The role of soil characteristics, soil tillage and drip irrigation in the timber production of a wild cherry orchard under Mediterranean conditions

Antonio J. Molina[1], Ramon Josa[2], M. Teresa Mas[2], Antoni M.C. Verdú[2], Pilar Llorens[3], Xavier Aranda[1], Robert Savé[1] and Carme Biel[1]

[1]Institut de Recerca i Tecnologia Agroalimentàries (IRTA), Caldes de Montbui, Barcelona, Spain

[2] Escola Superior d'Agricultura de Barcelona, DEAB-Universitat Politècnica de Catalunya, Castelldefels, Barcelona, Spain

[3] Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona, Spain

Corresponding author: Antonio J. Molina

Contact Address: IRTA-Torre Marimon; C-59 Km 12, 1; 08140 Caldes de Montbui; Spain

Telephone number: +34902789449 ext. 1320

Fax number: +34938650954

E-mail: antonio.molina@irta.cat

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ABSTRACT

Over the last decade high-quality timber plantations have increased in Europe because of the constant high market price of timber and economical incentives from the EU. These latter are mainly due to timber plantations' role in CO_2 capture. Noble wood plantations have also been established in Mediterranean areas, but many of them suffer from low growth rates due to deficient plantation management and/or non-optimal environmental conditions. Furthermore, little information exists about soil and water management in these plantations and how different soil characteristics may affect management results. In this study, a trial was established in a pure wild cherry plantation under Mediterranean conditions. The trial evaluated the effects that soil type (bad performance *versus* good performance for woody crops), soil management (soil tillage *versus* no tillage), irrigation regime (drip irrigation *versus* no irrigation) and their interactions may have on wood production. Soil water content and the spontaneous vegetation that appeared in the alleys of the no-tillage treatments were also measured.

The results showed that sandy-clay-loam soil with a water-holding capacity of 101.5± 5.2 mm had 65% more wood volume increase during the study period than sandy-loam soil with a water-holding capacity of 37.9±8.0 mm. Conventional tillage or zero tillage with the presence of spontaneous vegetation did not differ significantly in wood volume increment, regardless of the type of soil. Although soil water content was significantly increased by tillage in sandy-loam soil, this effect was not enough to increase tree wood volume. On the other hand, the application of drip irrigation did increase wood production by up to 50%. Therefore, 10 years less on the plantation's rotation length can be anticipated when applying irrigation: from 40 to 30 years (sandy-clay-loam soil) and from 56 to 46 years (sandy-loam soil).

In conclusion, deep soil characterization of the site is essential before deciding whether to develop a plantation of this type in areas under soil water content limitations caused by deficient soil structure and texture. In addition, our results show important savings can be made by reducing soil tillage, as less tillage leads to greater ground cover and biodiversity. Further investigations are required to examine how long-lasting the effects are and what other benefits can be expected when this type of plantation is managed in a more sustainable way.

INTRODUCTION

Wild cherry tree (*Prunus avium* L.) is present in most mixed-forest ecosystems with a temperate climate in Eurasia. Poland and Germany are the European countries where its natural area is greater, with about 40,000 ha in each (Ducci et al., 2013).

Wild cherry timber is one of the most highly valued noble woods in Europe and prices can reach up to 1,000 €/m^3 (Loewe et al., 2013; Martinsson, 2001). Nowadays, though wild cherry plantations have steadily increased over the last 25 years in Europe, self-production is still far away from satisfying the furniture industry's demand (Ducci et al., 2013).

The increase in the cultivated area of noble wood has been promoted by reforestation programmes (e.g. EEC Regulation 2080/92), not only because of its economic value, but also due to its roles in improving biodiversity and CO_2 capture and in the diversification of land uses (Cambria and Pierangeli, 2012).

Wild cherry plantations have also been established in Mediterranean areas, though to a lesser extent. Here irrigation is frequently used to confront summer drought (Ducci et al., 2013). This is especially necessary in soils with low water-retention capacity, as is the case in several places in Spain where plantations have been established (Vilanova, personal communication). Nowadays, many of these plantations suffer low growth rates due to deficient plantation management and/or non-optimal environmental conditions (Aletà and Vilanova, 2014).

Intensive management is normally required for noble wood plantations in Mediterranean regions. Silvicultural guidelines and scientific papers about managing this type of plantation focus on two main aspects: on the one hand, how timber production is affected by pruning or thinning (Cisneros et al., 2006; Kupka, 2007; Springmann et al., 2011) and, on the other, how the mixing of wild cherry trees with other species, in mixed plantations (Kerr, 2004; Loewe et al., 2013) or in agroforestry systems (Campbell et al., 1994; Chifflot et al., 2006; Dupraz et al., 1995), affects tree growth. In contrast, little attention has been paid to evaluating the effects of soil and water management on the timber production of pure plantations (Ripoll Morales et al., 2013) or to evaluating the effects of different management under distinct soil types.

