling design in Figure 4. Yields of durum wheat and soybean were estimated after stove drying at 80°C until constant weight. Table 4 shows the intercrop yields of durum wheat and soybean for the year 2016.

Table 4. Yield characteristics of durum wheat and soybean, in double-cropping system as winter and summer crop, respectively, during the year 2016 (values in brackets present standard errors of the means). Different letters indicate significant differences between mean values. * indicates significant difference between plots or transects.

| 2016 crops Plot | Durum wheat grain yield (Mg ha$^{-1}$) | Soybean grain yield (Mg ha$^{-1}$) |
|---|---|---|
| Alley centre | 4.88 (0.12) ns | 4.47 (0.08) a |
| Alley edge-East | 4.64 (0.26) | 3.67 (0.33) b |
| Alley edge-West | 4.79 (0.19) | 3.85 (0.18) b |
| ANOVA P- value | | |
| Transect | 0.001* | 0.402 |
| Plot | 0.684 | 0.046* |

We performed a two-way analysis of variance (ANOVA) to examine the influence of the two factors (*Transect* and *Plot)* on intercrop yields (Table 4).

The ANOVA shows, that the plot position along the North-South direction (*Transect*) affected the yield of durum wheat (Table 4), but there was no an effect in the east-west direction (*Plot*). The yield data of durum wheat as affected by Transect treatment are not presented in this report because they require further analysis.

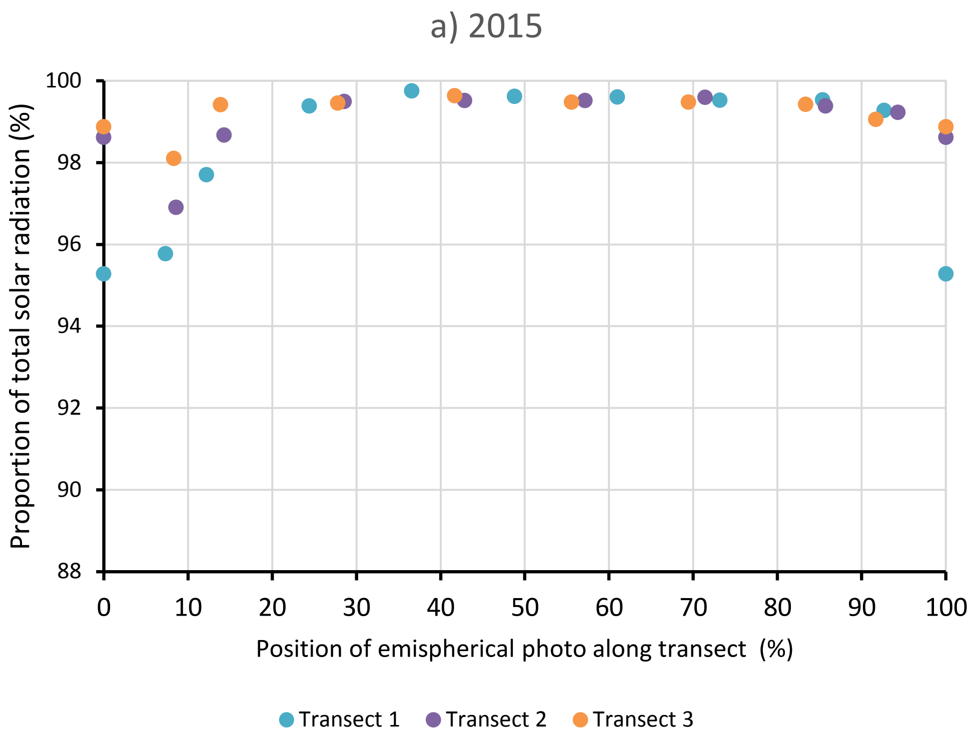
By contrast for the soybeans, the plot position along transects (east-west direction between two hedgerows of trees) influenced the soybean yields. The central plots had significantly ($p < 0.05$) higher yields than plots near the tree rows. There was not an effect in the North-South direction (Transect) (Table 4).

**4.3 Assessment of trees shade on intercrops by digital hemispherical photo**

Hemispherical photos of the crop were taken (Figure 6).

Figure 6. Measuring solar radiation distribution, with hemispherical photos, across intercrop alley (with soybean) between 4 years old tree rows, on 28 July 2016.

