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Assessment of water use efficiency of fruit trees for sustainability in the El Ghanima irrigated farm (Medjerda river basin, North Tunisia)

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تقييم كفاءة استخدام المياه لأشجار الفاكهة من أجل الاستدامة في مزرعة الغنيمة المسقية (حوض نهر مجردة، شمال تونس)

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Abstract:
The El Ghanima Farm is located at Sidi Brahim district, as the closest irrigated area downstream of Sidi Salem dam. The climate is semiarid with annual precipitation around 450 mm yr-1. The irrigated cropping system is diversified including vegetable crops, fruit trees, and field crops; this study focuses on fruit trees. The El Ghanima society manages the largest agricultural farm in the district, with an area of 320 ha. The water source needs are provided by pumping from wadi Medjerda through Sidi Salem release and groundwater during water shortage. This study aims to identify the exploitation plan for optimal economic profitability (DT m-3) in the irrigated farm of El Ghanima. This plan takes into account the irrigation water availability, its quality, and the pedoclimatic characteristics of the study area. The approach involves accounting for expenses and revenues, as well as calculating irrigation water consumption to assess the water economic profitability. The goal is to identify the crop that maximizes the irrigation water value and tolerates technical, water, and pedoclimatic constraints. Results indicate that the water profitability is influenced by crop water requirements and tolerance to salinity, water cost, and price market. Considering cropping system of the farm, almond and citrus trees are currently the most profitable crops in terms of water use efficiency. However, these crops are sensitive to salinity and may become less profitable in the future. Olive trees and pomegranates are more tolerant to salinity and may become more attractive options in the long term. Water-saving techniques and improved water management practices are essential for sustainable irrigation. Overall, this study provides valuable insights into the complex relationship between water availability, crop selection, and profitability in the context of water scarcity. The findings can be used to guide future agricultural development in Sidi Brahim district and other water-scarce regions.

Keywords: Valorization, irrigation, availability, profitability, Medjerda.

الملخص
تقع مزرعة الغنيمة في معتمدية سيدي إبراهيم، وهي أقرب منطقة مروية في مصب سد سيدي سالم. المناخ شبه جاف مع هطول أمطار سنوي يبلغ حوالي 450 ملم/سنة. النظام الزراعي المروي متنوع ويشمل محاصيل خضروات وأشجار فاكهة وحبوب، مع تركيز هذه الدراسة على أشجار الفاكهة. تدير شركة الغنيمة أكبر مزرعة زراعية في المنطقة، بمساحة 320 هكتارًا. يتم توفير احتياجات مصدر المياه عن طريق الضخ من وادي مجردة عبر تصريف سيدي سالم والمياه الجوفية خلال فترات شح المياه. تهدف هذه الدراسة إلى تحديد خطة الاستغلال لتحقيق الربحية الاقتصادية المثلى (دينار تونسي لكل متر مكعب) في المزرعة المروية في الغنيمة. تأخذ هذه الخطة في الاعتبار توافر مياه الري وجودتها والخصائص المناخية لمنطقة الدراسة. تعتمد المنهجية على حساب المصاريف والإيرادات، وكذلك استهلاك مياه الري لتقييم الربحية الاقتصادية للمياه. الهدف هو تحديد المحصول الذي يعظم قيمة مياه الري ويتحمل القيود الفنية والمائية والمناخية والتربة. تشير النتائج إلى أن ربحية المياه تتأثر باحتياجات المحاصيل المائية وتحملها للملوحة وتكلفة المياه وأسعار السوق. بالنظر إلى النظام الزراعة بالمزرعة، تعد أشجار اللوز والحمضيات حاليًا أكثر المحاصيل ربحية من حيث كفاءة استخدام المياه. ومع ذلك، فهذه المحاصيل حساسة للملوحة وقد تصبح أقل ربحية في المستقبل. في المقابل، تُظهر أشجار الزيتون والرمان تحملاً أعلى للملوحة وقد تصبح خيارات أكثر جاذبية على المدى الطويل. تعد تقنيات توفير المياه وتحسين ممارسات إدارتها ضرورية لضمان الري المستدام. بشكل عام، تقدم هذه الدراسة رؤى قيمة حول العلاقة المعقدة بين توفر المياه، واختيار المحاصيل، والربحية في سياق ندرة المياه. يمكن استخدام هذه النتائج لتوجيه التطوير الزراعي المستقبلي في معتمدية سيدي إبراهيم ومناطق أخرى تعاني من شح المياه.

