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A novel framework for assessing ecosystem services through agroecological practices

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Ecosystem services (ESs) are increasingly recognized as critical indicators of agricultural sustainability, yet existing assessment frameworks often lack applicability at farm level or fail to account for the synergistic effects of agroecological practices. In response, we developed the APES (Agroecological Practices for Ecosystem Services) framework within the Horizon 2020 RADIANT project. APES is a participatory, practice-based tool designed to assess 22 ecosystem services (eight provisioning and fourteen regulating/supporting) based on the implementation of agroecological practices. The framework was developed through a literature review and refined via participatory workshops with farmers and stakeholders in Greece and Scotland. Provisioning services are assessed through farmer perceptions and crop diversity, while regulating and supporting services are evaluated based on the degree of practice implementation. An illustrative case study on dairy farms in Northern Italy demonstrates the practical application of APES and highlights how ecosystem services emerge from the combination and interaction of multiple strategies within diversified systems. By making ESs visible and actionable, APES supports farmers, researchers, and advisors in driving agroecological transitions and informing more sustainable food system planning.

KEYWORDS

agroecology, ecosystem services assessment, sustainable farming systems, practice-based framework, farm level assessment

Highlights

- APES assesses 22 ecosystem services using farm-level agroecological practices.
- The framework links specific practices to ESs via literature and participatory input.
- Provisioning services are evaluated through farmer perception and crop diversity.
- Regulating/supporting services scored via a gradient of agroecological practice implementation.
- APES supports ecological visibility and agroecological transitions at farm scale as well as at territorial level.

1 Introduction

Agricultural systems are increasingly being recognized not only for their capacity to produce food, feed, and raw materials, but also for the broad array of ecosystem services (ESs) they generate or compromise. The concept of ecosystem services refers to the benefits humans derive from ecosystems, encompassing provisioning services - such as food, fiber, and energy - as well as regulating, supporting, and cultural services, including pollination, nutrient cycling, soil fertility, landscape heterogeneity, and climate regulation. As biodiversity loss, soil degradation, and climate change intensify, the ability of farming systems to maintain ecological functions has become a central concern in both science and policy (Mabhaudhi et al., 2022; Jenkins et al., 2023).

Assessing ecosystem services in agriculture is now considered essential to support transitions toward more sustainable and resilient food systems. Global policy agendas - including the EU Green Deal, the Biodiversity Strategy, and the Sustainable Development Goals - emphasize the multifunctionality of agriculture and call for evidence-based tools to guide land-use and farm-level decisions (Rodríguez-Ortega et al., 2014; Pascual et al., 2017). Evaluating how different farming practices impact ESs is crucial for identifying systems that promote resource efficiency, ecological resilience, and climate adaptation (Lungarska and Chakir, 2024). Moreover, making these services visible through assessment enables us not only to highlight the benefits of certain farming models, but also to expose the hidden environmental costs of intensive, input-dependent systems (Vidaller and Dutoit, 2022; Soulé et al., 2023).

In recent years, a growing number of frameworks have emerged to assess ecosystem services in agricultural systems. These include quantitative models based on biophysical or land-cover data, participatory approaches integrating local knowledge, and tools combining multiple sustainability indicators. For instance, the work of Boeraeve et al. (2020) highlights how agroecological systems contribute to bundles of ecosystem services, using a multi-criteria approach that integrates landscape and farm-level indicators. Similarly, the method developed by Soulé et al. (2023) seeks to link ecosystem service provision with environmental impacts, offering a decision-support tool at farm level. Other approaches, such as those by Andersson et al. (2015) and Rodríguez-Ortega et al. (2014), examine ES delivery through social–ecological lenses, emphasizing farmer perceptions, landscape structure, and livestock systems. While these contributions have significantly advanced our understanding, most existing ES frameworks face key limitations: they often prioritize provisioning services, lack specificity in linking practices to services, or require high levels of technical data and expertise that constrain their use by farmers (Schipanski et al., 2014; Vidaller and Dutoit, 2022).

In parallel, there is increasing interest in approaches that ground ecosystem service assessments in the actual practices implemented on farms, particularly those informed by agroecology. Agroecological systems are characterized by biodiversity enhancement, circular resource flows, and knowledge co-creation, and they depend on context-specific practices such as crop diversification, soil conservation, intercropping, agroforestry, and the use of local varieties. Yet the ecosystem services provided by these practices are often underrepresented in policy frameworks and undermeasured in conventional ES assessment tools (Temesgen and Wu, 2018; Boeraeve et al., 2020; Mabhaudhi et al., 2022).

While the ecosystem services framework offers a powerful lens to evaluate the ecological and societal benefits of farming systems, it is not without critique. Scholars have pointed out its inherently anthropocentric orientation, which tends to value nature primarily in terms of its utility to humans, often reducing complex ecological relationships to quantifiable outputs or economic proxies (Silvertown, 2015; Muradian and Gómez-Baggethun, 2021). This risk of instrumentalizing nature can obscure intrinsic values, ecological integrity, and the ethical dimensions of human–nature relations (Raymond et al., 2013; Arias-Arévalo et al., 2017). Furthermore, the ES framework has been critiqued for its tendency to simplify social–ecological complexity and undervalue situated knowledge systems, especially those embedded in rural or traditional agroecosystems (Buizer et al., 2016; Peredo Parada and Barrera Salas, 2024). Nonetheless, within the current socio-economic context, dominated by market logics, reductionist indicators, and externalized environmental costs, the ES framework remains a strategically valuable tool. It enables researchers, farmers, and policymakers to make visible the often-overlooked ecological functions and public goods generated by diversified and agroecological farming systems (Andersson et al., 2015; Balzan et al., 2020).

Agroecology offers a promising lens to overcome these limitations. As both a science and a practice-based approach, agroecology integrates ecological principles into farming systems, fostering biodiversity, circular resource flows, and context-specific knowledge. Agroecological practices, including intercropping, organic fertilization, conservation tillage, cover cropping, agroforestry, and the use of local seeds - are known to enhance ecosystem services across multiple domains, yet their contributions remain difficult to measure in a practical and systematic way (Wezel et al., 2014; Nicholls and Altieri, 2018).

In response to these gaps and critiques, we present a novel assessment tool: the APES – Agroecological Practices for Ecosystem Services framework. Developed within the Horizon 2020 RADIANT project, APES is a participatory, practice-based tool designed to assess ecosystem services generated through agroecological practices at farm level. The framework evaluates twenty-two ecosystem services - eight provisioning and fourteen regulating/supporting - by linking each service to specific agroecological practices. Designed to be accessible and adaptable, APES enables both farmers and researchers to assess not only the positive contributions but also the missed ecological opportunities associated with current management strategies. In doing so, it provides a concrete tool to support transitions toward agroecology by enhancing ecosystem visibility, enabling knowledge co-production, and informing more just and sustainable food systems.

