System Report: Cereal Production beneath Walnut in Spain

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Work-package	4: Agroforestry for arable farmers
Specific group	Cereal production beneath walnut for quality timber production in Spain
Deliverable	Contribution to Deliverable 4.10 (4.1): Detailed system description of a case study system
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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

During the 2010s, intensive hardwood plantations, using chemical inputs and high levels of energy inputs to reduce the rotation length, have substantially increased in many Spanish regions. Periodical harrowing, irrigation and the use of herbicides and mineral fertilizers are controversial management practices because of the high costs and their impact on soil and water pollution (Babcok et al. 2003; World Bank, 2008). Agroforestry could help to reduce the net financial costs of these plantations and improve the delivery of environmental services (Rigueiro-Rodríguez et al. 2009; López-Díaz et al. 2011).

This systems description relates to an intensive plantation of walnut for the production of quality timber located in Toledo (Spain) owned by the company Bosques Naturales S.A. This company owns 1300 hectares in Spain for quality timber production with forestry certification by FSC.

3 Update on field measurements

Field measurements described in the research and development protocol (Moreno et al. 2015) started in 2014 and will continue until the end of 2016. All measurements have been and will be conducted by researchers from the UEX team. In total the study includes three cropping seasons (2013-2014, 2014-2015, and 2015-2016). Each year different cereal species and cultivars were sown in a silvoarable plantation of hybrid walnuts. This report presents some preliminary results collected during the first two years.

4 Description of system

The experiment was carried out in Toledo (Spain) in an 8-year old hybrid walnut (*Juglans major* x *regia*) plantation (Table 1 and 2), with a density of 333 trees ha^{-1} owned by the company Bosques Naturales S.A. Missing data will continue to be sourced during 2016.

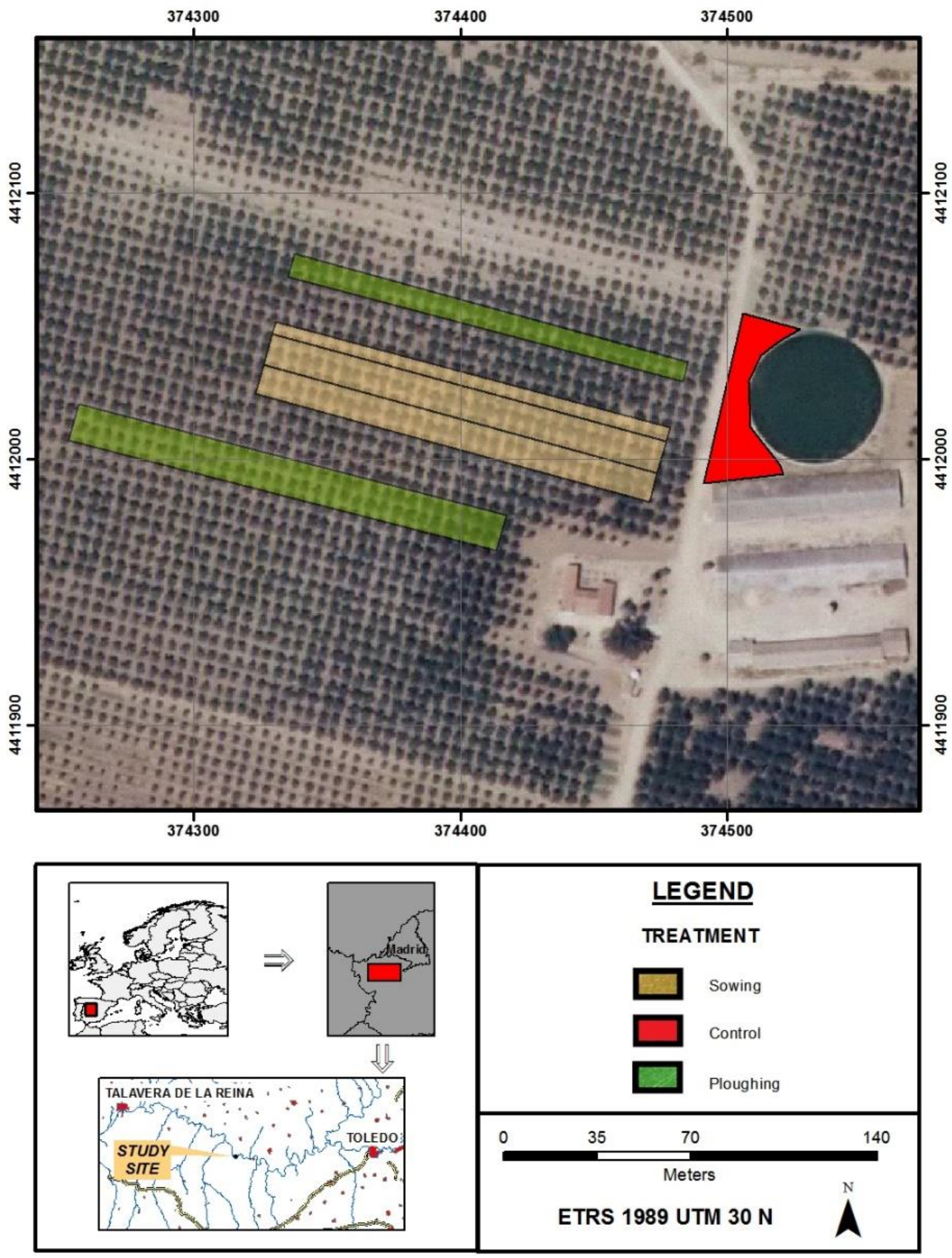
Table 1**.** General description of cereal production beneath walnut

