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THE IMPACT OF REGENERATIVE AGRICULTURE IN 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 offer the performance of the 3 alternatives considering different priorities of 2 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. Sustainability, acceptance, and stability of the scenarios was achieved and provided an integrated view of impacts that can help decision making.

Keywords: multicriteria analysis; ecosystem services; regenerative agriculture; CAP; Green Deal

1. Introduction

Prunus Dulcys crops in the provinces of Almeria, Granada, and Murcia, are traditionally carried out 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 inputs 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 (ES) 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 ES in existing policies [9]. The main objective of this work is to compare 2 different sustainable land management alternatives of RA: native cover crops (NCC) and seeded cover crops (SCC) to conventional management (CM), and their impact on ES in rain-fed almond farms.

2. Materials and methods

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Available data and newly-obtained data were organized in a framework of ES organized in (i) large ES groups, (ii) ES subgroups and (iii) financial indicators (Table 1). Three land management alternatives representing different agricultural practices in rainfed almond crops were defined: CM with 3-4 tillage operations per year [1], NCC that consists in enhancing a green cover under the almond trees based on the natural seed bank of the soil, with one, 2 or no tillage operations per year; and SCC that consists in 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, 2022
	Soil fertility	OC	Fernández-Soler, 2022
		N	Fernández-Soler, 2022
		P	Fernández-Soler, 2022
		Ca	Fernández-Soler, 2022
		Mg	Fernández-Soler, 2022
		C:N	Fernández-Soler, 2022
		Soil respiration	Fernández-Soler, 2022
Regulating	Climate regulation	Carbon stock	Fernández-Soler, 2022
		Greenhouse gas emissions (GHG)	Martín-Gorriz et al., 2020; Almagro et al., 2017
	Nutrient regulation	OC balance	Martinez Mena et al., 2020
		N balance	Martinez Mena et al., 2020
		P balance	Martinez Mena et al., 2020
		CEC	Fernández-Soler, 2022
	Erosion control	Sediment yield	Martinez Mena et al., 2020
		Soil MWD	Fernández-Soler, 2022
		Soil density	Fernández-Soler, 2022
		Above-ground biomass	Fernández-Soler, 2022
Provisioning	Food	Production	Almagro et al., 2016; Gorriz et al., 2020; De Leijster et al., 2020; Ózbolat et al., 2023
	Water	Soil available water content	Fernández-Soler, 2022
Cultural	Natural character	Natural elements	Interviews & surveys (2020-20023)
	Identity	Satisfaction	Interviews & surveys (2020-20023)
	Agricultural and natural heritage	Legacy	Interviews & surveys (2020-20023)
Financial indicators	Profit	Cost-benefit	Almagro et al., 2016; Gorriz et al., 2020; De Leijster et al., 2020; Ózbolat et al., 2023

[1] 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) to 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 respectively [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 ES. Cultural services are related to intangible benefits that can be expressed in various ways. We transformed indicators 'natural character', 'identity', and 'agricultural and natural heritage' to a qualitative -/+ scale (Table 1) [10]. Values for 'natural character' based on [11]. Values of "identity" and "agricultural and natural heritage" were established based on a personal satisfaction index of farmers including 'inspiration', 'spiritual experience', and 'cognitive development' indicators as stated in [12].

2.2. Data sources

Production data per year was established as the average data provided by farmers, national statistics [13] and scientific literature in [2,4,6,14]. Almond price per year was calculated as the average between information provided by farmers, exchange price (Lonja de Murcia), and data as published in [6,14].

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 [10] was used as it allows for the incorporation of both quantitative and qualitative data through the construction of an effects table, standardization and ranking of values, and the assignment of weights to each effect [10]. 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 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 [12].

For the group of supporting ES, 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]. 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 3 regulating ES (Table 2): Climate regulating indicators provided an insight into net carbon sequestration, showing higher GHG under SCC but also higher carbon stocks in soil compared to other alternatives [17]. 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, that showed a decrease of 82.86% and 70.8% under NCC and SCC [1].

Provisioning ES indicators used were 'production' and 'soil available water content' (AWC), were 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 incresed by 1.95% [2,6,14].

Cultural indicators were taken from value trees based on the interviews with farmers, following [10] 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.

