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Techno-economic, environmental and social assessment of precision agriculture for stone fruit production

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Abstract

Precision agriculture is a powerful solution to mitigate the environmental impact of agricultural systems, optimize crop inputs and cost reduction. The aim of this work is to analyze the benefits of precision farming practices (irrigation, fertilization and phytosanitary treatment) through a life cycle sustainability assessment (environmental, economic and social impacts) using a detailed life cycle inventory for stone fruit production compared to traditional production. The 8-year life cycle inventory was provided by a local producer in southern Spain. The system boundaries include a "gate to farm gate" approach using 1 kg of stone fruit as the functional unit. The streamlined analysis incorporates environmental, life cycle cost and social risk analysis for this crop production. The results show that the reduced input requirements of the precision agriculture scenario led to lower environmental damage, reduced economic costs and lower social risks, with average impact reductions ranging between 20-30% in most sustainability categories.

Keywords: life cycle sustainability assessment; variable application of inputs; nectarine.

1. Introduction.

Spain was the second largest exporter of fruit and vegetables in the world and the main supplier of fruit to the EU in 2020, with an annual production of €14,595 M (MAPA 2021). In 2021, stone fruit exports reached a record value of €1370 M, with an export volume of 9,476,665 t. The Region of Murcia is responsible for 27% of Spain's stone fruit production. However, the sector is facing a crisis, mainly due to the sharp increase in production and processing costs (e.g. fertilizers, phytosanitary products, plastics, electricity and fuel), the geopolitical situation and the effects of climate change (e.g. late frosts, droughts, heatwaves...). In addition, consumers are changing their purchasing preferences and are increasingly concerned about the conditions under which food is produced and whether their purchase has undesirable environmental and social impacts.

In order to understand the holistic impact of products on the market, a methodology called Life Cycle Sustainability Assessment (LCSA) has been developed over the last 20 years, which assesses and integrates the areas of environmental, economic, and social impacts (Klöpffer 2003). **Table 1** provides a summary of studies using the LCSA method on different agricultural products. The authors use the same theoretical framework of LCSA (Environmental Life Cycle Assessment (LCA) + Life Cycle Costing (LCC) + Social Life Cycle Assessment (s-LCA)), but the studies differ in the methods, impact indicators and databases used.

Precision agriculture (PA) techniques are currently a powerful solution for reducing the environmental impact of agricultural systems (Bacenetti et al. 2020). They contribute to a precise and optimized use of crop inputs (fertilizers, phytosanitary products and water) through variable application (Zude-Sasse et al. 2016), which also leads to reduced costs (Heege 2013). The aim of this study is to assess the sustainability in all three impact areas (environmental, economic and social) of the application of PA in the stone fruit life cycle.

2. Materials and method.

This study describes the impacts of the production of stone fruit (*Prunus persica var. nucipersica*) assessed by LCSA (LCA+LCC+s-LCA) according to the UNEP / SETAC theoretical framework (UNEP 2011). Inventory data were used from an orchard located in the municipality of Cieza (Murcia) in south-eastern Spain.

Table 1*. Key papers on LCSA in agricultural products.*

References	Functional Unit (FU)	Methods / indicators			Conclusions
		Environmental LCA	Economic LCC	Social LCA	
(Omran, Sharaai, and Hashim 2021)	1 t of crude palm oil.	Eco-indicator 99 / Climate change, ecotoxicity, acidification, eutrophication and 5 indicators more.	Initial investment cost, operational and maintenance costs, and the end of life cost.	Mill workers (job satisfaction and fair salary) and local community (safe and healthy living condition).	The scores for the impact categories analysed were averaged to produce an overall impact score for each area. The best sustainability score was for the social dimension with 3.7/4, followed by the economic dimension with 3.25/4 and the environmental dimension with 2.5/4.
(De Luca et al. 2018)	1 ha of olive crop.	CML baseline V3.03 / Land occupation and Climate change.	Profitability and investment feasibility.	Worker (fair salary, job opportunities), local community (safe) and consumer (feedback mechanism)	The analysis showed stakeholders the importance of environmental and social sustainability, particularly in terms of toxicity and worker health. The low-dose/no-work scenario was the best performer in all selected categories except employment opportunities.
(Martínez-blanco et al. 2014)	1 t of tomato.	CML 2001 / acidification, eutrophication and 8 indicators more.	Operational and maintenance costs.	Worker (freedom of association), local community (contribution to welfare) and consumer (feedback mechanism).	The comparability and reliability of the results were strongly influenced by the definition of the functional unit and the system boundaries. Compost was the worst fertiliser option regardless of the area. The results for nitric acid and potassium nitrate were similar, but nitric acid had lower impacts in most categories.

