Climate resilience and sustainability in olive oil production: International practical approaches and lessons

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KEY CHALLENGES FOR OLIVE OIL VALUE CHAIN IN TÜRKIYE

KEY DATA

Türkiye		
900 K ha	***200 M trees***	***1250 oil mills***
92% rainfed 8% irrigated area 307 K tonnes olive oil/year(2020-2026)		688 oil mills 3 phases (55%) 563 oil mills 2 phases (45%)
Average 3.8 ha 320 K olive farmer		

KEY CHALLENGES

***CLIMATE CHANGE**: drought, heat and extreme events*
Soil degradation
Alternate bearing
Water scarcity
Waste management at mills
Price volatility

CLIMATE CHANGE SCENARIOS | · TÜRKIYE

Sources: WBC-CCKP, FAO, Todaro et al. 2022, RCP4.5 & RCP8.5

🌡 TEMPERATURE RISE (°C vs. baseline 1986–2005)

	RCP 4.5			RCP 8.5		
	ST 2021–2040	MT 2041–2060	LT 2076–2095	ST 2021–2040	MT 2041–2060	LT 2076–2095
ES Spain	+0.97	+1.47–1.6	**+1.97**	+1.10	+1.98–2.1	**+4.04**
TN Tunisia	+0.90	+1.3–1.5	**+1.89–1.9**	+1.10	+1.8–1.98	**+3.9–4.04**
TR Turkey	+1.18	+1.70–	**+2.73**	+1.62	+2.48–	**+5.19**

💧 PRECIPITATION CHANGE (% vs. baseline)

	RCP 4.5			RCP 8.5		
	ST	MT	LT	ST	MT	LT
ES Spain	−3.1%	−2.6 to +5%	**−3.9 to −40%**	+1.4%	−5.8 to −10%	**−16 to −50%**
TN Tunisia	−0.2%	−6 to −9%	**−9 to −18%**	+0.7%	−9%	**−16 to −18%**
TR Turkey	+1.8%	−3.1 to +3%	+2.1%	+2.1%	−2.7%	**−2.0 to −15%**

TR Turkey

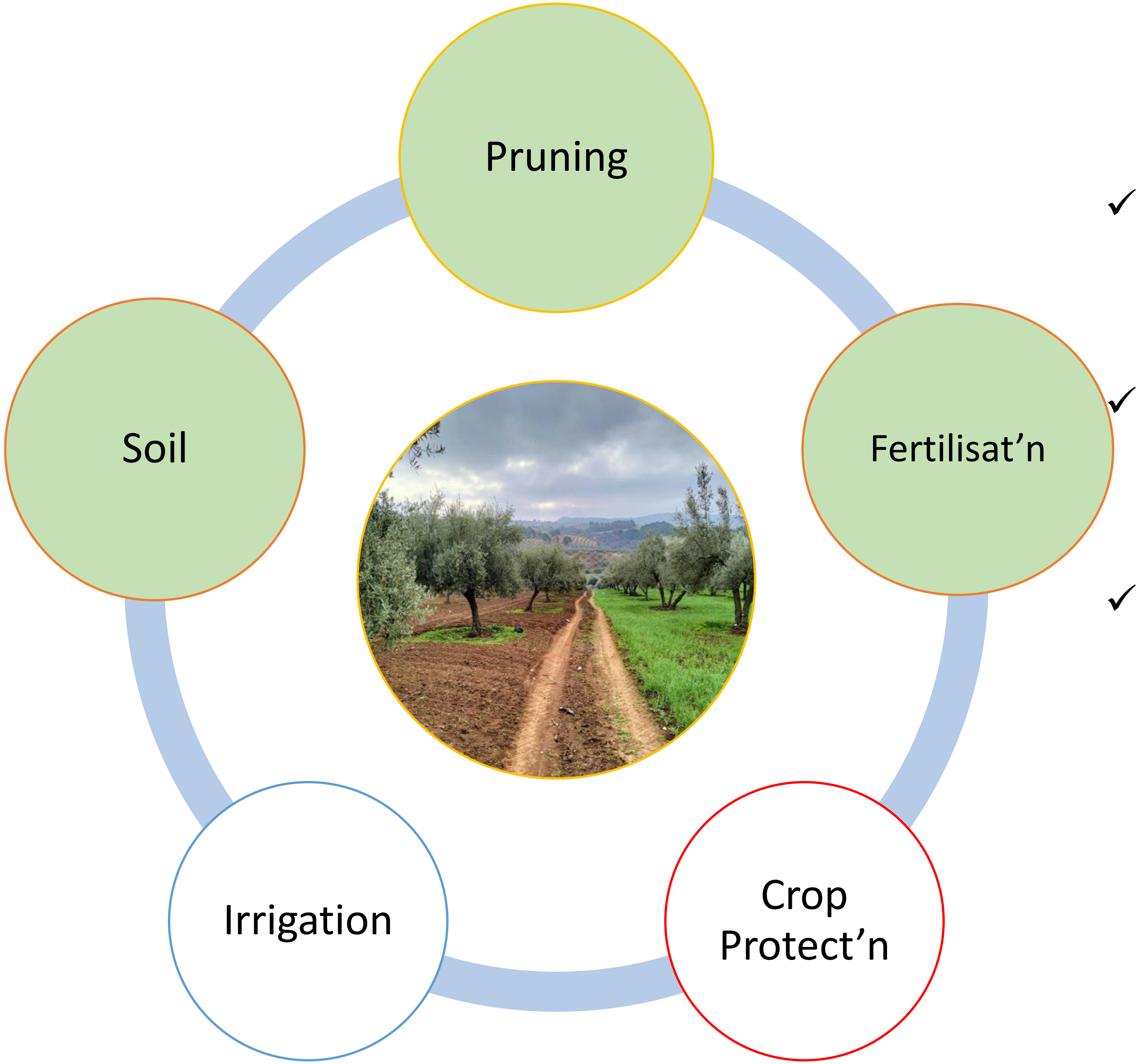
+5.19°C by 2100 (RCP8.5)

−15% annual rainfall

- **Highest long-term warming of the three countries under RCP**8.5
- **Heatwave days: 5 (ST) → 23.5 consecutive days (LT, RCP8.5) in Aegean**
- 92% rainfed olive groves; expansion into inner Anatolia increases exposure
- Soil loss 12,159 t/ha/yr in newly converted olive lands (local study)

Mediterranean hotspot: Temperature rising 1.4× faster than global average · Turkey faces highest long-term warming (+5.19°C) · Tunisia longest heatwaves (38 days) · Spain highest precipitation loss (−50%) · All three countries must treat climate adaptation as an emergency

Sustainable Olive Production & Climate Resilience



- ✓ **Optimization of Cultural Practices:** Reduce tillage, pruning, and crop protection to ensure production efficiency while maintaining economic and social viability.
- ✓ **Resource & Soil Stewardship:** Reduce water and fertilizer use through precision management to preserve long-term soil health and ecosystem integrity.
- ✓ **Climate Resilience:** Enhance the olive grove's ability to withstand environmental shifts by adopting sustainable techniques.