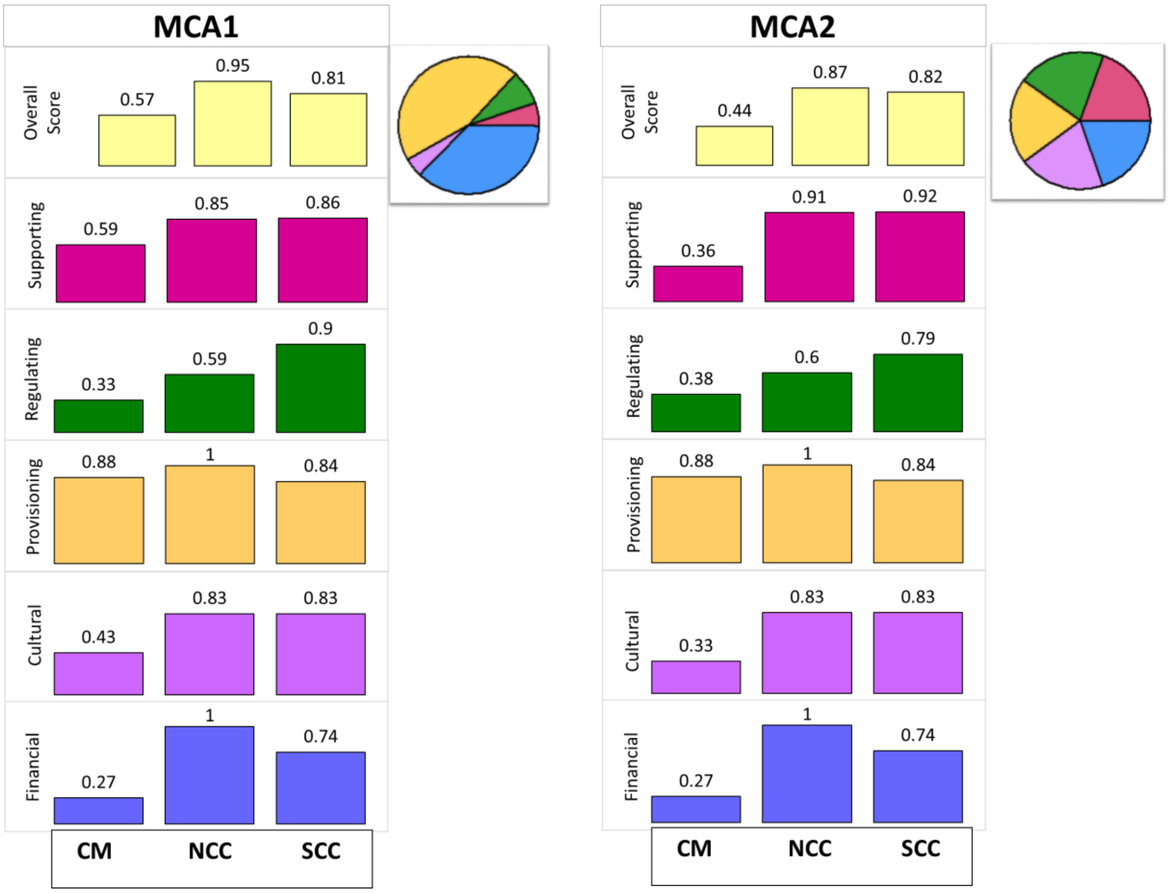
Profit was calculated as the difference between operational costs and net benefit (with CAP subsidies) per ha, showing a 276.47% and 179.2% increase in NCC and SCC, respectively.

Table 2. Effects table: CM (conventional management), NCC (natural cover crops), & SCC (seeded cover crops).

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-CO2g^{-1} Cod^{-1}	maximum	0.40	0.57	0.48
Ca & 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	2,570.93	2,813.71	3,463.75
GHG	C	kg^{-1} CO2 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/100g	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	€ ha^{-1} yr^{-1}	maximum	67.49	254.06	188.42

3.2. Comparison of the scenarios

Two MCAs were conducted, with different weight distribution based on the analysis of the farmer's value trees. Distribution of weights were 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 MCA. Scores for different groups of ES and 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 slighly worse (0.84) in both MCAs. Regarding financial indicators, MCA results show NCC had the highest score, followed by SCC and 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 differnce in MCA1, with the exeption of supporting, and most notably regulating ES, where SCC show 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 [16,18]. In this context MCA tools can help to these mentioned purposes integrating different type of data and evaluate complex scenarios, ensuring a holistic approach to sustainability [19]. 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 in the integrated evaluations local context and stakeholder engagement providing a mechanism for gathering context-specific data and fostering the active participation of affected parties in the decision-making process [20,21]. One effective and underexplored method to incorporate stakeholder views is the use of value analysis of stakeholders. Analysing the values is crucial for building trust and collaboration between scientists and practitioners and give us also 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 farmers income. In this manner, soil regeneration and the sustainability of local crops and farmers ways of life can be guaranteed for the near future [18].

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 favours 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 the secondary crop, the extension of plagues due to the secondary crop and many others. To overcome the social barriers for adoption a large cooperation between farmers, extension services and scientists is needed to determine whether they are real constraints or not in each specific-local conditions.

4. Conclusions

From the agricultural management scenarios analysed 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 ES and based on first-hand field information.

The inclusion of cultural ES, the economic indicators, and the perspectives of the 2 different group 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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