الكلمات المفتاحية: تثمين المياه، الري، التوفير، الربحية، وادي مجردة.

1. Introduction

The agricultural sector is the primary consumer of freshwater, representing over 80% of the global water usage [1]. In Mediterranean regions, the interplay between climate change and population growth can reduce water availability, therefore intensifying the difficulty of satisfying the existing demand for freshwater resources [2]. Consequently, the enhancement of water use efficiency (WUE) becomes an urgent necessity in order to ensure the sustainability of irrigated agriculture [3]. Improving water management at farm and district levels can lead to a significant betterment of WUE [4]. From an economic standpoint, the choice of crop type to be planted, can improve WUE and may help to produce ‘more crop per drop’ leading to optimal economic profitability [5].

The Medjerda river basin, specifically the El Ghanima irrigated farm within the Sidi Brahim irrigation district, plays a critical role in the region's agricultural productivity. However, the area faces challenges associated with water scarcity, making it imperative to optimize water use. Given the Mediterranean climate, characterized by hot, dry summers and variable rainfall, farmers must carefully select crops that not only yield high returns but also maximize WUE [6]. Strategic crop selection can significantly influence the sustainability of agricultural practices in water-limited environments like this one.

Recent studies emphasize the importance of integrating WUE into crop planning and management strategies to ensure long-term sustainability in irrigated agriculture [7]. This is particularly relevant in regions like Sidi Brahim, where the balance between water supply and agricultural demand is increasingly precarious. By focusing on crops that are both economically viable and efficient in water use, farmers can enhance the resilience of their operations against the pressures of climate change and water scarcity [8]. Moreover, improving WUE is not just about reducing water consumption but also about achieving higher productivity per unit of water used, which can contribute to the overall economic sustainability of the farming systems in the region [9].

The present study aims to evaluate the water use efficiency of various crops cultivated in the El Ghanima irrigated farm, with the goal of identifying those that offer the best balance between economic returns and sustainable water use. By analyzing crops like olive, almond, citrus, and pomegranate, this research seeks to provide actionable insights that can inform fruit tree selection and water management practices. The findings are intended to support decision-makers and farmers in optimizing crop choices to enhance both agricultural sustainability and economic profitability in the Medjerda river basin.

2. Material and methods

2.1. Study area

The El Ghanima irrigated farm is located within the Sidi Brahim irrigation district inside the Medjerda river basin (Delegation of Testour, Governorate of Beja –Tunisia–) (Figure 1). The irrigated farm is limited in the sure part by Oued Khalled. The study area is characterized by a semi-arid climate with hot, dry summers and mild, rainy winters. The average annual rainfall is around 500 mm, concentrated between November and March. The average annual temperature is about 18°C, ranging from 4°C in winter to 35°C in summer. It is characterized by rolling hills and plains, with elevations ranging from 200 to 400 meters above sea level. The main water sources for irrigation are groundwater from 06 wells and surface water from the Oued Medjerda. The availability of water resources is limited, particularly during the dry summer months. The perimeter is equipped with a network of canals and pipelines for water distribution with 25 hydrants with flow rates ranging from 5 to 8 l/s operating for 16 hours. The main irrigation system used is drip irrigation. The farm is primarily agricultural land, with olive groves, almond orchards, citrus plantations, and pomegranate trees being the main crops. Some areas are also used for grazing and forestry.

