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The role of primary producers in agricultural waste management: Perceptions and challenges in the transition to a circular economy

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Electronic supplementary material

Appendix 1–2
Figures S1–S2
Tables S1–S7

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APPENDIX 1: METHODOLOGY

Economic importance of primary production

Table S1. Agricultural and livestock production in Spain (2023)

Subsector		Value (million EUR)
Agricultural	vegetables	13 142.5
	fruit	11 096.6
	cereals	3 066.4
	forage plants	2 800.6
	olive oil	2 502.8
	wine and grape juice	1 069.8
	industrial plants	1 056.4
	potatoes	841.8
	others	169.6
Livestock	pork	11 547.8
	bovine	3 715.9
	poultry	3 212.4
	sheep and goats	1 196.9
	equine	85.5
	others	165.5

Source: Own elaboration based on Anuario de Estadística del Ministerio de Agricultura, Pesca y Alimentación del Gobierno de España of 2023 (MAPA 2024)

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Characterization of producers

A. Attributes of primary producers. The surveyed primary producers typically fall within the age range of 26 to 55, with an average experience of 19.3 years in agricultural and livestock work. Educational backgrounds vary from primary school to university studies. Interestingly, the age distribution of the surveyed primary producers deviates from the 2020 Spanish Agrarian Census for farm owners, reflecting a younger demographic. However, this aligns more closely with the age distribution of those employed in primary production (PP) according to INE (2023), suggesting that the survey primarily represents the workers overseeing farm activities. The territorial distribution mirrors that of agricultural holdings indicated by the 2020 Agricultural Census (INE 2022) (Figure S1).

B. Characteristics of the farms. Around 70% of the farms primarily engage in agricultural production, consistent with the 2020 Agricultural Census (INE 2022). The major crops in agriculture include arable crops, citrus fruit trees, and olive groves. In livestock farming, white coat pigs, beef and dairy cattle, and sheep/goats are predominant. Economic size, measured by sales figures, typically ranges from EUR 8 000 to EUR 499 999, with a notable prevalence of large holdings. In general, 84.6% of primary producers have agriculture or livestock as their main activity. The majority of respondent-owned farms range from 10 to 99.9 ha (Figure S2). The technical factors of agricultural and livestock farms align with those indicated by the Spanish Agricultural Census of 2020 (INE 2022).

C. Waste management and knowledge of the concept of circular economy. Ninety-eight percent of respondents reported adhering to regulations in treating agricultural residues post-production, involving methods such as delivery to waste treatment plants or the use and sale of by-products. However, nearly 70% encountered challenges managing specific waste types due to the absence of specialized treatment plants in their areas, leading to prolonged waste management. Additionally, 65.7% of primary producers claimed perception of the economic system based on CE, while 11.9% had heard of it.

D. Environmental perception. Primary producers expressed a moderate to high environmental perception, encompassing environmental perception (EA), subjective norms (SN), perceptual control (PC), general environmental care attitudes (GECA) and views on regulatory proposals (RP) (Table S2). Notably, Spanish farmers and livestock breeders emphasized the necessity of waste management to uphold good practices for consumers. They underscored the shared responsibility among various stakeholders, emphasizing the role of the Administration. While primary producers advocated against the tightening of waste management laws or increased economic sanctions, they called for more resources to enhance management capacity and improve the training of PP workers.