Environment-friendly soil management is increasing in Europe due to EU incentives (e.g. Sustainable Land Management practices, UNEP-UNDP-UNCCD, 2008) and a more concerned society, especially in areas subjected to high erosion risk and water constraints such as the Mediterranean. Zero tillage or no tillage (NT), like the most extreme cases of reduced soil tillage (T), may contribute to reducing / compensating for the negative effects of conventional soil tillage on soil properties, such as high water loss because of direct soil evaporation, destruction of soil structure, nutrient losses, soil compaction, high erosion rates and increased surface runoff (Jemai et al., 2013; Palese et al., 2014; Soane et al., 2012). Moreover, crop yield in tree plantations is not generally less under NT than under T. Although a reduction in crop production under NT has sometimes been described (Martínez-Mena et al., 2013), in most cases the effect is not significant or is even positive. For example, Gómez et al. (1999), Hernández et al. (2005), Palese et al. (2014) and Soriano et al. (2014) found that production did not differ significantly under NT or T in Mediterranean olive orchards; Montanaro et al. (2012) found higher fruit yield under NT management in peach orchards; Raimundo (2003) showed that nut production was not significantly different between NT and T; and Martins et al. (2010) found that chestnut yield was lower under T than in the different NT systems tested. Thus, NT does not clearly promote reduction in the yield of fruit and nut trees in Mediterranean areas. These findings are a sound basis for the hypothesis that wood production will behave in a similar way.

One NT method is to allow spontaneous vegetation to remain, as against NT with commercial seeded cover crops. The first method is cheaper, may be stable over time due to self-reseeding (Bond and Grundy, 2001) and may enhance the biodiversity of an agro-ecosystem, since ruderal vegetation is an integral component of agro-ecosystems and plays an important role in diversifying the land (Marshall et al., 2003).

To the authors' knowledge, this is the first study of noble timber plantations that compares yield under different soil types, soil managements and irrigation regimes. To this end, a trial was established in a pure wild cherry plantation under Mediterranean conditions. It aimed to evaluate the effects that soil type (bad performance *versus* good performance for woody crops), soil management (soil tillage *versus* no tillage), irrigation regime (drip irrigation *versus* non-irrigation) and their interactions may have on wood production. Soil water content and the spontaneous vegetation that appeared in the alleys of the no-tillage treatments were also complementary measured.

MATERIAL AND METHODS

Situation and environmental characteristics of the study site

The study was carried out from 2011 to 2013 at the IRTA-Torre Marimon experimental facilities (Caldes de Montbui, NE Spain, at 159m a.s.l).

The experimental plantation was located on an alluvial terrace with carbonated alluvial deposits as parent materials (IGME, 1976). Before tree planting, two soil samples revealed two different scenarios of water availability for plants growing there: in the eastern part, a sandy matrix with high gravel and stone content was found, while in the western part a silt matrix with some gravel was observed.

The climate is Mediterranean with mean annual values (1991-2010) for temperature, evapotranspiration and rainfall of 14.4 ± 0.2°C, 846.8 ± 23.3 mm and 599.4 ± 33.4 mm, respectively.

Cherry orchard and experimental design

The trees in the experimental wild cherry plantation (clone Salamanca 4) were planted for timber production in 2008. Tree density was 625 trees ha^{-1} with spacing of 4 m between trees and rows (16 m^2 per tree). Rows followed a north-south orientation. The mean values of height and diameter at breast height at the beginning of the experiment, in December 2010, were 4.7±0.1 m and 5.7±0.1 cm, respectively. In line with timber production practice for obtaining trunks free of branches, tree pruning in September 2011 and June 2013 removed approximately one third of the total biomass. Total dry biomass removed ranged from 0.8 to 10.9 kg $tree^{-1}$ as a consequence of tree vigour differences.

The experiment used a split-plot design with three replications arranged in a complete block design. The main plot factor was soil management (T, soil tillage or NT, no tillage) and the subplot factor was drip irrigation (I, irrigated or NI, non-irrigated). The subplots were separated from each other by buffer tree rows and each subplot contained four sample trees.

Irrigated treatments were drip-irrigated from May to September with 4 emitters (16 l h^{-1} $tree^{-1}$) located 25 and 50 cm from the trees on their north and south sides. Daily doses were calculated at the beginning of each week as a function of the weekly sums of reference evapotranspiration (ET_0) ($Kc'\cdot ET_0$, Kc´ values from 0.26 to 0.6 depending on the month) and rainfall (R) during the previous week ($I= Kc'\cdot ET_0-R$), and applied from Monday to Friday. There was no irrigation when ET_0 was lower than R.

Total irrigation was 125, 214 and 300 mm in 2011, 2012 and 2013, respectively. The low irrigation amount in 2011 was due to an irrigation system malfunction on successive days in early summer.

Soil was tilled with a mouldboard ploughing to a depth of 30 cm every 3-4 months. In the no-tillage treatments, spontaneous vegetation was mowed every two months along the irrigation lines, and twice a year on the rest of the land surface. Plant residues were left on the ground as mulch.