2 Materials and methods

2.1 The APES framework development and general description

The development of the APES (Agroecological Practices for Ecosystem Services) framework followed a two-phase process involving both a comprehensive literature review and multi-actor participatory engagement. Initially, scientific literature provided the conceptual foundation for linking agroecological practices to ecosystem service (ES) provision. However, to ensure the framework's relevance and usability across diverse agricultural contexts, its design was tested and refined through two participatory workshops conducted within the scope of the Horizon 2020 RADIANT project.

The first of these workshops took place during the CREATOR event in Athens, Greece, in June 2022, bringing together farmers, researchers, policy actors, and food chain stakeholders. The second workshop was held in Orkney, Scotland, in July 2022, as part of a similar CREATOR event. In both workshops, participants were invited to brainstorm collaboratively around two central questions: (1) Which ecosystem services are perceived as most important or under pressure in their farming systems? and (2) Which farming practices do they consider most influential in enhancing or degrading these services? Insights from these workshops proved crucial in grounding the framework in real-world farming experiences and socio-ecological contexts. Participants' inputs helped refine the scope of relevant services and informed the final selection of practices to be included as indicators. This co-development process also contributed to the legitimacy and usability of the tool by incorporating knowledge from across the agricultural knowledge and innovation system (AKIS), including farmers, consumers, processors, advisors, and researchers. While geographically located in two specific countries, the Athens workshop included a diverse group of stakeholders from different Mediterranean and European regions. This allowed for a broader range of perspectives to inform the development of the framework, despite the limited number of workshop locations.

The APES framework, resulting from the above mentioned co-development process, is designed to quantify ecosystem service delivery through a series of practice-based indicators applied at farm level. In total, the framework evaluates twenty-two ecosystem services: eight provisioning services (e.g., food, feed, fiber, genetic resources) and fourteen regulating and supporting services (e.g., soil fertility, pest regulation, climate regulation, biodiversity conservation). These services were defined and categorized based

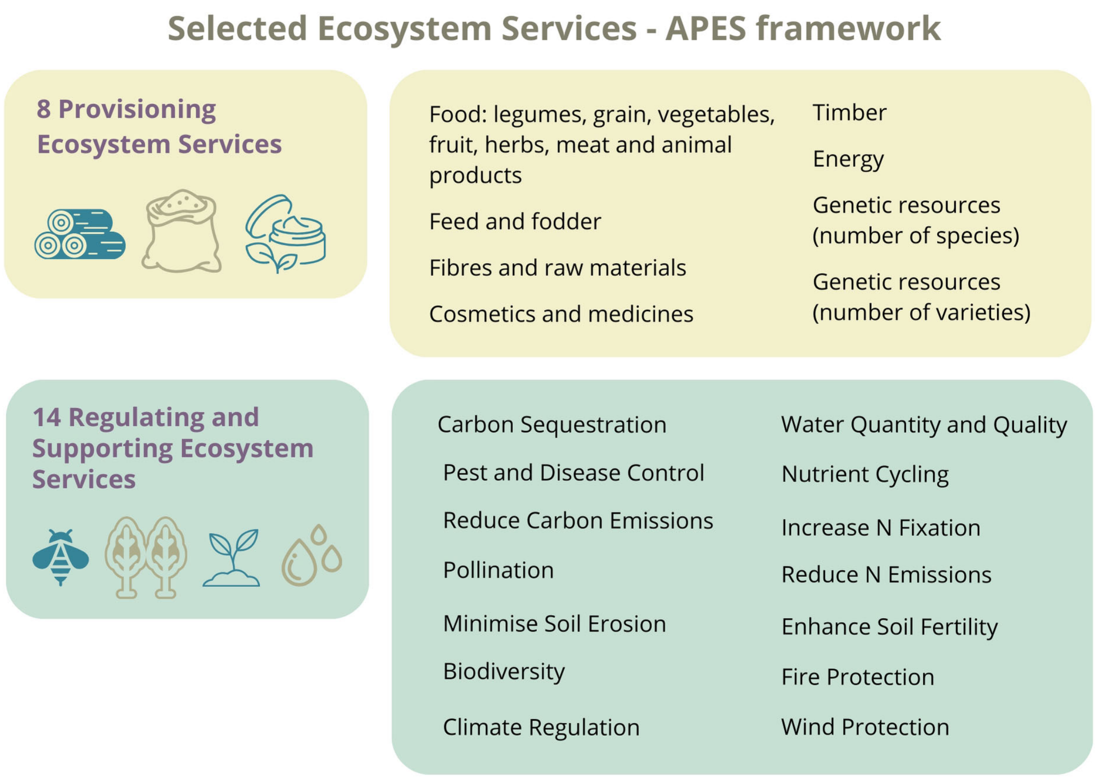

FIGURE 1
Selected ecosystem services.

 10.3389/fagro.2025.1648022

on the Common International Classification of Ecosystem Services (CICES) (https://cices.eu/) to ensure consistency with widely recognized ES typologies (see Figure 1).

2.2 Assessment of provisioning ecosystem services with the APES framework

Given the diversity of provisioning ecosystem services and the challenge of capturing their value through conventional metrics, we adopted a qualitative, perception-based approach that draws on farmer-reported satisfaction with yields and crop diversity. This aligns with broader calls in the literature to expand and adapt provisioning service assessment beyond purely economic or production-based indicators (Anand and Gupta, 2020). The evaluation of provisioning ecosystem services in the APES framework is grounded in the principle that farmers are uniquely positioned to assess the productivity and performance of their systems. As a result, we adopted an approach based primarily on farmers' perceptions of satisfaction with yields, complemented by quantitative measures of crop and varietal diversity for genetic resources. This method ensures that the evaluation reflects not only ecological performance but also context-specific knowledge and experience, which are critical in agroecological systems.

Provisioning services such as food, feed, fiber, raw materials, energy, cosmetics and medicines, and timber are evaluated through farmer self-assessment of yield satisfaction. During the participatory assessment, farmers are asked to rate their satisfaction on a three-point scale: 1: not satisfied, 2: moderately or averagely satisfied, 3: very satisfied.

This scale is used to score each provisioning service relevant to the farm's production system. The emphasis on subjective yield satisfaction recognizes that agroecological productivity is often measured in terms that go beyond yield quantity, such as stability, diversity, cultural relevance, and input efficiency.

For genetic resource services, which are a crucial component of provisioning in agroecological systems, the evaluation is based on the number of species and varieties cultivated. This reflects the role of crop and varietal diversity in enhancing resilience, food security, and long-term sustainability. The number of crops (species) adopted at farm level is assessed using a scale from: 1: only one crop, 2: two to three crops, 3: more than three crops.