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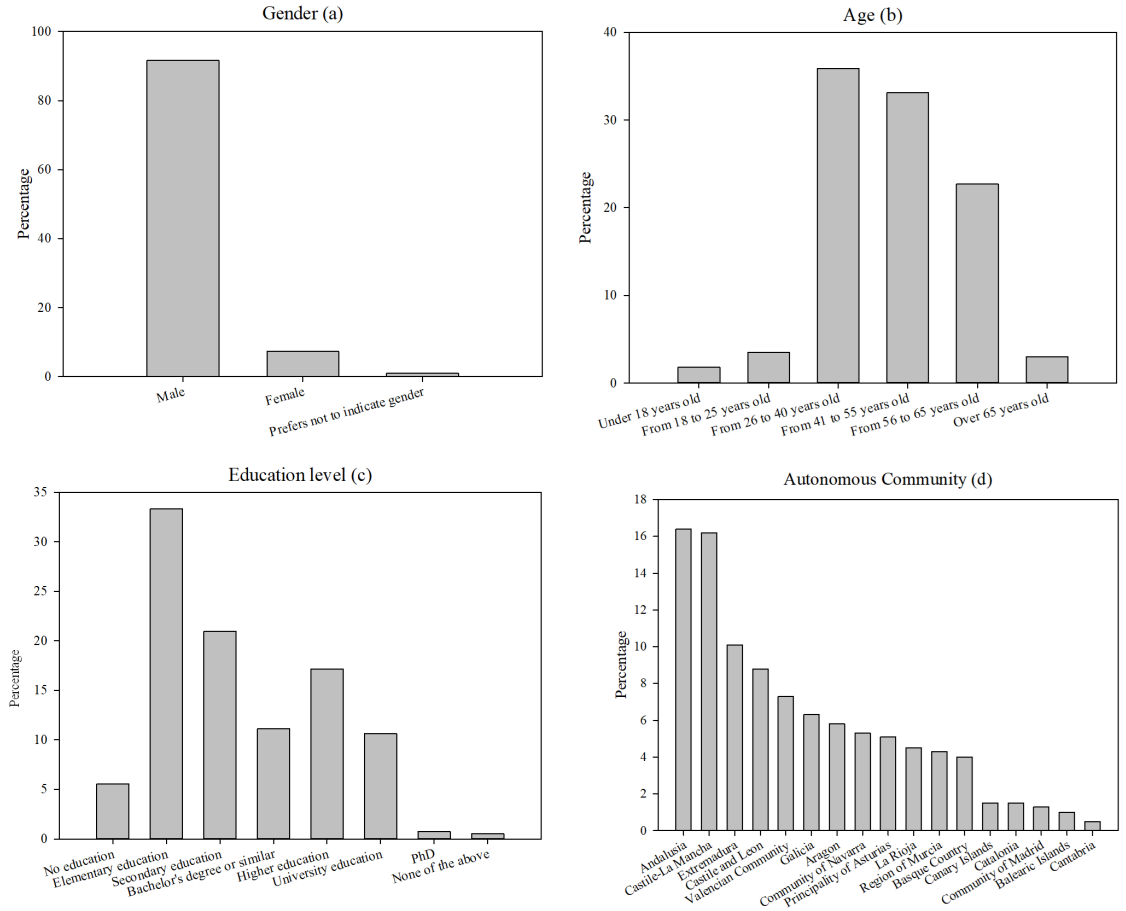

Figure S1. Attributes of Spanish primary producers surveyed: (A) gender; (B) age; (C) level of education; (D) autonomous community