Finally, several meteorological variables (rainfall, air temperature and humidity, wind velocity and direction and solar radiation) were monitored at an automatic weather station located in a clearing 50 m from the cherry plantation. Penman-Monteith FAO reference evapotranspiration (Allen et al., 2006) was calculated by using these data.

Soil characteristics

To characterize the soil variability within the experimental plantation in greater detail, three soil samples were taken during the study period:

(i) A morphological characterization of soil profile in two open pits on the edges of the plantation (Table S1).

(ii) Three composite samples in each subplot (depths of 0-0.25 m, 0.25-0.50 m and 0.50-1.00 m), from two points at distances 1 and 2 m from the trunk of an inside tree.

The soil samples were dried and sifted through a 2-mm sieve to calculate the following characteristics (analytical methods specified): soil texture (densitometry), soil pH (soil: water ratio= 1:2.5, w/vol), electrical conductivity (soil extract 1:5 w/vol), calcium carbonate (after HCl treatment, the CO_2 emitted is manometrically measured) and organic carbon (acid-dichromate digestion) (USDA-NRCS, 2004).

(iii) A specific sampling to determine gravel and stone content. Soil volumes from 0.0080 to 0.0156 m^3 (0.20*0.20*0.20 m and 0.25*0.25*0.25 m) were extracted from two sampling locations per block. Samples were sieved through a 2-mm sieve to retain particles bigger than 2 mm. These pits were also used to measure soil bulk density (compliant cavity method, USDA-NRSC, 2004).

Soil water-holding capacity in the subplots was calculated by the Saxton et al. model (1986). This used the soil texture and soil depth calculated from (ii) and the volumetric stone content calculated from (iii), with the latter considered as an empty soil volume (stone water-holding capacity = 0 mm).

The main characteristics of the soil profiles observed were (see Table 1 for detailed information according to soil depth): i) the gravel and sand content was higher in block 1 than in block 3; block 2 was the transitional stage between them; ii) the organic matter content was very low in the topsoil of all blocks; and iii) no soil nutrient deficiencies were observed. The high range of soil texture and gravel content resulted in sharp differences in soil water-holding capacity between blocks 1 and 3 (Figure 1). For its part, block 2 showed soil characteristics from the other two blocks and thus higher variability in the soil water-holding capacity of its subplots (Figures 1 and 2).

Evaluating the wood volume increment in cherry trees

Wood production was expressed as the volume increment of saleable wood from the cherry trees (WVI, m^3) between January 2011 and December 2013. As trees in 2013 still showed good apical dominance, we considered that the entire volume increment during the study period was saleable wood. To this end, diameter at breast height (DBH, cm) and total height (H, m) at the beginning and at the end of the study period were used as follows, by considering tree form as a conical frustum:

$$WVI = 1/3 \cdot \Pi \cdot H \cdot [R^2 + r^2 + (R \cdot r)]$$

where R and r are the circumference radius at the tree base and at the maximum tree height (H), respectively. R and r were estimated as a function of DBH according to a linear regression of diameter *versus* height (y =-1.44 x + 11.86, R^2 = 0.98, N = 10,818 trees), calculated with data from 6 different wild cherry clones for timber where diameter was measured in 50-cm height increments along the tree trunks (Vilanova et al., unpublished data).

Volume increment of saleable wood was analysed by analyses of variance and least-square mean separation methods, following the above-mentioned split-plot experimental design. The statistical analyses were performed twice: taking into account the three blocks and ruling out block 2, as it had characteristics that were a mix of the other two blocks, thus reducing variability in the data for this heterogonous block. Both the main plot factor (soil management) and the subplot factor (irrigation) had two levels, with block considered a fixed factor. All analyses were computed by the GLM procedure of Statistical Analysis Systems (SAS, 1999).

Complementary measurements: soil water content under tree cover and spontaneous ruderal vegetation

Volumetric soil water content ($cm^3\ cm^{-3}$) was measured at 0-30 cm soil depth from May 2012 to September 2013. Twelve 30 cm-long TDR probes (details of the probes in Martínez Fernández and Ceballos, 2001), one in each subplot, were placed vertically 12.5 cm north of one of the four sampled trees (equidistant from the first drip emitter and the tree trunk in the irrigated treatments). Every two weeks, readings were taken with a TDR measuring device (Time Domain Reflectometry, TEKTRONIX, 1502 C) and were later converted to soil water-content values, following Topp et al. (1980). T-student tests compared NT and T treatments in each block studied. Previously, homogeneity of variances was tested (Levene test). All analyses were computed using Statistical Analysis Systems (SAS, 1999).

The spontaneous ruderal vegetation in the NT plots was monitored during the three seasons (2011-2013). Two permanent 0.25 m^2 randomly assigned quadrats were placed in each of the three blocks considered. Each quadrat was sampled to obtain the species composition, following Bolòs et al. (1993), and the total surface covered by vegetation through visual identification (%).

The plant community was analysed in terms of floristic and functional structures. Floristic structure was summarised in terms of biodiversity. Functional structure was characterised by Raunkiaer life forms and the flowering season.

