

HOW IRRIGATION CAN FACILITATE CONSERVATION AGRICULTURE PRACTICES AND RESULTS: PRACTICAL CASE IN SOUTH-EAST OF FRANCE

COMMENT L'IRRIGATION PEUT FAVORISER LES PRATIQUES ET LES RÉSULTATS DE L'AGRICULTURE DE CONSERVATION : CAS PRATIQUE AU SUD- EST DE LA FRANCE

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Abstract

This study examines how irrigation can support the successful implementation of conservation agriculture (CA) in Mediterranean environments, using a long-term field experiment conducted in southeastern France. The region faces strong climatic constraints, including low rainfall and high evapotranspiration, resulting in frequent water deficits that limit crop productivity and complicate the adoption of CA practices. In rainfed systems, crop diversification and the establishment of cover crops are particularly challenging, reducing the effectiveness of CA. The Oraison trial, conducted since 2013, compares rainfed and irrigated systems under conservation agriculture. Results show that CA significantly improves soil properties compared to conventional farming, including higher soil organic matter (+33%), increased carbon storage (+16%), enhanced microbial activity (+100%), and greater biodiversity, particularly earthworms. However, irrigation plays a critical role in enhancing these benefits. It facilitates the implementation of CA principles by enabling reliable cover crop establishment and more diversified crop rotations, including summer crops. Irrigation increases biomass production returned to the soil by 75%, which in turn boosts soil carbon inputs and biological activity. Economic results show that irrigation improves profitability (+118%) due to higher yields and yield stability, although it also increases labor and energy use. At the same time, irrigation modifies soil functioning by accelerating organic matter mineralization, which may limit long-term carbon accumulation if not balanced by sufficient biomass inputs. Overall, the study demonstrates that irrigation is a key enabler for conservation agriculture in dry Mediterranean regions. It improves system performance, stabilizes production, and enhances soil functions. However, careful management is required to balance increased biological activity with adequate carbon inputs in order to sustain soil fertility over the long term.

Keywords: conservation agriculture; climatic constraints; rainfed and irrigated systems; soil properties; biomass production.

RESUME

Cette étude examine la manière dont l'irrigation peut contribuer à la mise en œuvre réussie de l'agriculture de conservation (CA en milieu méditerranéen, à partir d'une expérience de terrain à long terme menée au sud-est de la France. La région fait face à de fortes contraintes climatiques, notamment de faibles précipitations et une évapotranspiration élevée, donnant lieu aux déficits hydriques fréquents limitant ainsi la productivité des cultures et compliquant l'adoption des pratiques de CA. Dans les systèmes pluviaux, la diversification des cultures et la mise en place des cultures de couverture posent particulièrement des difficultés, ce qui réduit l'efficacité de CA. L'essai d'Oraison, mené depuis 2013, compare les systèmes pluviaux et irrigués dans le cadre de l'agriculture de conservation. Les résultats montrent que le CA améliore de manière significative les propriétés du sol par rapport à l'agriculture conventionnelle, y compris une teneur plus élevée en matière organique (+33%), un stockage accru du carbone (+16%), une activité microbienne renforcée (+100%) et une plus grande biodiversité, en particulier relevant de vers de terre. Cependant, l'irrigation joue un rôle essentiel dans l'amplification de ces avantages. Elle facilite la mise en œuvre des principes de CA en permettant la mise en place fiable

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de cultures de couverture et des rotations culturales plus diversifiées, y compris des cultures d'été. L'irrigation augmente de 75% la production de biomasse restituée au sol, ce qui stimule à son tour les apports en carbone au sol et l'activité biologique.

