Long-term impacts of inter-cropping and reduced tillage on ecosystem services in dryland agriculture

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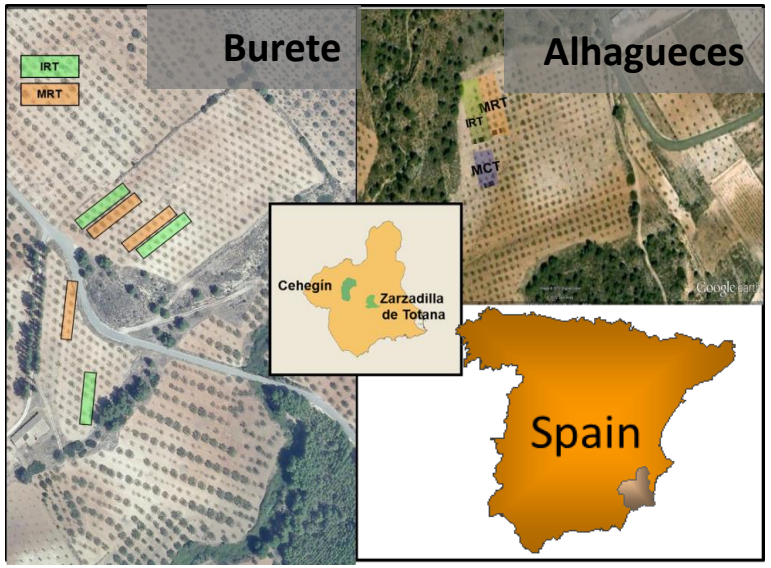
Study site, experimental design and objectives

Long-term (**2009-2018**) environmental impact and delivery of ecosystem services of crop diversification (inter-crop with legumes/cereal) in two rainfed almond orchards (*Prunus dulcis Mill.*) compared to a monocrop system with different tillage intensity under Mediterranean semiarid conditions.

Ecosystem services studies were related to:

- support (carbon sequestration)
- regulation (hydrological cycle)
- provision (crop yield)



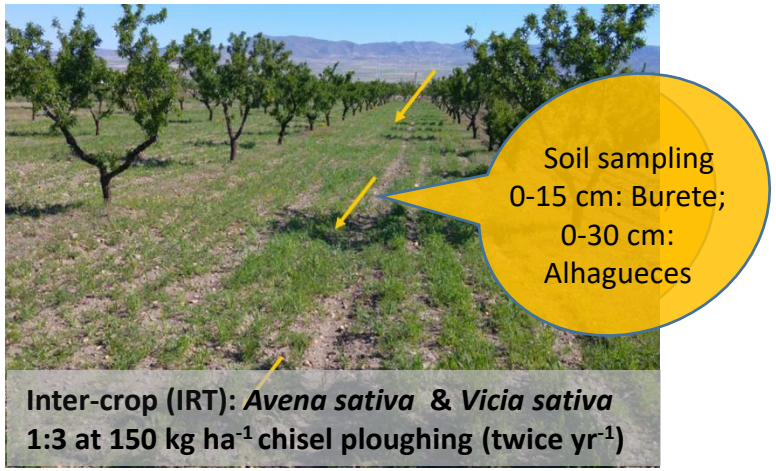
At both farms, trees are in rows with a 7 m × 7 m spacing and no fertilizers were applied during the study.

6 plots in a randomized-block design, with three replicates per each treatment. Each plot comprised seven almond trees: the five central trees were used for all soil measurements.

Soil types: Calcisols (FAO, 2006); silt-loam texture, high contents of $CaCO_3$ (~45%), a pH (H_2O, 1:5) of 8.7, and an electrical conductivity of 140 ± 2.8 µS cm−1.

