Life CLIMATREE

Deliverable D3
Report on the impact assessment of tree crop ecosystem function restoration

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1. Introduction

Woody perennial crops have the potential to provide several ecosystem services in addition to the fruit production. Because of their perennial nature, in contrast with herbaceous crops, trees can accumulate and store CO_2 in their woody structure. However, in fruit tree crops, it is not possible to seasonally decide where to plant the crop or not depending on the availability of resources as it is possible for annual crops. This is important under scarce water conditions, such as in the Mediterranean area. Because of this, in order to properly assess the impact of restoring ecosystems with tree crop plantations is necessary to carry out a concomitant analysis of carbon fixation and water use. In this sense the evaluation of the net ecosystem carbon exchange rate (F_{NEE}) of crop fields is crucial for assessing the potential of tree crop ecosystems function restoration. Under the pressure of the increasing climate change concerns, the carbon balance according to vegetation types has become paramount for calculating the carbon budget of different regions, the footprint of agricultural practices and the possible mitigation effect of agricultural policies.

In the present Deliverable, the impact assessment of woody perennial crops for the ecosystem function (i.e. carbon accumulation) has been obtained under two scenarios: 1) under no limitations of water restrictions and for a citrus orchard eastern Spain, and 2) by assessing responses to different water availability regimes in almond trees

2. Scenario 1. Increase the plantation under no restrictions of irrigation

In the Mediterranean countries coastal areas, the initial suggestion is to plant evergreen trees because of their high potential for carbon fixation in their structure. However, in order to proceed with his suggested ecosystem restoration action, it is required to properly identify the potential gain in CO_2 fixation and the associated water consumption costs. In this sense, the objective of the activities carried out within the Climatree project was to quantify and assessing carbon fixations and water consumption in a citrus trees orchard.

2.1 Methodology employed

Data were obtained during three growing season at a 400-ha commercial farm planted with Hernandina mandarin (Citrus x clementina, hort. ex Tan) grafted onto Carrizo Citrange (Citrus x sinensis, Osb. 3 Poncirustrifoliata, Raf.) at a spacing of 6 m by 3 m. The orchard was located in eastern Spain (39°27'15" N, 0° 33'32" W), at 105 m above sea level with the prevailing winds coming from the west, between 240º and 300º (53% of winds) (Figure 1). The area is characterized by a Mediterranean climate with warm, dry summers and mild winter conditions with an average annual reference evapotranspiration (ETo) and rainfall of 1.100 and 500 mm, respectively.

Figure 1. Location of the study area in eastern Spain. The dashed circle delimits the footprint of 90% of the fluxes. Ortophoto resolution is 0.5 × 0.5 m2.

The commercial plot was flat and drip-irrigated during the growing season, with 6 self-flushing pressure compensating on-line emitters set to irrigate at a rate of 4 l h-1 per tree, arranged in two lines. The trees were mature, with an average height of 2.80 m and the area shaded by the canopy was 66% of the allotted spacing. Soil was sandy loam in texture. Irrigation was applied daily to fulfil crop evapotranspiration (ETc), but this did not preclude that during the three season-long experiments, some periods of water deficit might have occurred due to failure in the irrigation system or periods of unexpected higher evaporative demand. ETc values were estimated as the product of ETo (calculated with the Penman–Monteith method - Allen et al. 1998), and month-specific crop coefficients (Kc) (Castel et al. 1987).

Sensible heat (H), latent heat (λE) and carbon (Fc) fluxes were measured by EC equipment installed at a height of 6.5 m on a scaffold, placed in the center of the plot Figure 2. The equipment consisted of (i) a three-dimensional sonic anemometer (model CSAT3; Campbell Scientific Inc., Logan, UT, USA) to measure vertical (w) and horizontal (u) wind speed and sonic air temperature Ts and (ii) a high-frequency open-path infra-red gas analyser (IRGA) to measure CO_2 (Ca) and water vapour (q) concentrations in air (model LI-7500, LI-COR, Lincoln, USA). The separation between the anemometer and the gas analyzer was 0.30 m during the whole measurement period. All the sensors were fed by solar panels and connected to a datalogger (model CR10X, Campbell Scientific Inc.) operating at 10 Hz. Data were processed to obtain 30 minutes covariances and then averaged for each 24 h, including nocturnal data, to obtain the daily averages.

The raw measured fluxes of carbon (Fc), water vapour (λE), sensible heat (H) and momentum (τ) were corrected using the frequency response functions derived by Moore (1986); i.e. frequency response on sensor separation, path length averaging and signal acquisition and processing time. Fc and λE were also corrected for density fluctuations according to Webb et al. (1980).

Figure 2. Images for the Eddy Covariance system installed over a large and flar citrus orchards. In the bottom figures are depicted the sensors for determining net radiation and sensible and latent heats (left) and soil heat (right).