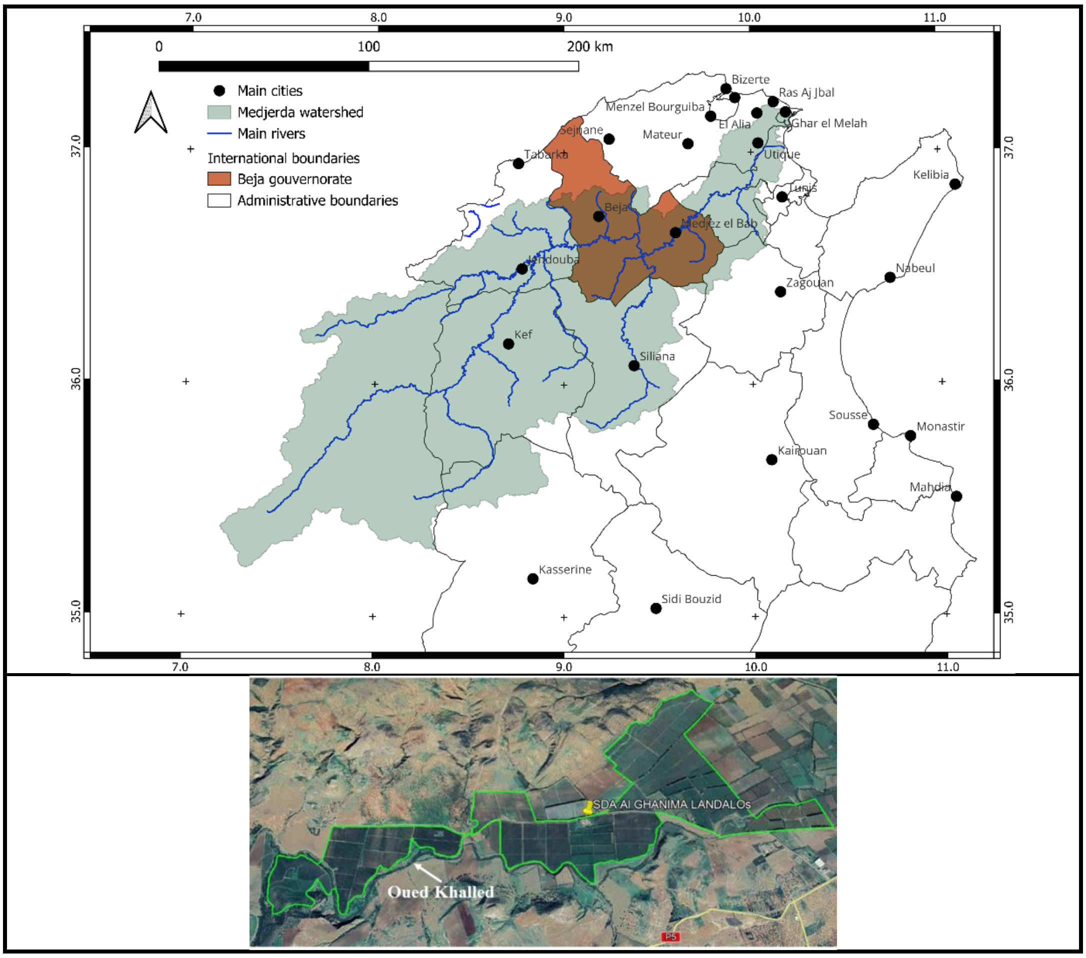

Figure 1: Localisation of Tunisian administrative and Medjerda watershed boundaries (top) and El Ghanima irrigation farm (down).

2.2. Gross irrigation water requirements calculation (GIR)

The gross irrigation water requirement refers to the total amount of water needed to irrigate a crop, taking into account the losses related to the efficiency of the irrigation system [10]. It is calculated as,

$$\mathrm{GIR} = \frac{\mathrm{NIR} + \mathrm{LF}}{\mathrm{EFF}}$$

were,

- GIR: gross irrigation water requirements (mm day^{-1});
- NIR: net irrigation water requirements (mm day^{-1});
- EFF: Irrigation efficiency (decimal fraction);
- LF: leaching fraction (dimensionless).

$$\mathrm{NIR} = \mathrm{ETc} - \mathrm{Peff} = \mathrm{Kc} \times \mathrm{ETo} - \mathrm{Peff} = \mathrm{Kc} \times \mathrm{ETo} - (\mathrm{Ptot} \times 0.8)$$

were,

- ETc: crop-specific potential evapotranspiration (mm day^{-1});
- Peff: effective precipitation (mm day^{-1});
- ETo: potential evapotranspiration (mm day^{-1});
- Kc: crop coefficient (dimensionless);
- Ptot: total precipitation (mm day^{-1}).

The ETo is calculated using the Blanney-Criddle formula [11]:

$$ETo_{BC} = (8.12 + 0.46 \times T) \times p$$

where:

ETo_{BC}: ETo Blanney-Criddle reference evapotranspiration (mm day^{-1});
T: mean temperature (°C);
p: mean percentage of annual daytime hour.