SOIL MANAGEMENT AND COVER CROPS TUNISIA CASE

EXCESSIVE SOIL TILLAGE
4-6 times

+

ABSENCE OF COVER CROP
Monoculture

Soil erosion
In Tunisia, *it has been estimated, using the RUSLE-TN model, that the average soil loss through erosion is about* ***32.5 tonnes/ha./year***

Soil fertility degradation
Significant decrease of OM (%)

	1947	1981	1998	2002	2004
Enfidha	2-4	1	0,6	0,4	0,4
Boughrara	1	0,7	0,5	0,2	0,2

Source : Institut de l'olivier

Significant decrease of OM (%)

SOIL MANAGEMENT AND COVER CROPS
TÜRKIYE CASE

- Conventional tillage (ploughing, harrowing, rotary mowing) **applied twice** yearly regardless of slope gradient, leaving soils bare and unprotected at the onset of high-intensity autumn rainfall (Esetlili et al. 2014)

IMPACT

Severe Erosion
Field-quantified soil losses in the **Akhisar region reach 12.2 t ha^{-1} $year^{-1}$** under olive orchards, against 3.97 t ha^{-1} $year^{-1}$ under natural vegetation cover an excess loss of over 8 t ha^{-1} $year^{-1}$ directly attributable to current land use and management practices (Esetlili et al. 2014).

SOC Decline
Absence of organic amendments depletes soil organic carbon, reducing biological activity & water retention. **38% of olive-growing soils are below the critical threshold for organic matter**, meaning even modest climate shocks could lead to significant drops in yield

No cover crop
Bare inter-rows expose soil to wind/rain erosion; lost biodiversity & beneficial fauna

Reduced/No-Till and Cover Crops

Impact on soil fertility and olive tree productivity in the Mediterranean : Review of indexed scientific literature

>200
Indexed articles (WoS/Scopus)

85%
Erosion reduction

×4–5
SOC increase

≈0
Yield loss

Sources: Soil & Tillage Research | Agriculture Ecosystems & Environment | Agronomy | Sustainability (MDPI) | Land | Plant and Soil

Scientific Publications & Quantified Impacts

Mediterranean olive groves — No-till / Reduced tillage / Cover crops

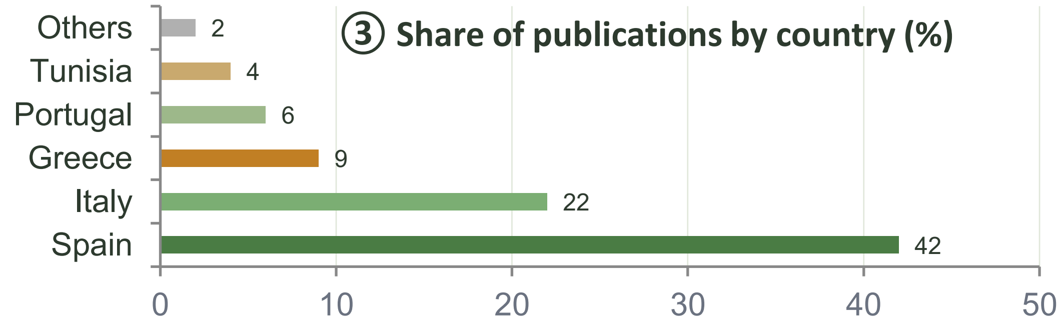
① Publications by country (WoS / Scopus)

Country	Est. no. of articles	Share % publications	Main topics	Key journals
ES Spain	~90–100	40–45 %	Erosion, SOC, hydrology	Soil Tillage Res. • AEE
IT Italy	~50–60	20–25 %	Cover crops, yield, OM	Agronomy • Sustainability
GR Greece	~20–25	8–10 %	Legume cover crops, biodiversity	Agronomy (MDPI) • Land
PT Portugal	~10–15	5–7 %	Runoff, erosion	Land • J. Hydrology
TN Tunisia	~8–10	3–5 %	Cover crops, fertility, oil	Sustainability • Agronomy
MA Morocco / Others	~5–8	< 3 %	*Research gap*	FAO / CIHEAM reports
TOTAL Mediterranean	**>200**	**100 %**	Majority in semiarid zones	WoS / Scopus Q1–Q2

② Quantified impacts (Mediterranean, field studies)

Indicator	Conventional tillage	No-till + cover crop	Change (CC vs CT)
Soil loss (erosion)	**7.5 t/ha/yr**	**0.8 t/ha/yr**	**−85 to −90 %**
SOC loss / year	1.8 t C/ha/yr	−0.15 t C/ha/yr	−76 to −90 %
SOC stock (LT, 15 yrs)	−42 % (stock)	+Stable / accum.	+4 to 5× conc.
Soil organic matter	< 0.5 %	2–4.3 %	+75 % (SOM)
Surface runoff	High (baseline)	−37 % runoff	−38 to −50 %
Soil water retention	Low	+33 % (moisture)	+41–51 % (spring)
Total soil nitrogen (TN)	−30 % (15 yrs)	Improved	+0.25 Mg N/ha/yr*
Olive tree yield	Baseline	≈ stable	0 to slight +
Microbial biodiversity	−58 % vs CC	Enriched	Significant