General description of system	
Name of group	Cereal production beneath walnut in Spain
Contact	Gerardo Moreno
Work-package	4: Agroforestry for arable farmers
Associated WP	Arable farmers
Geographical extent	Plantations of walnut for the production of quality timber are found in Europe, United States, China and Chile.
Estimated area	The company Bosques Naturales S.A owns 1300 hectares in Spain for quality timber production with forestry certification by FSC.
Typical soil types	Fluvisols
Description	Walnut is commonly planted on arable land in orchards or on borders of arable land with other trees. Growing walnut for timber production has become increasingly popular due to the high value of its timber and its fast growth. Currently, several agroforestry systems have been established using walnut trees intercropped with cereal production and fodder crops (Pisanelli et al. 2006; Mohni et al. 2009). Its principal aspect is the diversity of products provided by the system. So, this system can increase growth and/or quality of the walnut trees or provide an early financial return to help offset the costs associated with establishing the walnut plantation (Cabanettes et al. 1999; Chiffot et al. 2006).
Tree species	Walnut: *Juglans regia*, *J. nigra* and *J. major* and hybrids.
Tree products	High value timber
Other provisioning services	Possibility of using tree prunings as livestock fodder or as biomass.
Regulating services	The trees increase carbon storage.
Habitat services and biodiversity	This system can give shelter to birds.
Cultural services	Rural employment

Table 2. Description of the specific case study system

Specific description of site	
Area	0.5 ha
Co-ordinates	39°50’56’’ N 4°28’03’’W (39,8488, -4,4675)
Site contact	Gerardo Moreno
Site contact email	gmoreno@unex.es
Example photograph	
 Cereals grown beneath walnut; the irrigation system for the trees can be seen in the tree row on the left hand side.	
Possible modelling scenarios	
Comparison	Technical and economic analysis of cereal growing in the alley
Climate characteristics	
Mean monthly temperature	15.3°C
Mean annual precipitation	437 mm
Details of weather station (and data)	Data from 1961-2002 from the 3303E weather station at Carpio de Tajo, accessed from website (http://sig.magrama.es/93/ClienteWS/siga/Default.aspx?nombre=CH_ESTACIONES&claves=DGA.CH_ESTACIONES.CLAVE&valores=3303E).

