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Proceeding Paper

The Impact of Regenerative Agriculture on Provisioning Ecosystem Services: An Example in Southeast Spain †

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Abstract: The objective of this work is to evaluate the impact of regenerative agriculture alternatives in rainfed almond crops on a range of ecosystems services. A Multi-Criteria Analysis (MCA) was conducted to evaluate the different land management alternatives integrating different quantitative and qualitative indicators based on long-term field research. Three land management alternatives were analyzed: (i) conventional management, (ii) native cover crops, and (iii) seeded cover crops. MCA was able to evaluate the performance of the three alternatives considering different priorities of two groups of farmers (conventional and regenerative) and score the different scenarios. The alternative of natural cover crops had the best score in almost all the groups of ecosystem services and economic indicators. The sustainability, acceptance, and stability of the scenarios were achieved and provided an integrated view of impacts that can help decision making.

Keywords: multi-criteria analysis; ecosystem services; regenerative agriculture; CAP; Green Deal

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1. Introduction

Prunus dulcis Mill. crops in the provinces of Almeria, Granada, and Murcia are traditionally cultivated in extensive systems with low production and input levels [1]. However, some studies have shown that certain practices used in this type of production model, such as intensive ploughing, can decrease soil quality, leading to the loss of ecological system functions [2,3]. Currently, intensive tilling is performed on conventional rain-fed almond cultivation with low-input systems (3–5 annual passes) at a depth of up to 15–20 cm. Some alternative practices within regenerative agriculture (RA) include reduced tillage, allowing for the presence of vegetation cover for most of the year, which can be either natural (spontaneous) or sown (seeded cover crops). These regenerative practices improve soil quality by (i) reducing erosion [1], (ii) enhancing physical–chemical–biological soil parameters [4,5], and (iii) reducing greenhouse gas emissions [6]. This approach aims to restore and improve the health of agricultural systems and the surrounding ecosystems [7].

RA can enhance ecosystem services (ESs) in ways that are not always accounted for in traditional economic indicators [8]. This has led to a recognition of the urgent need to protect these services and has resulted in the creation of new policies and the inclusion of ESs in existing policies [9]. The main objective of this work is to compare two different sustainable land management alternatives of RA, native cover crops (NCCs) and seeded cover crops (SCCs), to conventional management (CM), as well as their impact on ESs in rain-fed almond farms.

2. Materials and Methods

Available data and newly obtained data were organized in a framework of ESs divided in (i) large ES groups, (ii) ES subgroups, and (iii) financial indicators (Table 1). Three land management alternatives representing different agricultural practices in rain-fed almond crops were defined: CM with 3–4 tillage operations per year [1]; NCC that consist of enhancing green cover under almond trees based on the natural seed bank of the soil, with 1, 2, or no tillage operations per year; and SCC that consists of seeding a mix of vetch (*Vicia sativa* L.) and common oat (*Avena sativa* L.) in a proportion of 3:1, at 150 kg·ha^{-1}. Cover crops were seeded yearly in autumn and incorporated into the soil with a cultivator in early May.

Table 1. ES indicators, and sources of data used to evaluate the management scenarios.

ES		Indicators	Data Sources
Group	Subgroup		
Supporting	Habitat	Cover crop	Fernández-Soler et al., 2024 [5]
	Soil fertility	OC	Fernández-Soler et al., 2024 [5]
		N	Fernández-Soler et al., 2024 [5]
		P	Fernández-Soler et al., 2024 [5]
		Ca	Fernández-Soler et al., 2024 [5]
		Mg	Fernández-Soler et al., 2024 [5]
		C:N	Fernández-Soler et al., 2024 [5]
		Soil respiration	Fernández-Soler et al., 2024 [5]
Regulating	Climate regulation	Carbon stock	Fernández-Soler et al., 2024 [5]
		Greenhouse gas emissions (GHG)	Martín-Gorriz et al., 2020 [6]; Almagro et al., 2016 [2]
	Nutrient regulation	OC balance	Martinez Mena et al., 2020 [1]
		N balance	Martinez Mena et al., 2020 [1]
		P balance	Martinez Mena et al., 2020 [1]
		CEC	Fernández-Soler et al., 2024 [5]
	Erosion control	Sediment yield	Martinez Mena et al., 2020 [1]
		Soil MWD	Fernández-Soler et al., 2024 [5]
		Soil density	Fernández-Soler et al., 2024 [5]
		Above-ground biomass	Fernández-Soler et al., 2024 [5]
Provisioning	Food	Production	Almagro et al., 2016 [2]; Martín-Gorriz et al., 2020 [6]; De Leijster et al., 2020 [10]; Ozbolat et al., 2023 [4]
	Water	Soil available water content	Fernández-Soler et al., 2024 [5]
Cultural	Natural character	Natural elements	Interviews and surveys (2020–2023)
	Identity	Satisfaction	Interviews and surveys (2020–2023)
	Agricultural and natural heritage	Legacy	Interviews and surveys (2020–2023)
Financial indicators	Profit	Cost–benefit	Almagro et al., 2016 [2]; Martín-Gorriz et al., 2020 [6]; De Leijster et al., 2020 [10]; Ozbolat et al., 2023 [4]

All data used in the construction of the ES indicators and for evaluating the scenarios were generated within the Soil and Water Conservation Group of CEBAS-CSIC.