Sur le plan économique, les résultats montrent que l'irrigation améliore la rentabilité (+118%) grâce à des rendements plus élevés et à une meilleure stabilité des rendements, même si elle augmente également l'utilisation de la main-d'œuvre et de la consommation d'énergie. En même temps, l'irrigation modifie le fonctionnement du sol en accélérant la minéralisation de la matière organique, donnant lieu à la limitation de l'accumulation de carbone à long terme si ce phénomène n'est pas compensé par des apports suffisants en biomasse. Dans l'ensemble, l'étude démontre que l'irrigation est un facteur clé pour l'agriculture de conservation dans les régions méditerranéennes arides. Elle améliore les performances du système, stabilise la production et renforce les fonctions du sol. Cependant, une gestion rigoureuse est nécessaire pour équilibrer l'activité biologique accrue avec des apports adéquats en carbone afin de préserver la fertilité du sol à long terme.

Mots-clés : Agriculture de conservation; Contraintes climatiques; Systèmes pluviaux et irrigués; Propriétés du sol; Production de biomasse.

Introduction

The impact of climate change on cereal production in the Mediterranean region is significant. In southeastern France, the rainfall balance (precipitation minus potential evapotranspiration) is markedly negative compared to other French regions. Moreover, according to climate projections (ALADIN RCP 4.5 and 8.5), this deficit could worsen by approximately 100% in spring and 34% in summer. The consequences for crop physiology are potentially severe: increased spring water stress, higher risk of cereal burn, and grain abortion in summer crops.

To mitigate these negative effects, farmers can implement several strategies, including selecting varieties better adapted to climate stress, adjusting agricultural practices (such as sowing dates, irrigation, and fertilization), and adopting agroecological approaches focused on improving soil fertility. Conservation agriculture is one such approach. To optimize its effectiveness, irrigation can be a valuable asset, helping to accelerate and amplify its benefits. Conservation agriculture (CA) is characterized by minimal soil disturbance, the maintenance of permanent soil cover, and crop rotation diversification (FAO definition). Numerous studies have demonstrated its positive effects on erosion control, carbon sequestration, water infiltration, and soil biodiversity (Cordeau et al, 2024).

Other studies have also shown a higher probability of winter wheat yield gains under CA compared to conventional systems in dry regions (Su et al., 2021; Marguerie et al., 2025). These advantages are essential for addressing climate change and enabling agriculture to respond to environmental and climatic challenges. However, in arid environments, implementing the three pillars of conservation agriculture can be very challenging, as demonstrated by the CAMA project (Conservation Agriculture in the Mediterranean Area). Under rainfed conditions, crop rotation diversification remains difficult—even in southeastern France—which can lead to additional challenges for weed management in no-till systems. For the same reason, establishing summer cover crops after harvest is highly risky, with an average success rate of only two years out of ten. For these climatic reasons, irrigation could serve as a key enabler for the successful implementation of conservation agriculture in dry regions and for maximizing its positive effects on soil protection, carbon sequestration, and soil biodiversity.

Material and Methods

A long-term field trial conducted in Provence by Arvalis, in collaboration with an expert farmer, Daniel Brémont (Oraison: 43.93097855710623, 5.9227156795522475), has been investigating different technical approaches for the successful implementation of conservation agriculture (CA) in arid environments since 2013. Over the period 2005–2025, the site is characterized by an average annual temperature of 13.4°C, average annual rainfall of 624 mm, and a negative climatic water balance, with potential evapotranspiration exceeding precipitation by 377 mm. No soil tillage has been carried out on

the experimental plots since 2008, which have been entirely managed under direct seeding and without livestock integration.

The trial consists of 31 plots (6 m wide and 180 m long). Between 2013 and 2021, 18 plots were managed under rainfed conditions and 13 under irrigation. Since 2022, the irrigated plots have been transferred to a neighboring field that has also been managed under CA since 2008. In addition, two external plots managed by private farmers -one irrigated and one rainfed- are used for soil comparisons in order to quantify the effects of conservation agriculture.