The proportion of solar radiation transmitted below the canopy, as determined using the Gap Light Analyser software (Frazer et al. 1999) for hemispherical photos is shown in Figure 7. There were significant differences in solar radiation values across the crop alley, with a maximum towards the alley centre for both 2015 and 2016. However, as the poplar trees are only three/four-years old, the differences in solar radiation were small: about 3% in 2015 up to 14% in 2016.



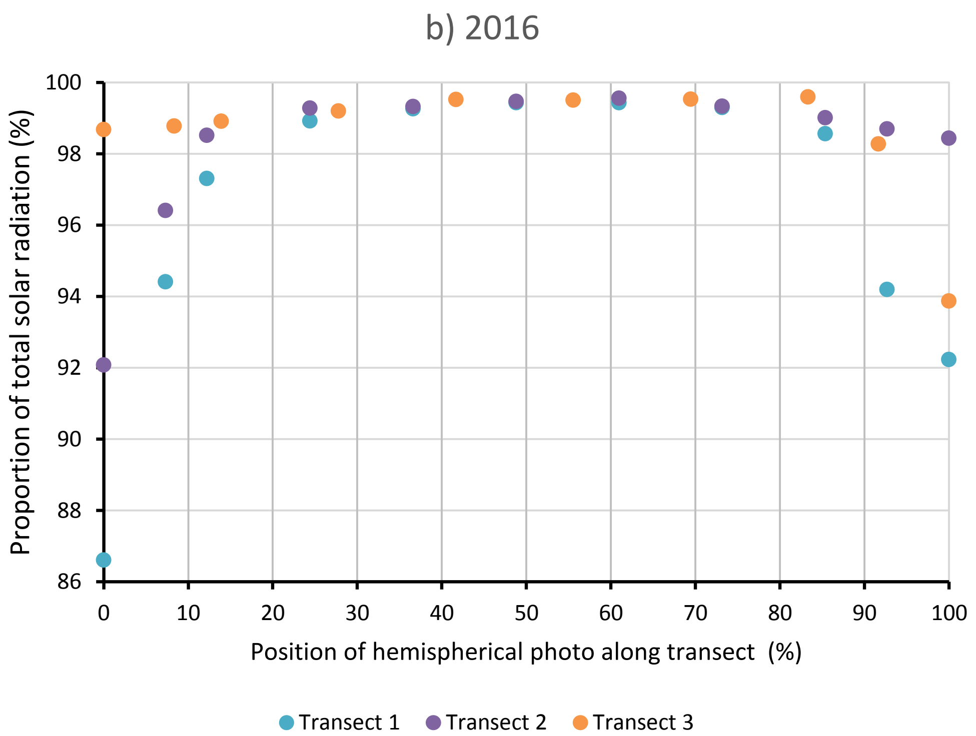




Figure 7. Percentage of total solar radiation transmitted below the poplar canopies and at different distances from poplar rows in crop alleys in (a) July 2015 and (b) in July 2016. Measurements were obtained with hemispherical photos taken with a digital camera moved across alleys along three transects (symbolised with different colours). Each point represents a single observation. Distance from tree row is expressed in percentage: from the eastern (0%) to the western side (100%) of each transect.

### 4.4 Stable isotopes

The nitrogen isotope composition ($\delta^{15}N$) vs the carbon isotope composition ($\delta^{13}C$) of poplar and sugar beet leaves are shown in Figure 8. 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 the poplar. This finding suggests higher WUE because of enhanced photosynthetic capacity in sugar beet, rather than because of a higher stomatal control.