The study area covers 40 ha with 667 plants per ha and produces an average of 35 t ha-1 yr-1 of fresh fruit, considering production data over a period of 8 years. The study was carried out considering the principles of ISO 14040 – 14044 (ISO 14040 2006; ISO 14044 2006), which includes four iterative stages: Goal and scope definition, life cycle inventory analysis, life cycle impact assessment and life cycle interpretation. The former two stages are described in sections 2.1 and 2.2, and the latter two in section 3. Results and discussion /interpretation. Sections 2.5, 2.6 and 2.7 explain how the environmental, economic, and social aspects have been assessed.

2.1. Goal & Scope definition. The objective of this study is to evaluate the environmental, economic and social life cycle performance of a stone fruit production system, considering two scenarios: variable input application using PA technologies and uniform input application using traditional (T) technologies. The functional unit (FU) was defined as 1 kg of nectarines, unpackaged (in bulk), at the farm gate. The system boundaries consider only the *gate – to - gate* (core) procedures of the total value chain for the assessment of the three impact areas, as shown in **Figure 1**. Both scenarios follow the same system boundaries and FU, but differ in the dose estimation methods and technologies used to apply the inputs. In this work, PA techniques focus on *sensing-recording* (sensors mounted on ground stations that collect information to characterize spatial and temporal variability of key agricultural parameters such as yield, soil fertility, moisture content and plant physiological state) and *response technologies* (hardware and software that together can vary the application of agricultural inputs in space and time in the field).

The irrigation schedule in the PA scenario is based on the calculation of adjusted crop evapotranspiration (ETc adj) and the use of volumetric soil moisture probes and flowmeters with networked data loggers, together with a private on-site weather station. The traditional scenario follows an irrigation schedule based on the calculation of crop evapotranspiration (ETc) and weather data from the SIAM station network (SIAM 2020).

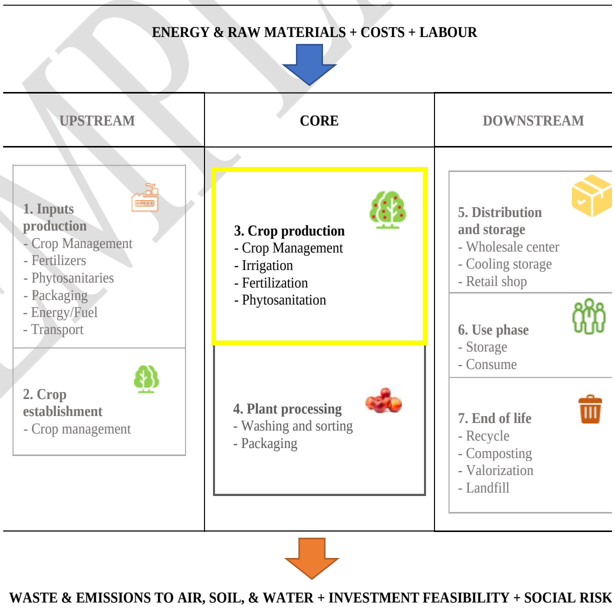

Figure 1. *Life cycle and system boundaries using the gate-to-gate approach (yellow square).*

The fertilizer plan in the PA scenario considers yields per plot sector, two soil and leaf analyses and chemical analyses of fertigation and drainage water carried out throughout the season. In the traditional scenario, the programme describes average production yields of the plot, one soil analysis per season and fertilizer supplier's recommendations.