Likewise, the number of varieties per crop is assessed as follows: 1: one variety per crop, 2: two varieties per crop, 3: three or more varieties per crop.

This dual approach, combining qualitative self-assessment with quantitative diversity indicators, ensures that the provisioning dimension of ecosystem services is captured in a way that is both farmer-led and ecologically meaningful. The full system of assessment for provisioning ESs is presented in Table 1.

The reliance on perception-based indicators for assessing provisioning ecosystem services reflects the importance of farmer knowledge in agroecological systems. This approach acknowledges that yield satisfaction is context-dependent, influenced by local conditions, goals, and resource availability. It offers an inclusive entry point for farm-level assessment, especially where quantitative yield data may be lacking. Moreover, the choice to adopt perception-based indicators was also intentional in order to keep the APES tool accessible, and not overly complex to apply for farmers and facilitators, therefore enhancing its usability in diverse real-world contexts.

TABLE 1 Indicators to assess the Provisioning Ecosystem Services.

Provisioning ecosystem Services	Method	Indicators and values (1-3)
Food: legumes, grain, vegetables, fruit, herbs, meat and animal products	According to the perspective of the farmer on the yield. The values assigned can be:	1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Feed and fodder		1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Fibres and raw materials		1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Cosmetics and medicines		1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Timber		1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Energy		1 - not satisfied, 2 - average satisfied, 3 - very satisfied
Genetic resources (number of species)	According to the number of crops adopted at farm level:	1- 1 crop, 2 - 3 or more crops, 3 - more crops
Genetic resources (number of varieties)	According to the number of varieties adopted at farm level:	1- 1 variety per crop, 2 - 2 varieties per crop, 3 - 3 or more varieties per crop

2.3 Assessment of regulating and supporting ecosystem services through practices indicators

The set of sixteen agroecological practice indicators used to assess the provisioning of regulating and supporting ecosystem services in the APES framework was developed through an extensive literature review and synthesis of existing methodologies. These indicators reflect practices that are widely recognized for their potential to enhance key agroecosystem functions such as nutrient cycling, soil fertility, biodiversity, and climate regulation.

The selection of practices draws heavily on the OASIS system (Original Agroecological Survey Indicator System) proposed by Peeters et al (Peeters et al., 2021), which offers a simple yet comprehensive methodology for assessing agroecological transition at farm level. The OASIS framework served as a conceptual starting point for structuring the indicators and aligning them with internationally recognized categories of ecosystem services.

Further refinement was informed by foundational reviews on agroecological practices. For instance, Wezel et al. (2014) provided an extensive typology of practices - including crop diversification, agroforestry, green manures, and biological pest control - that have been shown to contribute to sustainable agriculture. Their work highlights how these practices operate synergistically to support regulating and supporting ESs, such as soil health and pest regulation. Similarly, Nicholls and Altieri (2018) emphasized the role of agroecological strategies in amplifying ecological functions at the landscape scale, reinforcing the importance of context-specific implementation.

The indicators also build on comparative analyses of agroecological and organic farming regulations by Migliorini and Wezel (2017), which identified convergences and divergences in practice-based standards and their implications for environmental outcomes. These insights were key to shaping the scope of the indicators used in the APES framework, ensuring they are both ecologically grounded and practically applicable across different farming systems.

Each of the sixteen indicators is applied at the farm level, where it is scored based on the degree to which the corresponding practice is implemented. This scoring system was developed from the literature and adapted to reflect observable gradients of adoption, ranging from non-implementation to full integration within a system-level agroecological design. The resulting scores serve as proxies for the expected contribution of each practice to specific ecosystem services, allowing for a structured and transparent evaluation of service delivery at farm scale.

The Indicators for assessing Regulating and Supporting Ecosystem Services, their relative descriptions and the scoring thresholds are displayed in Tables 2 and 3.

To evaluate regulating and supporting ecosystem services (ESs) within the APES framework, each ES is assigned a score that reflects the degree to which relevant agroecological practices are implemented on the farm. Specifically, the score for each service is calculated as the average of the individual scores assigned to all practices identified as contributing to that service. This method ensures that the assessment captures the cumulative effect of multiple farming practices on the provision of a given ES, acknowledging the synergistic nature of agroecological systems. Therefore, all agroecological practices are assumed to contribute equally to each associated ecosystem service. This equal-weighting approach was chosen to ensure transparency and facilitate ease of use in participatory and farm-level contexts. However, it is important to acknowledge that in practice, the magnitude and relevance of each practice's contribution to a given ecosystem service may vary depending on environmental conditions, implementation intensity, and interactions with other practices. Future versions of the framework could explore differentiated weighting schemes based on empirical data, expert judgment, or modeling approaches to better reflect the relative importance of each practice. Such refinements would enhance the analytical power of the tool while maintaining its usability for farmers, advisors, and policymakers. Methods for participatory workshops and farmer surveys should be described in greater detail to enable replication.

To establish robust and meaningful links between practices and ecosystem services, an extensive literature review was carried out. This review identified evidence-based associations between specific agroecological practices and the ESs they are known to support. The resulting matrix defines which practices contribute to which services, allowing for a transparent and consistent scoring process grounded in scientific and applied knowledge.

The outcome of this matching process, linking each of the sixteen agroecological practice indicators to the relevant regulating and supporting ESs, is visually presented in Figure 2, which forms the basis for calculating service-level scores in the APES framework. The detailed references and evidence used to justify the associations between agroecological practices and the ecosystem services they support are provided in Table 4, which displays the specific literature underpinning the matching process.

2.4 Testing the framework on a case study

The APES framework was implemented starting in July 2022 to evaluate ecosystem services through farm-level agroecological practices. As an illustrative example, we present here the results from one case study carried out during the development phase of the framework. This example is intended solely for demonstrative purposes, to show how the APES tool can be practically applied to assess ecosystem services.

The selected case study involved a group of livestock farms located in Northern Italy, primarily focused on forage-based dairy production. These farms are characterized by diversified meadow systems, which include the integration of leguminous forage crops. This diversification not only supports feed autonomy but also contributes to soil health, biodiversity, and overall ecosystem service provision. As such, the case study provides a relevant and practical example to demonstrate the functionality and applicability of the APES tool in a real-world farming context.

3 Results and discussion

3.1 Provisioning ecosystem services provided by the case study

The results (Figure 3) highlight that the selected case study provides high levels of provisioning ESs in relation to food and feed production.

Food-animal products and feed and fodder both reached the maximum score (3), indicating that farmers are highly satisfied with the productivity and yield of these components. This reflects the strong focus of these livestock farms on dairy and forage production, particularly for high-value products like Parmigiano Reggiano.

