Impact of shade and tree root pruning on soil water content and crop yield of winter cereals in a Mediterranean alley cropping system

Héctor Daniel Inurreta-Aguirre[ID] · Pierre-Éric Lauri · Christian Dupraz · Marie Gosme

Abstract Pruning tree roots in alley cropping systems (ACS) could reduce underground competition and thus increase crop productivity. However, these management operations impose a stress on the trees, increase production costs and given the complexity of ACS; they may not lead to an increase in crop yield. Thus, the objective of this study was to measure the impact of root pruning in a Mediterranean ACS on soil water content and on the yield of two varieties each of barley and durum wheat. To achieve this, an experiment with three different treatments was conducted: monocrop (MC), and two 23-year-old hybrid walnut ACS, with (ACS_RP+) and without (ACS_RP−) root pruning. In each system, grain yield and yield components were measured and the microclimate and soil water content were recorded during the growing season. The ACS had lower incident radiation in the understory than MC and this radiation was unevenly distributed along the alley. Besides, ACS had lower air temperature during the day and higher at night in comparison with MC. Also, soil water content was higher in ACS than in MC. Within ACS, the soil water content was similar until the tree budburst but thereafter lower in ACS_RP−. The grain yield of both cereals was lower in ACS than in MC. Among the ACS there were no differences in grain yield or in any yield component for both cereals. From the above, it can be concluded that, under the conditions presented in the study, the root pruning increased the water available for the crops, but this did not increase crop yield. It is inferred that the main limiting factor for grain yield in the studied ACS was other than soil water.

H. D. Inurreta-Aguirre (✉)
Campo Experimental Cotaxtla, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, 91700 Medellín de Bravo, Veracruz, Mexico
e-mail: inurreta.daniel@gmail.com

P. Lauri · C. Dupraz · M. Gosme
UMR 1230 SYSTEMS, INRA,
34000 Montpellier, Hérault, France
e-mail: pierre-eric.lauri@inra.fr

C. Dupraz
e-mail: dupraz@supagro.inra.fr

M. Gosme
e-mail: marie.gosme@inra.fr

Introduction

Durum wheat and barley are important crops in the Mediterranean basin (FAO 2016). In this region, cereals are usually sown in autumn and due to the seasonality of the rain, commonly suffer drought stress at the end of their cycle (Savin et al. 2009). Agroforestry could help to alleviate this problem. By reducing incoming radiation (Artru et al. 2017) and

wind (Campi et al. 2009), trees impact temperature and humidity of air and soil (Gosme et al. 2016), as well as evapotranspiration (Kanzler et al. 2018). This microclimate can increase the water available to the crop (Lin 2010) and the crop's water use efficiency (Bai et al. 2016).

However, agroforestry could also cause negative effects due to the competition for resources between the trees and the crops (in addition to possible allelopathic effects caused by tree roots (Jose and Gillespie 1998)). Roughly, crop growth depends on the intercepted radiation and its biomass use efficiency (Monteith 1994), therefore, shade is an important constraint to it. Besides, the effect of agroforestry on soil moisture may be counterintuitive, depending on environmental conditions (Fernández et al. 2008). While trees reduce evapotranspiration through the modification of the microclimate (Padovan et al. 2018), soil water is lost via the tree transpiration. Therefore, trees may reduce crop productivity due to competition for water, potentially more than they can improve yield through their beneficial microclimate (Cannell et al. 1996). The presence of trees could also impact the availability and uptake of nutrients by the crop (Sharma et al. 2012). In short, agroforestry systems are complex, and the potential positive and negative interactions have a high spatial and temporal variability (Ong and Kho 1996). The net impact of these interactions on crop productivity depends on the initial conditions of the system and ongoing management.

Alley cropping systems (ACS) are a type of agroforestry systems in which crops are grown in alleys formed by rows of trees or shrubs (Wilson and Kang 1981). Management practices aimed at reducing competition between trees and crops can be easily carried out in ACS. Underground interactions between trees and crops could be reduced by tree root pruning. Tree root pruning can increase soil water content in the surface soil layers (Hou et al. 2003), but this management operation has an economic cost and cause damage to the tree, reducing their productivity (Burner et al. 2009). Thus, before considering it as a viable management practice, it is important to know if it manages to reduce the impact on crop yield in a specific ACS.