Source: Authors' own elaboration

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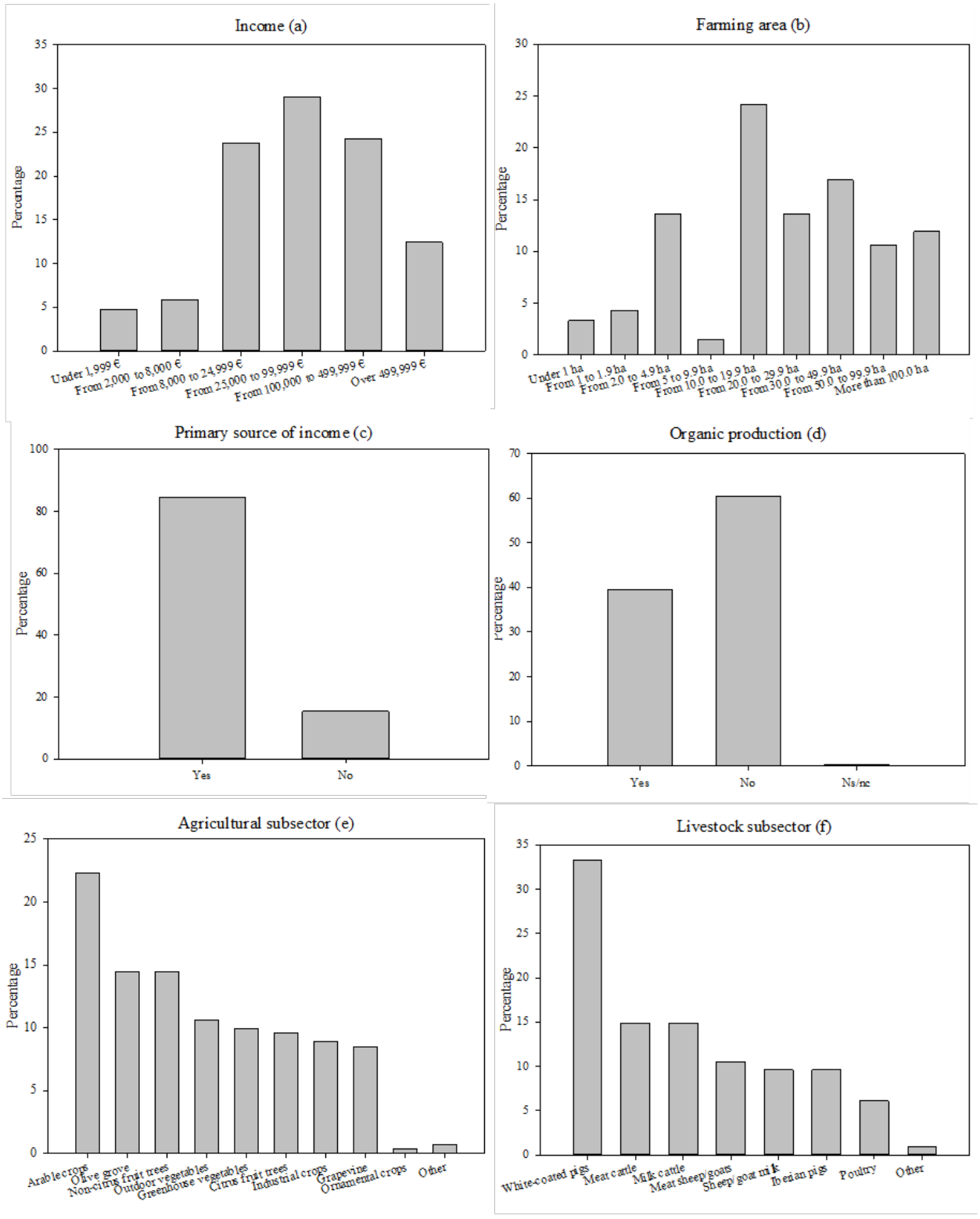

Figure S2. Attributes of Spanish farms: (A) farm income; (B) farm area; (C) primary production as main source of income; (D) organic production; (E) agricultural subsector; (F) livestock subsector.

Source: Authors' own elaboration

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Table S2. Average environmental perception of the Spanish primary producer.

Statement	Code*	Value
Recycling waste from my farm is a best practice	ea1	3.94
Recycling my farm waste is good for the environment	ea2	3.94
Recycling my agricultural waste improves the ecological image of my agricultural or livestock farming activity	ea3	3.63
Recycling waste in agriculture or livestock farming is an absolute necessity	ea4	4.09
Managing my farm waste helps to justify good practices to consumers	ea5	4.03
Most people who are important to me think that recycling waste in agriculture or livestock farming is absolutely necessary	sn1	3.91
Most of the people who are important to me think that I should recycle the waste from my farming activity	sn2	3.96
I believe that most agricultural and/or livestock farmers will recycle more and more waste in their farming activities	sn3	3.33
I find it very easy to recycle agricultural waste	pc1	2.44
My knowledge of recycling and the environmental impact caused by the waste generated on my farm is sufficient for efficient waste management	pc2	3.06
The resources (human and material) available on my farm are sufficient to correctly manage the waste generated in my activity	pc3	3.05
Whether or not I apply waste management depends entirely on me and not on the factors that facilitate or hinder agricultural waste management	pc4	2.34
Human beings seriously affect the environment	geca1	3.71
Every living must be cared for	geca2	4.24
By recycling, I contribute to reducing the amount of agricultural or livestock waste	geca3	3.56
The Administration should improve my training in agricultural and livestock waste management	rp1	3.77
The Administration should subsidise the management of residues	rp2	3.99
The Administration should increase the number of waste management plants on my territory	rp3	3.96
The Administration should increase environmental control to sanction farmers or stockbreeders who carry out bad practices regarding waste management	rp4	3.69
The Administration should implement a traceability system to identify farmers and ranchers who do not manage their waste	rp5	3.87
The Administration should tighten environmental regulations	rp6	2.76

*Statement code. Scale: 1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree
Source: Authors' own elaboration

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APPENDIX 2: RESULTS

Table S3. Sociodemographic variables of surveyed farmers by cluster.