The phytosanitary programme in the PA scenario is based on disease warnings from the company (based on weather data and specific risk models) and monitoring by counting the presence of insects, mainly controlled by pheromone traps. In the traditional scenario, the supplier's fungicide and insecticide application programme is only considered according to calendar and crop stage.

2.2. Life cycle inventory analysis. **Table 2** shows the inventory of inputs per season in the nectarine life cycle by FU. The inventory was compiled using data from a fruit production (both scenarios) and processing company in Murcia. Background secondary inventory data for energy use, transport, machinery and irrigation were sourced from Ecoinvent v3.7.

Table 2. *Life cycle inventory analysis by FU in precision agriculture (PA) vs. traditional (T) scenarios. * Active ingredient*

Crop Production			T		PA	
			Process inventory	Economic inventory	Process inventory	Economic inventory
CROP INPUTS Fertilization	Unit	€	Quantity	€	Quantity	€
13-0-46	kg	1.22	1.57E-02	1.92E-02	1.33E-02	1.63E-02
15-0-0-26,5 Ca	kg	1.17	8.42E-03	9.85E-03	7.16E-03	8.37E-03
21-0-0-60 SO3	kg	1.21	7.32E-03	8.86E-03	6.22E-03	7.53E-03
0-53-0	kg	1.2	5.13E-03	6.16E-03	4.36E-03	5.23E-03
			3.66E-02	4.40E-02	3.11E-02	3.74E-02
Irrigation						
Water	m^3	3.30E-01	1.29E-01	4.26E-02	9.03E-02	2.98E-02
Electricity	kWh	3.70E-01	4.24E-02	1.57E-02	2.97E-02	1.10E-02
				5.83E-02		4.08E-02
Phytosanitation*						
Fungicides	kg	5.30E+01	2.67E-05	1.42E-03	2.40E-05	1.27E-03
Insecticides	kg	5.20E+01	1.87E-04	9.73E-03	1.68E-04	8.76E-03
			2.14E-04	1.11E-02	1.92E-04	1.00E-02
PA technologies	ha	8.21E-03	0	0	1	8.21E-03
OTHERS						
Technical staff	hr	14	3.60E-03	0.0504	4.10E-03	5.74E-02
Machinery	ha	1.60E-02	8.60E-03	1.38E-04	7.74E-03	1.24E-04
Fuel	l	1.60E+00	1.44E-03	2.30E-03	1.11E-03	1.77E-03
Transport	tkm	1.10E+00	2.83E-02	3.11E-02	2.41E-02	2.65E-02
				8.40E-02		9.40E-02
			TOTAL	1.974E-01	TOTAL	1.822E-01

2.3. Environmental impact assessment. The analysis was performed on Simapro v9.2, using as a reference the product category rules (PCR) for fruits and nuts (EPD 2019) and the EF 3.0 assessment method (ELCD 2020). The impact categories considered were climate change, photochemical ozone formation (POF), acidification (A), eutrophication of freshwater (E) and water use (W).

2.4. Economic assessment. In both production scenarios only gate-to-gate costs were considered (i.e. from the gate of purchase of inputs and resources to the farm gate). The economic feasibility assessment includes only the purchase costs (C) for the company as defined in equation (1). The market prices of phytosanitary and fertilizers were obtained from the company Frutas Esther S.A. 2022. The price of water correspond to the local irrigation association of Cartagena (Murcia, Spain) (CRCC 2022). The electricity tariff correspond from the value of the national mix (Som Energia 2022). The price of fuel was obtained from the Spanish confederation of freight transport (CETM 2022). The price of PA management was obtained from various specialized companies: Soil and leaf analysis (CSR Laboratorio 2023); fertiliser and irrigation online management system (ModpoW 2023); traps, attractants and pheromones (PROBODELT 2023); disease warning software and weather station (TAMIC. 2022). **Table 2** shows the purchase costs for the PA and traditional scenarios, a comparative analysis is provided in results **section 3.2.**

$$\text{Purchase Costs (C)} = C_{\text{fertilization}} + C_{\text{irrigation}} + C_{\text{phytosanitary}} + C_{\text{PA technologies}} + C_{\text{technical staff}} + C_{\text{machinery}} + C_{\text{fuel}} + C_{\text{transport}}. \quad \textbf{(1)}$$

2.5. Social risk assessment. The was carried out using the sectorized economic inventory for the conventional and PA scenarios and the social risk data from the Social Hotspot Database (SHDB) (UNEP 2020). Costs were converted (deflator) from 2022 € to 2011 USD according to official inflation and currency conversion ratios.