Map of system



The layout of the experimental area in the 2014-2015 cropping season

Soil type	
Soil type	WRB classification: Fluvisol Fluvisols are soils developed in alluvial deposits which are named from the Latin "*fluvius*" which means river. (FAO. 2001). These soils receive fresh material or have received it in the past and still show the stratification (FAO, 2015).
Soil depth	>140 cm
Soil texture	Sandy loam
Additional soil characteristics	pH 5-6 Slope < 5%
Tree characteristics	
Species and variety	Walnut (Nat7 clone - *Juglans x intermedia* Mj209xRa)
Date of planting	2007
Intra-row spacing	5 m
Inter-row spacing	6 m
Tree protection	None
Crop/understorey characteristics	
Species	• 3 varieties of wheat (*Triticum aestivum* L): CCB Ingenio, Sublim, Nogal • 4 varieties of barley (*Hordeum vulgare* L): Basic, Lukhas, Hispanic, Rgt Dulcinea • 1 variety of triticale (*Triticosecale*)
Management	Intensive management with irrigation and fertilization.
Crop products	Cereal crops provide grain and straw as products. Additionally, cereal stovers are a source of nutrients and organic matter, which increases soil fertility and quality.
Regulating services	The crops increase carbon storage. The alley cropping system can also help to: suppress weed species, reduce soil compaction, increase infiltration of rainwater and reduce erosion.
Fertiliser, pesticide, machinery and labour management	
Fertiliser	600 kg 8:12:12 (NPK) ha^{-1} and 120 kg urea (46%) ha^{-1}.
Pesticides	None
Machinery	Need for tractor access between trees for the fertilisation and the ploughing application.
Manure handling	Not necessary in field
Labour	The farm is ploughed once a year
Financial and economic characteristics	
Costs	Unknown

5 Description of tree component

5.1 Tree species

The walnut hybrid Mj209xRa *Juglans major* x *regia* comes from the pollination from *J. major* with pollen of *J. regia*, and is more tolerant of less well-drained sites. *J. major* is a walnut tree which grows to a height of 15-20 m and it originates from the southwest of North America. *J. regia* is a walnut tree from Eurasia which grows to a height of 25-30 m. The resulting hybrid exhibits vigorous growth.

5.2 Tree spacing and hedgerow design

In our experimental plot, walnut trees were planted in 2007 at a regular spacing of 5 m x 6 m: trees spaced 5 m of distance within the row, and rows spaced 6 m (333 trees per ha). In February 2016, tree diameters were on average 16.3 cm at breast height, and 10-11 m high.

5.3 Tree growth

Tree growth was significantly reduced in the silvoarable system compared to pure plantation (Figure 1). In 2014, differences were very acute, with 2.61 cm (± 0.30 cm of standard deviation) of stem diameter increment for control trees and only 1.31 ± 0.45 SD cm for silvoarable ones ($F_{1, 66} = 171$, $p<0.001$). In 2015, differences were less but still significant. While stem diameter of control trees increased in 0.84 ± 0.36 SD cm, for silvoarable trees the increase was only 0.76 ± 0.13 SD cm ($F_{1, 237} = 22.2$, $p < 0.001$). Among cultivars, the effect was least with barley variety "Basic" and greatest with wheat variety "Ingenio" (0.80 ± 0.12 SD cm and 0.68 ± 0.20 SD cm, respectively). Pattern of tree height mirrored stem diameter increment (Figure 1).