Parameter	Subparameter	Active (%)	Passive (%)
Sex	male	90.9	93.5
	female	8.7	3.7
	preferes not to say	0.3	2.8
Educational level	no education	2.1	15
	primary education	29.4	44.9
	secondary education (ESO or similar)	23.1	15
	higher education (Baccalaureate or similar)	13.3	4.7
	higher education	19.6	10.3
	university degree	11.5	8.4
	doctoral degree	1.0	0
	none of the above	0.0	1.9
Location	Andalusia	16.4	16.8
	Aragon	5.9	5.6
	Canary Islands	1.7	0.9
	Cantabria	0.7	0.0
	Castile and Leon	8.4	10.3
	Castile-La Macha	17.1	13.1
	Catalonia	1.7	0.0
	Community of Madrid	1.7	0.0
	Foral Community of Navarre	5.9	3.7
	Valencian Community	7.0	8.4
	Extremadura	8.7	14
	Galicia	8	1.9
	Balearic Islands	1.0	0.9
	La Rioja	3.8	5.6
	Basque Country	4.9	1.9
	Principality of Asturias	4.2	7.5
	Region of Murcia	2.4	9.3

Source: Authors' own elaboration

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Table S4. Descriptor parameters of agricultural holdings by cluster.

Parameter	Subparameter	Active (%)	Passive (%)
Activity	agriculture	69.6	74.8
	livestock	30.4	25.2
Agricultural sub-sector	arable crops	24.6	16.3
	industrial crops	9.5	6.3
	vegetables under greenhouse	12.6	3.8
	outdoor vegetables	11.1	10.0
	olive groves	11.6	22.5
	grapevine	7.0	11.3
	non-citrus fruit trees	14.1	16.3
	ornamental crops	0.5	0.0
	citrus fruit trees	8.0	13.8
	other agriculture	1.0	0.0
Livestock sub-sector	sheep/goats for milk	12.6	0.0
	sheep/goat meat	10.3	11.1
	Iberian swine	6.9	18.5
	beef cattle	13.8	18.5
	cattle for milk	16.1	11.1
	white-coat swine	32.2	37.0
	poultry meat	6.9	3.7
	other livestock	1.1	0.0
Experience in the sector		13.7	34.2
Organic production		39.9	39.3
Primary production as main livelihood		85.3	82.2
Performs waste management		97.6	99.1
Has problems to manage waste		67.1	70.1

Source: Authors' own elaboration

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Table S5. Average environmental perception of the Spanish primary producer by cluster.

Parameter	Code	Active	Passive
Recycling waste from my farm is a best practice	a1	4.08	3.56
Recycling my farm waste is good for the environment	a2	4.08	3.58
Recycling my agricultural waste enhances the ecological image of my agricultural or livestock farming activity	a3	3.80	3.16
Recycling waste in agriculture or livestock farming is an absolute necessity	a4	4.29	3.55
The management of my farm waste helps to justify good practices to consumers.	a5	4.17	3.66
Most of the people who are important to me think that waste recycling in agriculture and livestock farming is absolutely necessary	sn1	4.05	3.52
Most of the people who are important to me think that I should recycle the waste from my farming activity	sn2	4.09	3.60
I think that most farmers and/or livestock breeders will recycle more and more waste in their farming activities	sn3	3.33	3.32
It is very easy for me to recycle my agricultural waste	pc1	2.48	2.37
My knowledge of recycling and the environmental impact caused by the waste generated on my farm is sufficient for efficient waste management	pc2	3.06	3.09
The resources (human and material) available on my farm are sufficient for the proper management of the waste generated in my activity	pc3	3.03	3.11
Whether or not I apply waste management depends entirely on me, and not on the factors that facilitate or hinder the management of agricultural waste	pc4	2.40	2.22
Human beings seriously affect the environment	pea1	3.95	3.07
Every living thing must be cared for	pea2	4.37	3.90
By recycling, I contribute to reducing the amount of agricultural or livestock waste	pea3	3.67	3.28

Scale: 1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree
Source: Authors' own elaboration

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Table S6. ANOVA analysis.