3. Results and discussion.

3.1. Environmental impact. **Table 3** describes the emissions of 9.33E-02 kg CO^2 per FU in the traditional scenario and 7.01E-02 kg CO^2 per FU in the PA scenario. The largest decrease between the scenarios was in water use with 29.9%. The smallest decrease between the scenarios was in eutrophication with 17.6%. The PA scenario shows an average decrease of the indicators of 23.4%. On average, 0.22% of the difference in environmental impact between the scenarios is due to the introduction of precision agriculture technology. According to Núñez-Cárdenas et al. 2022, the implementation of PA technologies in fertilization, irrigation and phytosanitary reduced the average environmental indicators in stone fruit crops by 21%.

Table 3. *Environmental impacts assessment by FU. (Dif. %: reduction comparing Traditional vs. PA scenarios. PA_{tech} %: impact of the PA technologies in PA scenario).*

Impact Category	Unit	Traditional	Precision agriculture	Dif. %	PA_{tech} %
Climate change	kg CO2 eq	9.33E-02	7.01E-02	-24.8	0.36
Photochemical ozone formation	kg NMVOC eq	5.87E-04	4.68E-04	-20.3	0.18
Acidification	mol H+ eq	7.71E-04	5.83E-04	-24.3	0.25
Eutrophication, freshwater	kg P eq	1.51E-05	1.24E-05	-17.6	0.25
Water use	m^3 depriv.	1.29E-01	9.04E-02	-29.9	0.05

3.2. Economic results. **Figure 2** illustrates the average economic savings in crop input consumption, ranging from 10% for phytosanitary, 15% for fertilizers and 30% for water and electricity use. Savings in fuel, transport and machinery were -23%, -15% and -10% respectively. The average cost difference between the scenarios was 8%. The costs of cultural management (thinning, pruning, harvesting, etc.) are not included as they are not affected by PA technologies.

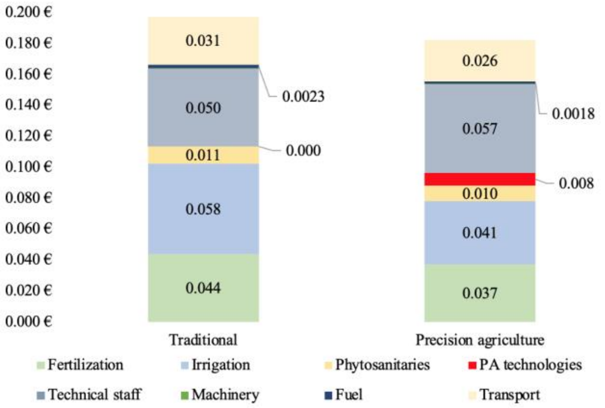

Figure 2. *Economic viability results per functional unit between Traditional and Precision agriculture scenarios.*

The cost of technical staff is higher in the PA scenario because more hours of monitoring are required. The net saving of the PA technologies scenario was 532 € $ha^{-1}yr^{-1}$ (gross saving 1064 € $ha^{-1}yr^{-1}$). The investment cost of PA technologies and technical staff was 532 € $ha^{-1}yr^{-1}$.

Bellvert et al. 2020, analyzed the economic savings of PA technologies in electricity and irrigation water use corresponding to a 59% increase in gross profit.