2.1. Interviews

Twenty semi-structured in-depth interviews were conducted and served 2 purposes: (i) provide information on almond prices, costs of inputs, and priorities regarding ecosystems services, and (ii) analyze the values behind the choice of practices. A value tree was constructed for each farmer based on the qualitative information provided in their responses and later combined in 2 common value trees for conventional and regenerative farmers [3]. A part of the interview results was incorporated in the evaluation as cultural ES indicators and financial indicators. Furthermore, the perspectives of the farmers were used to assign weights to the different groups of ESs. Cultural services are related to intangible benefits that can be expressed in various ways. We transformed the indicators 'natural character', 'identity', and 'agricultural and natural heritage' to a qualitative −/+ scale (Table 1) [11]. Values for 'natural character' were based on [12]. Values of 'identity' and 'agricultural and natural heritage' were established based on a personal satisfaction index of farmers including the 'inspiration', 'spiritual experience', and 'cognitive development' indicators as stated in [13].

2.2. Data Sources

Production data per year were established as the average data provided by farmers, national statistics [14], and the scientific literature in [2,4,6,10]. Almond price per year was calculated as the average between information provided by farmers, exchange price (Lonja de Murcia), and data as published in [6,10].

Physical, chemical, and biological soil properties indicators were extracted from published work in [1,5,6] and available datasets at CEBAS-CSIC, as seen in Table 1.

2.3. Multi-Criteria Analysis

Software Definite 3.1 [11] was used as it allows for the incorporation of both quantitative and qualitative data through the construction of an effects table, for the standardization and ranking of values, and for the assignment of weights to each effect [11]. Maximum standardization was used according to the positive or negative effect of each parameter with the exception of parameters 'cover crop' (binary yes/no) and the C:N relation (interval scale with optimal relation set at 30:1 as in [15]. Weights were established using the pairwise comparison method based on knowledge derived from the interviews and soil experts at CEBAS-CSIC.

3. Results and Discussion

3.1. ES Provided by the Different Management Alternatives

The effects table (Table 2) was constructed by combining the concept and selection of indicators for ES from [13].

For the group of supporting ESs, C:N and soil respiration were used as the main indicators since this process has been a focus of attention due to its importance as the primary source of carbon flux from the soil and as an essential component in the carbon cycle in terrestrial ecosystems [16]. The C:N relation was increased by 7.6% and 9.60%, whilst soil respiration increased by 42.5% and 20% under NCC and SCC, respectively. This is consistent with previous research showing the benefits of cover crops to the microbial community, accelerating the composting of organic matter [5,15].

We considered three regulating ESs (Table 2): climate-regulating indicators provided insight into net carbon sequestration, showing higher GHGs under SCC but also higher carbon stocks in soil compared to other alternatives [6]. NCC and SCC show higher nutrient losses in sediment yields but a higher Cation Exchange Capacity (CEC) of analyzed soil as stated in [2]. For erosion control, we had quantitative information on sediment yield and physical properties obtained in the field. The main erosion control indicator used was sediment yield, showing a decrease of 82.86% and 70.8% under NCC and SCC [1].

The provisioning ES indicators used were 'production' and 'soil available water content' (AWC), where SCC showed the lowest production values, decreasing 28.96%, and the highest AWC, increasing 14.06%. NCC showed a 29.6% increase in production, whilst soil water content increased by 1.95% [2,6,10].

Cultural indicators were taken from value trees based on the interviews with farmers, following [11] a −/+ scale, where --- corresponds to a 'very negative effect' and +++ a 'very positive effect'. NCC and SCC showed equally positive results when compared to CM.