The rainfed system is dominated by winter crops (durum and common wheat, barley, oats, faba bean, and pea) sown during the rainy autumn period, as well as forage crops (alfalfa and sainfoin). Chickpea, sown in January or February, is the only crop grown outside the autumn season. Spring and summer crops are not included in this trial due to their excessively high failure rate under rainfed conditions. In irrigated systems, crop rotations are primarily based on durum wheat, maize, and soybean (Figure 1). The trial includes only conservation agriculture (CA), with no comparison against other production systems such as conventional or organic farming. Indeed, the primary objective was to support farmers in developing decision-making rules to successfully implement CA in southeastern France. The second objective was to assess the multiple effects of CA across several dimensions: yield, economic performance, labor requirements, soil fertility, soil water dynamics, carbon sequestration, and biodiversity.

These multiple effects have been analyzed in two ways: first, by evaluating the long-term trajectory of system performance, and second, through comparisons with neighboring conventional reference plots. These plots are not part of the trial but are representative of regional practices, characterized by ploughing and the absence of soil cover during intercrops. The multi-performance assessment was mainly carried out on durum wheat, as were the soil measurements, although some indicators—particularly those related to soil fertility—are not crop-specific. The crop rotations in the conventional system can be considered similar to those in CA in terms of crop types, but not in their temporal sequence (i.e., crops are not grown in the same years). Therefore, the study compares two production systems, each with its own characteristics and management practices.

Additional comparisons between CA and conventional systems were conducted at the crop rotation scale, particularly from an economic perspective. Simulations were performed using two representative rotations for each system: alfalfa / durum wheat / forage pea / faba bean / soft wheat under CA, and durum wheat / barley / forage pea under the conventional system. The software Systerre[®] was used for this characterization of CA multiperformance. Finally, the long-term dataset, combined with the irrigated versus rainfed setup, made it possible to assess the role of irrigation in the technical success of the system, as well as its contribution to the overall performance of conservation agriculture in a Mediterranean context.

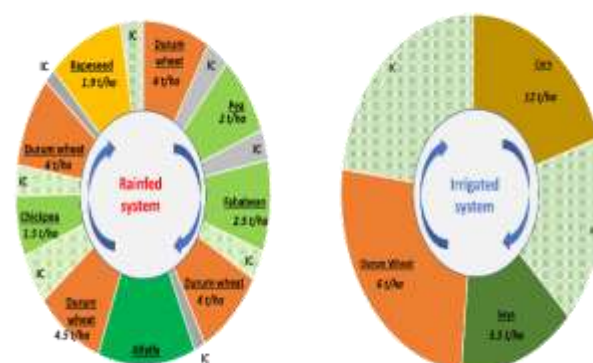


Figure 1: main crop rotation in the Oraison trail in rainfed and irrigated system

3. Results

3.1 Global performances of Conservation Agriculture on durum wheat production

Compared to the conventional system, the results of the trial show an interesting level of multi-performance in durum wheat production, using various types of indicators: economic, production, social, biodiversity, and soil fertility. The comparison was conducted under rainfed conditions in order to highlight the benefits of conservation agriculture within the specific climatic constraints of southeastern France.

Physical and chemical fertility of soils

Compared with the conventional plot, organic matter content increased by approximately 33% in the 0–30 cm layer (2.5% vs 1.8%), while soil carbon stocks were 16% higher down to a depth of 120 cm. In line with this higher organic matter content, microbial biomass was significantly increased (+140%), as was annual nitrogen mineralization (+190% compared to the conventional system), according to the biologically mineralizable nitrogen indicator measured by anaerobic incubation (7 days at 40°C). The potential implications for reducing nitrogen inputs are currently being assessed.

Soil biodiversity

Data from Oraison show a higher earthworm density under conservation agriculture (CA), with an average increase of +120% over the 2022–2024 measurement period compared to the conventional system, based on equivalent sampling dates (93/m² under CA vs. 19 under Conventional). In particular, the abundance of anecic earthworms increased markedly (+161%) under CA. By enhancing vertical porosity through their movement between soil surface and deeper layers, these organisms may partly explain the observed improvement in water infiltration capacity (+135%).

Microarthropods (mites, springtails, and myriapods) were also more abundant under CA (+120%). Springtail populations, in particular, were 20% higher than in the conventional system. Living in both soil and litter, microarthropods play a key role in accelerating organic matter decomposition, as reflected by the increase in glucose decomposition activity (+110%).