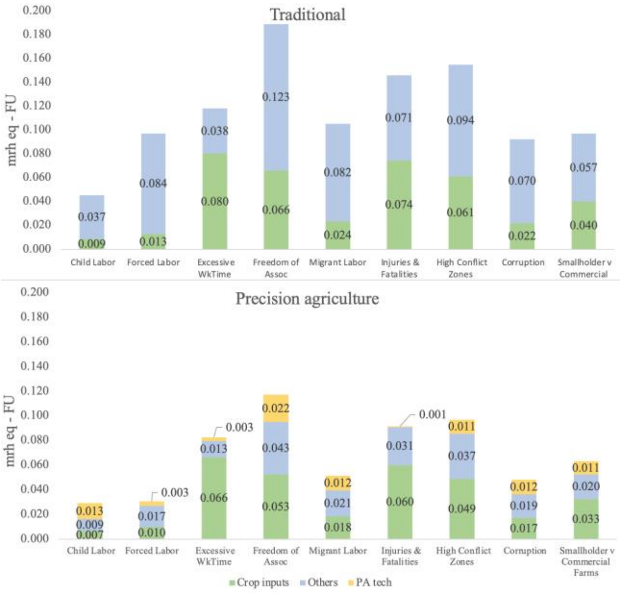

Figure 3. *Medium risk hour eq per functional unit for each impact category between Traditional and Precision agriculture scenarios.*

3.3. Social impact. As shown in **Figure 3**, the purchase of inputs and crop production are the most socially risky stages in all impact categories due to the social risks associated with the agricultural sector in Spain. According to this assessment, the categories of Forced Labour, Excessive Work Time, Freedom of Assoc., Migrant Labour and Injuries & Fatalities, contribute the most to social impact risk. The PA scenario shows an average decrease in the average medium risk hour of 41.5%. The largest reduction was in the forced labour category (68.5%) and the smallest in excessive working time (30%). In the crop production phase of agricultural stage, injuries and fatalities, migrant labour and freedom of association are the impact categories with the highest contribution to medium risk hours (Núñez et al. 2022). A specific social impact analysis would be necessary to corroborate these social risk findings.

4. Conclusions.

This study shows that of PA technologies have the potential to significantly reduce environmental damage not only that caused by climate change, but also FPO, A, E and water use, thus contributing positively to the objectives of the Common Agricultural Policy and the European Green Deal. These reductions are achieved with a low environmental impact from the production and implementation of these techniques (average 0.22% of the total impacts avoided in the PA scenario).

The cost analysis shows a difference of 8% between the scenarios. The cost of implementing PA, including technical staff, was 532 € ha^{-1} yr^{-1}, with total net savings of 532 € ha^{-1} yr^{-1}. The social risks of the traditional scenario were higher than those of the PA scenario because of the lower cost requirements of the latter. Specific life cycle social analysis would need to be carried out to corroborate these findings. Overall, reduction in environmental, economic and social impacts caused by the implementation of PA were estimated to range between 20-30%.

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References

Bacenetti, Jacopo et al. 2020. “May Smart Technologies Reduce the Environmental Impact of Nitrogen Fertilization? A Case Study for Paddy Rice.” *Science of The Total Environment* 715: 136956.

Bellvert, J. et al. 2020. “Optimizing Precision Irrigation of a Vineyard to Improve Water Use Efficiency and Profitability by Using a Decision-Oriented Vine Water Consumption Model.” *Precision Agriculture 2020 22:2* 22(2): 319–41. https://link.springer.com/article/10.1007/s11119-020-09718-2 (September 22, 2021).

CETM. 2022. “Precios Del Gasóleo, Evolución Mes a Mes.” https://www.cetm.es/evolucion-precios-gasoleo/ (April 27, 2022).

CRCC. 2022. “Precio Del Agua Para Riego.” https://www.crcc.es/2021/06/14/nuevo-precio-del-agua-para-riego-14-junio-2021/ (April 27, 2022).

CSR Laboratorio. 2023. “Catálogo de Análisis de Suelos Agrícolas -.” https://csrlaboratorio.es/laboratorio/agricultura/suelos-agricolas/catalogo-de-analisis-de-suelos-agricolas/ (April 26, 2023).