In terms of genetic resources, the farms scored moderately: species diversity received a score of 2, suggesting that at least three different crop or livestock species are being cultivated or raised, which contributes to system resilience and feed autonomy.

TABLE 2 The indicators for assessing regulating and supporting ecosystem services with relative descriptions.

APES indicators		
1	Conservation and no-tillage systems	The soil is disturbed minimally (no more than 3 – 5 cm deep) and with no inversion (soil 'cracking' up to 25 cm is allowed to de-compact the soil). The crop is seeded directly into a mulch or living crop (which is usually mown, rolled or tarped prior to seed), without any soil disturbance preceding.
2	Use of plant reproductive material adapted to local conditions	(seeds, seedlings, plants, cuttings, etc.) manage stress factors well, do not require large inputs of fertilizers, pesticides and water, and can be propagated/saved for the following year. This involves peasant/folk seed, cultivars bred in and for organic conditions, heirloom seed, population varieties, and stress-tolerant cultivars and species - such as neglected and underused crops that could be used as an alternative to winter wheat (e.g., triticale, oats, spelt) or to maize (e.g., sorghum, millet) for instance.
3	Crop rotation	Long and diverse crop rotation, Legume-based temporary grasslands in crop rotations, Pulses in crop rotation
4	Intercropping	Simple crop mixtures (e.g., cereal and pulse), Polycultures with push-pull crops, Permanent soil cover with companion species of the main crop(s), Using allelopathic crops, Inter-row permanent crops
5	Cover crops	Mixtures of legume-based green manure, Cover crops, Soil fertility management with complex mixtures of green manures, Complex mixtures of green manures (cover crops), Main crop sown in green manure mulch
6	Soil organic matter input	Compost tea, Green manure, Composting, Balanced fertilization, Using organic manure - farmyard manure, Recycled crop waste, Wood chips (or ramial wood chip (RWC), Organic agroindustrial waste, Biochar, Straw Mulching, inoculation with mycorrhiza
7	Water management practices	Drip irrigation, Mulching, Dryland farming, Proper irrigation scheduling (e.g.,irrigating at night), Buried clay pot irrigation in market gardening, Drainage; Collection of rainwater, Recycling of greywater, Desalination of irrigation water
8	Ecological infrastructure and landscape and habitat management	Surface ponds, Micro-dams, Stone bunds, Terraces, Fog collection, Infiltration trenches, Ponds, Wells, Alley cropping, Contour lines/keyline design, Hedges, Hedge-row networks, Windbreaks, use of shading trees, etc.
9	Agroforestry	Windbreaks, use of shading trees, etc., Trees and other woody species can produce fruit, timber, firewood, forage, etc., Hedges, wooded strips, and tree lines, Traditional European agroforestry systems include the 'bocage' (hedge-row network) in livestock breeding regions, grazed traditional orchards, pollard tree rows, and the Mediterranean open forest associating several oak species and grazed by cattle, sheep and pig (Dehesa/Montado). Silvoarable systems. Silvopastoral systems. Forest farming.
10	Sampling and monitoring for pests, disease, soil health and weeds abundance	Sampling and monitoring for pests and their natural enemies. Regular sampling and monitoring for disease symptoms. Regular physical, biological, and chemical soil diagnostics. Regular observation of weed abundance and richness.
11	Organic pest and disease control	Organic Pest and disease control derived from plants and plant extract
12	Rotational or extensive grazing	Adoption of optimum stocking rate for the seasonal grass production. Transhumance.
13	Mixed stocking	Integration of different livestock species (e.g., cattle, sheep, goats) within the same farm system. Mixed stocking can reduce parasite load, increase forage use efficiency, and diversify production.
14	Local breeds adapted to the territory	Choice of livestock breeds and species: rather than opting for the most productive breeds that require many inputs and are not well-adapted to an efficient conversion of grass and other cellulose-rich feed into milk and meat, the system should be designed with the local geography and climate zone in mind, and the choice of animal type should be determined in function of its ability to adapt to agroecological systems. Dual-purpose breeds
15	On farm or local production of forage, diversified feeding and low nitrogen feed (not soy)	Considering feed management: use of cellulose-rich forage; pasture-fed ruminants, good proportion of pasture-based feed for monogastrics. Preparing hay/silage/haylage for winter feeding. A minimal percentage of concentrated feed should be given to the animals, especially during the finishing period for meat animals, or during the lactating period for dairy animals. Using cereals and pulses from the farm's own production is a transition practice towards a fully developed agroecological system.
16	Sustainable practices in the management of animal manure	Implementation of practices that ensure the environmentally sound management of animal manure, such as appropriate storage, composting, and timely application to fields. These practices reduce nutrient losses, minimize greenhouse gas emissions, and improve soil fertility.

However, varietal diversity was rated lower (score 1), pointing to the use of only one variety per crop. This highlights an area where there is potential to expand genetic diversity, for example by introducing more varieties of alfalfa or other forage crops.

The farms did not report contributions to other provisioning services such as fibers and raw materials, cosmetics and medicines, timber, or energy, all of which received a score of 0. This is consistent with their specialized production model.

3.2 Regulating and supporting ecosystem services provided by the case study

In Table 5, we report the scores assigned to each practice indicator, based on the data collected in the field.

The case study displays a generally good level of adoption of agroecological practices across several key areas.

TABLE 3 The Indicators for assessing regulating and supporting ecosystem services with relative scoring details.