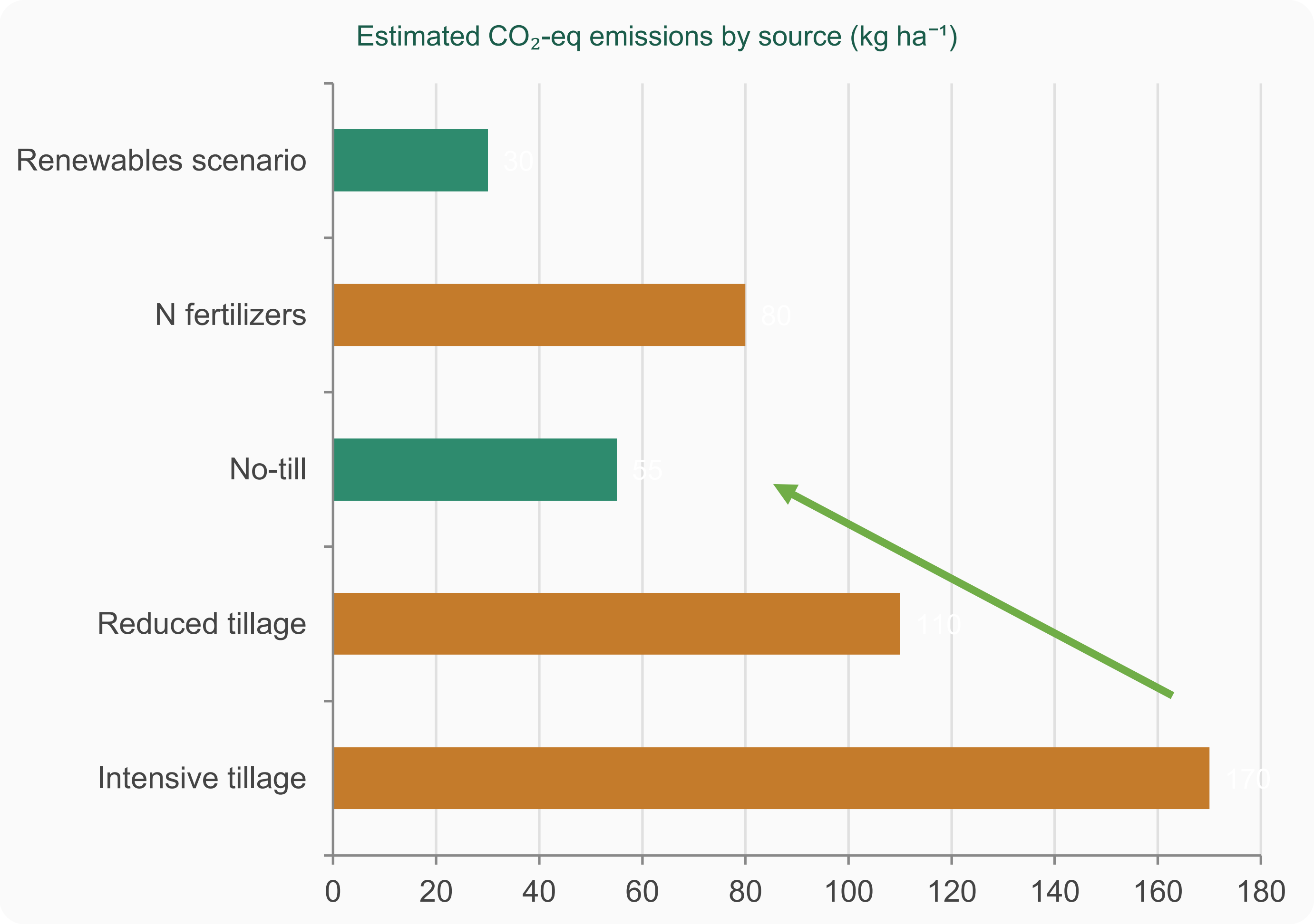
③ Share of publications by country (%)



** First 3 years of cover crop establishment (Soil & Tillage Res. 2021) | CT = conventional tillage | CC = cover crop | LT = long term*

Sources: Lozano-García et al. 2020 (Sci. Total Env.) | UCO / IFAPA Spain | Ben-Salem et al. 2018 | MDPI Agronomy 2022–2024 | Systematic review Sustainability 2024

Carbon Emissions — Tillage

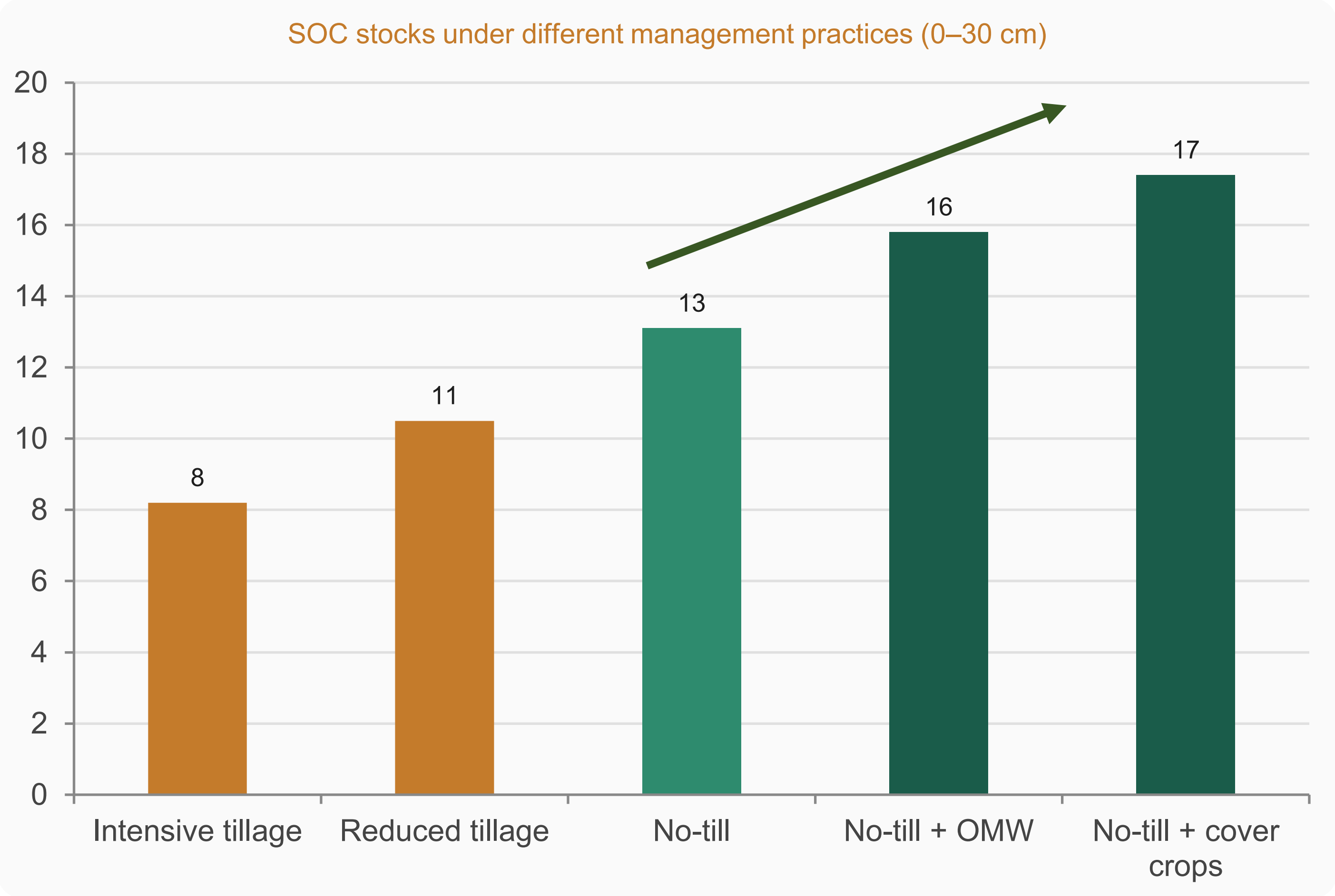


Tillage — Main Emission Driver

Intensive tillage is the primary source of carbon emissions, both through direct fuel combustion and accelerated SOC oxidation, contributing up to 60% of total farm emissions in rainfed conditions.