Input level

Regarding pesticide use (Treatment Frequency Index, TFI), the level observed in CA durum wheat is higher than in the conventional system (+32%), mainly due to the need to control cover crops and weeds prior to sowing. However, at the crop rotation scale, herbicide use is reduced by approximately 11%, due to lower input requirements in forage crops. Fuel consumption is significantly lower under CA (–57% for durum wheat production), while nitrogen inputs are similar between the two production systems for this crop.

Water dynamics

Soil profiles showed that soil water holding capacity changed only slightly after 10 years of conservation agriculture (CA) in the Oraison trial. Over a depth of 120 cm, it reached 116 mm under CA, compared with 101 mm in the neighboring conventional plot. These results are consistent with those reported by Aletto (2023), indicating that soil texture remains the primary factor determining water storage capacity. In contrast, water infiltration, measured using the Beerkan method, increased by 135% under CA.

This improvement leads to faster field accessibility, better soil bearing capacity, and a reduced risk of runoff, particularly following intense rainfall events, which are potentially frequent in autumn in this region. These trends have been confirmed in other sites in the PACA region and the Adour–Garonne basin, as well as in several Mediterranean countries within the framework of the CAMA project (Marguerie et al., 2024).

Yields and economic margins

In terms of durum wheat yield, results are similar between conservation agriculture (CA) and conventional farming in southeastern France. However, yield advantages under CA have been reported in more arid regions (Su et al., 2021; Marguerie et al., 2025). For durum wheat grown under CA in Oraison, gross margins improved by approximately 30%, mainly due to a substantial reduction in mechanization and fuel costs. However, when considered at the crop rotation scale, profitability is similar between conventional and CA systems. This can be explained by the greater crop diversification required in CA, which includes crops with highly variable yields and therefore less predictable economic returns. This is particularly the case for certain legumes (faba bean, pea, alfalfa), which are less frequently included in conventional rotations and are associated with greater production variability.

3.2 Impact of irrigation on the application of conservation agriculture principles

Securing the implementation of the pillars of the CA

Conservation agriculture (CA) is often practiced under rainfed conditions in Mediterranean areas (CAMA project; Marguerie et al., 2024), with particularly positive results for soil fertility. The results of the Oraison trial show that irrigation clearly facilitates the implementation of CA principles. In irrigated systems, the establishment of cover crops between cash crops is easier, thanks to longer intercrop periods extending from September/October to March/April. During these periods, rainfall is generally sufficient to ensure the emergence and biomass development of cover crops.

In contrast, under rainfed conditions, intercrop periods mainly occur during summer, when the water balance is consistently negative. This strongly limits the establishment of cover crops, with failure observed in approximately 8 out of 10 years based on field experience in Oraison. Without irrigation, the main strategy to successfully maintain plant cover is the use of semi-permanent covers such as alfalfa or sainfoin, which can persist for several years and coexist with successive cash crops. These covers are expected to regrow after harvest.

At the beginning of the crop rotation, semi-permanent covers can also be harvested as forage and provide additional ecosystem services, particularly for weed management, which is especially challenging in sequences dominated by winter crops.

However, the main limitation of semi-permanent covers lies in managing competition with the cash crop. Some results indicate that, to avoid yield penalties, the biomass of the semi-permanent cover should remain below 1 t dry matter per hectare at the wheat flowering stage. In cases of insufficient regulation, yield losses can reach up to 50% (Marguerie, 2025). This was not observed in Oraison due to careful management. Furthermore, the regrowth of semi-permanent cover remains uncertain and highly dependent on herbicide use in the associated cash crop. Depending on weed pressure, certain herbicides may completely destroy the cover. Beyond the results obtained in Oraison, it is important to note that semi-permanent covers are rarely used in North Africa and southern Europe due to the high risk of water competition with cash crops (CAMA project).