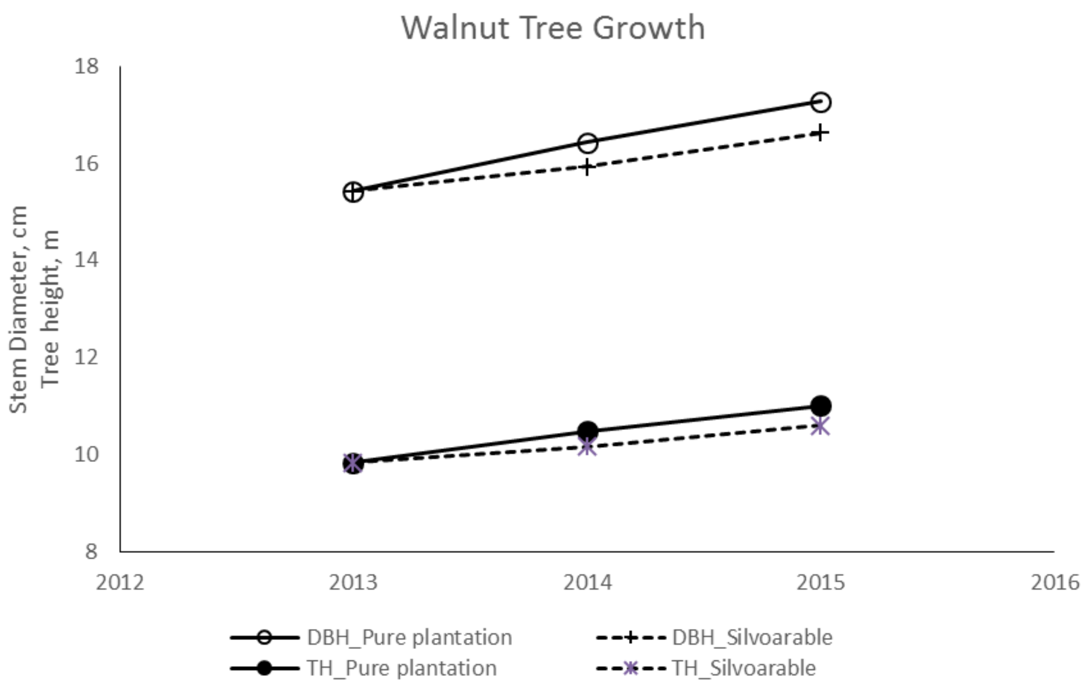
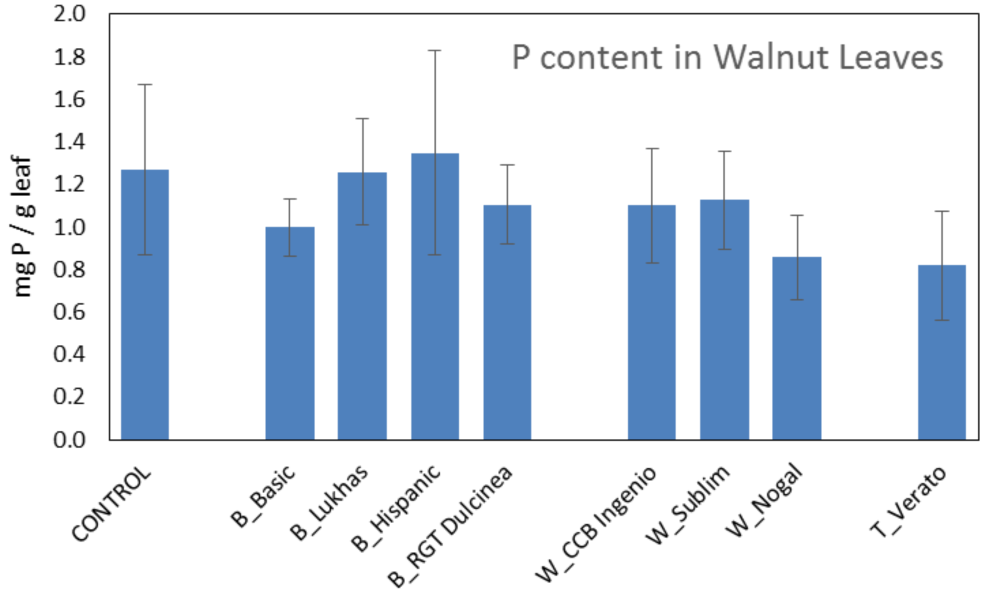


Figure 1**.** Tree stem diameter (DBH: diameter at breast height) and height (TH) measured in walnut trees in December of three consecutive years, including two cycles of cereal intercrop (2013-2014 and 2014-2015).