The irrigation efficiency (EFF), also called "'project efficiency of irrigation water use", refers to the volume of water evapotranspirated by the crop as a ratio of the volume of water diverted from the river or reservoirs at the inlet to an irrigation project or pumped from the groundwater [12]. The EFF is the product between water conveyance efficiency (η_c) and water application efficiency (η_a).

The η_c refers to the efficiency with which water is transported from the water source (such as a reservoir, canal, or river) to the irrigation fields, calculated as:

$$\eta_c = \frac{W_f}{W_s}$$

The η_a refers to the percentage of the total water applied to a field that is actually used by the crops for growth and transpiration, calculated as,

$$\eta_a = \frac{W_u}{W_f}$$

where:

Wf: Water delivered to the field (mm);
Ws: Water released from the source (mm);
Wu: Water used by the crops (mm).

The Leaching fraction refers to the portion of irrigation water that percolates through the root zone and beyond, carrying excess salts away from the root zone. It is calculated as,

$$LF = \frac{EC_w}{(5 \times EC_s) - EC_w}$$

where:

EC_w electrical conductivity of irrigation water (mS cm^{-1});
EC_s: Electrical conductivity of the soil or soil solution at the time of application (mS cm^{-1}).

2.3. Water use efficiency calculation

To calculate WUE two parameters must be determined carefully: the gross margin (GM) and the net margin (NM). The GM refers to the difference between the revenue generated from irrigated crop and the costs associated with the production process, excluding fixed costs and overheads.

$$GM = \text{Total revenue} - \text{Variables costs}$$

The NM represents the actual profitability of an irrigated crop after deducing the depreciation, calculated as,

$$NM = GM - \text{depreciation}$$

Gross and net margin were computed for olive, almond, citrus and pomegranate crops, taking into account income and variable costs obtained from El Ghanima farm data base. Average yields and product prices, during last agricultural years, were also obtained from El Ghanima farm data base. The WUE can be calculated from an agronomic and economic perspective. Regarding the economic perspective, the WUE can be obtained by dividing the gross or net margin by the annual volume of irrigation water applied to the crop ($EWUE_{GM}$, and $EWUE_{NM}$, respectively), resulting in performance indicators in units of DT m^{-3}.

$$EWUE\ (DT\ m^{-3}) = \frac{\text{NM or GM}}{\text{Applied water}}$$

In this study we will use only net margin to calculate EWUE. We can also calculate the WUE by dividing the annual yield obtained by the crop by the annual volume of irrigation water applied to the crop (AWUE), resulting in performance indicators in units of kg m^{-3}.

$$\text{AWUE}\ (\text{kg m}^3) = \frac{\text{Yield}}{\text{Applied water}}$$

3. Results and discussion

3.1. Gross and net margin estimation

As noted in the previous section, the estimation of the GM for olive, almond, citrus and pomegranate has been carried out by 1) determining the production costs, and 2) determining the value of production. Table 1 represents the GM of the studied crops during the agricultural year of 2017-2018.

All tables should be inserted in the main text article at its appropriate place.

Table 1: Variables costs (DT ha^{-1}), fixed variables (DT m^{-3}), revenues (DT ha^{-1}), gross margin (DT ha^{-1}), and net margin (DT m^{-3}) of olive, almond, citrus and pomegranate crops during the 2017/2018 agricultural year.

	Fruit tree	Olive	Almond	Citrus	Pomegranate
Variable costs	Insurance	310	648	1700	560
	Rent	385	385	385	385
	Overhead costs	457	831	2625	895
	Water	515	615	1746	340
	Inputs	735	1474	5147	1503
	Labor	488	742	5851	1057
	Subcontracted work	156	952	3260	0
	Network maintenance	6	51	204	100
	Mechanical traction	437	297	1300	251
	Total	3 489	5 995	22 218	5 091
Fixed cots	Depreciation	550	400	800	0
Revenue	Revenue per crop	7 755	16 198	45 000	14 000
Gross margin	Gross margin	**4 266**	**10 203**	**22 782**	**8 909**
Net margin	Net margin	**3 716**	**9 803**	**21 982**	**8 909**

The estimation of GM and NM shows that citrus and almond crops are the most profitable, demonstrating that high revenues can absorb high costs effectively. Pomegranates achieve stable profitability with low costs, while olives show lower profitability due to insufficient revenue to cover costs. This analysis suggests that revenue optimization or cost reduction strategies could improve profitability for less profitable crops.