Under typical northern Mediterranean conditions, it is unknown how much of the reduction in cereal productivity under ACS is due to underground competition and how much to aerial competition. Therefore, under these conditions, it is important to quantify the benefit of tree root pruning. The objective of this study was twofold: a) to assess the impact of ACS in comparison with monocrop on the microclimate, the soil water content and the crop yield of two different varieties of durum wheat and barley; b) to assess the effect of root pruning in ACS on the same variables.

Material and methods

Study site

The experiment was carried out in 2017 in the "Restinclières Agroforestry Platform (RAP)" (INRA 2017) in southern France (43° 42'N, 3° 51'E). The climate is hot-summer Mediterranean (Csa in Köppen classification) and the soil is deep calcareous silty clay.

Experimental treatments

The experimental design consisted of three systems: a monocrop (MC), ACS with (ACS_RP+) and without (ACS_RP−) root pruning. Both ACS were placed in 13-m-wide alleys with an east-west orientation between rows of 23-year-old hybrid walnut trees (*Juglans nigra* X *regia* type NG23). Trees had a mean height of 11.3 m ($\pm$1.6) and a bole height of 4.6m ($\pm$0.9). Within-row spacing between trees ranged from 4 to 12 m due to a previous tree thinning in the plot, resulting in a mean tree density of 96 trees ha^{-1}. The MC was carried out in an adjacent plot devoid of trees.

Each system was split into 24 microplots (1.55 x 6 m). In the case of ACS, the distribution of the microplots was: four along the sowing direction (one per cereal cultivar), parallel to the tree line by six across the alley, perpendicularly to the tree line. The MC had a similar distribution, imitating the ACS. The selection of varieties was done according to their phenology. For durum wheat the early variety was Claudio and the late one Karur, while for barley the early variety was Orpaille and the late one KWS Cassia (Fig. 1).
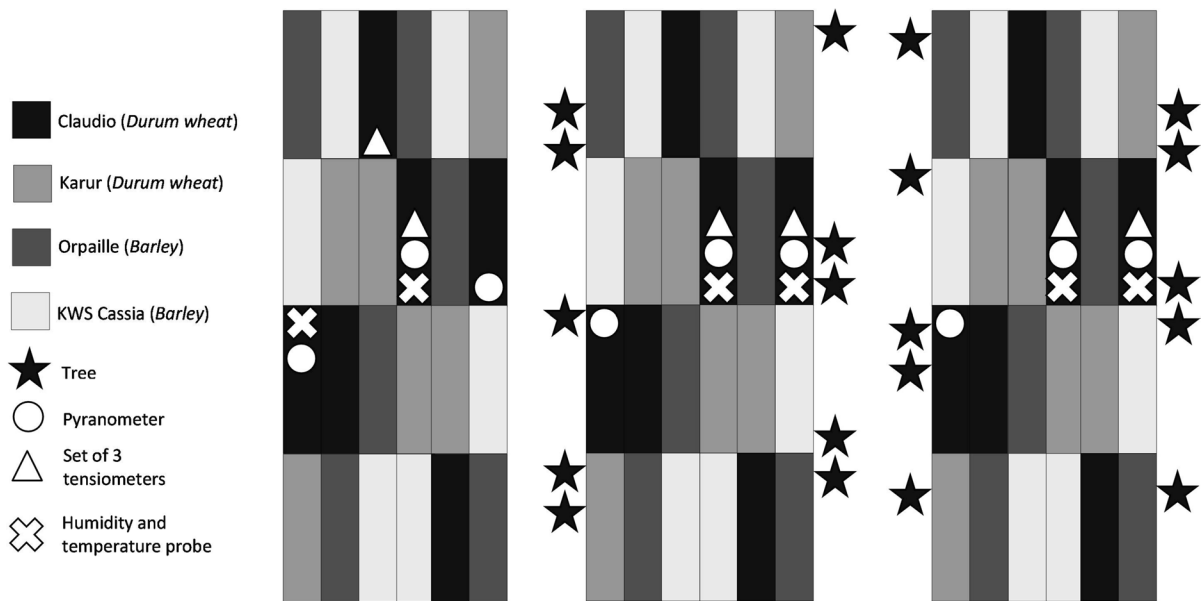
Fig. 1 Spatial distribution of the trees, the experimental plots and the sensors in MC, ACS_RP + and ACS_RP−

Management practices

The root pruning was done on October 21, 2016, using a tractor-mounted root pruner with a blade going at a depth of one meter that was dragged along the alley two meters from the center of the tree line. The soil was prepared with a rotary harrow on October 31, 2016 and the sowing of all microplots was done on November 7, 2016, at a density of 300 seeds per m^2. The seeds were pretreated with PREMIS 25FS (active ingredient: triticonazole) to prevent fungal infection. An application of 6L/ha of the herbicide Athlet (200 g/l Bifenox + 500 g/l Chlortoluron) was done on March 14, 2017. Two applications of mineral fertilizer (50 kg of nitrogen per hectare in each one), were carried out on February 21, 2017 and April 8, 2017, respectively. During the whole crop cycle, no irrigation was applied in the experiment. Harvest was done at maturity, on July 6, 2017.