Monocrop under conventional tillage (MCT) chisel ploughing (3/5 times yr^{-1})

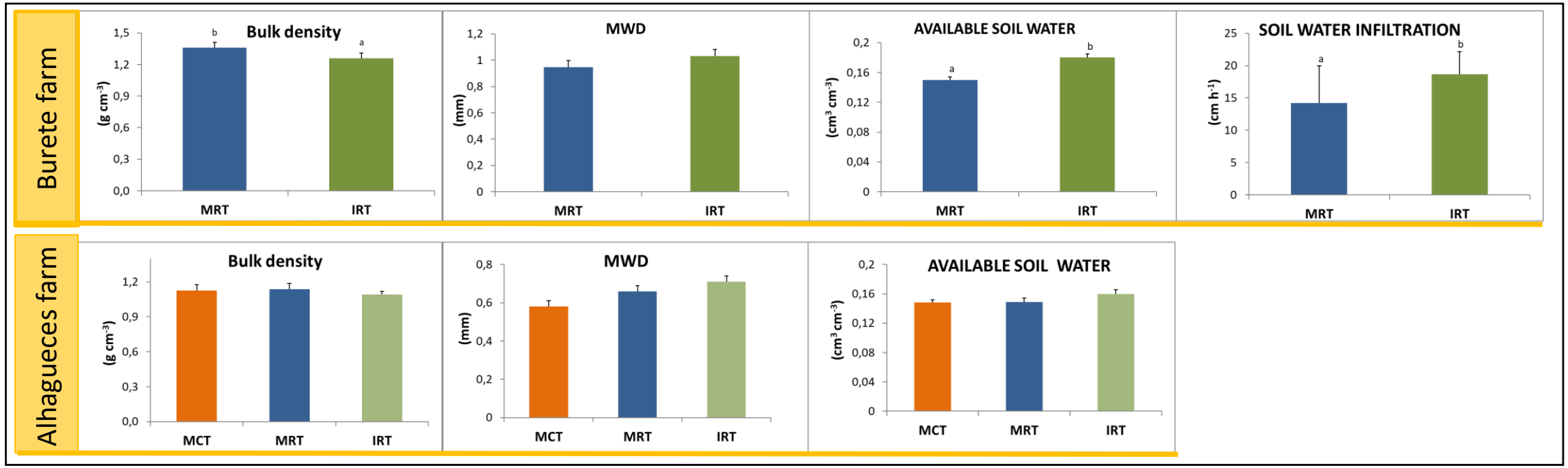
Monocrop under reduced tillage (MRT) chisel ploughing (twice yr^{-1})



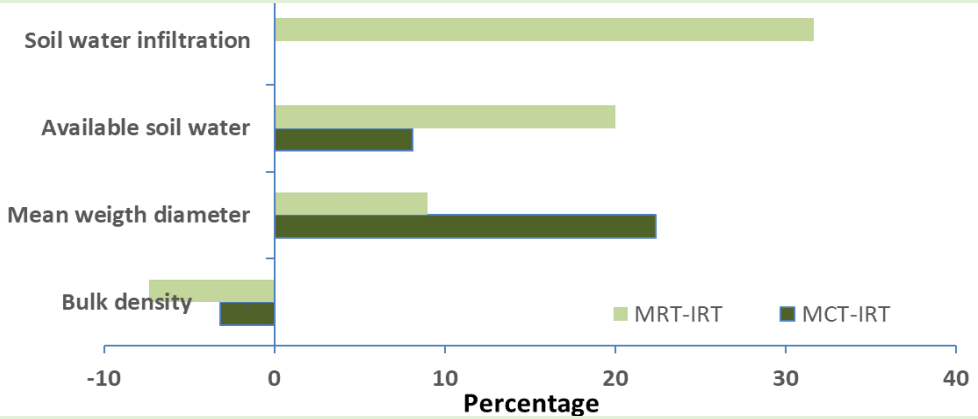
Inter-crop (IRT): *Avena sativa* & *Vicia sativa* 1:3 at 150 kg ha^{-1} chisel ploughing (twice yr^{-1})

Soil sampling date: November 2015 (Burete); November 2018 (Alhagueces)