Note: Values are indicative estimates from field experiments in arid Tunisia (Sfax region)

Soil Organic Carbon (SOC) Dynamics



Key Findings

- SOC content ranges from 5.16 g kg^{-1} (surface) to 1.60 g kg^{-1} (subsoil) in arid rainfed olive orchards
- No-till combined with OMW application increases SOC by up to +112% vs. intensive tillage
- Soil carbon storage potential: up to 105.55 Mg ha^{-1} CO_2-eq in top 32 cm
- Rainfed orchards: 0.303 Mg C ha^{-1} yr^{-1} | Irrigated: 0.374 Mg C ha^{-1} yr^{-1}
- Soil quality (texture, initial OM) strongly conditions the SOC response to management

Source: field experiments in Sfax region — arid Tunisia (Gargouri et al., 2014–2024)

Why Farmers Resist?

Barriers to adopting no-till & cover crops in olive orchards

FARMER

?

HEALTHY ORCHARD

No-till + Cover Crops

BARRIERS

Key insight

The barriers are NOT technical — they are primarily economic, cultural, and institutional.
Scientific evidence is available, but does not yet reach farmers.

Water competition
Cover crops compete with olive trees for scarce water — a critical risk in rainfed semiarid orchards

Deep-rooted tradition
Tillage seen as essential for weed control & soil quality — a multi-generational cultural norm

Fear of yield loss
Farmers fear 1–3 year productivity decline during transition before long-term benefits appear

Lack of adapted equipment
No-till seeders & cover crop mowers are costly and rarely accessible to smallholder farmers

Weak extension services
Agricultural advisory units are closed or underfunded — no technical support for new practices

No policy incentives
No subsidies or legal frameworks reward conservation; no-till is excluded from support schemes

Livestock integration
Grazing animals damage cover crops — the livestock–cropping conflict is a key structural barrier

Climatic unpredictability
Erratic rainfall timing makes reliable cover crop establishment difficult, especially in the south

Sources: Barriers & Facilitators in Mediterranean Olive Groves — Agronomy 2020 | Conservation Agriculture Tunisia — J. Nat. Sci. 2018 | Frontiers Sustainable Food Systems 2025 | Groundcovers Semiarid — Water 2020 | Cover Crops Mediterranean — Sustainability 2024

Adaptive Water Management Strategies for Olive Orchards: From Field to Digital (WATER RESOURCES CONSERVATION)

RDI/SDI · Drip & SDI · Treated wastewater · Biological tools · Mulching · Smart irrigation · Precision agritech

WATER-SAVING STRATEGIES

Regulated & Sustained Deficit Irrigation (RDI/SDI)

Irrigation scheduling

- Apply water deficits during pit-hardening stage (low sensitivity); full supply at bloom & fruit set
- RDI saves 25–30% water; improves WP 5–20% with <15% yield reduction
- SDI: uniform reduction throughout season — simpler but less precise than RDI
- Increases polyphenol content → quality premium

Fernández Escobar et al. 2025; Ben-Gal et al. 2021; Romero-Trigueros et al. 2019

Drip & Subsurface Drip Irrigation (SDI)

Delivery technology

- Drip irrigation cuts water use by 30–50% vs open-canal systems; SDI (buried emitters) reduces evaporation further and suppresses weeds
- Türkiye: converting to drip could save ~38 billion m³/yr nationally
- Reduces soil compaction & improves fertilizer distribution (fertigation)

Asia Times 2023; FAO-WEPS Tunisia 2022; DSİ 2022

Treated Wastewater (TWW) for Irrigation

Non-conventional water

- Tunisia operates 61 WWTPs; ~7,000 ha currently irrigated with TWW — target 100,000 ha by 2030
- TWW (EC ~3 dS m^{-1}) increases olive fruit yield +35% vs freshwater control
- Must combine with salt-tolerant cultivars & AMF inoculation to mitigate salinity risk
- Turkey: research on wastewater reuse expanding in Aegean and Marmara basins

National Academies 2007; Romero-Trigueros et al. 2019; Hamdali et al. 2025

Mycorrhizae (AMF) & PGP Bacteria

Biological technology

- AMF (Glomus deserticola, Gigaspora margarita) improve leaf water status & photosynthesis under saline TWW irrigation in cv. Chetoui
- PGPR maintain RWC, Chl content & PSII efficiency under drought (induced systemic tolerance — IST)
- Combined AMF + PGPR formulations yield stronger multi-stress protection than single-strain inoculants
- Low-cost, scalable biological input — compatible with organic and integrated management

Hamdali et al. 2025; Timmusk et al. 2014; Yohannes et al. 2022

Mulching & Soil Water Retainers

Soil conservation

- Organic mulch (straw, pruning residues): reduces soil evaporation, improves OM & water retention
- Synthetic mulch (black polyethylene film): cuts evaporative soil loss by up to 50%; suppresses weeds
- Hydrogels/PAM (polyacrylamide): absorb 200–500× weight in water; extend inter-irrigation intervals in sandy soils
- Particularly effective for young orchard establishment in arid zones

Fernández Escobar et al. 2025; Zagaria et al. 2023; Mohawesh & Durner 2008

SMART IRRIGATION: SENSORS, APPS & DIGITAL DECISION-SUPPORT TOOLS

Sensor-Based Precision Irrigation

- Trunk dendrometers, microtensiometers, sap flow sensors & leaf patch clamp pressure probes monitor plant water status in real time
- IoT soil moisture sensors + weather stations trigger irrigation only when deficit exceeds threshold — eliminating excess application
- Satellite & drone imagery for spatial variability mapping across heterogeneous orchards

Digital Apps & Decision Support

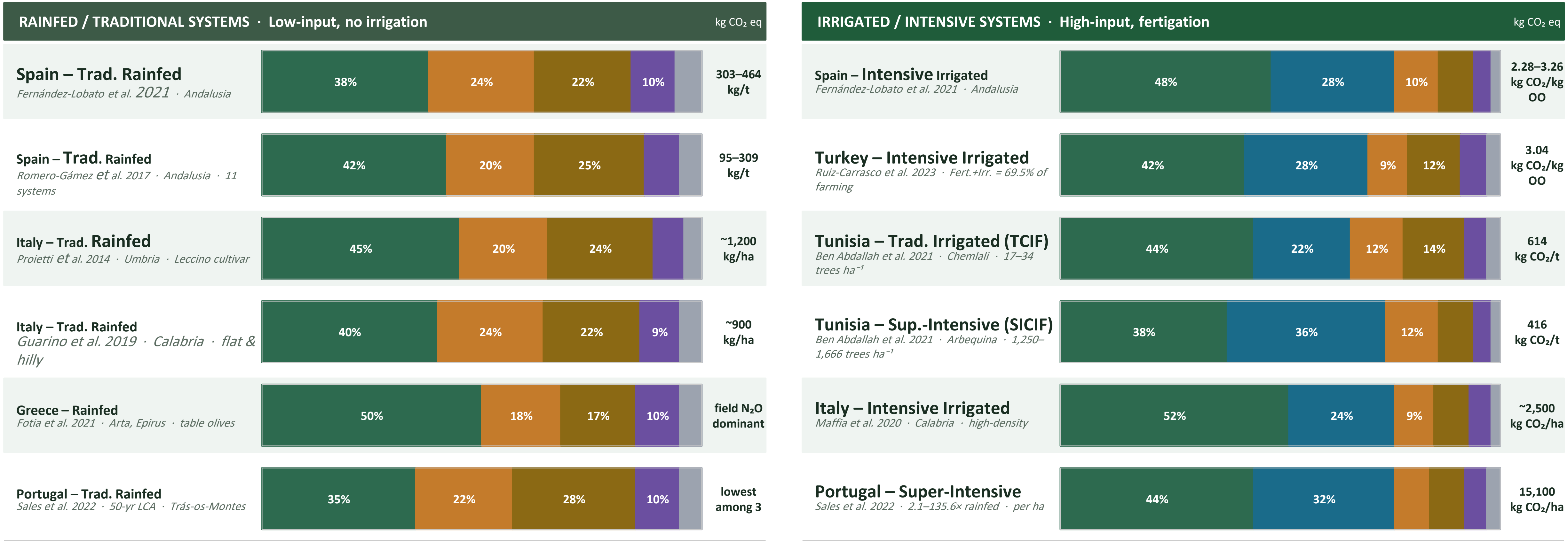
- Apps calculate ETc-based irrigation scheduling adapted to crop stage, cultivar and local meteo
- Tunisia: CropsTalk (smart irrigation + fertigation app, pay-per-plan), IrWise (IoT remote irrigation control, soil moisture, weather), TerraSens/FLAHTIK (satellite + rain gauge + IoT)
- Turkey: Orbiba Robotics (AI-powered precision farm automation) — part of 20+ agritech startups active in Aegean olive zones