Impact of irrigation on Biomass production and returned to the soil under conservation agriculture

One of the main drivers of organic matter (OM) increase under conservation agriculture (CA) is the amount of biomass returned to the soil. By comparing rainfed and irrigated systems in the Oraison trial across four crop rotations, it can be observed that the total biomass returned to the soil increased by 75% with irrigation (7.3 vs. 3.4 t DM ha⁻¹). More specifically, the biomass from cover crops returned to the soil increased by 21%, in line with the previously described effects of improved establishment conditions, while crop-derived biomass increased by 118%. This increase in crop biomass is explained by higher grain yields—and consequently greater straw production—under irrigation, as well as by the inclusion of high-biomass summer crops in the rotation. As a result, the total humified carbon, estimated using the AMG® model, is 73% higher under irrigated conditions.

Table 1 : contribution of crops and cover crops to biomass production and humified carbon storage:

	2015-2021				
	Rainfed		Irrigated		Diff. Irrigated-Rainfed
	Rotation 1	Rotation 10	Rotation 18	Rotation 28	
Total biomass returned to the soil (tDM/ha/year)	5.9	6.1	10.6	10.4	75%
Crop biomass returned to the soil (tDM/ha/year)	3.0	3.7	7.4	7.3	118%
Cover crop biomass returned to the soil (tDM/ha/year)	2.8	2.4	3.2	3.1	21%
Total humified carbon (t/ha/year)*	1.1	1.0	1.8	1.7	73%

Impact of irrigation on Soil biodiversity and soil function under conservation agriculture

Some soil biodiversity indicators are modified by irrigation in Oraison (Figure 3). Organic matter content is higher under irrigated conditions (+51% in the 0–30 cm layer), mainly due to the factors described previously. Several indicators suggest a shift toward a more biologically active and mineralizing soil system under irrigation. This is reflected in a decrease in the C/N ratio (–20%) and in the fungi-to-bacteria ratio (–43%), indicating a shift toward more bacteria-dominated functioning.

Nitrogen mineralization appears to be enhanced under irrigation, as shown by increases in biologically mineralizable nitrogen (+21%) and arylamidase activity (+60%). Overall, nutrient availability is greater under irrigated conditions, resulting from both increased microbial activity and improved soil moisture. This is associated with more dynamic organic matter turnover, characterized by a higher proportion of labile carbon and a lower proportion of stabilized organic matter pools.

Regarding soil fauna, the limited number of replicates ($n = 3$) does not allow for robust statistical conclusions, and results should therefore be interpreted as indicative trends. Mann–Whitney test p -values are provided for guidance. A positive effect of irrigation is observed for earthworms (+33% in abundance and +171% in biomass; $p = 0.4$) and carabid beetles (+200%; t -test $p = 0.06$). In contrast, a negative trend is observed for springtails ($p = 0.4$) and total microarthropods ($p = 0.2$).

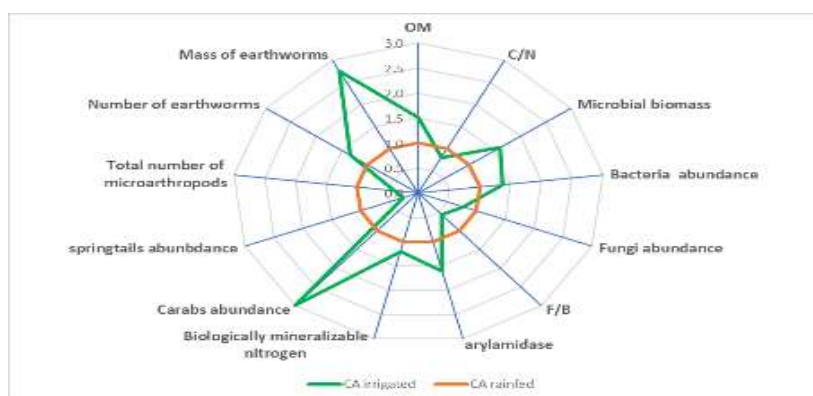

Figure 3: impact of irrigation and soil conservation effects on soil biodiversity and dynamics (left figure: reference CA rainfed; right figure: reference conventional rainfed)

Figure 4 illustrates the hierarchy of the effects of conservation agriculture (CA) and irrigation. Regarding soil mineralization processes, the effect of irrigation is enhanced under CA, as evidenced by changes in C/N ratio, fungi-to-bacteria ratio, and arylamidase activity. In terms of soil biodiversity, the influence of CA appears to be stronger than that of irrigation for earthworm populations, whereas this pattern is not observed for springtails or total microarthropod communities.