Net ecosystem carbon fluxes (FNEE) was then computed from the 30-minute Fc fluxes (after performing gap filling) by calculating the average daily and monthly fluxes. The water use efficiency (WUE) of the orchard was calculated during in the day time as FNEE/λE. Following Baldocchi (1997), the canopy layer CO2 storage term was disregarded in the calculation of FNEE rates, as it was assumed that tree spacing facilitated ventilation, ensuring an efficient gas mixing even at low wind speeds.

Apart from H, LE and Fc fluxes, the net radiation (Rn) and the soil heat flux density (G) were also measured. Rn was measured with a net radiometer (CNR2, Kipp & Zonen, Delft, The Netherlands), mounted on a telescopic mast and maintained at approximately the same height as the EC system. The soil heat flux density (G) was measured at three locations, differing in the amount of radiation reaching the soil and soil wetness, with three heat flux plates (model HFP01, Campbell Scientific, Logan, USA) buried at 0.05 m in depth. The plates were placed one below the trees' row, at 1/4 of the distance between trees (0.87 m from the trunk), in an area wetted by the drip irrigation emitter, one in the intersection of the diagonals of the rectangle formed by four trees (the point with highest incident radiation) and one in an intermediate position. The total area was then divided into three parts, each one representative for the shading pattern to the measurement positions. Then, the soil heat flux was obtained by the average of the measured values from the flux plates at three different positions, weighted by their respective representative areas. Three soil thermistors, buried at 0.025 m in depth close to the plates, allowed for the calculation of the heat storage of the soil above the plates for correcting G via the combination method (Kimball and Jackson 1975). A CR1000 datalogger (Campbell Scientific Inc., Logan, UT) collected data from these sensors every minute, and stored the 30 min averages as well.

Additionally, half-hourly ET0 was calculated using the FAO Penman–Monteith equation (Allen et al. 1998), using the net radiation (Rn) registered in the net radiometer sensor mounted on the telescopic mast and air temperature (Ta), relative air humidity (RH), and wind speed (U) values recorded in an automated weather station located near the orchard.

2.2 Results obtained

The measured evapotranspiration (ETc, water consumption rates) ranged from 0.03 to 4.27 mm/day. Mean annual ETc values were 1.88±0.79, 1.53±0.62 and 1.81±0.84 mm/day in three experimental seasons under evaluation

The daily F_{NEE} ranged between -11.8 and 13.5 g CO_2/m^2/day, -15.5 and 18.9 g CO_2/m^2/day and -16.7 and 22.3 g CO_2/m^2/day in each of three experimental seasons, respectively (data not shown). Based on a complete analysis of one year of data the citrus orchard fixed 3.855 kg CO_2/ha/year, demonstrating its ability to fix carbon. Daily *WUE* values ranged between 0.06 and 10.8 g CO_2/kg, 0.21 and 13.3 g CO_2/kg and 0.24 and 13.5 g CO_2/kg in 2008, 2009 and 2010, respectively (data not shown). On a seasonal basis mean annual *WUE* was 5.1 ± 1.9 g CO_2/kg

The orchard reduced its net assimilation and *WUE*, acting as a carbon source during the rainiest period of the season. The effects of deep wetting a dry soil on its gas exchange are (i) to expel from the pores to the atmosphere, replaced by water, air with very high

CO_2 concentration down to the lower profiles; and (ii) re-activation of the heterotrophic respiration from the soil biota and the autotrophic growth respiration from the tree roots in the newly wetted soil volume.

2.3 Conclusions

Cumulative ET during the study period, measured directly with the EC method, were lower than the irrigation volumes estimated by using the monthly crop coefficients proposed by Castel et al. (1987) or those proposed by FAO-56. Regarding the carbon FNEE fluxes on the annual basis, the mandarin orchard was shown to be a carbon sink. Estimates for carbon balance. **The seasonal carbon fixation by a citrus orchard was found to be around 3.855 kg CO_2/ha/year at a cost of evapotranspiring (consuming water) of 6970 m^3/ha.**

2.4 References employed

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper nº 56. FAO. Roma (Italia). 300p.

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Castel JR, Bautista I, Ramos C, Cruz G (1987) Evapotranspiration and irrigation efficiency of mature orange orchards in Valencia (Spain). Irrig Drain Syst 3: 205–217.

Webb EK, Pearman GI, Leuning R (1980). Correction of flux measurements for density effects due to heat and water-vapor transfer. Q J R Meteorol Soc. 106 (447): 85–100.

1. Scenario 2. Increase the plantation under low availability of water resources

1.1 Methodology employed

The experiment was carried out in an almond plot (*Prunus dulcis* var. “Belona”) located on the “Las Dehesillas” farm, belonging to the municipality of Hellín (Albacete) (38º 22 '58.18' 'N, 1º 30 '32.72' 'Or, 500 masl). Its proximity to the provincial limit of Murcia, influences the rainfall regime, closer to the semi-desert ombroclimate, characteristic of this region. With an average annual precipitation in the last five years of only 268 mm. The duration of the trial covers the period between 2018 and 2020. In the trial, several deficit irrigation treatments were applied in order to obtain the water productivity as total biomass yield versus water application.