APES indicators		Scoring			
		0 - Zero integration	1 - input reduction - efficiency	2 - Input substitution	3 - System redesign
1	Conservation and no-tillage systems	Deep ploughing (more than 30 cm in depth) or rotavating one or more time per year	Ploughing maximum 30 cm in depth and/or using power harrow once a year	Reduced tillage up to 5 cm (e.g., superficial disc-harrowing, wide-cutter or rotary hoe), strip tillage, ridge tillage	No-till
2	Use of plant reproductive material adapted to local conditions	0 local varieties	30% of UAA (Utilized Agricultural Area) is cultivated with plant reproductive material adapted to local conditions	30-50%	More than 50%
3	Crop rotation	mainly monocrop	2–3 year- rotation	4–5 year rotation	more than 6 years-rotation
4	Intercropping	0 intercropping on UAA	30% UAA	30–50 UAA	>50
5	Cover crops	The soil is covered with plants less than 6 months of the year on the total farm land	The soil is covered for 6 to 8 months a year on the total farm land	The soil is covered for 8 to 10 months a year	The soil is covered at least 11 months of the year
6	Soil organic matter input	No organic matter inputs (the fertility management is completely based on synthetic fertilizers)	Rarely used Organic inputs and/or only in a small part of the farm (up to 30% of used farmed land)	Moderate use of practice and/or in up to one half of the farmed land	Several strategies are implemented in at least 75% of the farmland
7	Water management practices	No implementation of techniques, practices and strategies for conserving water, noticeable inefficient water use in the farm	Water conservation practices used rarely and/or only in a small part of the farm (up to 30% of the farmed land (on land where applicable)	Moderate use of water conservation practices, in 31 - 50% of the farmed land	Water conservation practices often used on more than 50% of the farmed land
8	Ecological infrastructure and landscape and habitat management	Not implemented at all	Rarely present only in a small part of the farm (up to 10% of the farmed land)	Moderate presence, in up to 30% of the farmed land	Different ecological infrastructures often present, up to 50% of the farmed land
9	Agroforestry	Not implemented at all	Rarely used and/or only in a small part of the farmed land (less than 25%)	Moderate use, in up to one half of the farmed land (25 - 50%)	Often used, in more than one half of the farmed land
10	Sampling and monitoring for pests, disease, soil health and weeds abundance	zero monitoring	only on main crop	on more than 1 crop	on all the farm
11	Organic pest and disease control	Chemicals inputs, not include organic products	30% Organic pest control, purchased	30% - 50% Organic pest control, purchased	Only organic pest control and 50% self-produced
12	Rotational or extensive grazing	No grazing on grassland	at least 3 summer months of grazing, under 2 Livestock unit/ha	at least 4 – 6 months a year animals feed on grassland, under 2 Livestock unit/ha	>6 months, under 2 Livestock unit/ha
13	Mixed stocking	No livestock	1 species	2 species	>2 species
14	Local breeds adapted to the territory	Modern breeds, no local breeds	1 local breeds	2 local breeds	the farmer mostly raises low demanding animals adapted to the local conditions, uses natural drugs and a good level of preventive methods;
15	On farm or local production of forage, diversified feeding and low nitrogen feed (not soy)	No local production of forage	Dietary intake: ruminants 40 fibers - 60 concentrated feeding purchased as Monthly mean of feed	Dietary intake: ruminants 50 fibers - 50 concentrated feeding (up to 50% self-produced of fodder and concentrate) as Monthly mean of feed	Dietary intake: ruminants 50 fibers - 50 concentrated feeding (more than 50% of self-produced of fodder and concentrate) as Monthly mean of feed
16	Sustainable practices in the management of animal manure	manure stocked on sealing plateaux	30% of manure is Composted and spread on the fields with right timing and methods	50% of manure is Composted and spread on farm with right timing and methods	100% of manure is Composted and spread on farm with right timing and methods

Crop rotation and intercropping received with a high score (2), indicating the implementation of diverse crop sequences and mixed cropping systems with use of leguminouse crops These practices are known to support nitrogen fixation, improve soil fertility, and reduce nutrient emissions.

Cover crops, water management practices, and sustainable animal manure management also scored 2, suggesting consistent efforts to maintain soil cover, conserve water, and recycle nutrients through well-timed and locally applied manure composting.

On the other hand, certain practices such as ecological infrastructure, agroforestry, wind protection, and fire protection received a score of 0, indicating that these areas are either not implemented or largely underutilized. These represent potential areas for future improvement to enhance landscape connectivity and climate resilience. Practices such as use of local breeds, on-farm forage production, and organic pest control achieved a high score (2), reflecting strong integration of agroecological principles in the livestock system - particularly in relation to feeding strategies and

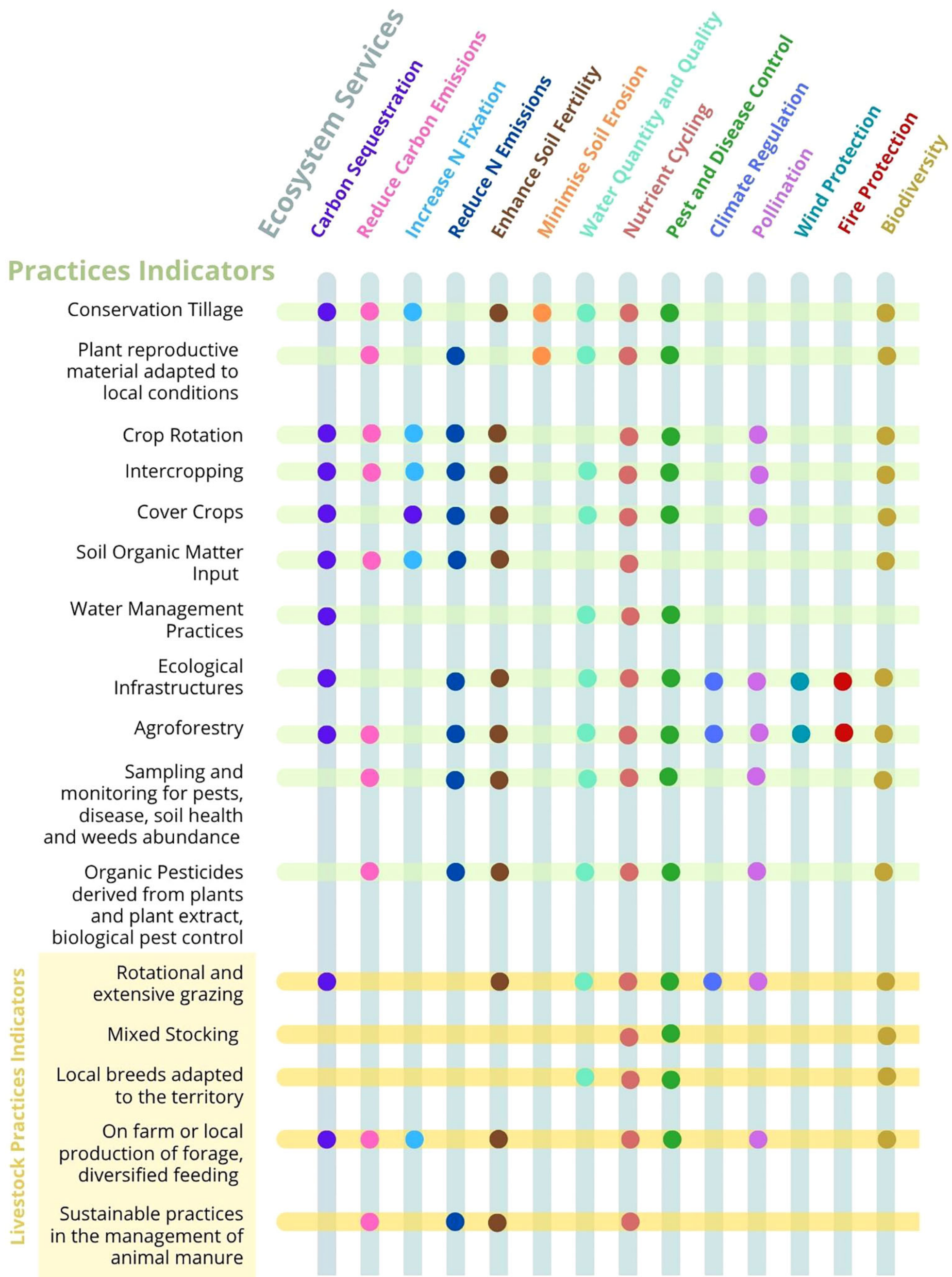

FIGURE 2
The Indicators for assessing regulating and supporting ecosystem services.