Parameter	Root mean square	d*f*	Fisher's *F* test	*P*-value
Knowledge of Circular Economy	0.691	391	3.280	0.071
The Administration should increase the number of waste management plants on my territory	1.237	391	2.337	0.127
The Administration should subsidise waste management	1.168	391	2.100	0.148
Location (Autonomous Communities)	24.979	391	1.958	0.162
Whether or not I apply waste management depends entirely on me and not on the factors that facilitate or hinder the management of agricultural waste	1.578	391	1.440	0.231
Activity	0.206	391	1.014	0.314
Performance or non-performance of waste management	0.080	391	0.891	0.346
I find it very easy to recycle agricultural waste	1.490	391	0.578	0.447
Primary production as the main source of income	0.132	391	0.558	0.455
Livestock Subsector	5.053	391	0.554	0.457
The resources (human and material) available on my farm are enough for the proper management of the waste generated in my activity	1.415	391	0.358	0.550
Problems in waste management	0.219	391	0.312	0.577
My knowledge of recycling and the environmental impact caused by the waste generated on my farm is enough for an efficient waste management	1.729	391	0.063	0.801
Organic production	0.241	391	0.012	0.913
I think most agricultural and livestock farmers will recycle more and more waste in their farming activities	1.683	391	0.003	0.960
Sex	0.106	391	0.001	0.980

Source: Authors' own elaboration

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Table S7. Multiple linear regression that relates the years of dedication to PP to the other factors of the respondents and the technical and economic parameters of their farms.

Model	Parameter	β non-standardised	SD	β standardised	*t*	*P*-value
1	production system	0.054	0.074	0.027	0.726	0.468
	income	0.006	0.035	0.008	0.171	0.864
	EA	–0.023	0.070	–0.018	–0.332	0.740
	SN	–0.036	0.060	–0.031	–0.591	0.555
	PC	–0.025	0.042	–0.024	–0.600	0.549
	waste management	0.193	0.128	0.055	1.508	0.132
	surface	0.010	0.017	0.022	0.566	0.572
	sex	–0.010	0.110	–0.003	–0.092	0.927
	education	–0.054	0.026	–0.086	–2.098	0.037

EA – environmental perception; *SN* – subjective norms; *PC* – the respondent's perceptual control; GECA – the respondent's general environmental care attitudes; RP – the respondent's position on regulatory proposals
Source: Authors' own elaboration

Table S8. Multiple linear regression that relates the age of the respondents to the other social factors of the respondents and the technical and economic parameters of their farms

Model	Parameter	β non-standardised	SD	β standardised	*t*	*P*-value
2	production system	–0.721	0.804	–0.033	–0.896	0.371
	main source of income	–0.999	1.301	–0.033	–0.768	0.443
	knowledge of circular economy	–0.175	0.485	–0.013	–0.362	0.718
	EA	–0.458	0.762	–0.033	–0.602	0.548
	SN	0.168	0.658	0.013	0.255	0.799
	PC	0.488	0.455	0.043	10.073	0.284
	RP	–0.182	0.669	–0.014	–0.272	0.786
	waste management	–2.252	10.394	–0.059	–10.615	0.107
	waste management problems	0.949	0.849	0.041	10.117	0.265
	surface	0.318	0.190	0.063	10.678	0.094
	sex	1.556	1.198	0.047	10.299	0.195
	years dedicated to PP	–0.452	0.283	–0.065	–10.597	0.111

EA – environmental perception; *SN* – subjective norms; *PC* – the respondent's perceptual control; GECA – the respondent's general environmental care attitudes; *RP* – the respondent's position on regulatory proposals; PP – primary producers
Source: Authors' own elaboration