A total of 10 treatments were applied a summarized in Table 1 combining: i) different irrigation regimes (100, 60 and 30% of the estimated crop evapotranspiration (ETc) and a regulated deficit irrigation (RDI) where stress was only imposed during the kernel filling (i.e. mid-June to end of August), ii) one or two drip lines installed and iii) a soil management consisting of having a bare soil or a cover crop installed in the inter-row orchard as depicted in Figure 1. The cover crop consisted of a mixture of plant leguminous and grass species (*Onobrychis viciifolia*, *Vicia sativa* and *Trifolium alexandrinum*) and (*Festuca arundinacea*, *Dactylis glomerata*, *Lolium rigidum*)

Treatment	Irrigation Regime	Number of drip lines	Soil management
T0	100% ETc	2	Bare soil
T1	60% ETv	2	Bare soil
T2	60% ETc	2	Cover crop
T3	60% ETc	1	Bare soil
T4	30% ETc	2	Bare soil
T5	30% ETc	2	Cover crop
T6	30% ETc	1	Bare soil
T7	RDI	2	Bare soil
T8	RDI	2	Bare soil
T9	RDI	2 -1	Bare soil

Table 1. Summary of the different management options employed in the almond demo trail.

Figure 1. Image of the almond trail with the different soil management options with bare soil or cover crops.

3.2 Results obtained

The effects of the management options carried out during the three seasons was quantified at the end of the project activities during August 2020 taking advantage of the project extension granted. All deficit irrigation treatments applied reduced yield with respect to the control (Table 2) even if this reduction was not statistically significant for treatment T1 that was watered at 60% of ETc. However, the deficit irrigation regime applied were able to improve water productivity (Table 2). This is important because the biomass production by each unit of water can be improved when deficit irrigation is applied.

Treatment	Irrigation applied (mm)	Yield (kg/tree)	Water productivity (kg/m3)
T0	400	11,1a	0,79
T1	237	9,9ab	1,19 (+50%)
T2	213	7,9bc	1,06 (+33%)
T3	204	10,6ab	1,48 (+87%)
T4	104	8,0b	2,20 (+177%)
T5	114	6,5c	1,63 (+105%)
T6	124	7,2bc	1,66 (109%)
T7	140	8,5b	1,73 (+218%)
T8	142	9,1b	1,83 (231%))
T9	172	9,0b	1,50 (188%)

Table 2. Summary of the effects different management options employed in the almond demo trail on yield and water productivity. Different letters indicate statistically significant differences at $P<0.05$.

Particularly the RDI strategy investigated was particularly effective in increasing water productivity and therefore can be proposed as an ecosystem function restoration practice to ensure fixing atmospheric CO_2 with limited water resources. This is because the RDI is an irrigation strategy where the water restrictions are imposed only in those phenological periods less sensitive to water restrictions. On the other hand, the use of cover crops cannot be suggested as an ecosystem function restoration in semi-arid climates because it reduced the allocation of yield biomass in comparisons with bare soil conditions (Table 2). The use of a single drip line in comparisons with the standard approach of having two drip lines per tree row, yielded not conclusive results because while under 60% ETc regime it allowed increasing water productivity but the opposite was found under 30% ETc

For a more in-depth analysis of the effects of the different practices on the ecosystem function, in Table 3 it is reported the vegetative growth and indexes for allocation efficiency. It is important to note how the all the deficit irrigation strategies reduced canopy diameter but clearly increased the reproduction efficiency evaluated using the yield by trunk cross sectional area index.

Treatment	**Tree canopy diameter (m)**	**Relative trunk growth (%)**	**Yield/TCSA (Kg/cm2)**
T0	4,07a	85,1a	2,23a
T1	3,52b	70,7b	2,50ab
T2	3,32c	78,2b	3,14bc
T3	3,42b	59,0c	2,34ab
T4	3,42b	77,8b	3,10b
T5	3,28c	84,4a	3,81c
T6	3,38bc	77,0b	3,44bc
T7	3,62b	83,5a	2,92b
T8	3,67b	62,9c	2,72b
T9	3,36bc	76,3bc	2,75b

Table 3. Summary of the different management options employed in the almond demo trail on tree vegetative biomass growth and the ecosystem functioning partitioning function Yield by Trunk Cross Sectional Area (TCSA).

1.2 Conclusions

Under conditions of water scarcity, the use of a regulated deficit irrigation strategy was the most convenient for increasing water productivity. This allows increasing the efficiency of carbon fixation under conditions of limited availability of water resources. **In inland areas and under conditions of limited water resources, as an ecosystem function restoration strategy, it is therefore suggested to crop almond trees under regulated deficit irrigation resulting in very significant water savings.**