In addition, in 2012 we sampled on 9 different days from April to mid-June to obtain the specific aboveground biomass ($g\ m^{-2}$) and the surface covered by each species. The biomass data were used to calculate the Shannon-Wiener diversity index (H’) as follows:

$$H' = \sum p_i \cdot \log_2 \cdot p_i$$

where p_i is the proportion of the biomass of i species in the total sample of S species.

Biodiversity and the proportions of total cover were subjected to pooled analyses of variance for measurements over time (Gomez and Gomez, 1984), with two main factors considered: block and time of observation. Homogeneity of variances was tested: square root transformation was chosen to homogenize the variance in biodiversity, while the arcsine of the proportion was chosen for total ground cover. When the main effects or the "block x time of observation" interaction were significant ($P<0.05$), least square means were computed and compared (Tukey-Kramer method). The total aboveground biomass (g m^{-2}, dry weight; only for 2012) data were transformed (natural logarithm) prior to a single-factor (block) analysis of variance. The GLM procedure of Statistical Analysis Systems (SAS, 1999) was used for the analyses.

RESULTS

Meteorological conditions during the experiment

Annual rainfall (2011, 2012 and 2013) was 773, 462 and 640 mm, while reference evapotranspiration was 1,026, 1,025 and 854 mm, respectively. Figure 3 shows the contrasted monthly distributions of rainfall and potential evapotranspiration, together with the average monthly values for air temperature. All the growing seasons were characterized by rainfall deficits and high water evaporation demands (up to 3.7 kPa for DPV).

Wood volume increment in the wild cherry trees (WVI)

Results from the analysis showed that WVI was mainly affected by irrigation, with volumes up to 50% higher under the irrigation regime than under no irrigation, which highlights the importance of irrigation during stress periods under Mediterranean climate conditions, as was expected (Table 2). In contrast, soil management has no significant effect on WVI, although, in the analysis that took into account the three blocks, the block x soil management interaction was highly significant ($P=0.0014$). The relative importance of the two factors involved in the interaction can be measured by observing the ANOVA performed with only two blocks, where the block effect was significant while the soil management effect was not. The least-square means of the levels of the effects considered in the ANOVAs (Table 3) revealed that the block effect was more important than the soil management treatment effect in explaining the variance in WVI. There was a great difference in the means comparing block 1 and block 3, achieving intermediate values in block 2. On excluding block 2 from the analysis, significant differences between block 1 and 3 were found in the WVI means, whereas the mean values obtained in tillage and in no-tillage treatments were not significantly different.

Soil water content under tree cover

Figure 4 shows the means of soil water content averaged through the blocks during the study period and grouped by irrigation conditions. The variability of the time series (standard deviations) indicated that soil type clearly affected soil water content, especially in the irrigated treatments in the 2012 and 2013 growing seasons (Figure 4.b). In these irrigated treatments, variation in mean soil water content during the study period was low (from 0.4 to 0.3 $cm^3\ cm^{-3}$). In contrast, soil water content in the NI treatments had higher ranges, reaching very low values (close to 0.1 $cm^3\ cm^{-3}$) in summer periods and recovering to maximum values of 0.37 $cm^3\ cm^{-3}$ in the 2013 winter. Furthermore, NT and T treatments behaved in different ways, depending on the block. No significant differences were found in blocks 2 or 3 in the t-student tests ($p= 0.55$ and $p=0.67$, respectively), while soil tillage involved higher soil water content in the T treatments of block 1 ($p=0.042$).

Spontaneous ruderal vegetation in the NT plots: biodiversity, cover percentage and biomass

During the study period, a total of 45 species from 17 botanical families were observed in the permanent quadrats located in NT plots (Table S2). The number of taxa and botanical families increased over the three years.

Therophytes were the predominant life form (81.4%, or 93% if 5 taxa that are not exclusively therophytes are included). The predominant morphotype was dicotyledonous (86.7%). The specific composition of the plant community made blooming possible throughout the year, but it was particularly important from April to September, when the highest percentages of species at that phenological stage were found (>50%) (Table S2).

As all the sources of variation that affect biodiversity and total ground cover were significant at $p<0.05$ level except block, ground cover did not differ much between the three blocks in the plantation. The overall mean values were 6.83 for biodiversity and 53.78% for total ground cover. The block x time interaction was clearly significant ($P< 0.0005$ in both variables); the evolution of the total ground cover least square means over time showed a similar trend for the three blocks, although the curves were interlaced (Figure 5).

For the aboveground biomass of the spontaneous vegetation (AB) and its ecological diversity, calculated by the Shannon-Wiener diversity index, H', between 18 April and 13 June 2012, the results showed that there were significant differences between blocks (analyses not shown). Block 3 had the highest AB and at the same time the lowest H'. Thus, there was also a gradient of ecological diversity in the study plantation. The mean values of the H' were around 2, which dramatically decreased at the end of the spring period.