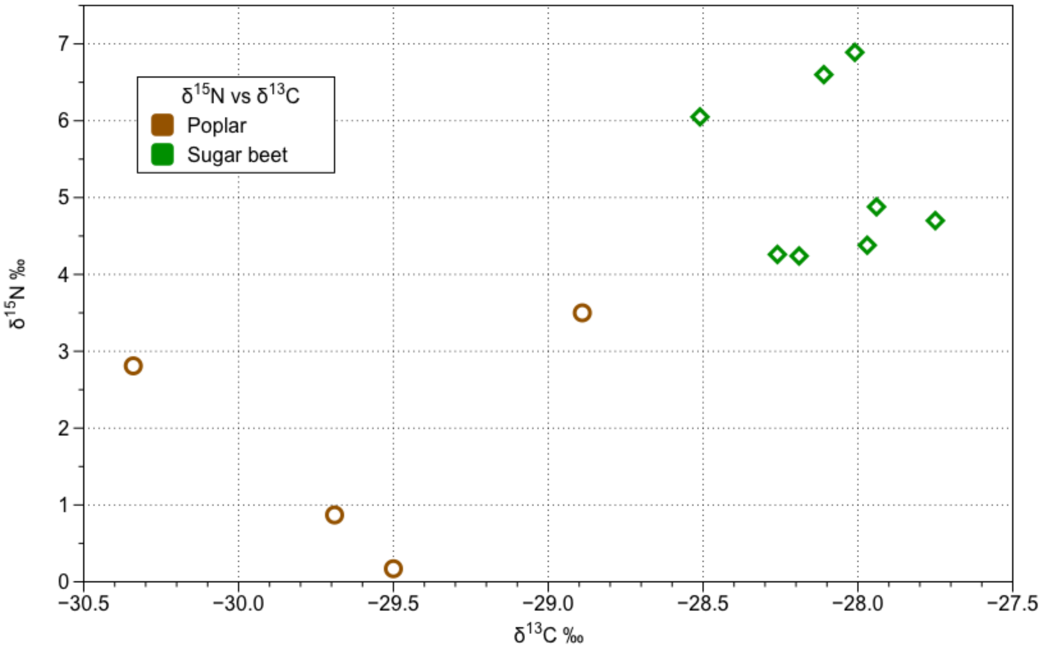



Figure 8. Nitrogen isotope composition ($\delta^{15}N$) vs carbon isotope composition ($\delta^{13}C$) of poplar (brown circle) and sugar beet (green diamond) leaves, in the year 2015.

On the nitrogen side, enriched values of $\delta^{15}N$ in sugar beet is likely due to the high nitrogen fertilization (about 130 kg N ha$^{-1}$). The relatively low values of $\delta^{15}N$ measured for poplars could suggest that trees are 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. Further measurements on the root material could provide deeper information on this relevant issue.

Figure 9 shows the mean values of $\delta^{18}O$ of soil water, collected along soil profile and on the ditch bottom, and of xylem water of poplar and soybean, sampled at the end of July 2016. Oxygen stable 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 so the water table and the waters in the shallow, medium and deep soil layers usually differ in their isotopic compositions. No isotopic effects occur during water uptake by roots or during xylem transport, so that xylem water $\delta^{18}O$ is the average of the different water sources used by the plant.