5.4 Tree nutrient concentration

The nutrient content of walnut leaves is affected by cereal cultivation. In 2014, the P content of leaves in intercropped trees was reduced significantly respect to control trees (1.84 ± 0.60 SD vs 2.23 ± 065 SD mg P g^{-1} leaf, respectively; $F_{1,65}$ = 6.37; p = 0.014). For N content, differences were only marginally significant (18.3 ± 1.9 SD vs 16.9 ± 3.1 SD mg P g^{-1} leaf, respectively; $F_{1,58}$ = 3.47; p = 0.675). In 2015, comparing mean values by species and cultivars of cereal intercropped, these differences were generally confirmed. N content was reduced significantly for wheat (Nogal and Sublim cultivars) and triticale in respect to control trees ($F_{3,51}$ = 3.05; p = 0.037; Figure 2a). For phosphorus significant differences were confirmed only for triticale and for Nogal among the wheat cultivars (p = 0.045 and p = 0.015, respectively; Figure 2b).



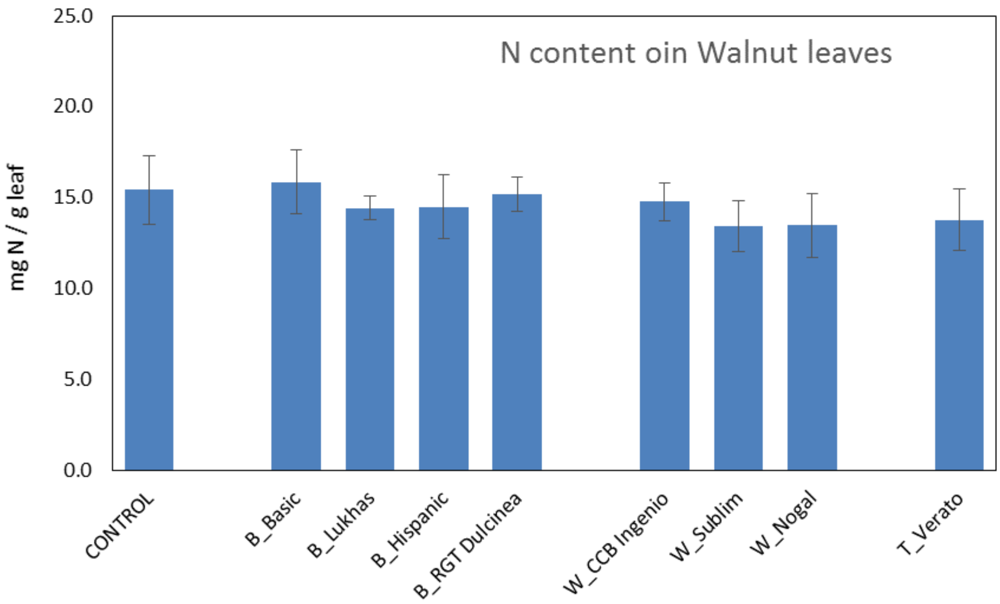


Figure 2. Effect of cereal intercrop on nutrient status of walnut leaves in 2015 (a: Phosphorus; b: Nitrogen). Vertical bars denote standard deviations.

6 Description of crop component

6.1 Crop species

Different cereal species and cultivars have been cultivated in autumn (and harvested the spring of the following year) in the 4 m wide alleys in between tree rows (1 m uncultivated at both side of the tree rows). The list of species and cultivars are listed in Table 3. After ploughing, cereals were sown in autumn 2013, 2014 and 2015, at a rate of 200 kg grain ha^{-1} for wheat, and 180 kg ha^{-1} for barley and triticale. In all cases cereal was fertilized with 600 kg ha^{-1} of a 8:12:12 $N:P_2O_5:K_2O$ compound fertilizer at the time of sowing and with 120 kg ha^{-1} of urea (46%) in spring.