TABLE 4 Literature review linking practices indicators to regulating and supporting ecosystem services.

	Agroecological practices indicators	Regulating and supporting ecosystem services													
		Increase C sequestration	Reduce C emissions/ mineralization	Increase N fixation	Reduce N emission	Enhance soil fertility (biological, physical, chemical)	Minimize soil erosion	Water quantity and quality	Nutrient cycling	Pest and disease control	Climate regulation	Pollination	Wind protection	Fire protection	Biodiversity at landscape, specie and genetic dimension
1	Conservation Tillage	(Hussain et al., 2021; Khan and Wang, 2023)	(Yue et al., 2023; Alasinrin et al., 2025)	(van Kessel and Hartley, 2000; St-Martin and Bommarco, 2016; Hartman et al., 2018; Singh et al., 2020)	0	(Singh et al., 2013; Hartman et al., 2018; Singh et al., 2020)	(Wezel et al., 2014; Seitz et al., 2019; Chalise et al., 2020; Liang et al., 2024; Jug et al., 2025)	(Liang et al., 2024; Jug et al., 2025)	(Hartman et al., 2018; Singh et al., 2020)	(Jasrotia et al., 2023; Jug et al., 2025)	0	(Carvalheiro et al., 2021; Tschanz et al., 2024)	0	0	(Liang et al., 2024; Jug et al., 2025)
2	Use of plant reproductive material adapted to local conditions	0	(Lazzerini et al., 2014; Odeku et al., 2024)	0	(Lazzerini et al., 2014; Odeku et al., 2024)	0	(Shelef et al., 2017; Li et al., 2020)	(Chivenge et al., 2015; Shelef et al., 2017)	(Shelef et al., 2017; Li et al., 2020)	(Shelef et al., 2017; Li et al., 2020)	0	0	0	0	(Shelef et al., 2017; Li et al., 2020)
3	Crop rotation	(Lazzerini et al., 2014; Triberti et al., 2016; Kumar et al., 2018; Guillaume et al., 2022; Liu et al., 2022; Loges et al., 2024)	(Liu et al., 2022; Yang et al., 2024)	(Anglade et al., 2015; Kebede, 2021)	(Liu et al., 2022; Yang et al., 2023)	(Kocira et al., 2020; Kebede, 2021; Liu et al., 2022)	(García-Ruiz, 2010; Reddy, 2017; Kocira et al., 2020)	0	(Kocira et al., 2020; Kebede, 2021)	(García-Ruiz, 2010; Wezel et al., 2014; Reddy, 2017; H. ming et al., 2019; Kebede, 2021; Belmain et al., 2022; Altieri et al., 2024; Bommarco, 2024)	0	(Kocira et al., 2020; Kebede, 2021)	0	0	(Kocira et al., 2020; Kebede, 2021)
4	Intercropping	(Cong et al., 2015; Li et al., 2024)	(Maitra et al., 2023; Yang et al., 2023)	(van Kessel and Hartley, 2000; Anglade et al., 2015; Kebede, 2021)	(Gui et al., 2024; Yu et al., 2025; Zhang et al., 2025)	(Wezel et al., 2014; Kebede, 2021)	(Wezel et al., 2014; Belmain et al., 2022; Drinkwater and Snapp, 2022)	(Wezel et al., 2014; Yin et al., 2020; Drinkwater and Snapp, 2022)	(Kebede, 2021)	(Wezel et al., 2014; Reddy, 2017; H. ming et al., 2019; Kebede, 2021; Belmain et al., 2022; Drinkwater and Snapp, 2022; Altieri et al., 2024; Bommarco, 2024)	0	(Kebede, 2021; Hüber et al., 2022; Fijen et al., 2025)	0	0	(Kebede, 2021; Brandmeier et al., 2023)
5	Cover crops	(Mazzoncini et al., 2011; Poeplau and Don, 2015; Seitz et al., 2019; Seitz et al., 2023)	0	(Büchi et al., 2015; Drinkwater and Snapp, 2022)	(Muhammad et al., 2019; Fernandez Pulido et al., 2023)	(Drinkwater and Snapp, 2022)	(Wezel et al., 2014; Kocira et al., 2020; Drinkwater and Snapp, 2022; Clement et al., 2024)	(Kocira et al., 2020; Delgado et al., 2021)	(Kocira et al., 2020; Drinkwater and Snapp, 2022)	(Kocira et al., 2020; Altieri et al., 2024; Bommarco, 2024)	(Smith et al., 2013; Delgado et al., 2021)	(Eberle et al., 2015; Fijen et al., 2025)	0	0	(Kocira et al., 2020; Fijen et al., 2025)
6	Soil organic matter input	(Triberti et al., 2016; Kowalska et al., 2020; Criscuoli et al., 2021; Li et al., 2022; Panettieri et al., 2022; Chen et al., 2023; Fontana et al., 2023; Gao et al., 2023; Hayatu et al., 2023; Soria et al., 2023; Xiao et al., 2023)	(Smith, 2008; Li et al., 2022)		(Lazzerini et al., 2014; Gao et al., 2023)	(Ravichandran et al., 2022; FAO, 2024)	(Wezel et al., 2014; Chalise et al., 2020; Martinez-Mena et al., 2020; Ravichandran et al., 2022)	(Bhadha et al., 2017; Ravichandran et al., 2022)	(Ravichandran et al., 2022; FAO, 2024)	(Wezel et al., 2014; Ravichandran et al., 2022; Altieri et al., 2024)	0	(Chen et al., 2021; Jakhro et al., 2025)	0	0	(Kocira et al., 2020; Jakhro et al., 2025),
7	Water management practices	(Li et al., 2022; Xiao et al., 2023)	0	0	0	0	(Ravichandran et al., 2022; FAO, 2024)	(Ravichandran et al., 2022; FAO, 2024),	(Ravichandran et al., 2022; Zhou et al., 2023; FAO, 2024; Thomas et al., 2024)	(Manda et al., 2021; Ravichandran et al., 2022; Haider et al., 2023)	0	0	0	0	0