Integration is key. RDI/SDI + drip/SDI delivery + TWW reuse + biological inoculants + mulching + smart IoT monitoring = a sustainable water management continuum that preserves olive productivity under climate-driven water scarcity in Tunisia and Turkey.

Global Warming Potential (GWP) Contribution by Fertilization in rainfed and intensive planting systems

Literature synthesis · Mediterranean basin · Cradle-to-farm-gate · Farming phase contribution to GWP

Fertilization
Irrigation / Energy
Herbicides / PPP
Soil tillage / Machinery
Harvest / Transport
Other



KEY FINDING Fertilization dominates GWP in ALL systems (35–55%). In rainfed systems, herbicides/PPP (18–24%) and soil tillage (17–28%) are the 2nd and 3rd hotspots. In intensive/irrigated systems, **irrigation energy (24–41%)** surges to rival fertilization, pushing herbicide/tillage contributions below 12%. Fertilization + irrigation together account for **69–90% of GWP in intensive systems** / *Sources: Romero-Gámez et al. 2017; Fernández-Lobato et al. 2021; Sales et al. 2022; Ruiz-Carrasco et al. 2023; Fotia et al. 2021; Guarino et al. 2019; Ben Abdallah et al. 2021 (Tunisia)*

Deviation Optimal Percentage (DOP) -Guided Fertilization Adjustment: Nutrient Savings & Environmental Co-Benefits

Dynamic 4R (Plot B) vs. Static 4R (Plot A) · Sminja, Tunisia · 2019–2022 mean · per tonne of olives

Yield B: +15.2%
9.65 vs 8.38 t ha^{-1}
amplifies all reductions

FERTILIZER INPUT REDUCTIONS (kg ha^{-1} · 4-year mean)

N — Nitrogen

-12.9% mean reduction

−17.0 kg ha^{-1} saved

Year-by-year reductions:

2019	A: 124.2	B: 104.24	-16.1%
2020	A: 142.36	B: 130.27	-8.5%
2021	A: 128.48	B: 113.64	-11.6%
2022	A: 129.08	B: 108.12	-16.2%

P — Phosphorus

-28% mean reduction

−12.7 kg ha^{-1} saved

Year-by-year reductions:

2019	A: 39.6	B: 16.54	%
2020	A: 36.87	B: 34.71	-5.9%
2021	A: 54	B: 41.35	-23.4%
2022	A: 50.7	B: 37.82	-25.4%

K — Potassium

-19% mean reduction

−13.1 kg ha^{-1} saved

Year-by-year reductions:

2019	A: 58.58	B: 48.46	-17.3%
2020	A: 59.8	B: 50.19	-16.1%
2021	A: 72.6	B: 60.81	-16.2%
2022	A: 84.6	B: 63.64	-24.8%

ENVIRONMENTAL CO-BENEFITS PER TONNE OF OLIVES (Plot B vs Plot A · 2019–2022 mean)

		Reduction	A	B
Global Warming	*kg CO_2 eq t^{-1}*	-14.6%	354.9	303.1
Terrestrial Acid.	*kg SO_2 eq t^{-1}*	-20.9%	3.1100	2.4600
Marine Eutrophication	*kg N eq t^{-1}*	-20.3%	0.0472	0.0376
Freshwater Eutrophication	*kg P eq t^{-1}*	-16.7%	0.0784	0.0653
Land Use	*m^{2}a crop eq t^{-1}*	-27.8%	89.4	64.6
Water Consumption	*m^3 t^{-1}*	-9.9%	474.4	427.4
Fossil Scarcity	*kg oil eq t^{-1}*	-13.2%	108.7	94.4

Source: Larbi et al. 2026 · LCA data: SimaPro v9.6, Ecoinvent 3.10, ReCiPe 2016 Midpoint H · N, P, K computed from field inventory (Table 1)

OPPORTUNITIES TO ADDRESS THE SITUATION

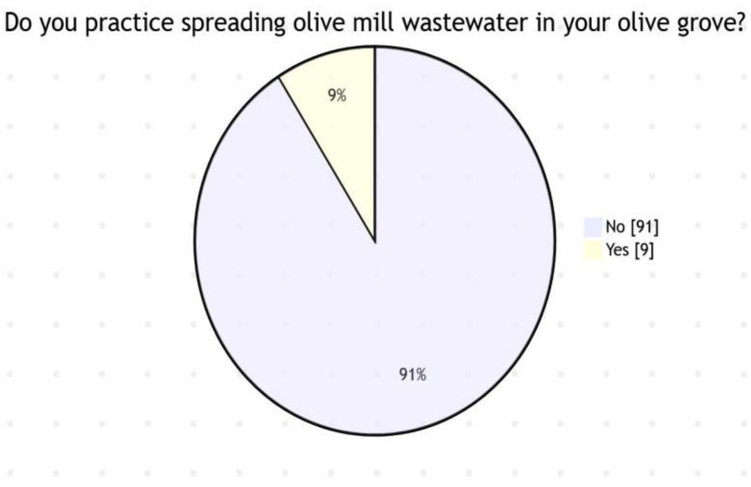
♻ Circular Economy

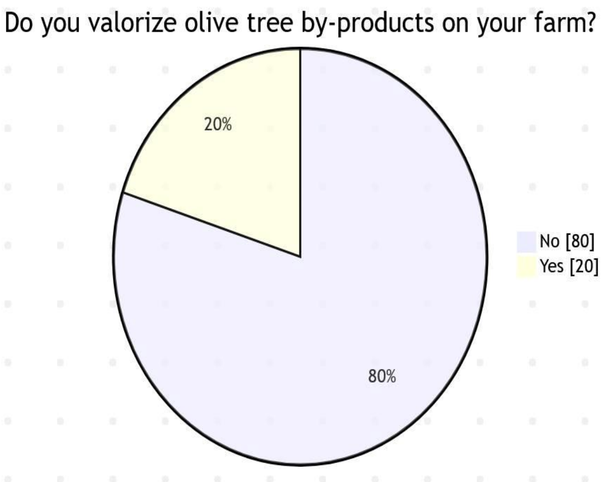
- OMWW soil spreading (50 m^3/ha)
- Chopped pruning wood as mulch
- Compost from pomace + prunings
- Biochar from olive residues