Collected data

The microclimate was monitored in three observation points in each system, whose location is shown in Fig. 1. Microclimate variables were air temperature, measured with temperature probes (HMP155,

Campbell Scientific, USA) and solar global radiation, measured with pyranometers (SP1110, Campbell Scientific, USA).

Considering that the observation points were few and unable to measure spatial variability, the measurement of the incident radiation was complemented with hemispherical photographs. Thus pyranometers were used for measuring the temporal variability of light and hemispherical photographs its spatial variability. The hemispherical photographs were taken from the center of each of the 25 (2 systems in ACS * 3 sowing lines * 4 genotypes + 1 position in MC) microplots at three different times: with the leafless trees, at the end of short shoot growth stage, and at crop harvest. The sowing lines were the same where the microclimate sensors were placed, corresponding with the north, central and south parts of the alley. In MC, only one position was used since there was no spatial heterogeneity in incident radiation. The photosynthetic photon flux density (PPFD) was calculated from each hemispherical picture using the software Winscanopy (Regent Instruments, Canada). Then, the values of the different dates were interpolated to generate a dynamic per microplot. Finally, the values for each day were then summed over the whole growing season.

Soil water content was described through the soil matric potential (SMP) measured with a set of tensiometers. In each system, two sets of tensiometers were placed next to the south and center microclimate observation points. Each set consisted of three tensiometers at different depths: 1m, 1.5m and 2m. The value of all tensiometers was measured at noon every week along the crop cycle.

The grain yield and the yield components were measured only in three lines of the microplots. These were the same lines where the microclimate was monitored, corresponding with the north, central and south parts of the alley. Grain yield was decomposed into five yield components: number of plants per square meter, number of tillers per plant, percentage of fertile tillers, number of grains per spike and the weight of one thousand kernels.

Data treatment and statistical analysis

To explain variability for the climate variables, a selection of the best model was made according to the AIC in a backward sense, considering as an initial model one that included the system, the position in the alley (for the ACS) and their interaction as fixed effects. For the air temperature, the best model included only the systems and not the position in the alley or the interaction, thus the results from the two microclimate observation points (see Fig. 1) in each system were averaged. However these variables showed a strong diurnal effect, so they were grouped into day and night. The solar global radiation considered both the system and the position in the alley (but not the interactions), thus the three microclimate observation points across the alley (see Fig. 1) were treated separately.

To avoid the difference between MC and both ACS masking the differences between ACS_RP+ and ACS_RP−, the analysis was carried out in two stages: first, comparing MC with ACS pooled and then excluding MC from the analysis to compare ACS_RP+ and ACS_RP−. It was decided to carry out the first stage in this way, to increase the variability of the ACS evaluated; pool together ACS RP and ACS RP−, caused more diverse conditions to be evaluated against MC.

For PPFD, different linear models were compared, based on the Akaike information criterion (AIC),

which allowed us to determine if the system (first MC vs ACS and then ACS_RP+ vs ACS_RP−), the position in the alley and the interaction between them had an effect on each dependent variable. In the statistical analysis of the SMP the depth of the tensiometer was also included in the model as a fixed effect. For the yield and the yield components a similar strategy was used, comparing several models and choosing the best one according to the AIC. For these variables, the system (first MC vs ACS and then ACS_RP+ vs ACS_RP−), the variety and the interaction were considered. Finally, multiple comparisons were performed with Tukey HSD using the best model. In all comparisons, the threshold for significance was set at $\alpha=0.05$.

Results

Microclimate

The air temperature showed a "buffer effect" in both ACS, with lower temperatures during the day and higher temperatures at night compared to MC (Fig. 2). This buffer effect appeared approximately 1 month after tree budburst. After tree budburst, air temperature in ACS_RP+ was always cooler than in ACS_RP−, both day and night.

