Assessing the impact of irrigation-based agricultural intensification in Tunisian olive-growing systems from a water–energy–food–environment nexus perspective

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INTRODUCTION AND AIM

Tunisia, a leading global producer of olive oil, is boosting olive production by transitioning from rain-fed to intensive systems to increase food security, economic growth, and rural employment.

Tunisia is boosting olive production by transitioning from rain-fed to intensive systems, aiming to increase food security, economic growth, and rural employment

Sustainable practices that optimize the water-energy-food nexus are essential for ensuring the region's long-term food security and economic growth.

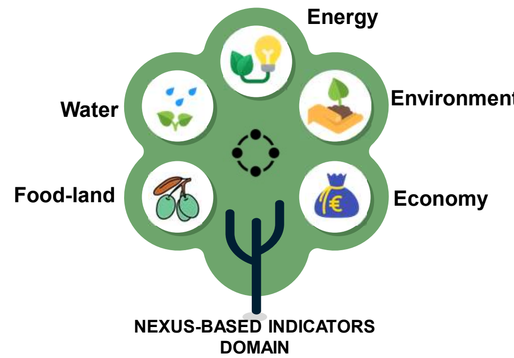
MATERIALS AND METHODS

The study utilized a Water-Energy-Food (WEF) nexus to evaluate the sustainability of various olive cultivation systems in Tunisia, comparing traditional cultivation with intensive methods (Table 1). The analysis follows the proposed methodology by Fabiani et al. (2020). A cradle-to-farm-gate life cycle inventory (LCI) to predict LCA-based indicators using ReCiPe 2016 method.. The analysis involved data collection (Table 1) and modeling on farm emissions using IPCC (2006) and Nemecek and Kagi (2007) guidelines.

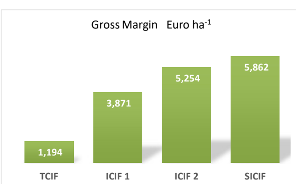
Table 1. Input and crop yield data for various olive systems in Tunisia. Source Abdallah et al. (2021).

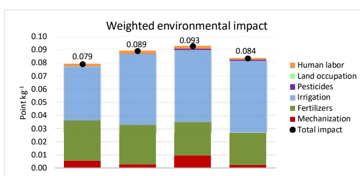
Parameter	Unit	Traditional, conventional, Irrigated (TCIF)	Intensive, conventional Irrigated (ICIF1)	Intensive, conventional Irrigated (ICIF2)	Super-intensive, conventional Irrigated (SICIF)
Main cultivar	-	Chemlali	Chemlali	Arbosana	Arbequina
Density	trees ha^{-1}	17 - 34	204-278	416-555	1250-1666
Yield	kg ha^{-1}	2,159	7,000	9,500	10,600
Irrigation water	m^3 ha^{-1}	550	2,350	3,240	3,600
Irrigation electricity	kWh ha^{-1}	205.5	878	1,210.52	1,345.1
Nitrogen	kg N ha^{-1}	18	119	136	145
Phosphorus	kg P_2O_5 ha^{-1}	6	36	51	59
Potassium	kg K_2O ha^{-1}	7	45	77	97
Total pesticides	kg ha^{-1}	0.05	0.43	4.23	9.28
Diesel fuel	liter ha^{-1}	33	53	51	134
Human labor	h ha^{-1}	240	956	1148	751

- The on-farm emissions were calculated following the methodology of previous studies (Canaj and Mehmeti, 2022).
- The background emissions were retrieved from the EcoInvent 3.1 database.
- OpenLCA software was used for nexus-based assessment.



RESULTS





Intensive farming systems yield higher gross margins but result in 17.1% greater environmental impacts and a 33.4% higher water scarcity footprint,

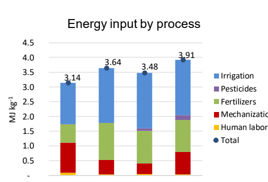
Eco-efficiency decreases as the management intensity increases raising concerns about their long-term sustainability due to increased water and energy use.

Table 2. Environmental impacts at midpoint and endpoint level of various olive production systems in Tunisia (red: highest; green lowest; orange and blue indicating intermediate levels).