	Conventional rainfed	CA rainfed	Conventional irrigated	CA irrigated
OM		0.1	0.1	0.7
C/N		-0.2	-0.1	-0.5
Microbial biomass		0.5	-0.2	1.2
Bacteria abundance		-0.4	-0.5	0.0
Fungi abundance		-0.2	-0.9	-0.6
F/B		0.2	-0.4	-0.6
b-glucosidase		1.1	-0.8	0.7
arylamidase		0.6	0.3	1.2
CKMnO4		-0.1	0.0	0.8
Microbial C		0.5	-0.2	1.2
Biologically mineralizable nitrogen		-0.1	-3.1	0.2
Carabs abundance		-2.0	0.6	-0.4
springtails abundance		4.3	3.5	2.3
Total number of microarthropods		1.3	0.9	0.0
Number of earthworms		2.6	2.2	3.0
Mass of earthworms		3.5	3.4	5.0

Figure 4: effect of irrigation or conservation agriculture on soil proprieties with conventional rainfed as reference (scale log2 centered on 0)

Impact of irrigation on Organic Matter dynamic and soil carbon storage under conservation agriculture

In 2019, soil carbon storage was approximately 17% higher under irrigated CA compared to rainfed CA, corresponding to an additional +19 t C ha⁻¹ over the 0–120 cm soil profile. A particularly strong accumulation of organic matter was observed in the topsoil, contributing to improved protection against erosion.

Soil analyses conducted in both irrigated and rainfed plots (0–20 cm) in 2015, 2020, and 2025 show a faster increase in organic matter under rainfed conditions. This result is consistent with a higher level of mineralization under irrigation. It is also noteworthy that irrigation was discontinued on some historically irrigated plots of the trial in 2022. The first soil analyses conducted in 2025 indicate a decrease in carbon storage. This decline can be explained by reduced carbon inputs (due to lower biomass production from both cover crops and cash crops), combined with sustained biological activity. As a result, carbon mineralization exceeds carbon inputs, leading to a net loss of soil organic matter.

Impact of irrigation on CA performances

The overall multi-performance of the crop rotations in Oraison, with and without irrigation, is presented in Table 2.

Table 2: multiperformance of rainfed and irrigated crop rotation in conservation agriculture in the trial in Oraison (Systerre)

		Rainfed crop rotation							Irrigated crop rotation			
		Oodrychis	Oodrychis	Durum wheat	Forage pea	Winter fababean	Soft wheat	Average crop rotation	Com	Soya	Durum wheat	Average crop rotation
Agronomy	Yield	0.6	0.6	4.6	2.1	1.8	4.8		13.0	4.0	5.9	
	Lolium management											
	Dicotyledons management											
	Nitrogen furniture by crops											
	Soil covering											
Economy	Revenue (€/ha)	754	754	1149	522	432	869	747	2360	1120	1413	1631
	Total input costs (€/ha)	93	93	488	412	519	479	347	1157	736	544	812
	Direct margin with subsidies (€/ha)	549	549	557	-49	-180	239	277	748	277	682	569
	Total nitrogen inputs (kg/ha)	0	0	189	0	0	184	62	212	0	198	137
	Nitrogen Use Efficiency (kg N/unit produced)			4.1			3.8	4	1.6		3.4	2
Technical	Total Active Ingredient pesticides (g/ha)	547	547	2897	2292	3201	2895	2063	1517	1380	1346	1414
	Total treatment frequency index	1.0	1.0	4.2	4.0	3.8	4.3	3.0	3.4	0.8	3.0	2.4
	Irrigation amount (m3/ha)								3740	2800.0	652.2	2398
	Working time (h/ha)	1.8	1.8	3.5	3.6	3.3	3.3	3	8.1	5.9	4.0	6
	Gross Energy production (MJ/ha)	9756	9756	72557	32226	29486	74231	38002	206539	79640	92487	126222
Environn ement	Total Primary Energy Consumption (MJ/ha)	2900	2900	14116	4592	4925	15717	7525	65850	42233	23801	43961
	Total green house emissions (kgéqCO2/ha)	116	116	1730	229	235	1879	717	2263	668	1910	1614