According to pyranometer data, both ACS had less global solar radiation in comparison with MC. This reduction in solar radiation was surprisingly high in January (74% compared to MC), later, this reduction decreased during February (95% compared to MC) and increased steadily after that (83% compared to MC, averaging the rest of the months). In both ACS, the shade effect presented clear differences according to the position in the alley. The shade effect in the north part of the alley (i.e. south of the trees) was almost imperceptible, meanwhile, in the south part (i.e. north of the trees) about 25% less total radiation was received at the end of the cycle (data not shown).

Comparing the PPFD from MC with both ACS pooled together, the presence of a system-position interaction in the best model, led us to compare MC with ACS grouped by position (north center and south) (Fig. 3). The north of the alley was not significantly different from MC, but the center received significantly less light over the whole season, and the south part even less. PPFD under the trees was

Fig. 2 Differences in air temperature between MC and ACS pooled. The values were calculated using a moving average calculated from a database per hour and considering a time step of a week
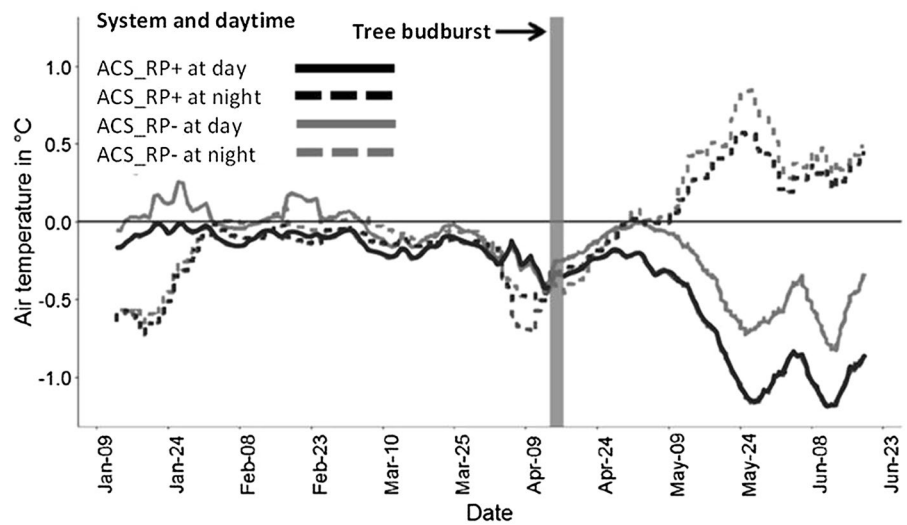

Fig. 3 Sum of Photosynthetic Photon Flux Density (PPFD) from sowing to harvest, computed from hemispherical pictures in MC and in ACS pooled, split by the position in the alley. Error bars represent the standard deviation ($n=8$ in agroforestry: 2 systems * 4 positions along the crop alley). There is no error bar for MC because hemispherical pictures were taken on one microplot only
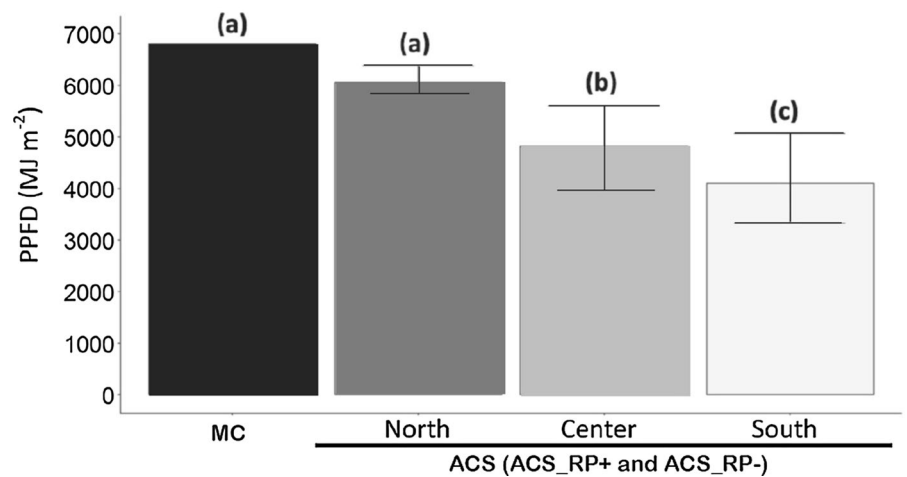

0.89, 0.71 and 0.60 relative to full sun conditions in the north, center and south part of the alley, respectively. In the analysis in which ACS_RP+ was compared to ACS_RP−, the best model was the one that considered only the position in the alley, showing that there were no differences between the ACS in terms of light.