Exploring circular economy approaches

Goal: move from a linear, extractive model to a regenerative system that restores soil, supports farmers, and cuts emissions

CIRCULAR ECONOMY | LOW ADOPTION & HIGH POTENTIAL





Survey data (APNI, 2024): by-product valorisation among Tunisian olive growers

⚠ **Only 20% of farmers valorize by-products. Only 9% apply OMWW.**
Major gap between scientific knowledge and field practice.
Policy support and farmer incentives urgently needed.

- 1,030,956 t olives/yr
- ~650,000 t pomace
- ~1.26 M m^3 OMWW/yr
- Evaporation ponds dominant
- No legal OMWW framework
- Biochar/compost emerging

💧 OMWW (margine)

50 m^3/ha regulated; 9,380 ha treated in Tunisia (2025). Law Decree 2013-1038.

🧱 Olive Pomace

Compost (TS, DTS, THU, TOS types) + biochar pyrolysis + animal feed + briquettes.

🍂 Pruning Wood

Chopped mulch or biochar feedstock. Current practice: burning → must change.

800–850 kg by-products per tonne of olives → enormous untapped potential

PRUNING RESIDUES AS MULCH AND BIOFERTILIZER

Current practices

Recommended practices

1 ton of Pruning Residues Contains:

Carbon (C) **410 kg**	Nitrogen (N) **9.7 kg**
Potassium (K) **9.5 kg**	Phosphorus (P) **1.4 kg**

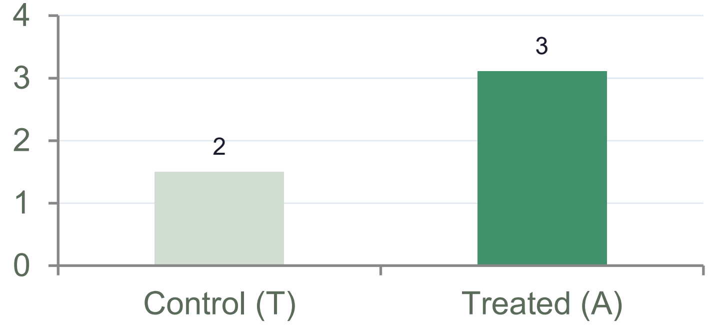
Burning Pruning Waste Should Be Addressed

Open-field burning increases TA by 12%, PMF by 8%, eutrophication by 10%. Residue mulching, composting or bioenergy recovery could reduce these by 20–35%.

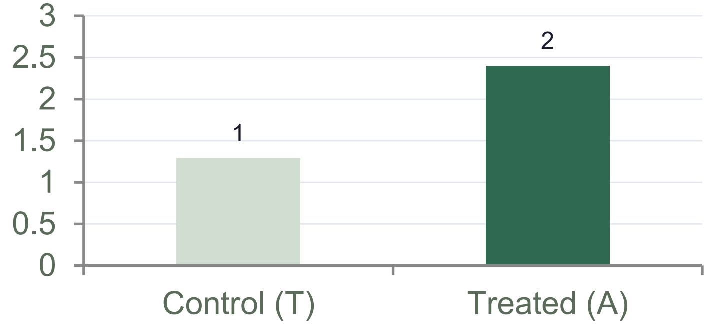
SOIL MANAGEMENT | LONG-TERM IMPACT OF CHOPPED PRUNING WOOD ON SOIL NUTRIENTS

3 applications over 6 years — treated (A) vs. control (T) — Tunisia (Olive Institute)