Each June, the cereal was sampled at maturity in quadrats of 40 x 50 cm (n = 12-15). Above-ground biomass, grain biomass, number of grain per plant, and grain weight (weight of 100 grains) was measured in the lab. The phenological state of the cereal cultivars will be assessed in 2016 at the time of walnut leaf-emergence.

Table 3**.** List of cereal species and cultivars tested in the Bosques Naturales silvoarable site in Central Spain (Carpio de Tajo, Toledo).

	2013-2014	2014-2015	2015-2016
Barley	Doña Pepa, Azara	Basic, Lukhas, Hispanic, Dulcinea	Hispanic, Graphic, Meseta, Pewter
Wheat	Kilopondio, Bologna	CCB Ingenio, Sublim, Nogal	CCB Ingenio, Nogal, Boticelli, Idalgo
Triticale		Verato	Verato, Montijano

Table 4**.** Site management parameters

Feature	Average value
Distance between rows (inter-row tree spacing)	6 m
Tree distance within a row (intra-row tree spacing)	5 m
Tree strip width	2 m
Crop width	4 m
Crop length	20 m
Mean breast diameter (1.3 m)	16.08 cm
Trees per hectare	333
Rotation	40 years
Proportion of area occupied by crop	66.7%
Sowing date	November
Harvest date	Mid-June

6.2 Cereal yield

There were significant differences between the monoculture cereal and agroforestry cereal treatments in terms of total crop biomass both in 2014 ($F_{1,124} = 4.16$, $p < 0.001$) and 2015 ($F_{1,200} = 7.00$, $p = 0.008$). In 2014, differences were significant only for two barley cultivars (more crop biomass in silvoarable plots) but not for wheat cultivars (Table 5). In 2015, crop biomass was higher in the silvoarable than in the control plots for all cereal species and cultivars, but differences were significant only for barley and not for wheat and triticale. Among barley cultivars, differences were greatest with the cultivar Hispanic (Table 6).

Concerning grain yield, differences among systems were also significant in 2014 ($F_{1,124} = 12.3$, $p < 0.001$) and 2015 ($F_{1,196} = 14.22$, $p < 0.001$). In 2014, again differences were significant for two barley cultivars (higher grain yield in intercrop plots) but not for wheat cultivars (Table 5). In 2015, differences were significant for the three cereal species, but while grain yield was higher in silvoarable plots compared with control plots for barley, for wheat and triticale the contrary was found (Table 6). Among barley cultivars, the silvoarable treatment was more positive for the barley cultivar called Basic than for the other cultivars. Amongst the wheat cultivars, the differences were only significant for Sublim and Nogal.

Table 5**.** Mean values and standard deviations of total and grain biomass (Mg dry matter ha^{-1}) produced in 2014 by different cereal species and varieties in the silvoarable and control plots. Asterisks indicate significant among control and intercropped plots (* for p > 0.05 and ** for p < 0.01; after LSD Post-Hoc Test).

Cereal species	Cultivar	Mean total biomass ± SD ($Mg\ ha^{-1}$ cultivated)		Mean grain yield ±SD ($Mg\ ha^{-1}$ cultivated)	
		Control	Intercrop[1]	Control	Intercrop[1]
Barley	Doña Pepa	6.50 ± 1.60	7.83 ± 1.94 *	1.29 ± 0.85	1.94 ± 0.74 *
	Azara	6.13 ± 1.38	7.60 ± 1.76 *	1.09 ± 0.33	1.77 ± 0.85 **
	Mean	6.32 ± 1.50	7.72 ± 1.86 **	1.19 ± 0.65	1.85 ± 0.80 **
Wheat	Kilopondio	8.53 ± 0.82	8.43 ± 1.88	1.20 ± 0.53	1.33 ± 0.38
	Bologna	7.92 ± 1.21	8.14 ± 2.09	1.13 ± 0.34	1.46 ± 0.56
	Mean	8.23 ± 1.08	8.29 ± 1.99	1.16 ± 0.45	1.39 ± 1.99
Total		7.27 ± 1.62	8.00 ± 1.95	1.17 ± 0.56	1.62 ± 0.70