Soil moisture

The crop cycle was typical in terms of rainfall, receiving a total of 477 mm from November 7 to July 6 (Of which 31% fell in autumn, 29% in winter, 36% in spring and 4% in summer). Comparing the SMP between MC and the two ACS pooled, the best model was the one that considered the system, the depth at which the tensiometer was placed and the interaction between these two factors. The difference between the systems and the depths became clearer after the tree budburst. The MC had a lower SMP in comparison with both ACS. The three different depths in the two ACS, showed no difference between them; meanwhile, the three different depths at MC were significantly different between them (1m<1.5m<2m). In the first two depths, SMP in the two ACS was significantly higher than MC, reaching a difference (at the beginning of May) of around 250% and 100%, at 1m and 1.5m, respectively. However, at 2m there was no difference between the systems (Fig. 4).

Fig. 4 The soil matric potential (SMP) along the crop cycle for the different modalities. **A** SMP in the ACS pooled and MC at different depths averaging the data from the two positions in the alley (center and south); and **B** SMP in ACS_RP+ and ACS_RP−, at different positions in the alley averaging the data from the three depths (1, 1.5 and 2 m)
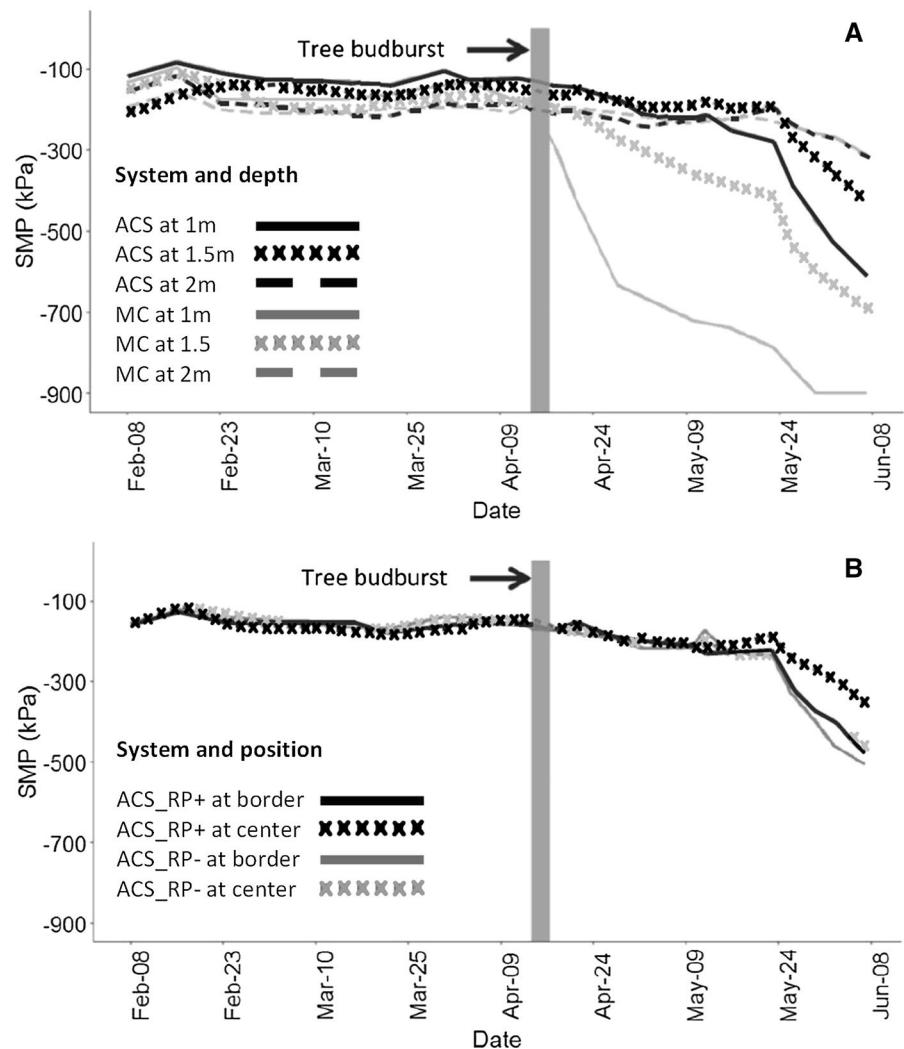
In the subsequent analysis comparing ACS_RP+ and ACS_RP−, the best model to explain the SMP comprised all the effects (system, depth, and position in the alley) and all the double interactions. Therefore, the model was reformulated, considering the system, the position in the alley and the interaction between them, as fixed effects and the depth and their interactions as random effects. The best mixed model (according to AIC) was the one that considered the system and the position in the alley (not their interaction) as fixed effects and the depth as a random effect. The multiple comparisons showed that SMP was significantly higher in ACS_RP+ than in ACS_RP−. Similarly, it was higher in the central part than in the south of the alley.