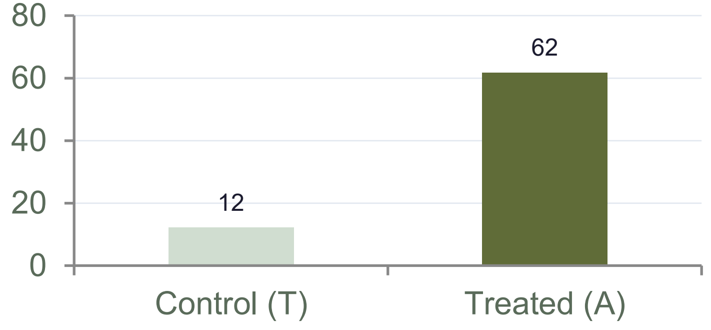
OM (%) in soil **+107%**



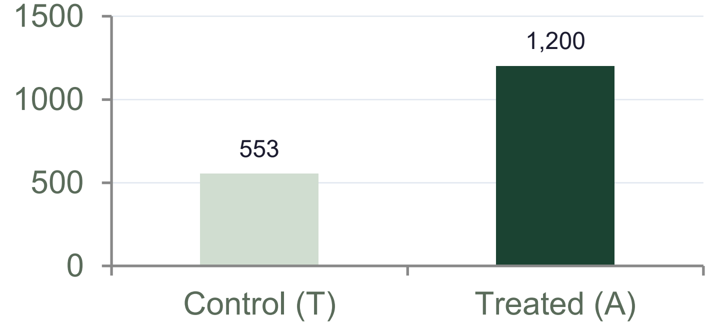
N in soil (g/kg) **+86%**



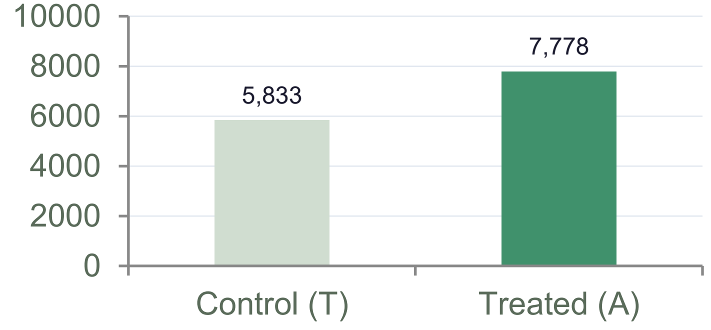
P_2O_5 (mg/kg) **+409%**



K_2O (mg/kg) **+117%**



Ca (mg/kg) **+33%**



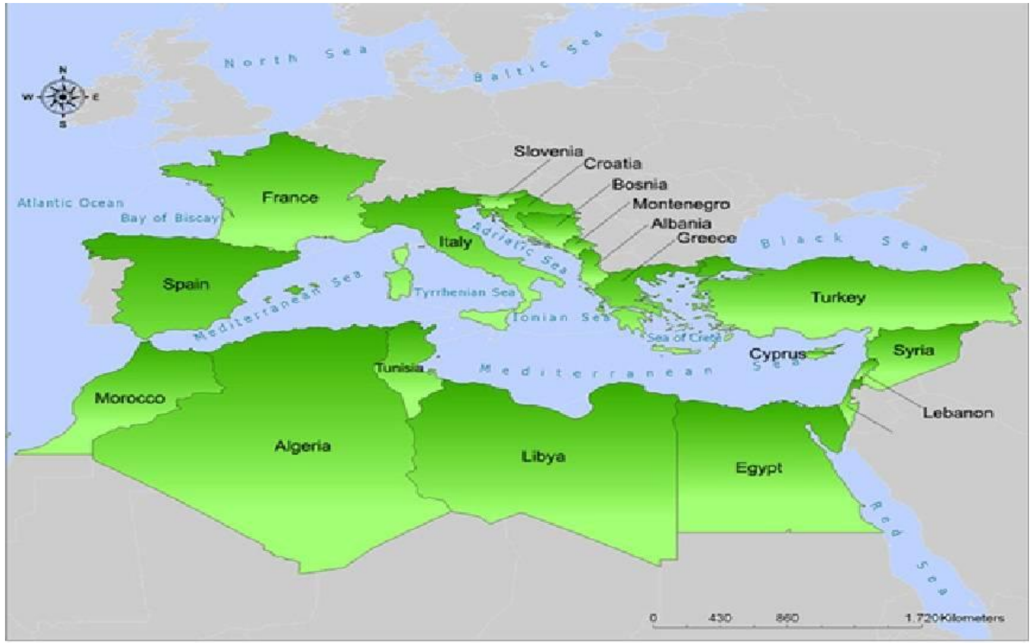
Mg (mg/kg) **+24%**

All elements showed significant increases after 3 applications. Mg showed no significant change. These results support pruning wood as a substitute for synthetic fertilizers.

✅ Mulching with Chopped Pruning: Key Results

- 75–80% soil loss reduction at 17,500 kg DM/ha (Prosdocimi et al., 2016)
- Runoff coefficient reduced by 20–32% vs. mechanical tillage
- Increases SOM, water retention and carbon sequestration

CIRCULAR ECONOMY | OMWW PRODUCTION VOLUMES & POLLUTION PROBLEM



Mediterranean olive-producing countries

Key Environmental Problem

High BOD/COD · phytotoxic polyphenols · soil & water contamination

OMWW Volumes by Country & Extraction System

ES **Spain**	100% 2-phase	**Wet pomace — no OMWW problem**
IT **Italy**	45% 2-phase / 55% 3-ph	**1.3–1.5 M m³ OMWW/yr**
TN **Tunisia**	17% 2-ph / 76% 3-ph / 7% trad.	**1.5–2.5 M m³ OMWW/yr**
TR **Türkiye**	% 2-phase / 3-ph	**1.26 M m³ OMWW/yr**
MA **Morocco**	Mostly 3-phase	**1.5–3 M m³ OMWW/yr**

Spain's 2-phase system = best practice: no liquid OMWW produced — Tunisia still 76% 3-phase

CIRCULAR ECONOMY | OMWW AS BIOFERTILIZER — FIELD RESULTS

OMWW spreading in Tunisian olive orchard

Long-term Impact of OMWW (12 years, Tunisia)

Parameter	Control	50 m³/ha	100 m³/ha	Change
Olive yield (kg/ha)	746.8	799.7	950.5	+27%
OM (%)	**0.12**	**0.41**	**0.71**	**×5.9**
N (ppm)	187	420	795	×4.2
P (ppm)	25	34	64	+156%
K (ppm)	151	750	1,075	×7.1

50 m³/ha OMWW ≡

- 82 kg Urea
- 920 kg Potassium Sulphate
- 80 kg Super Phosphate 45%
- 30 tons of Manure

Türkiye: ~1.26 M m³ OMWW/yr produced; evaporation ponds dominant; no land-spreading regulation yet. Research underway at universities to demonstrate agronomic benefits (alternating well water / OMWW trials).

CIRCULAR ECONOMY | OMWW IMPACT ON SOIL ORGANIC MATTER & IMPLEMENTATION LIMITS

Impact of OMWW Spreading on Soil Organic Matter — Mediterranean Countries

Country	Dose	Effect on SOM	Duration	Reference
TN Tunisia	50–100 m³/ha/yr	SOM ↑ 15–25%; improved microbial activity	2–3 years	Mekki et al., 2006
IT Italy	30–80 m³/ha/yr	SOM ↑ gradually; soil chemical & biological improvement	3–5 years	Vella et al., 2016
MA Morocco	40–80 m³/ha/yr	SOM ↑; soil fertility improved; positive on maize	2 years	Belaqziz et al., 2016
TR Türkiye	**40 m³/ha/yr**	**Long-term SOM ↑; improved crop yields**	**4 years**	**Case study (Türkiye)**
JO Jordan	50–200 m³/ha	SOM ↑; soil chemistry improved; microbial stimulation	4 years	Ayoub et al., 2014/2016

In all five countries, SOM increased significantly after OMWW application, especially at moderate doses.

⚠ Limitations & Challenges of OMWW Land Spreading

- Deviation from recommended application rate → phytotoxicity risk
- Restricted spreading period (overlaps with rainy season)
- Prolonged administrative permitting procedures
- High transportation costs deter spreading on distant fields
- Quantities remain very high in peak production years
- Need to transition toward energy & biomolecule valorisation models

Transitioning from waste elimination logic to circular valorisation model (energy, biofertilizers, biomolecules) is the strategic priority

ON-FARM OLIVE COMPOST

Orchard Amendment — Circular Nutrient Management (2 phases oil mill producing around 2000 TONS OF WET POMACE)

6 months composting

INGREDIENTS

Pruning Residues

Lignocellulosic carbon structure — bulking agent, aeration

Wet Olive Pomace

Two-phase centrifugation by-product — rich in organic matter & phenolics

Poultry Manure

Nitrogen & mineral nutrient source — activates microbial decomposition

COMPOSTING PROCESS

Field application

Zero waste	By-product valorisation
Slow & sustained	Nutrient Release
+ Soil C	Organic Matter

Chemical characteristics of the produced compost

	Compost
Moisture	27,40%
Dry matter (%)	72,60%
Organic matter(%)	44,23%
Humic extract	11,55%
Carbon	25,72%
MO/C	1,72
C/N	17,5
K1 (humification)	0,25
N (%)	1,61%
P2O5 (%)	0,55%
K2O (%)	2,49%
Ca2O (%)	6,05%
MgO (%)	0,82%
Fe (%)	1,12%
Mn (%)	0,01%