Soil physical quality indicators



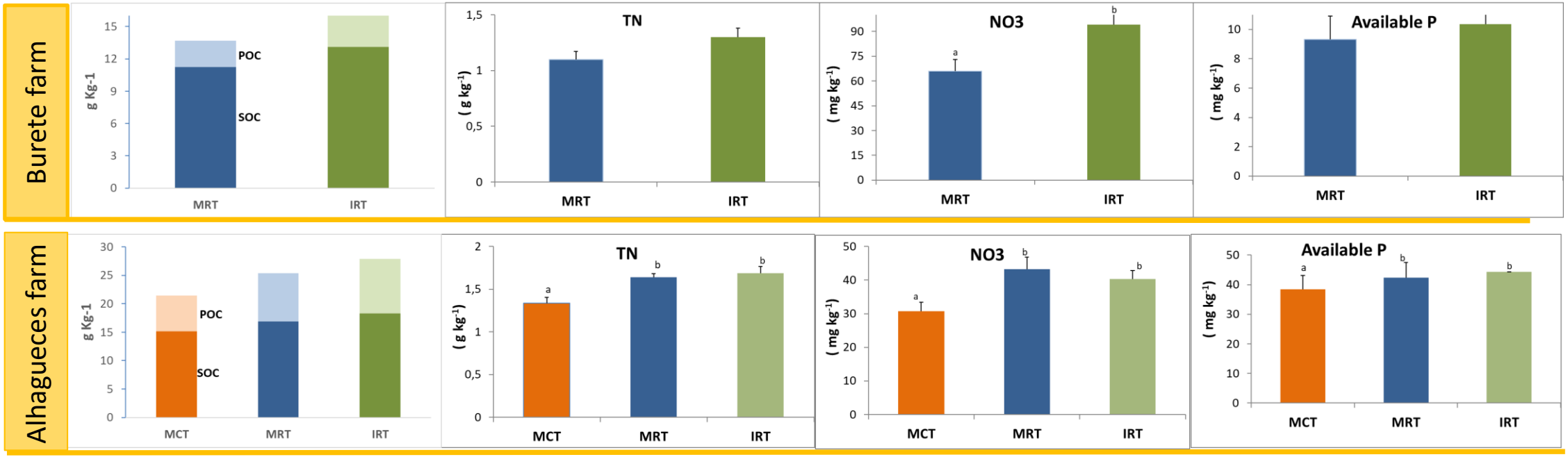
Percentage of change in soil physical parameters when monocrop (MCT or MRT) shifts to inter-cropping (IRT) systems



MCT: monocrop with conservation tillage; MRT: monocrop with reduced tillage

- Inter-cropping improved soil physical quality parameters related to soil structure (decrease in BD and increase in aggregate stability (MWD)) and hydrological cycling (increase of available soil water content and soil water infiltration).
- Changes in soil physical quality parameters with inter-cropping were more pronounced at Burete farm (after six years of inter-cropping implementation) than at Alhagueces farm (after nine years of inter-cropping implementation).