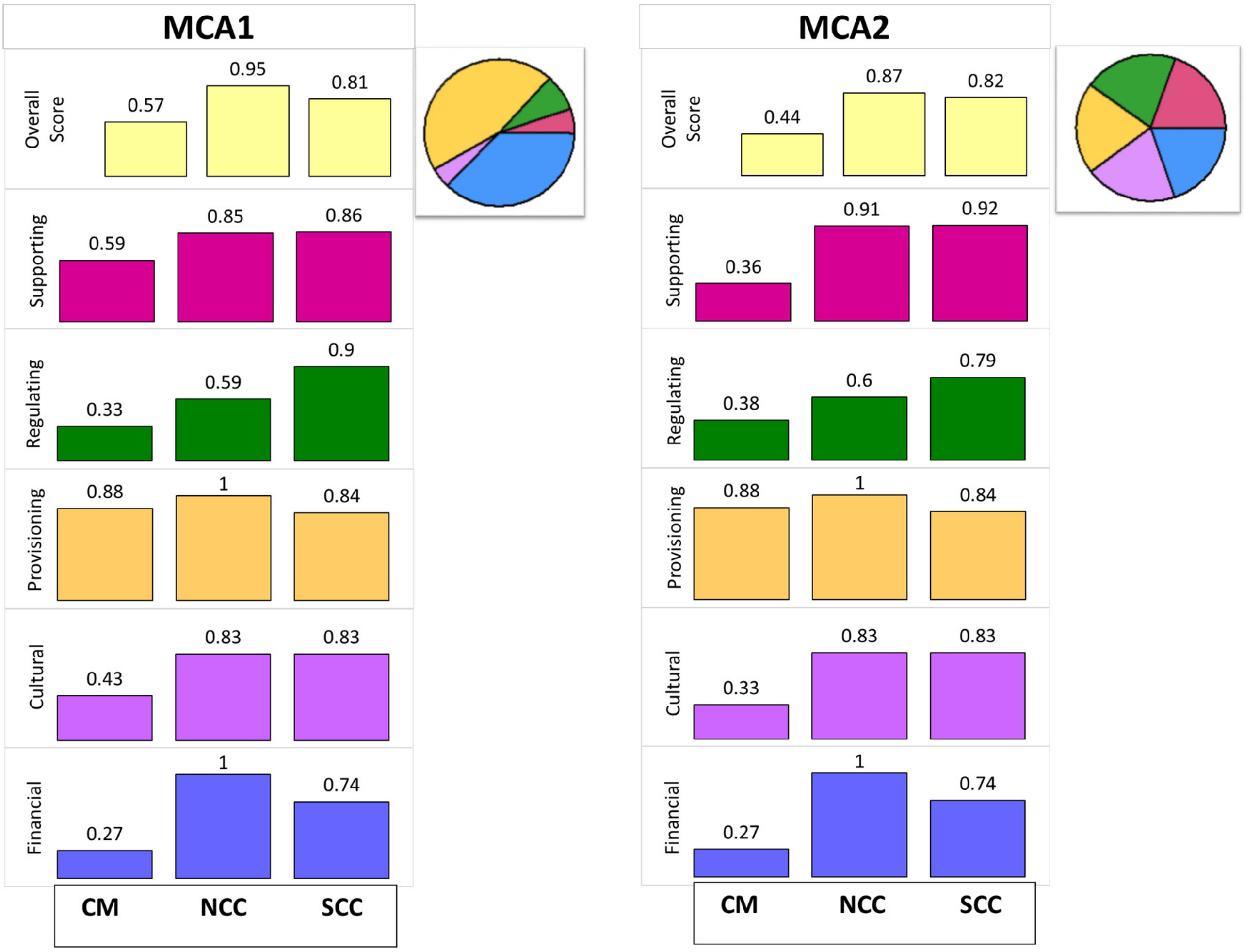
Table 2. Effects table: CM (conventional management), NCC (natural cover crop), and SCCs (seeded cover crop).

Indicators	Cost (C) or Benefit (B)	Unit	Standardization Method	CM	NCC	SCC
Cover crop	B	yes/no	Binary 1/0	no	yes	yes
OC	B	g kg^{-1}	maximum	11.74	11.81	16.01
N	B	g kg^{-1}	maximum	1.27	1.18	1.59
C:N	B		goal	9.27	9.97	10.16
Soil respiration	B	BRmgC-CO_2 g^{-1} Cod^{-1}	maximum	0.40	0.57	0.48
Ca and Mg	B	g kg^{-1}	maximum	27.53	30.72	26.80
P	B	ppm	maximum	16.34	20.86	22.17
Carbon stock	B	g ha^{-1}	maximum	2570.93	2813.71	3463.75
GHG	C	kg^{-1} CO_2 eq/ha^{-1}	maximum	120	97.50	177.50
OC balance	B	ppm	maximum	−1.54	−1.69	−0.90
N balance	B	ppm	maximum	−0.20	−0.15	−0.12
P balance	B	ppm	maximum	−28.45	−28.50	−23.83
CEC	B	meq/100 g	maximum	9.80	17.83	15.44
Sediment yield	C	g m^2	maximum	2.84	0.41	0.72
Soil MWD	B	mm	maximum	62.23	59.72	81.71
Above-ground biomass	B	g m^2	maximum	45.94	129.40	176.48
Production	B	kg $(kernel)^{-1}$ ha^{-1} yr^{-1}	maximum	159.46	206.67	113.28
Soil available water content	B	%	maximum	11.33	11.55	12.92
Natural elements	B	---/+++	maximum	---	++	++
Satisfaction	B	---/+++	maximum	0	++	++
Legacy	B	---/+++	maximum	0	++	++
Cost–benefit	B	EUR ha^{-1} yr^{-1}	maximum	67.49	254.06	188.42

Profit was calculated as the difference between operational costs and net benefit (with CAP subsidies) per ha, showing a 276.47% and 179.2% increase in NCC and SCC, respectively.