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TABLE 4 Continued

Agroecological practices indicators		Regulating and supporting ecosystem services													
		Increase C sequestration	Reduce C emissions/ mineralization	Increase N fixation	Reduce N emission	Enhance soil fertility (biological, physical, chemical)	Minimize soil erosion	Water quantity and quality	Nutrient cycling	Pest and disease control	Climate regulation	Pollination	Wind protection	Fire protection	Biodiversity at landscape, specie and genetic dimension
8	Ecological infrastructure, landscape and habitat management	(Montgomery et al., 2020; Weninger et al., 2021; Biffi et al., 2022; Holgerson et al., 2023; Holgerson et al., 2023)	0	0	(Weninger et al., 2021)	(Weninger et al., 2021)	(Song et al., 2023)	(Kedziora, 2010; Weninger et al., 2021)	(Montgomery et al., 2020; Weninger et al., 2021)	(Reddy, 2017; Montgomery et al., 2020; Weninger et al., 2021; Vega et al., 2023)	(Weninger et al., 2021; Rosenfield et al., 2022)	(Montgomery et al., 2020; Fonseca et al., 2021)	(Montgomery et al., 2020; Weninger et al., 2021; Song et al., 2023)	(Montgomery et al., 2020; Oliveira et al., 2023),	(Montgomery et al., 2020; Weninger et al., 2021; Altieri et al., 2024)
9	Agroforestry	(Lemaire et al., 2014; Brewer and Gaudin, 2020; Montgomery et al., 2020; Biffi et al., 2022; Carranca et al., 2022; Zomer et al., 2022; Yasin et al., 2023)	(Torres et al., 2017; Helgason et al., 2021),	(Videira e Castro et al., 2019; Kim and Isaac, 2022)	(Kim and Isaac, 2022; Luo et al., 2022; Shao et al., 2023),,	(Weninger et al., 2021)	(Shekmohammed, 2021; Jinger et al., 2022)	(Shekmohammed, 2021)	(dos Santos et al., 2018; Kim and Isaac, 2022)	(Reddy, 2017; Montgomery et al., 2020; Weninger et al., 2021)	(Montgomery et al., 2020; Shekmohammed, 2021; Weninger et al., 2021)	(Varah et al., 2020; Fijen et al., 2025)	(van Ramshorst et al., 2022; Barman et al., 2025)	(Damianidis et al., 2021; Spadoni et al., 2023)	(Udawatta et al., 2019; Shekmohammed, 2021)
10	Sampling and monitoring for pests, disease, soil health and weeds abundance	0	(Lazzerini et al., 2014)	0	(Lazzerini et al., 2014)	(Tahat et al., 2020)	0	(Tahat et al., 2020)	(Tahat et al., 2020)	(McCravy, 2018; Tahat et al., 2020), (McCravy, 2018)	0	(McCravy, 2018)	0	0	(McCravy, 2018)
11	Organic Pesticides derived from plants and plant extract, biological pest control	0	(Lazzerini et al., 2014)	0	(Lazzerini et al., 2014)	(Ngegba et al., 2022; Zarifa and Elmurod, 2025)	(Vega et al., 2023)	(Zarifa and Elmurod, 2025)	(Ngegba et al., 2022; Zarifa and Elmurod, 2025)	(Wezel et al., 2014; Belmain et al., 2022; Vega et al., 2023)	0	(Ngegba et al., 2022; Zarifa and Elmurod, 2025)	0	0	(Ngegba et al., 2022; Zarifa and Elmurod, 2025)
12	Rotational or extensive grazing	(Lemaire et al., 2014; Brewer and Gaudin, 2020; Brewer and Gaudin, 2020; Teague and Kreuter, 2020; Bai and Cotrufo, 2022; Jin et al., 2022)	0	0	0	(Teague and Kreuter, 2020; Bassignana et al., 2022; Sands et al., 2024)	(Pilon et al., 2017; Teague and Kreuter, 2020)		(Teague and Kreuter, 2020; Bassignana et al., 2022)	(Rapiya et al., 2019; Bassignana et al., 2022; Sands et al., 2024)	(Teague and Kreuter, 2020; Bassignana et al., 2022)	(Teague and Kreuter, 2020; Bassignana et al., 2022; Zarifa and Sands et al., 2024)	0	0	(Teague and Kreuter, 2020; Bassignana et al., 2022)
13	Mixed stocking	0	0	0	0	0	0	0	(Wang et al., 2021; Zhang et al., 2022)	(Fraser and Rosa Garcia, 2018; Rinehart, 2018)	0	0	0	0	(Fraser and Rosa Garcia, 2018; Wang et al., 2021)
14	Local breeds adapted to the territory	0	0	0	0	0	0	(Akinmoladun et al., 2019; Bassignana et al., 2022; Tulu et al., 2023)	(Velado-Alonso et al., 2021; Bassignana et al., 2022)	(Soares Fioravanti et al., 2020; Velado-Alonso et al., 2021)	0	0	0	0	(Alderson, 2018; Velado-Alonso et al., 2021)
15	On farm or local production of forage, diversified feeding and low nitrogen feed (not soy)	(Lin et al., 2020; Bai and Cotrufo, 2022)	(Doltra et al., 2018; Helgason et al., 2021)	(Stagnari et al., 2017)	0	(Stagnari et al., 2017; Cao et al., 2024; Berry et al., 2025)	0	0	(Coffey, 2014; Bassignana et al., 2022)	(Coffey, 2014; Franzluebbers and Martin, 2022)	0	(Coffey, 2014; Franzluebbers and Martin, 2022)	0	0	0

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TABLE 4 Continued

	Agroecological practices indicators	Regulating and supporting ecosystem services													
		Increase C sequestration	Reduce C emissions/ mineralization	Increase N fixation	Reduce N emission	Enhance soil fertility (biological, physical, chemical)	Minimize soil erosion	Water quantity and quality	Nutrient cycling	Pest and disease control	Climate regulation	Pollination	Wind protection	Fire protection	Biodiversity at landscape, specie and genetic dimension
16	Sustainable practices in the management of animal manure	0	(Helgason et al., 2021; Badagliacca et al., 2024)	0	(Chadwick et al., 2011; Meng et al., 2025)	(Badagliacca et al., 2024)	0	0	(Helgason et al., 2021; Berry et al., 2025)	0	0	0	0	0	

low-input animal health management. However, conservation tillage and biodiversity management at the landscape level showed limited implementation, with scores of 0 and 1 respectively, suggesting space for improvements in developing soil structure, improving carbon sequestration and enhancing habitat complexity. Figure 4 then shows the aggregated results, representing the final scores attributed to each ecosystem service evaluated in this case study.