	Compost
Dose	1000 Kg
Mat sèche (kg)	720
Mat organique (kg)	318
Carbone (kg)	257
Humification(kg humus)	82,8
Kg N (humification)	-8,28
Kg N (richesse)	16,7
Kg N (disponible culture)	8,42
Kg P2O5	5,5
Kg K2O	24,9
Kg Ca2O	60
Kg MgO	8,2
Kg Fe	11,2
Kg Mn	0,1

1 ton of compost provides

- ✓ 257 Kg of Carbon
- ✓ 8,42 Kg N
- ✓ 5,5 Kg P2O5
- ✓ 25 Kg of K2O

TS

Wet pomace (33%) + sheep manure (67%)

DTS

Dried pomace (50%) + sheep manure (50%)

THU

Wet pomace (33%) + horse manure (67%) + urea

TOS

Wet pomace (20%) + pruning wood (20%) + sheep manure (60%)

Soil Properties After 6 Years of 7 t/ha Compost Application

Treatment	OM: Init.→Yr6	N: Init.→Yr6	P avail. Init.→Yr6	K avail. Init.→Yr6	Oil content
TS	**1.36→1.9%**	**0.11→0.16%**	**8→30 mg/kg**	**510→710 mg/kg**	**19.7% a**
DTS	1.25→2.3%	0.09→0.19%	11→33 mg/kg	430→820 mg/kg	19.1% a
THU	1.2→2.1%	0.08→0.17%	10→54 mg/kg	450→840 mg/kg	19.9% a
TOS	1.2→2.2%	0.09→0.16%	11→80 mg/kg	505→870 mg/kg	19.8% a
Conv. Fert.	1.25→1.35%	0.07→0.11%	9→12 mg/kg	420→457 mg/kg	17.5% b

All compost treatments significantly outperformed conventional fertilization for SOM, N, P, and K. Compost with TOS showed highest K and P gains. Oil content was significantly higher with all composts vs. conventional (17.5%).

Composting duration: 6–7 months · Turning every 2 weeks · Moisture maintained at 40–60%

STUDY DESIGN

Carbon Credits from Olive Groves

PDO Estepa, Andalusia
J. Env. Management 2026

STUDY FACTS

15 Olive farms · 440 ha

5 Years crediting period

3 Soil zones per farm (C/EM/E)

2 Baselines: StaBL & SpeBL

CRCF EU Reg. 2024/3012

METHODOLOGY

Standardized Baseline (StaBL)

Typical PDO Estepa practices:
tillage + herbicide + inorganic N
Pruning mulch · Leaf litter only

Activity-Specific Baseline (SpeBL)

Each farm's current practices:
observed in autumn 2025
Varied cover crop / manure use

Carbon Farming Scenario (CF)

All farms: cover crops (60% inter-row)
pruning mulch · manure · pomace compost
No tillage · reduced inorganic N

	Standard base line	Specific activity base line	Carbon farming
Leaf litter	*YES*	*YES*	*YES*
Pruning mulch	*YES*	*YES*	*YES*
Spontaneous cover crop	✗	some	*YES*
Manure	✗	few	60%
Pomace compost	✗	✗	*YES*
Tillage	*YES*	*YES*	✗

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IMPACT OF CARBON FARMING PRACTICES ON CARBON CREDITS

vs. conventional baseline

−9.66

Mg CO_2 ha^{-1}

Net soil CO_2 balance under CF (sink)

+7.14

Mg CO_2 ha^{-1}

Soil CO_2 under baselines (source, not sink)

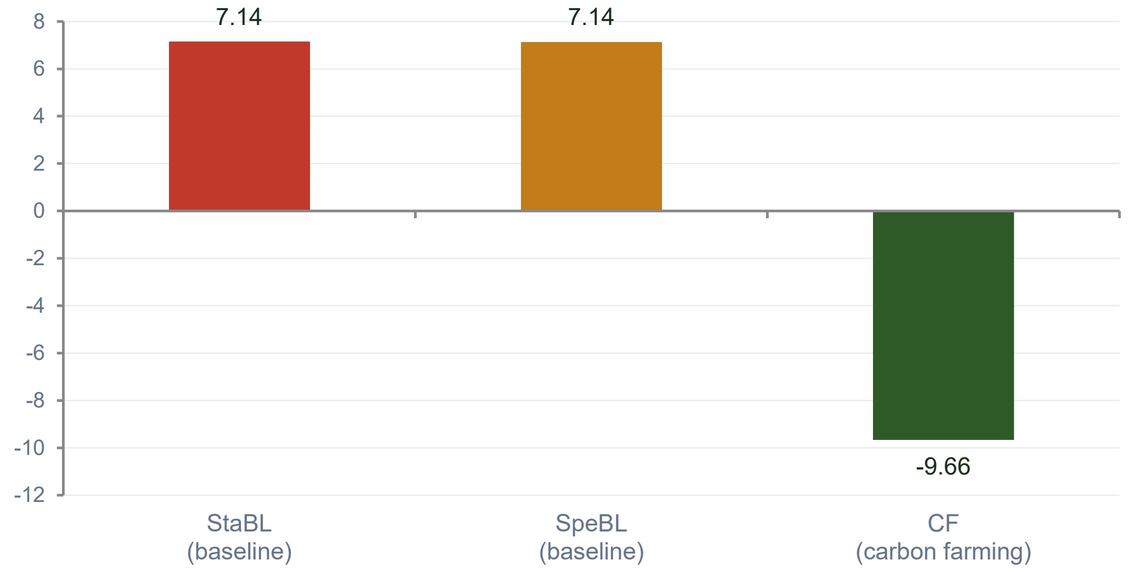
€47k

total · 440 ha

Revenue · 15 farms · 5 yrs
€5.3M if PDO Estepa scale

KEY RESULTS — SOIL C DYNAMICS, CREDITS & ECONOMIC VALUE

CUMULATIVE SOIL CO_2 BALANCE (Mg CO_2 ha^{-1} · 5 yrs)



- ✓ **Under conventional management, olive farm soils release CO_2 more than 7 tonnes per hectare over 5 years, caused primarily by soil tillage.**
- ✓ Switch to carbon farming, and the same soil becomes a **net carbon sink**, absorbing nearly **10 tonnes of CO_2 per hectare** over the same period.
- ✓ This reversal has a **direct economic value**. Every farm in this study generated between **14 and 20 carbon credits per hectare** : one credit equals one tonne of CO_2. At today's market price, the 15 farms together generated close to **€47,000 in just 5 years**.
- ✓ Now scale that up. The PDO Estepa covers 50,000 hectares. **Extend these same practices across the full designation, and the potential revenue reaches €5.3 million. Same land, same farmers but just a smarter way of managing what they already have.**

CF converts soil from CO_2 source → net sink

Cover crops + pomace drive SOC sequestration

StaBL: fairer credit distribution across farms

Cooperatives key to scale & reduce costs

PDO Estepa potential: €5.3M · 50,000 ha

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Março Zeytin
(Germencik, Aydin)
07/05/2026

The science is clear, the regulation exists, the market is ready, and the resources are already here. ***Carbon farming is not a future promise: it is an opportunity olive farmers can act on today.***