Soil chemical quality indicators



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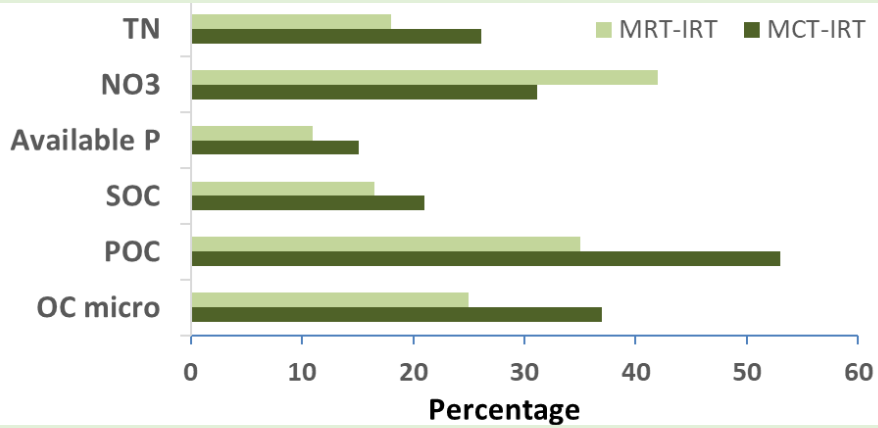
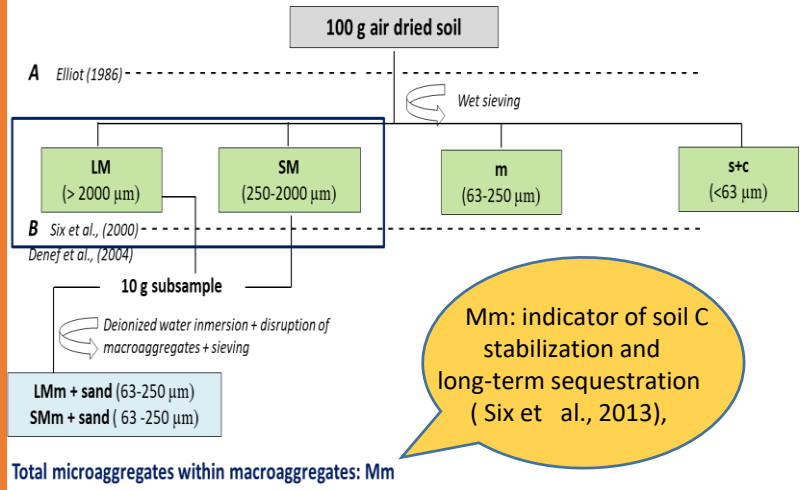
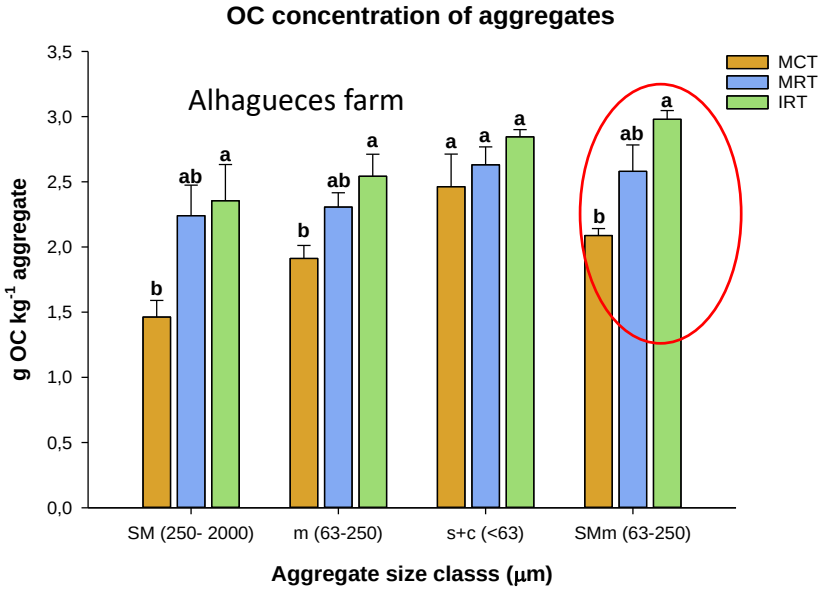


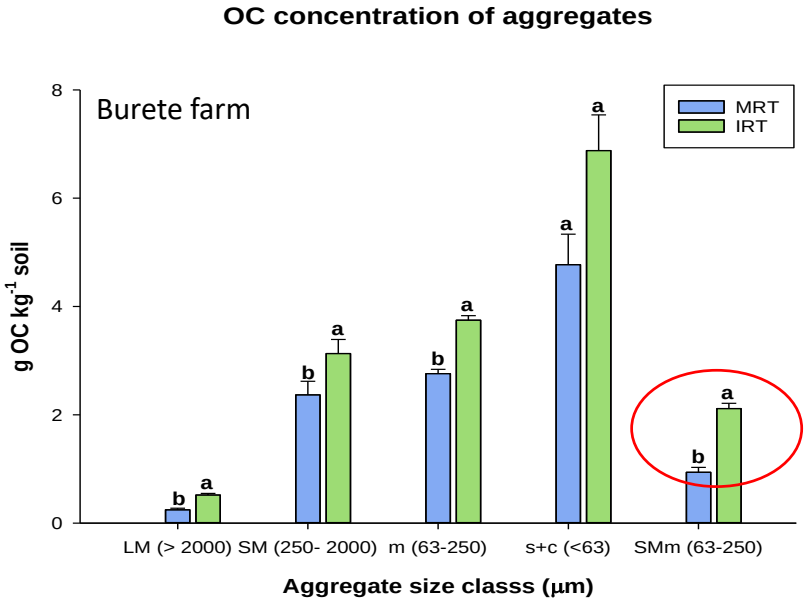
MCT: monocrop with conservation tillage; MRT: monocrop with reduced tillage

- Inter-cropping improved soil chemical quality parameters mainly related to Nitrogen (increments between 20 and 45% for total and mineral nitrogen, respectively) and Organic Carbon cycling (increments between 15 and 55% for SOC and labile OC pools, respectively).
- Changes in soil quality parameters with inter-cropping were, in general, more pronounced at Alhagueces than at Burete farm.