[1] Values are based on the cultivated area. To get yield values based on the whole plot area, multiply the yields by 0.666 (the cultivated alley was 4 m wide, and uncultivated trees lines were 2 m wide).

Table 6**.** Means and standard deviations of total and grain biomass (Mg dry matter ha^{-1}) produced in 2015 by different cereal species and varieties in the silvoarable and control plots

Cereal species	Cultivar	Mean total biomass ± SD ($Mg\ ha^{-1}$ cultivated)		Mean grain yield ±SD ($Mg\ ha^{-1}$ cultivated)	
		Control	Intercrop[1]	Control	Intercrop[1]
Barley	Basic	5.36 ± 0.97	6.12 ± 1.95	2.29 ± 0.90	3.23 ± 1.01 *
	Hispanic	4.79 ± 0.36	7.24 ± 2.06 **	3.24 ± 0.65	3.68 ± 0.95
	Lukhas	7.38 ± 1.41	7.57 ± 3.04	3.31 ± 0.96	3.91 ± 1.66
	Dulcinea	5.25 ± 0.80	5.96 ± 1.53	3.19 ± 0.84	3.08 ± 0.63
	Mean	5.52 ± 1.24	6.72 ± 2.27 **	3.03 ± 0.91	3.48 ± 1.18 *
Wheat	Ingenio	6.19 ± 0.51	6.97 ± 2.51	2.58 ± 0.77	2.15 ± 0.88
	Nogal	6.26 ± 0.89	6.90 ± 1.76	2.94 ± 0.93	1.89 ± 0.61 **
	Sublim	7.55 ± 1.23	7.70 ± 2.07	5.25 ± 0.99	2.38 ± 0.98 **
	Mean	6.84 ± 1.20	7.18 ± 2.11	3.92 ± 1.53	2.14 ± 0.86 **
Triticale	Verato	7.89 ± 0.70	8.41 ± 2.65	3.85 ± 1.28	2.86 ± 0.89 *
TOTAL		6.50 ± 1.39	7.10 ± 2.31	3.62 ± 1.39	2.94 ± 1.21

[1] Values are based on the cultivated area. To get yield values based on the whole plot area, multiply the yields by 0.666 (the cultivated alley was 4 m wide, and uncultivated trees lines were 2 m wide).

7 Future measurements

A list of future measurements is provided in Table 7.

Table 7. List of parameters measured in the tree, crop and soil

Element	Parameter	Method	Measured
Trees	Diameter at breast height	One measurement per year	Every January
	Leaf nutrients (N, P, K, Ca)	One measurement per year	Every summer
Crop	crop production	Three herbage samples (50 x50 cm) are taken from each plot using hand clippers at a height of 2.5 cm	Every year by mid-June
Soil	Organic matter content	Soil samples are taken each 10 cm until 1 m depth and OM is analysed	Uppermost soil layer sampled in spring 2015; samples of the whole soil profile planned for spring 2016
Nutrient availability in soil	N, P, K and Ca	Ion exchange membranes (50 cm^2) installed at 15-20 cm depth for one month in Spring	Planned for spring 2016
Soil moisture	%	Diviners are located in plots. Measurements are taken each 10 cm until 1 m each month	Planned for spring 2016
Carbon sequestration		Variations in carbon sequestration are calculated based in OM in soil and biomass in tree trunk and herbaceous and tree roots	Planned for spring 2016

8 Acknowledgements

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