Yield components

The best models, according to the AIC, to explain the variation in grain yield and yield components are shown in Table 1. For durum wheat, the grain yield and almost all the yield components (except the number of spikes per tiller) were significantly lower in the two ACS pooled than in MC. The Claudio variety had a thousand kernel weight 8% greater than the Karur variety; this difference was significant (Table 2). For barley, there was less agreement between yield components regarding the significant effects. For this crop, the two ACS pooled produced significantly less tillers per plant, grains per spike and the grain yield than MC. Meanwhile, the other

yield components did not show significant differences between the systems. The KWS Cassia variety had 33% more spikes per tiller than the Orpaille variety; this difference was significant (Table 3).

Considering that in the analysis between ACS_RP+ and ACS_RP− no selected model kept the system and only two yield components (the weight of one thousand kernels for durum wheat and the number of tiller per plant for barley) kept the variety, only these two multiple comparisons were made. The results of these comparisons were consistent with the previous analysis: in durum wheat, the Claudio variety had a thousand kernel weight 10% higher than the Karur variety, and in barley, the

KWS Cassia had a number of tillers per plant 14% higher than in Orpaille.

Discussion

Trees cast shade and create a buffer effect in the air temperature

In our study, ACS had a buffer effect on air temperature, with cooler days and warmer nights compared to the MC. This is in agreement with Karki and Goodman (2015), even though their experiment was a silvopasture located at a latitude of 32 °N. Barradas and Fanjul (1986) explained this phenomenon through

Table 1 Factors in the best models according to the Akiake information criterion to explain the variation in the grain yield and the yield components

[1] Weight of one thousand kernels; *NSE* No significant effect

Yield component	MC vs ACS (ACS_RP+ and ACS_RP−)		ACS_RP+ vs ACS_RP−	
	Durum wheat	Barley	Durum wheat	Barley
Plants m^{-2}	System	NSE	NSE	NSE
Tillers plant^{-1}	System	System + Variety	NSE	Variety
Spikes tiller^{-1}	System	Variety	NSE	NSE
Grains spike^{-1}	System	System	NSE	NSE
TKW[1] (g)	System + Variety	NSE	Variety	NSE
Yield (g m^{-2})	System	System	NSE	NSE

Table 2 Mean (± SD) of the grain yield and the yield components of durum wheat in the systems (MC and ACS pooled) and the varieties

System	Plants m^{-2}	Tillers plant^{-1}	Spikes tiller^{-1}	Grains spike^{-1}	TKW[1] (g)	Grain yield (kg ha^{-2})
MC	270 (±66)[a]	3.8 (±0.6)[a]	0.34 (±0.08)[b]	34.3 (±9.1)[a]	51.3 (±3.3)[a]	4,382 (±1,208)[a]
ACS	201 (±39)[b]	2.6 (±0.7)[b]	0.51 (±0.13)[a]	26.7 (±5.1)[b]	48.1 (±5.3)[b]	2,559 (±519)[b]
Claudio	218 (±53)	2.8 (±0.8)	0.47 (±0.11)	30.3 (±8.8)	51.4 (±3.1)[a]	3,153 (±1,071)
Karur	230 (±65)	3.1 (±0.9)	0.44 (±0.17)	28.1 (±5.9)	47.0 (±5.6)[b]	3,180 (±1,337)

Different small letters indicate significant differences between the means at $\alpha = 0.05$, being "a" significantly higher than "b"

[1] Weight of one thousand kernels

Table 3 Mean (± SD) of the grain yield and the yield components of barley in the systems (MC and ACS pooled) and the varieties