DISCUSSION AND CONCLUSIONS

This study evaluated the effect of two contrasted soil types (one with bad performance for woody crops and one of good agronomical quality), two irrigation regimes (drip irrigation *versus* no irrigation) and two kinds of soil management (soil tillage *versus* no tillage with the presence of spontaneous vegetation) on the timber yield of a wild cherry plantation during three years and under Mediterranean climate conditions.
Soil type led clearly to tree growth differences, as expected. The trees growing in sandy-clay-loam soil and the soil water-holding capacity (SWHC) of 101.5± 5.2 mm (block 3) showed 65% greater wood volume increase during the study period than the trees growing in sandy-loam soils, with a high presence of gravels and thus lower SWHC (37.9±8.0 mm) (block 1) (Table 2, right). However, when also considering data from block 2 in the ANOVA analysis (Table 2, left), the block effect was not significant. This was because soil in block 2 showed characteristics intermediate between the other two blocks and thus greater variability (SWHC of 68.1±26.3 mm). In consequence, in the ANOVA analysis with the three blocks, the block effect was smaller and the error term was higher, resulting in lower sensitivity to finding significant differences between the two contrasted soils in the timber production of our experimental plantation.

Conventional tillage (3-4 times per year to a depth of 30 cm) in our young wild cherry plantation did not lead to any significant differences in wood volume increment from years 4 to 6 of the plantation, when compared with zero tillage with the presence of spontaneous vegetation or with intercrops in agroforestry systems. Water availability is the main limiting factor when planting trees in association with herbaceous vegetation in dry climates such as the Mediterranean (Baldy et al., 1993; Miller and Pallardy, 2001). Observations in other Mediterranean tree plantations with zero tillage showed that fruit or nut yield did not increase when conventional tillage changed to natural vegetation ground cover (Hernández et al., 2005; Martins et al., 2010; Gómez et al., 1999; Palese et al., 2014, Soriano et al., 2014). Agroforestry systems with wild cherry trees in Mediterranean areas have shown contradictory results in relation to tree growth. Dupraz et al. (1995) observed a big decrease in trees' water use due to the presence of perennial herbaceous crops with larger root systems. In contrast, Chifflot et al. (2006) studied the effect that the presence of intercrop or spontaneous vegetation had on tree diameter growth as compared to weeded control by herbicide. These authors found greater diameter growth in the intercrop system, followed by control and by spontaneous vegetation.

In our case, the complementary measurements of soil water content to a depth of 30 cm and of spontaneous vegetation could help to interpret our results. The effect of soil tillage on soil water content varied according to soil type. Soil water content in block 1 increased through soil tillage by 14%, while no significant increases were observed in either block 2 or block 3. The results obtained in blocks 2 and 3 corroborate previous studies carried out under Mediterranean conditions, where no tillage had similar effects or was even more positive than soil tillage for both soil water storage and soil water dynamics (Palese et al., 2014; Martins et al., 2010; Celano et al., 2011). In this respect, the significant increase in soil water content induced by soil tillage in block 1 should have been counterbalanced by other effects promoted by no-tillage management, as the wood volume of wild cherry trees was not significantly affected by soil tillage in block l. Thus, the non-significant differences in spontaneous vegetation ground cover (visually estimated) between the blocks, or the lower aboveground biomass (calculated by weighing dry matter) found in block 1 than in the other two blocks, seem to indicate that the competition between trees and ruderal vegetation for resources such as water, light and nitrogen was very similar in all blocks or even lower in block 1. Therefore, we hypothesized that other negative factors caused by soil tillage on soil structure were of greater weight in block 1, although they are not sufficient to lead to timber differences.

The use of drip irrigation increased wood production in all types of soil studied, with up to 50% higher production under irrigation. This underlines the importance of avoiding soil water deficits if this species is to develop correctly in Mediterranean climate conditions, as expected (Juhász et al., 2013). This is especially important when assessing the rotation length of the plantation, i.e. the time required for obtaining optimum wood of high quality (diameter of 40 cm at breast height), and thus the economic benefits from the plantation. In this respect, by using diameter growth curves proposed for this species (Cisneros, 2004), and assuming that the observed differences are maintained during the whole lifespan of the plantation, a reduction of 10 years in rotation length would be expected when applying irrigation. In block 3, this would mean a reduction from 40 to 30 years (non-irrigated *versus* irrigated trees), whereas at the opposite site, block 1, the reduction would be from 56 to 46 years.

As soil tillage could be avoided and assuming that our results are maintained from year 3 to year 8 (6 years of soil tillage: during the first and second years soil tillage is required, since competition between young trees and spontaneous vegetation is likely to appear), we estimated the cost of dealing with soil tillage. Considering the normal prices in the region for mouldboard (100€ per hour; 3 hours required for the total plantation, 4 times per year) and for mowing the spontaneous vegetation (10€ per hour; 4 hours required for the total plantation, 4 times per year), we calculated that an 87% cost reduction could be achieved. This would be greater if the non-significant differences in wood growth are maintained in the future.