Representative crop rotations were used for the calculations. From an economic perspective, irrigation leads to higher gross margins (+118%), mainly due to increased productivity and greater yield stability. Total nitrogen inputs are lower in the rainfed system (−20%), due to the higher proportion of legumes in the rotation; however, nitrogen use efficiency is higher (+31%). Pesticide use is higher in the rainfed system (+31%), reflecting the greater frequency of winter crops in the rotation and the associated challenges in weed management, particularly for species such as *Lolium*. Working time is greater under irrigated conditions (+108%), mainly due to the management requirements of irrigation systems. Gross energy production is higher with irrigation (+232%), but this is accompanied by a substantial increase in energy consumption (+484%).

Conclusion and discussion

The results from the Oraison trial show that irrigation can act as a facilitator for the implementation of conservation agriculture (CA) in Mediterranean areas. It enables easier adoption of CA practices, as well as improved management of associated challenges such as weed control in no-till systems and the establishment of cover crops during intercrops. Furthermore, positive effects of irrigation on organic matter (OM) and carbon storage have been observed, in line with other studies and meta-analyses (Anton et al.; Edme et al.), which report an overall positive impact, particularly in semi-arid regions (up to +14.8%). However, some studies report contrasting results under conditions of high mineralization rates and intensive irrigation (Xiaochen et al., 2024). In such cases, heavy summer irrigation combined with rainfall during the rest of the year may accelerate carbon mineralization without sufficient compensation from biomass inputs. This mechanism may explain why OM accumulation is slower under irrigated conditions in Oraison, where soil analyses indicate higher mineralization rates under irrigation. Irrigation is therefore not automatically associated with an increase in OM: carbon inputs—through biomass production or organic amendments—must be sufficiently high to balance increased mineralization rates. The positive effects of irrigation on certain biodiversity indicators observed in Oraison are not yet well documented in the literature. However, Nielsen et al. also reported positive effects of irrigation on microbial biomass and activity, which can enhance OM decomposition. Similarly, the positive impact of irrigation on earthworm populations observed in Oraison has been reported by Marinissen et al. Overall, these effects appear to depend strongly on the intensity of water stress and irrigation levels.

Conversely, negative effects of irrigation on arthropod communities have been reported by Avalos et al., potentially linked to their thicker cuticle, which reduces sensitivity to water loss. In addition, irrigation may modify plant biomass composition, which in turn can significantly influence soil biodiversity dynamics.

From a multi-performance perspective, irrigation enhances the profitability of CA systems in Oraison and contributes to securing some of their beneficial effects, particularly in terms of soil protection. Compared to an irrigated conventional system, CA performs better in Oraison for several soil indicators, including organic matter (+49%), microbial biomass (+88%), and bacterial and fungal abundance (+42% and +22%, respectively). Higher C/N ratios, fungi-to-bacteria ratios, and biologically mineralizable nitrogen values under CA indicate more active carbon dynamics, highlighting the need for substantial carbon inputs to sustain long-term soil fertility.

A significant positive effect of CA on water infiltration rates was also observed in Oraison, in agreement with Aletto et al. (2023) and with similar magnitudes. This improvement could provide a basis for optimizing irrigation management, potentially reducing water requirements while limiting the acceleration of carbon mineralization induced by irrigation.

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