3.2. Water use efficiency estimation

Table 2 shows the WUE expressed in DT m^{-3} and kg m^{-3}.

Table 2: Yield (kg ha^{-1}), water applied (m^3 ha^{-1}), AWUE (kg m^{-3}), and EWUE$_{NM}$ (DT m^{-3}) of olive, almond, citrus and pomegranate crops during the 2017/2018 agricultural year.

Fruit tree	Yield (kg ha^{-1})	Water applied (m^3 ha^{-1})	Net margin (DT ha^{-1})	AWUE (kg m^{-3})	EWUE$_{NM}$ (DT m^{-3})
Olive	6 463	3 157	3 716	0.57	1.18
Almond	2 382	3 501	9 803	4.12	2.80
Citrus	50 000	8 293	21 982	0.44	2.65
Pomegranate	15 556	5 999	8 909	0.57	1.49

The results displayed in table 2 showed that:

1. Olive trees produced a moderate yield with a relatively low water requirement, resulting in a water use efficiency of 0.57 kg of yield per cubic meter of water. The financial efficiency of water use was 1.18 DT per cubic meter;
2. Although almond trees had a lower yield compared to other crops, they demonstrated a high water use efficiency (4.12 kg m^{-3}), indicating that almonds are very effective at converting water into crop yield. The financial return per unit of water was also high, at 2.80 DT per cubic meter;
3. Citrus trees had the highest yield but also required most water. Despite the high water requirement, the financial efficiency of water use was significant at 2.65 DT per cubic meter. However, the water use efficiency in terms of yield was lower, at 0.44 kg m^{-3};
4. Pomegranate trees had a moderate yield and water requirement, with a water use efficiency of 0.57 kg m^{-3}, similar to olive. The financial efficiency of water use was 1.49 DT per cubic meter, indicating a moderate return on water investment.

In summary, almond stood out with the highest water use efficiency in both yield and financial terms. Citrus had the highest yield but required most water, with a good financial return on water use. Olive and pomegranate showed similar patterns of water use efficiency, with moderate yields and financial returns.

3.3. Sensitivity analysis of costs and revenues variations

To validate the robustness of the results obtained in the previous analysis, we conducted a sensitivity analysis by performing two specific tests. First, we increased the costs by 20% (test 1), and second, we decreased the revenues by 20% (test 2). These adjustments were intended to assess the potential impact of variations in economic parameters on the outcomes. Table 3 and 4 presents the results of the sensitivity analysis.

Table 3: Impact of a 20% increase in costs (test 1) on net margin and water use efficiency for of olive, almond, citrus and pomegranate fruit trees during the 2017/2018 agricultural year.

Fruit tree	Costs + 20% (DT ha^{-1})	Revenue (DT ha^{-1})	Water applied (m^3 ha^{-1})	NM (kg ha^{-1})	$EWUE_{NM}$ (DT m^{-3})
Olive	4 847	7 755	3 157	2 908	0.92
Almond	7 674	16 198	3 501	8 524	2.43
Citrus	27 622	45 000	8 293	17 378	2.10
Pomegranate	6 109	14 000	5 999	7 891	1.32

Table 4: Impact of a 20% decrease in revenues (test 2) on net margin and water use efficiency for of olive, almond, citrus and pomegranate fruit trees during the 2017/2018 agricultural year.

Crop	Costs (DT ha^{-1})	Revenue – 20% (DT ha^{-1})	Water applied (m^3 ha^{-1})	NM (DT ha^{-1})	$EWUE_{NM}$ (DT m^{-3})
Olive	4 039	6 204	3 157	2 165	0.69
Almond	6 395	12 958	3 501	6 563	1.87
Citrus	23 018	36 000	8 293	12 982	1.57
Pomegranates	5 091	11 200	5 999	6 109	1.02

3.3.1. Impact of 20% increase in costs (test 1)

The results in table 3 showed that:

1. Olive: with a 20% increase in costs, the net margin decreased to 2 908 DT ha^{-1}, with a $EWUE_{NM}$ of 0.92 DT m^{-3}. The financial efficiency dropped, reflecting the sensitivity of olive trees to cost increases;
2. Almond: despite the increase in costs, almond still maintained a high net margin of 8 524 DT ha^{-1}, with a $EWUE_{NM}$ of 2.43 DT m^{-3}, indicating a strong resilience to market price;
3. Citrus: the net margin dropped to 17 378 DT ha^{-1}, and the $EWUE_{NM}$ decreased to 2.10 DT m^{-3}. Although affected, citrus still demonstrated good financial efficiency under increased costs;
4. Pomegranate: experienced a reduction in net margin to 7 891 DT ha^{-1}, with a $EWUE_{NM}$ of 1.32 DT m^{-3}. Pomegranates showed a moderate sensitivity to cost increases.