In conclusion, our results indicated that timber production with wild cherry trees is greatly affected by the water available in soil. Therefore, the deep soil of the site has to be characterised before a decision can be taken on whether a plantation of this type could be developed in areas under soil water-content limitations, such as block 1. Furthermore, drip irrigation gave higher timber production in all the soils studied, which could reduce rotation length by 10 years. Thus, this aspect should be carefully evaluated when the economic aspects of a plantation of this type are being assessed. However, in the short term, wood yield was not affected by soil tillage, as observed in other tree plantations, which suggests that less intense soil management would be possible in these plantations. This would also occasion environmental benefits such as the increased biodiversity of plant ground communities. Further studies of this type of plantation are required, to examine other questions, such as how long effects last (i.e., is the lack of effect of soil tillage on wood volume maintained during the whole lifespan of the plantation?), the different effects of soil tillage on soil water content depending on the soil type, and other benefits that could be expected if and when land is managed in a more sustainable way.

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Figure captions:

Figure 1. Soil water holding capacity (mm) of each block and treatment: T I: Tillage irrigation; T NI: Tillage No irrigation; NT I: No Tillage Irrigation and NT NI: No tillage No irrigation.

Figure 2. The cherry orchard study plot located at Torre Marimon (Caldes de Montbui, Barcelona, NE Spain) with the situation of the two pits opened (white square). The dotted line indicates the boundary between the two types of soil observed (see text for details), ICGC (2014).

Figure 3. Monthly cumulated rainfall and potential evapotranspiration (ET_0, mm) and mean monthly air temperature during the 3 years of experiment (2011, 2012 and 2013).

Figure 4. Mean soil water content in the 0-30 horizon (cm^3cm^{-3}) for the treatments: NT NI: No tillage No Irrigation; T NI: Soil Tillage No Irrigation; T I: Soil Tillage Irrigation; NT I: No Tillage Irrigation.

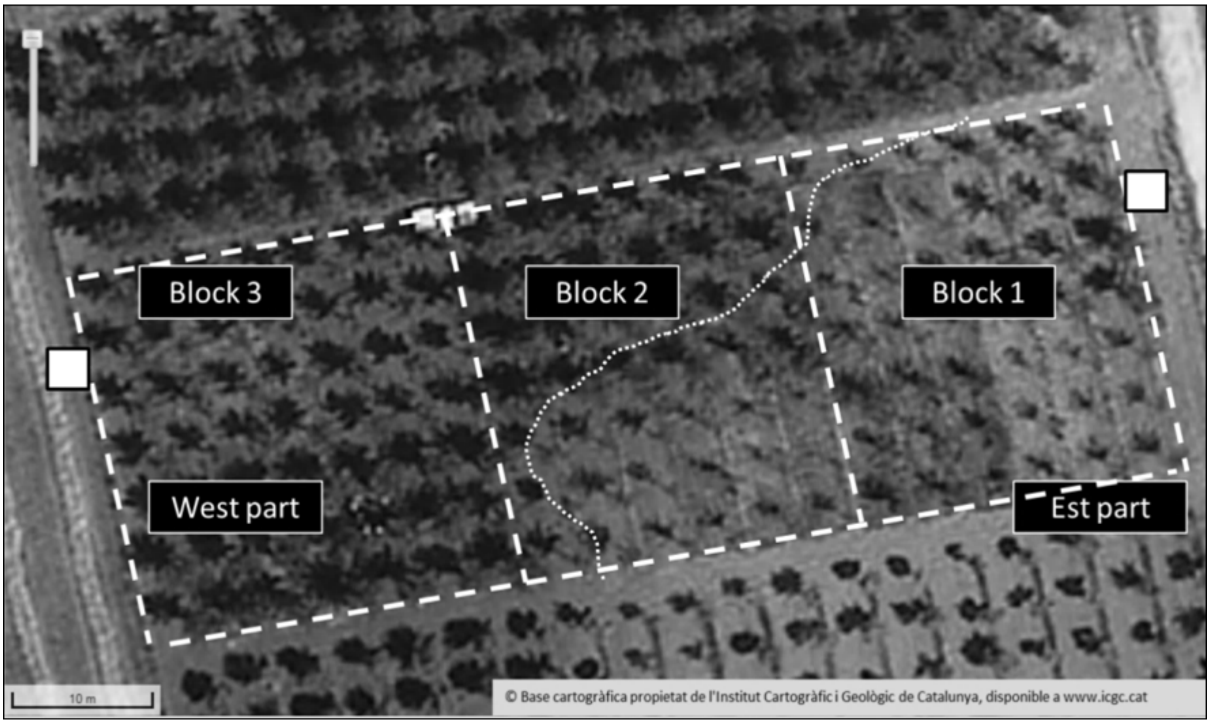
Figure 5. Least-square means of the total ground cover (arcsine transformed) over the time in the three blocks under no tillage management.