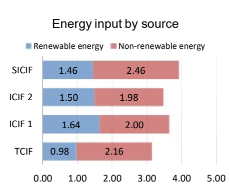
Name	Unit	TCIF	ICIF 1	ICIF 2	SICIF
MIDPOINT					
Fine particulate matter formation	kg PM2.5 eq	2.46	2.24	2.51	2.17
Fossil resource scarcity	kg oil eq	42.83	61.31	89.75	60.01
Freshwater ecotoxicity	kg 1,4-DCB	6.04	9.67	9.68	9.26
Freshwater eutrophication	kg P eq	0.67	0.26	0.21	0.19
Global warming	kg CO2 eq	613.86	516.76	549.40	415.83
Human carcinogenic toxicity	kg 1,4-DCB	7.12	9.31	10.50	8.85
Human non - carcinogenic toxicity	kg 1,4-DCB	154.55	244.52	245.82	234.74
Ionizing radiation	kBq Co-60 eq	7.00	11.38	12.84	11.10
Land use	m2a crop eq	190.57	67.12	51.53	46.85
Marine ecotoxicity	kg 1,4-DCB	8.37	13.38	13.38	12.74
Marine eutrophication	kg N eq	4.08	2.66	1.63	1.55
Mineral resource scarcity	kg Cu eq	1.57	2.08	2.24	1.98
Ozone formation, Human health	kg NOx eq	0.82	0.86	2.13	0.85
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.19	2.07	5.46	2.04
Stratospheric ozone depletion	kg CFC11 eq	0.014	0.008	0.006	0.006
Terrestrial acidification	kg SO2 eq	10.60	5.12	5.16	4.42
Terrestrial ecotoxicity	kg 1,4-DCB	487.18	833.73	838.71	741.13
Water consumption	m3	757.89	1051.34	1042.64	1033.05
ENDPOINT					
Human Health	DALY	4.10E-03	4.65E-03	4.84E-03	4.36E-03
Ecosystems	species.yr	1.83E-05	1.91E-05	1.97E-05	1.80E-05
Resources	USD2013	18.78	28.93	39.88	26.41

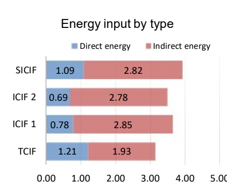
Table 3. Water performance indicators of various olive production systems in Tunisia.

Indicator	Unit	TCIF	ICIF 1	ICIF 2	SICIF
Water-energy efficiency	ratio	97.1	238.9	319.1	357.6
Water productivity	kg/m^3	3.93	2.98	2.93	2.94
Water intensity	m^3/kg	0.255	0.336	0.341	0.340
Water scarcity footprint	World m^3-eq/kg	12.43	16.38	16.62	16.58

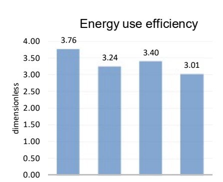


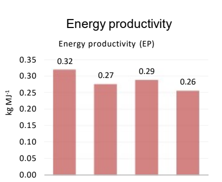
Transitioning to intensive systems increases specific energy input per kilogram by 25%.

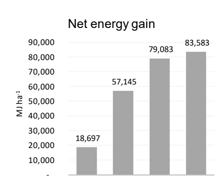




Non-renewable and indirect energy accounted for the majority of the total input energy share for Olive systems.







Intensive and super-intensive farming systems increase crop yield, they do so at the expense of energy efficiency and profitability, primarily because of the higher energy demands for irrigation process.

CONCLUSIONS

- Intensification boosts productivity by 3-5 times and generate greater financial benefits, but increases in water footprint, environmental impacts and energy footprint.
- Irrigation plays a major role in the overall eco-efficiency of irrigated olive cultivation.
- Irrigation Management Decision Support Systems (DSS) are urgently needed in intensive olive farming systems to provide data-driven insights that enhance efficiency and mitigate environmental impacts.
- The WEF nexus approach facilitates a comprehensive understanding of resource interactions, promoting sustainable management practices.

SustIn AFRICA
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