Soil organic carbon sequestration and stabilization



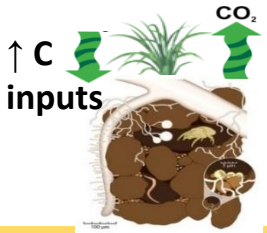




SOC balance at the plow layer after 6 and 9 years from inter-cropping implementation at Burete and Alhagueces farms, respectively.

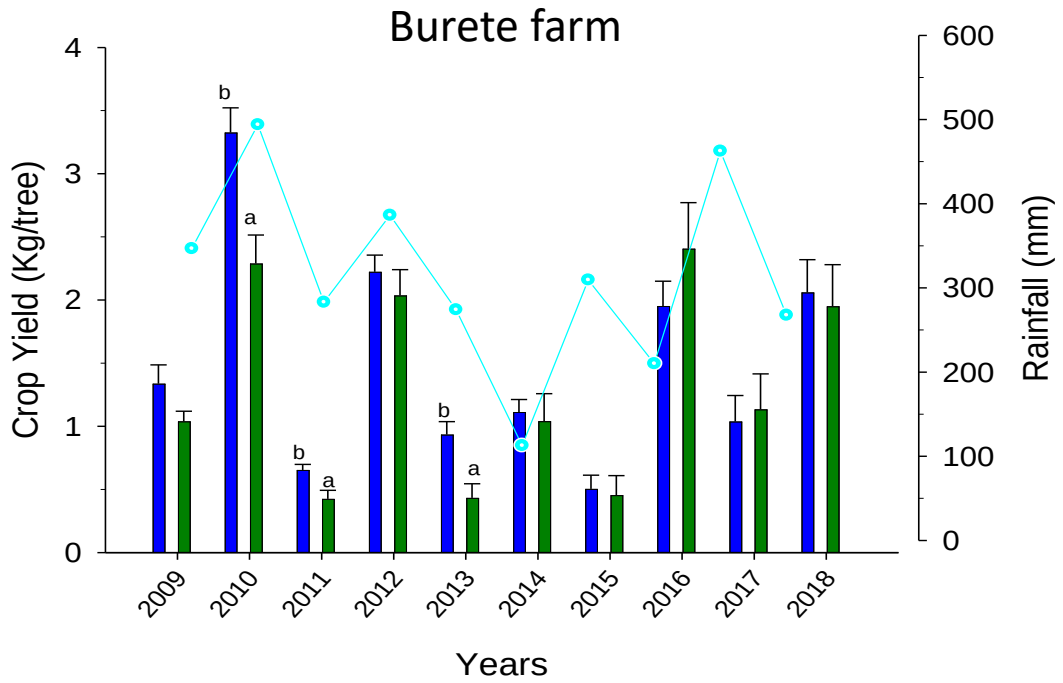
	Alhagueces farm			Burete farm	
	MCT	MRT	IRT	MRT	IRT
SOC stock ($g\ m^{-2}$)	4936.4	5688.8	5932.1	2234.4	2416.9
Δ SOC (%)		15	20		10
Plant C input ($g\ m^{-2}\ year^{-1}$)	0	75	73	34	54
C respired ($g\ m^{-2}\ year^{-1}$)	399	469	439	405	492
Mean residence time (SOC:Crespired)	12.4	12.1	13.5	5.5	4.9