3.2. Comparison of the Scenarios

Two MCAs were conducted, with different weight distributions based on the analysis of the farmer's value trees. The distribution of weights was balanced in the case of farmers applying RA managements, whilst with conventional farmers, they were skewed towards 'provisioning' ES and financial indicators. Nonetheless, MCA scores were similar. NCC performed better than SCC, which in turn performed better than CM in both MCAs. Scores for different groups of ESs and the total score are shown in detail in Figure 1. The scenarios NCC and SCC obtained similar results for supporting and regulating ES and identical scores in cultural ES in both MCAs. Provisioning ES scores showed better performance for CM and NCC with similar scores in both MCAs (0.88 and 1, respectively), with SCC performing slightly worse (0.84) in both MCAs. Regarding financial indicators, the MCA results show that NCC had the highest score, followed by SCC and then MC last, with scores of 1, 0.74, and 0.27, respectively, in both MCAs. Overall scores according to the different weights were consistent with individual scores and showed NCC as the best performing land management in both MCAs, with a slightly stronger difference in MCA1, with the exception of supporting and, most notably, regulating ES, where SCC shows the best performance.



(a) (b)

Figure 1. Scores of the different scenarios with different weight combinations (yellow: overall score; pink: supporting ES; green: regulating ES; orange: provisioning ES; purple: cultural ES; blue: economic ES). (**a**) MCA1 shows results for conventional farmers under their practices and views (as exposed in interviews). (**b**) MCA2 shows results for regenerative farmers under their practices and views (as exposed in interviews).

The transition to RA practices holds the promise of improving soil quality, reducing erosion, and mitigating GHG emissions. Comprehensive impact assessments are needed to inform decision making [16,17]. In this context, MCA tools can help in these mentioned purposes integrating different types of data and evaluating complex scenarios, ensuring a holistic approach to sustainability [18]. Sustainable agriculture encompasses not only physical and biological factors, such as soil quality and biodiversity, but also human and economic dimensions; furthermore, we also need to incorporate local context and stakeholder engagement in the integrated evaluations, providing a mechanism for gathering context-specific data and fostering the active participation of affected parties in the decision-making process [19,20]. One effective and underexplored method to incorporate stakeholder views is the use of the value analysis of stakeholders. Analyzing the values is crucial for building trust and collaboration between scientists and practitioners and also gives us criteria to prioritize the different interests in ecosystem services of the farmers. Impact assessments can capture these values among stakeholders, providing valuable guidance to decision makers in aligning plans with the prevailing values.

This study shows that RA practices can be used as a solution to enhance ES whilst enhancing cultural values and farmer income. In this manner, soil regeneration and the sustainability of local crops and farmers' ways of life can be guaranteed for the near-future [17].

By considering the local environmental context, socioeconomic factors, and specific management objectives, the results of this study suggest that NCC and SCC have the potential to provide multiple benefits in terms of ES and are economically even more profitable than CM. These regenerative practices (NCC and SCC) demonstrate positive impacts on supporting, regulating, provisioning, cultural ES, and financial indicators. While the specific effects may vary based on the management approach and farmer perspectives, the overall performance consistently favors NCC, making it a promising land management strategy for enhancing ecosystem health and agricultural sustainability. The low adoption of these practices is constrained by many sociological factors and non-scientific-based, traditional beliefs such as competition for water and nutrients between the main and secondary crop, and the extension of plagues due to the secondary crop. To overcome the social barriers for adoption of a large cooperation between farmers, extension services and scientists are needed to determine whether they are real constraints or not in each specific–local condition.

4. Conclusions

From the agricultural management scenarios analyzed in this research, NCC appears as the most sustainable scenario, close to SCC, using the 22 indicators selected including financial criteria, representing all the groups of ESs and based on first-hand field information.

The inclusion of cultural ES, the economic indicators, and the perspectives of the two different groups of farmers in the analysis allows a more interdisciplinary and robust evaluation than an evaluation on regulating, provisioning, and supporting ES based on physical, chemical, and biological indicators exclusively.

Further research and the wider adoption of these practices have the potential to contribute to more resilient and environmentally friendly agricultural systems, contributing to the sustainability of soil regeneration, local crops, and the livelihoods of farmers in semi-arid regions.

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