3.3.2. Impact of 20% decrease in revenues (test 2)

1. Olive: the net margin fell significantly to 2 165 DT ha^{-1} with a $EWUE_{NM}$ of 0.69 DT m^{-3}, indicating that olives are quite sensitive to decreases in revenue;
2. Almond: the net margin dropped to 6 563 DT ha^{-1} with a $EWUE_{NM}$ of 1.87 DT m^{-3}. Although impacted, almond trees still maintained a reasonable financial efficiency despite the revenue decrease;
3. Citrus: the net margin reduced sharply to 12 982 DT ha^{-1}, and $EWUE_{NM}$ fell to 1.57 DT m^{-3}. Citrus showed considerable sensitivity to revenue decreases but still retained a moderate level of financial efficiency;
4. Pomegranate: the net margin decreased to 6 109 DT ha^{-1}, with a $EWUE_{NM}$ of 1.02 DT m^{-3}. Pomegranate trees were moderately affected, but the impact was less severe compared to other fruit trees.

In summary, the sensitivity analysis pinpointed that:

1. Almond consistently showed the highest resilience to both cost increases and revenue decreases, maintaining strong net margins and water use efficiency across all scenarios. This indicates that almond trees are the most robust and economically efficient crop under varying economic conditions;
2. Citrus fruit trees, while yielding the highest, were more sensitive to economic changes, particularly revenue decreases, but still maintained a relatively high $EWUE_{NM}$;
3. Pomegranate trees displayed moderate sensitivity to both cost increases and revenue decreases, with a noticeable decline in financial efficiency but still maintaining acceptable margins;
4. Olive trees were the most sensitive to both cost increases and revenue decreases, showing significant declines in net margin and WUE_{NM}. This suggests that olive is more vulnerable to economic fluctuations compared to the other crops.

Conclusion

The study aimed to estimate the GM and NM of olive, almond, citrus, and pomegranate fruit trees and evaluate their WUE during the 2017/2018 agricultural year in the investigated farm of El Ghanima. Additionally, a sensitivity analysis was performed to assess the impact of cost increases and revenue decreases on these metrics. The profitability analysis showed that:

- Citrus and almond demonstrated the higher profitability, with citrus achieving the highest yield and almond showing exceptional financial efficiency per unit of water used;
- Pomegranate achieved stable profitability with relatively low costs, making them a moderately efficient fruit tree both in terms of water use and financial return;
- Olive showed lower profitability, with revenue barely covering costs, making them the least profitable fruit tree among the four studied.

Regarding the crops WUE, the results showed that:

- Almond: showed the highest WUE in both yield and financial terms, indicating strong efficiency in converting water into economic returns;
- Citrus: despite the high water requirement, citrus crops delivered significant financial returns per unit of water, though the yield efficiency was lower;
- Olive and Pomegranate: displayed similar WUE, with moderate yields and financial returns per unit of water used**.**

The sensitivity analysis indicated:

- Almond: consistently demonstrated the highest resilience to both cost increases and revenue decreases, making them the most robust fruit tree under varying economic conditions;
- Citrus: while having the highest yield, citrus trees were sensitive to economic changes, particularly revenue decreases, yet still maintained a relatively high $EWUE_{NM}$;
- Pomegranate: showed moderate sensitivity to both cost increases and revenue decreases, with a noticeable but manageable decline in financial efficiency.
- Olive: was the most vulnerable to economic fluctuations, with significant declines in net margin and $EWUE_{NM}$, suggesting a need for optimization in either revenue and cost management.

The results emphasize the importance of fruit trees' selection based on both profitability and water use efficiency. Almond emerges as the most economically efficient fruit tree, while olive may require targeted strategies to enhance profitability and resilience to economic variations.

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