System	Plants m^{-2}	Tillers plant^{-1}	Spikes tiller^{-1}	Grains spike^{-1}	TKW[1] (g)	Grain yield (kg ha^{-2})
MC	263 (±119)	7.4 (±2.3)[a]	0.33 (±0.07)	25.2 (±3.1)[a]	55.9 (±1.2)	5,874 (±609)[a]
ACS	291 (±102)	5.7 (±0.9)[b]	0.32 (±0.18)	19.3 (±3.5)[b]	55.3 (±2.4)	3,979 (±690)[b]
Orpaille	270 (±116)	5.8 (±1.5)[b]	0.39 (±0.19)[a]	20.5 (±4.2)	56.0 (±1.6)	4,531 (±1,251)
KWS Cassia	290 (±101)	6.8 (±1.7)[a]	0.27 (±0.06)[b]	22.1 (±4.6)	55.0 (±2.5)	4,678 (±1,049)

Different small letters indicate significant differences between the means at $\alpha = 0.05$, being "a" significantly higher than "b"

[1] Weight of one thousand kernels

two mechanisms: a) during the day, the monocrop has a higher air temperature due to a higher solar radiation load upon the crop canopy and soil surface; and b) during the night, the monocrop has a greater loss of long-wave radiation (heat loss) from the soil surface to the atmosphere and a cooling effect of cold winds coming from higher air layers. The difference in air temperature between the two ACS could be due to the position of the temperature probes given the irregular pattern of the trees in the line. This is based on the fact that the analysis of the hemispherical photos, which deals with spatial variability, did not show differences. Without a change in incident radiation, a change in understory air temperature is not explained.

An unexpected result in our study was the high reduction of solar radiation in the understory in January, with defoliated trees. A similar result was obtained by Talbot and Dupraz (2012) in a simulation experiment under similar conditions, reporting a reduction of 29% of the winter PAR transmittance by leafless trees. The explanation behind this phenomenon could be the low solar inclination in the winter, causing the sunbeams to cross numerous lines of tree trunks to reach the understory. In terms of solar radiation, it is normally assumed that the combination of deciduous trees and winter cereals complies with the central hypothesis of agroforestry (Cannell et al. 1996), promoting than the crop or the trees acquire resources that the other cannot access, however, our results question this assumption.

The data from the pyranometers and the hemispherical photos agreed the shade level varied along the alley. The analysis of the pictures also showed a reduction in transmitted light in the center and most importantly in the south part of the alley (i.e. north of the tree line), but not in the north of the alley. The high spatial and temporal variability of the solar radiation in the understory of the alley cropping system has been previously reported and is especially strong when the tree canopies do not touch on the tree line (Talbot and Dupraz 2012).

ACS increases soil water availability but reduces yield

According to our data, ACS, from tree budburst, increased the SMP at 1m and 1.5m depth compared to MC; however, at deeper layers (2m) this effect was not perceptible. It is worth noting that this reduction in the amount of water in the soil of MC with respect to ACS, was more noticeable after the tree began to have foliar shoots (with the subsequent restart of the transpiration process) and despite having had a good rainfall regime in the spring (172 mm evenly distributed). Considering the above, it is very likely that the differences between the systems were due to the shade effect. In different conditions, Zhao et al. (2012) also found that ACS could increase the soil moisture in the superficial layers while reducing it in deeper layers. The reason of why this effect only occurs in the superficial layers may be due to a reduction of the soil water evaporation caused by the shade, similar to the results reported by Siriri et al. (2013). Another possible explanation could be that, due to the lower biomass production by the crop in ACS (63% of crop aerial biomass relative to MC); there was lower crop water uptake.

Within both ACS, the position in the alley had a significant effect, with higher soil moisture in the central part of the alley than in the border. This positive correlation between soil moisture and distance to the trees within agroforestry systems is in agreement with published works, carried out in different locations with different trees and crops (Gamble et al. 2018; Huth and Poulton 2007; Jose et al. 2000). In general, trees have a greater water uptake in the areas close to the trunk.