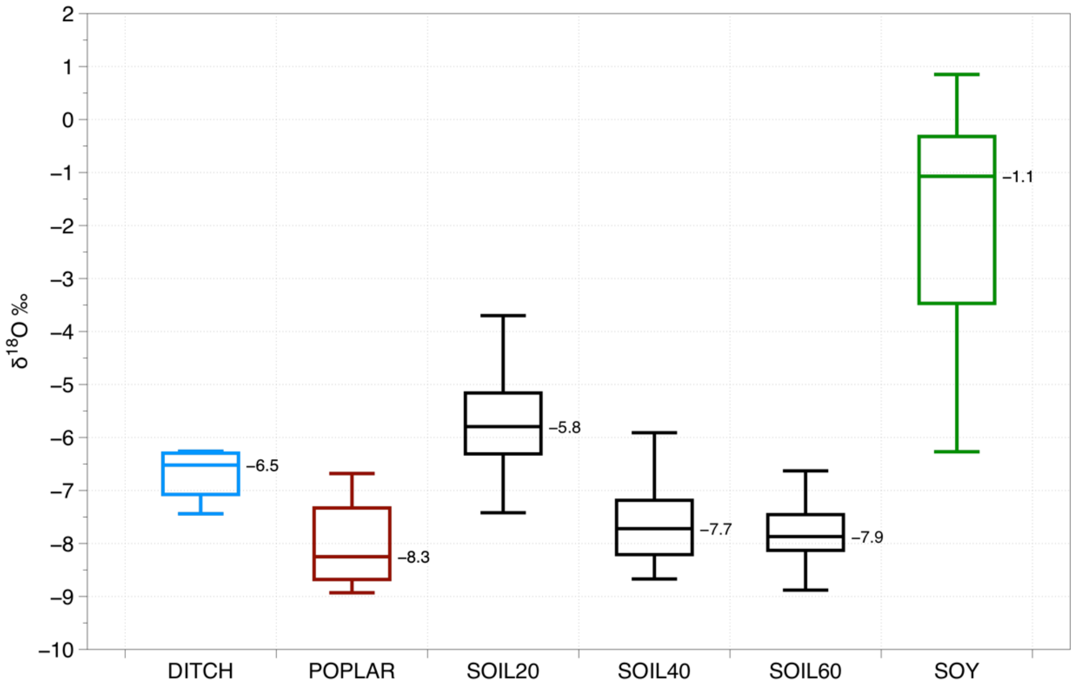



Figure 9. Distribution of $\delta^{18}O$ (median values shown) of soil water, sampled along soil profile (20, 40 and 60 cm deep, in black) and on ditch bottom (light blue), and of xylem water of poplar (brown) and soybean (green), in summer 2016.

Oxygen stable isotopes can be used for elucidating the strategies of plant water use in pure and mixed systems, based on variations in oxygen isotope composition of soil profiles and plant tissue waters (Lauteri et al. 2006). Indeed, $\delta^{18}O$ of xylem water provides relevant information in tracing the depth of root systems and the functional links between vegetation and different water sources in an ecosystem. Figure 9 shows that soil water $\delta^{18}O$ averages in the experimental field varied between – 5.8‰ at 20 cm depth and – 7.9‰ at 60 cm. Xylem water reflects the oxygen isotopic composition of water used by plant species as no isotopic fractionation occurs during water uptake and transport (Dawson et al. 2002). Data of $\delta^{18}O$ of xylem water for the species included in the alley cropping system are shown in Figure 9. These data clearly indicate inter-specific variability in patterns of water uptake. Soybean is the shallowest rooted species as the relatively enriched $\delta^{18}O$ value suggests. On the other hand, poplar trees were dependent on relatively deeper water during the summer. Summarizing, our data in Figure 9 show that poplars used a higher proportion of deep water sources than soybean, thus reducing competition for water in the studied alley cropping system.

## 5 Main lessons

We studied alley-cropping system established by incorporation of hybrid poplars and endemic oaks along the farm drainage ditches. Such a practice could enhance both financial and environmental value of the farmland.

According to the research findings obtained so far the following conclusions can be drawn:

i) Low-lying and flat alluvial soils, with frequent drainage ditches (at spacing of about 30-35 m), can be easily used for the establishment of alley cropping systems using fast growing hybrid poplars for timber production. Planting trees along one side of the drainage ditches optimizes the use of reclaimed land.

ii) Tree growth rate of hybrid poplar in such conditions are comparable to those of the same species planted in monoculture plantation;

iii) The expected poplar rotation, for reaching marketable trunk dimension, should be 14 years;

iv) Stem form and timber quality of hybrid poplars were not negatively affected in this study by the low planting density required by alley cropping system;

v) Survival of oak trees is high, although their growth rates are much lower than hybrid poplars, as expected since the establishment of the experiment;

vi) Intercrop management, in terms of machinery movement along the alleys and distribution of fertilizers and herbicides are not negatively affected by tree rows planted along the drainage ditches;

vii) Intercrop yields showed some decrement during the fourth year due to tree presence, with soybean, as a warm season crop, showing some negative effects of tree shading in the near proximity of alley edges;

viii) The above results can be used to validate simulation results (e.g. Graves et al. 2007) showing that the decrease in intercrop yields in poplar alley cropping systems. We found an intercrop decrease four years after planting.

ix) Stable isotopes studies showed early positive synergic interactions between intercrops and trees concerning soil water and nutrients, with poplar trees using soil moisture in deeper soil layers than intercrops, and likely reducing N leaching;

x) Further modelling studies should be applied to such alley cropping system based on poplar trees, for studying its financial profitability for farmers in Italy and other parts of Europe. Poplar trees are widely used for plantation forestry across temperate Europe with almost 900,000 ha of plantations in Europe and Turkey (Ma and Lebedys 2014);

xi) An Innovation leaflet, entitled “The incorporation of hybrid poplar and endemic oak in arable agroforestry systems along drainage ditches” has been produced within the AGFORWARD project and is available on line on AGFORWARD website.

## 6 Acknowledgements

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