ELCD. 2020. “European Commission Service Site.” https://eplca.jrc.ec.europa.eu/efMethodology.html (April 12, 2021).

EPD. 2019. 1.01 Environmental Product declaration International AB *Product Category Rule (PCR) - Fruits and Nuts - UN CPC 013*. https://www.environdec.com/PCR/Detail/?Pcr=14175.

Frutas Esther S.A. 2022. “Interview with Field Technician on Process and Economic Inventory of Nectarine Production in Murcia.” https://www.frutasesther.es/fincas/.

Heege, Hermann J. 2013. “Precision in Crop Farming: Site Specific Concepts and Sensing Methods: Applications and Results.” *Precision in Crop Farming: Site Specific Concepts and Sensing Methods: Applications and Results*: 1–356.

ISO 14040. 2006. International organization for standardization *Environmental Management - Life Cycle Assessment - Principles and Framework*. https://www.iso.org/standard/23151.html.

ISO 14044. 2006. International organization for standardization *Environmental Management - Life Cycle Assessment - Requirements and Guidelines*.

Klöpffer, Walter. 2003. “Life-Cycle Based Methods for Sustainable Product Development.” *International Journal of Life Cycle Assessment* 8(3): 157–59. https://link.springer.com/article/10.1007/BF02978462 (March 23, 2023).

De Luca, Anna Irene et al. 2018. “Evaluation of Sustainable Innovations in Olive Growing Systems: A Life Cycle Sustainability Assessment Case Study in Southern Italy.” *Journal of Cleaner Production* 171: 1187–1202.

MAPA. 2021. “Superficies y Producciones Anuales de Cultivo.” https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/superficies-producciones-anuales-cultivos/ (April 13, 2021).

Martínez-blanco, Julia et al. 2014. “Application Challenges for the Social Life Cycle Assessment of Fertilizers within Life Cycle Sustainability Assessment.” *Journal of Cleaner Production* 69: 34–48. http://dx.doi.org/10.1016/j.jclepro.2014.01.044.

ModpoW. 2023. “AgriTechnologies.” https://www.modpowagritech.com/campaigns/landing-202107c/ (April 26, 2023).

Núñez-Cárdenas, Pablo et al. 2022. “Environmental LCA of Precision Agriculture for Stone Fruit Production.” *Agronomy* 12(7). https://doi.org/10.3390/agronomy12071545.

Núñez, P. et al. 2022. “A Case Study on the Application of Product Social Impact Assessment to the Agri-Food Sector: Ready-to-Eat Beetroot.” *Proceedings of the 17th International Conference on Environmental Science and Technology* 17(September): 1–4.

Omran, N., A.H. Sharaai, and A.H. Hashim. 2021. “Visualization of the Sustainability Level of Crude Palm Oil Production: A Life Cycle Approach.” *Sustainability (Switzerland)* 13(4): 1–16.

PROBODELT. 2023. “Captura Masiva -Frutales de Hueso (Albaricoque, Nectarina, Melocotón, Ciruela) - Tienda Online Probodelt.” https://tienda.probodelt.com/cultivos/frutales-de-hueso-albaricoque-nectarina-melocoton-ciruela/ (April 26, 2023).

SIAM. 2020. “Sistema de Información Agraria de Murcia.” http://siam.imida.es/apex/f?p=101:1:660534674714209::NO::: (March 31, 2023).

Som Energia. 2022. “Histórico de Tarifas de Electricidad.” https://www.somenergia.coop/es/tarifas-de-electricidad/historico-de-tarifas-de-electricidad/ (April 27, 2022).

TAMIC. 2022. “Medida y Control | TAMIC, S.L.” http://www.tamic.es/es/ (April 26, 2023).

UNEP. 2011. *Towards a Life Cycle Sustainability A Ssessment: Making Informed Choices on Products.*

———. 2020. *Guidelines for Social Life Cycle Assessment of Products and Organizations 2020.*

Zude-Sasse, M, S Fountas, T A Gemtos, and N Abu-Khalaf. 2016. “Applications of Precision Agriculture in Horticultural Crops.”