Despite slight differences, the yield and yield components were impacted by ACS in the two crops. A subsequent analysis of the grain yield, using a mixed model with the PPFD as a fixed effect and the variety as a random effect, showed a conditional R^2 (interpreted as the variance explained by the entire model, including both fixed and random effects) of 0.52, showing the importance of incident radiation in the grain yield (data not shown). In similar conditions, the negative impact of ACS on crop yield through the number of tillers per plant and the number of grains per spike was previously reported (Arenas-Corraliza et al. 2018; Inurreta-Aguirre et al. 2018). In the same region, a strong negative correlation between shade and crop yield has been found (Arenas-Corraliza et al. 2018; Querné et al. 2017). Moreover, in studies that specifically analyze the impact of shade on cereals with no below-ground competition (i.e. artificial shade), the yield components more susceptible to shade are the number of tillers per plant (Barnes

and Bugbee 1991; Evers et al. 2006), the number of grains per spike (Acreche et al. 2009; Artru et al. 2017) and grain weight (Artru et al. 2017; Singh and Jenner 1984). Kemp y Whingwiri, (1980) have proposed that the reduction in the number of tillers were associated with a lower sugar concentration in leaf bases, while Mc Master et al., (1987) states that the shade has a greater impact on the survival of the tillers than on their appearance. Regarding to TKW, it is well known that the assimilates to fill the grains come either from current canopy photosynthesis or the translocation of non-structural reserves (Serrago et al. 2013). Thus, a reduction in the amount of the incoming radiation at grain filling stage will reduce the photosynthetic rate and therefore the amount of assimilates to fill the grain. It is interesting that ACS did not impact the TKW for barley but did for durum wheat. The contribution of remobilized carbon to the final weight of the grains could be different according to the crop conditions (Plaut et al. 2004; Yang et al. 2001). Considering that in some ACS (like this experiment) the higher amount of shade occurs at grain filling stage, the importance of the remobilization of non-structural assimilates becomes crucial. It would be interesting in future ACS studies to analyze the origin of the assimilated for the grain filling.

Root pruning slightly increases soil water content but does not have an impact on yield

In our experiment, root pruning significantly increased SMP in ACS and thus the soil water content. This increase in the soil water content in alley cropping due to the physical separation of the crop and tree root has been demonstrated previously in experiments carried out in different locations with different trees and crops (Hou et al. 2003; Wanvestraut et al. 2004). The objective to set the tensiometers at this specific arrangement (1m, 1.5m, and 2m) was to have a transect that would show the variations in soil moisture according to depth, reflecting the exclusion of the roots of the trees in the surface layers. However, we consider that future studies should be more detailed in describing the competition for water and nutrients specifically in the root zone of the crop (i.e. the first 30 cm of soil).

Despite this effect on soil water content, root pruning had no significant effect on yield or any yield component. This absence of effect could be related with the system conditions. For example, the tree density in our study (96 trees ha^{-1}) was higher than that studied by Wanvestraut (2004) (30 trees ha^{-1}) and the single windbreak studied by Hou (2003). In addition, previous analyses in our plot have shown that the trees have a deep root system (Cardinael et al. 2015). This result, combined with the strong reduction in yield in both ACS compared to MC, indicates that water was not the limiting factor of crop yield in ACS. Another issue that is worth highlighting and that could explain this null effect of tree root pruning on crop yield, is the timing in which it is reflected in a difference in the water content in the soil. This difference may have appeared very late in the season when the crop was close to physiological maturity. Long-term studies could shed light on this topic. Other potential explanations worth considering in future analyzes are crop sensitivity to water stress or the effect of the soil characteristics, specifically the water holding capacity.

Conclusion

According to our results, we conclude that root pruning is not a suitable management option for an alley cropping system in our edaphoclimatic conditions. In this study, crop yield was reduced in alley cropping system relative to monocrop conditions despite an increase in soil water content in agroforestry. Similarly, root pruning increased soil water content under the alley but this increase did not cause a higher productivity of the crop. These two main findings suggest that, in the conditions of the study, water was not the limiting factor, and so root pruning had no beneficial effect on the crop productivity. Given that root pruning has an economic cost and can negatively impact tree growth, in conditions such as those present in our study, it is not advisable.

It is important to carry out similar studies under other edaphoclimatic conditions. This experiment was carried out under a typical climatic year in the northern area of the Mediterranean in a plot with deep soil with a high water-holding capacity that refills every winter. However, the increment in soil water content caused by the tree root pruning could be significantly beneficial to crop productivity in drier conditions (e.g. those expected with climate change) or in soils

with a lower water holding capacity. Nevertheless, if these conditions were too adverse, the trees probably would not grow well either, especially if a root pruning is applied to them. Therefore, the range of edaphoclimatic conditions where tree root pruning in alley cropping could be useful (and therefore where it might be worth assess it) could be quite narrow.

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