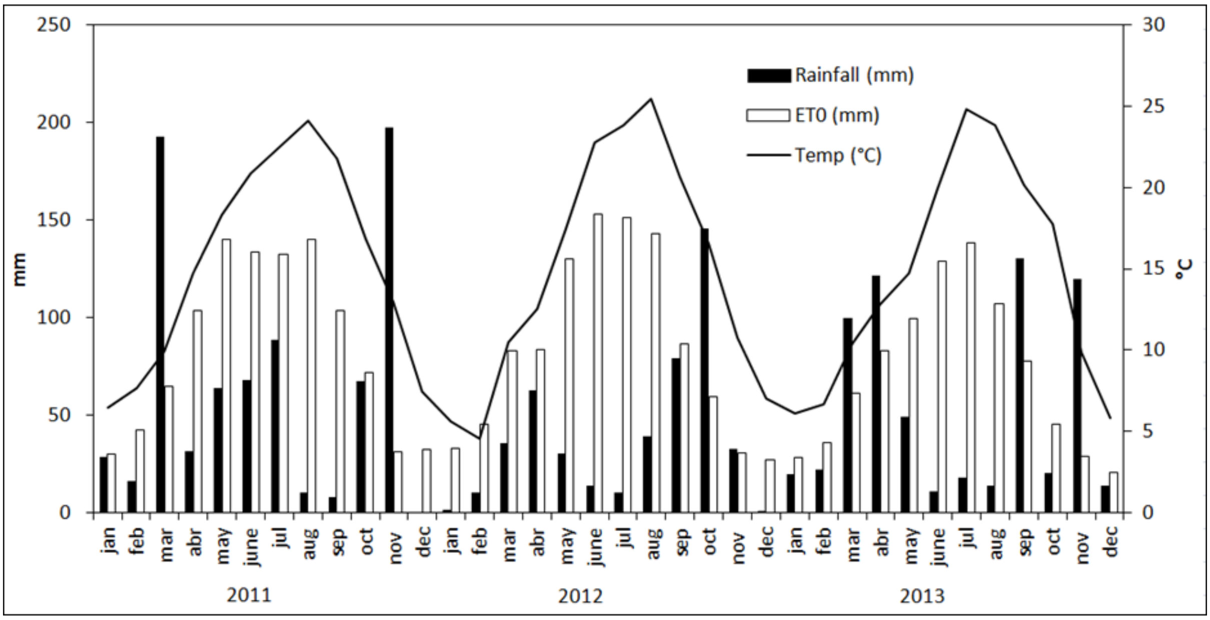
Table 1. Means (and standard deviations) of the main soil characteristics of the studied blocks. FC: field capacity, WP: wilting point. FC and WP were estimated according to Saxton et al. (1986).

	Depth (cm)	Texture	Volume of stones and gravels (cm^3/cm^3 soil)	FC - WP (% of soil volume)	Organic matter (% of dry weight)	pH
	0-25	Sandy-loam	0.53 (0.09)	11.43 - 4.70	1.19 (0.10)	7.92 (0.05)
	25-50	Sandy-loam	0.47 (0.12)	9.23 - 3.14	0.51 (0.09)	8.3 (0.12)
	50-100	Sandy-loam	0.47 (0.12)	8.80 -2.44	0.24 (0.06)	8.6 (0.06)
Block 1						
	0-25	Sandy-loam	0.46 (0.14)	18.79 - 9.05	1.56 (0.05)	7.88 (0.05)
	25-50	Sandy-loam	0.33 (0.19)	13.83 - 8.51	0.92 (0.17)	8.02 (0.07)
	50-100	Sandy-loam	0.33 (0.19)	14.15 - 6.10	0.58 (0.03)	8.3 (0.1)
Block 2						
	0-25	Loam	0.24 (0.05)	26.22 - 13.82	1.45 (0.12)	7.95 (0.03)
	25-50	Loam	0.04 (0.01)	24.21 - 12.67	0.81 (0.09)	8.05 (0.03)
	50-100	Loam	0.04 (0.01)	21.18 - 10.77	0.34 (0.10)	8.17 (0.02)
Block 3						

Table 2. Analysis of variance of the effects of block, soil tillage, and irrigation on the wood volume increase (m^3).

	Considering three blocks				Considering two blocks			
Factor	d.f.	MS	F value	P	d.f.	MS	F value	P
Block (B)	2	0.000645	9.98	0.0911	1	0.001202	186.28	0.0466
Soil tillage (T)	1	0.000383	5.92	0.1355	1	9.1569E-05	14.19	0.1652
B x T (Error a)	2	0.00006466	7.75	0.0014	1	6.451E-06	1.65	0.2107
Irrigation (Ir)	1	0.000909	109.02	<.0001	1	0.000294	75.04	<.0001
T x Ir	1	0.0000003	0.04	0.8506	1	1.606E-06	0.41	0.5276
Residual	40				26			


Block 3
Block 2
Block 1
West part
Est part
10 m
© Base cartogràfica propietat de l'Institut Cartogràfic i Geològic de Catalunya, disponible a www.icgc.cat