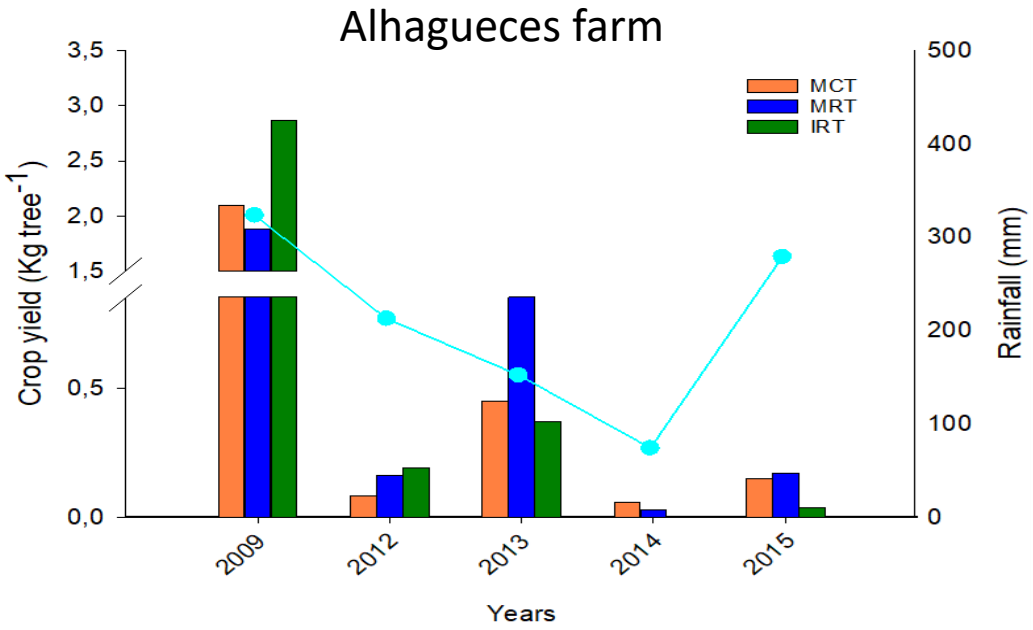
- **Longer mean residence times of SOC** → **Longer SOC preserved**



- Inter-cropping improves the physico-chemical stabilization of SOC by aggregates (promoted by plant litter incorporation).
- The lack of carbon inputs under MCT diminishes the formation and stability of soil aggregates explaining the relatively shorter mean residence time of SOC stocks.
- Reducing the tillage intensity did not decrease the amount of carbon released annually to the atmosphere.

Crop Yield





- During the first five years of inter-cropping implementation, a reduction in the main crop yield of ~ 30% respect to the monocrop was observed (mean values from the period **2009-2015**: 1.42 ± 0.09 and 1.12 ± 0.10 kg tree-1 for MRT and IRT, respectively). However, those differences decreased, or even were reverted from the **2016-2018** period (mean values: 1.70 ± 0.13 and 1.84 ± 0.2 kg tree-1 for MRT and IRT, respectively) independent of the rainfall.

- The improvement in the soil quality in the medium-term under an inter-cropping system might counteract the possible adverse effects of this management practice (competition for water and nutrients) on crop yield.

- An average increase of about 40% in the crop yield with inter-cropping respect to monocrop with conventional tillage (MCT) was observed during the first years of its implementation (**2009-2012**). However, a decrease of about 30% was observed during the following years (**2013-2015**) independent of the rainfall.

- Monocrop with reduced tillage (MRT) showed, in general, similar or even higher crop yield values than monocrop with conventional (MCT) tillage through the years.

Conclusions

✓ The improvement in soil physical properties with inter-cropping were more accentuated for soil structure and available soil water and infiltration capacity, while the improvement in soil chemical properties was more evident for those properties related to the N cycling (Total and mineral nitrogen) and labile organic carbon pools.

✓ Inter-cropping increased the OC stabilized in soil aggregates while no differences in soil CO_2 emissions to the atmosphere were observed compared to the monocrop system, highlighting the potential of inter-cropping for mitigating climate change through soil carbon sequestration.

✓ The effect of inter-cropping on soil physical and chemical properties and crop yield depended on the different prevailing climatic conditions (soil temperature and moisture regimes), soil characteristics, the legacy effect of previous management (amendment, tillage frequency) and species used for diversification.

✓ Positive effects on crop yield were observed (in one of the farms) after six years from inter-cropping implementation, highlighting the potential of inter-cropping in rainfed woody crops as a viable strategy for sustainable productivity in rainfed agriculture in the long-term.

Acknowledgements

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