250
200
150
100
50
0
mm
30
25
20
15
10
5
0
°C
Rainfall (mm)
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jan
feb
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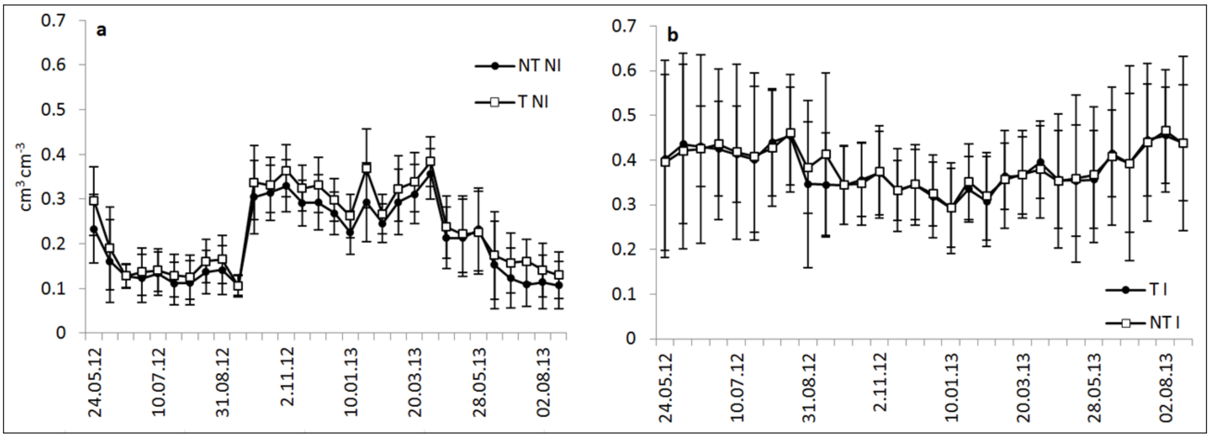
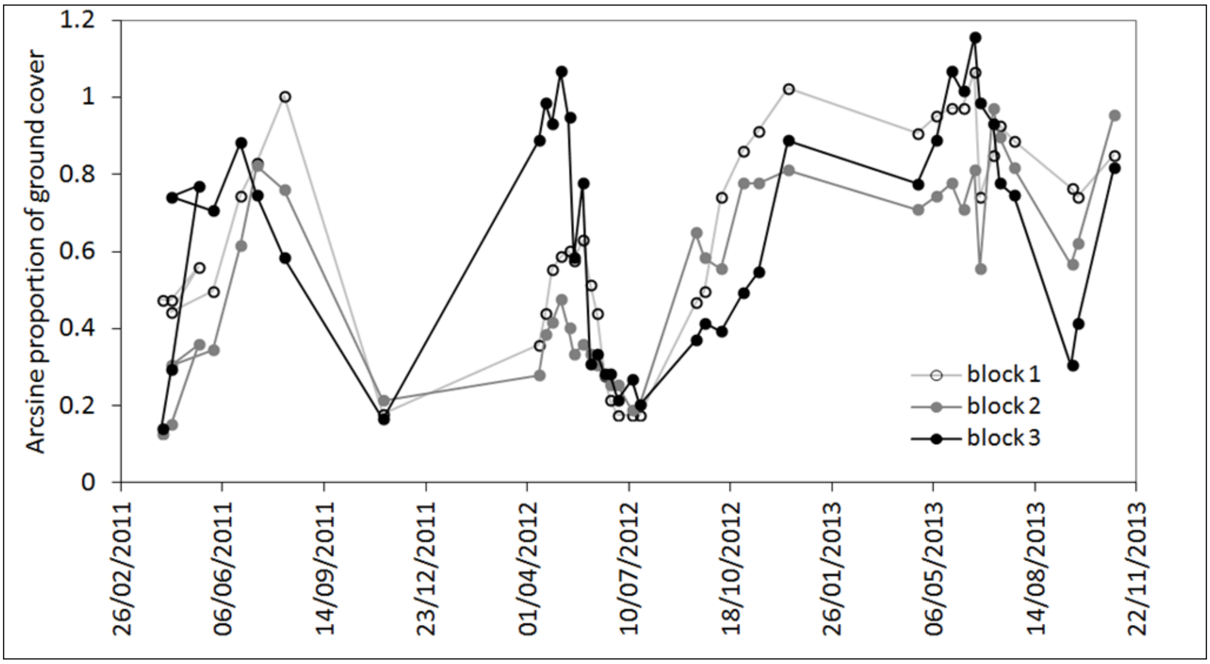
2011
2012
2013



a
NT NI
T NI
cm3 cm-3
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
24.05.12
10.07.12
31.08.12
2.11.12
10.01.13
20.03.13
28.05.13
02.08.13
b
T I
NT I


Arcsine proportion of ground cover
1.2
1
0.8
0.6
0.4
0.2
0
26/02/2011
06/06/2011
14/09/2011
23/12/2011
01/04/2012
10/07/2012
18/10/2012
26/01/2013
06/05/2013
14/08/2013
22/11/2013
block 1
block 2
block 3