The results of the regulating and supporting ecosystem services assessment reflect a moderate level of overall performance, with a mean score of 0.93 across all ecosystem services. Notable observations include: The highest-performing ecosystem services are nitrogen fixation (1.4), carbon sequestration (1.2), and reduction of carbon and nitrogen emissions (both 1.2), which align with the good adoption of practices like cover crops, crop rotation, and appropriate manure management. Soil fertility, pest and disease control, and nutrient cycling show medium-level scores (around 1.1 – 1.2), indicating functional but improvable contributions from farm practices. Climate regulation, wind protection, and fire protection received very low or zero scores (0.33 and 0 respectively), highlighting a lack of practices that contribute directly to climate resilience - such as agroforestry or shelterbelts. Pollination, water management, and biodiversity each scored 1.0 or slightly above, suggesting that while some supporting practices are in place, there's space to enhance landscape complexity and ecological infrastructure to better sustain these services.

3.3 The synergistic value of agroecological practices in ecosystem service provision

The APES framework represents a valuable opportunity to support farmers and other agri-food system stakeholders in making visible the ecosystem services delivered by their management decisions. Rather than assessing outcomes in isolation, the framework focuses on the practices implemented at farm level, offering a practical and accessible entry point for understanding and enhancing agroecosystem performance. By channeling scientific knowledge into a tool that can be co-used and co-adapted by farmers, researchers, and advisors, APES contributes to building a shared language and methodology around ecosystem services that is grounded in lived farming realities (Rodríguez-Ortega et al., 2014; Boeraeve et al., 2020).

One of the key strengths of the APES framework is its ability to capture the synergistic nature of agroecological practices. Ecosystem services are rarely the result of single interventions; instead, they emerge from the combination and interaction of multiple practices embedded within a holistic farming strategy (Wezel et al., 2014; Nicholls and Altieri, 2018). For example, the integration of organic fertilization, cover cropping, and crop diversification not only supports soil fertility and nutrient cycling but also strengthens resilience to pests and climatic variability (Schipanski et al., 2014; Mabhaudhi et al., 2022). APES allows users to trace these connections between practices and ecological functions, reinforcing the idea that ecosystem service delivery is

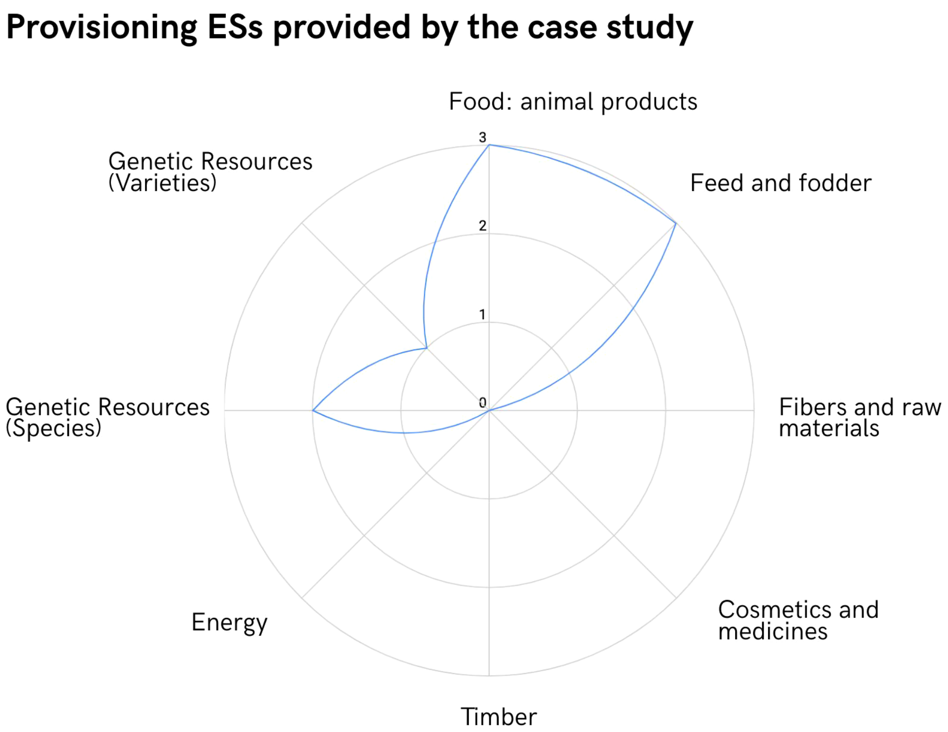

FIGURE 3
Provisioning ecosystem services (ESs) evaluated in the case study. Scores (0 – 3) are based on the level of service provision for each category.

TABLE 5 Practice indicators scores assigned to the case study.

	Indicators APES	Score
1	Conservation and no-tillage systems	0
2	Use of plant reproductive material adapted to local conditions	1
3	Crop rotation	2
4	Intercropping	2
5	Cover crops	2
6	Soil organic matter input	1
7	Water management practices	2
8	Ecological infrastructure and landscape and habitat management	0
9	Agroforestry	0
10	Sampling and monitoring for pests, disease, soil health and weeds abundance	1
11	Organic pest and disease control	1
12	Rotational or extensive grazing	1
13	Mixed stocking	0
14	Local breeds adapted to the territory	2
15	On farm or local production of forage, diversified feeding and low nitrogen feed (not soy)	2
16	Sustainable practices in the management of animal manure	2

cumulative, relational, and context-specific. In this way, APES not only informs assessments and planning but also supports agroecological transition pathways, helping to align day-to-day farming practices with broader sustainability and policy goals. As the framework continues to evolve, its ability to empower users with actionable, farm-level insights will be critical for fostering resilient, multifunctional, and ecologically grounded food systems (Temesgen and Wu, 2018; Soulé et al., 2023).

While in the introduction we acknowledged common critiques of the ecosystem services framework, particularly its anthropocentric orientation and tendency to simplify complex ecological and social dynamics, it is important to revisit these issues in light of the APES methodology. By grounding the assessment of ecosystem services in concrete agroecological practices, the APES framework seeks to enhance an ecological understanding of agricultural systems. The practice-based indicators offer a more operational and accessible entry point for farmers and advisors, potentially democratizing knowledge and supporting decision-making rooted in daily agricultural management. However, this same pragmatism may risk reinforcing instrumental views of nature if not accompanied by broader reflection on values, meanings, and long-term systemic approaches. Moreover, the focus on regulating and supporting services still privileges those functions that are more easily linked to agronomic outcomes. To mitigate this, future iterations of APES could explore ways to integrate more nuanced dimensions, such as cultural values, traditional knowledge, and non-material benefits, without compromising usability. This balance remains an ongoing

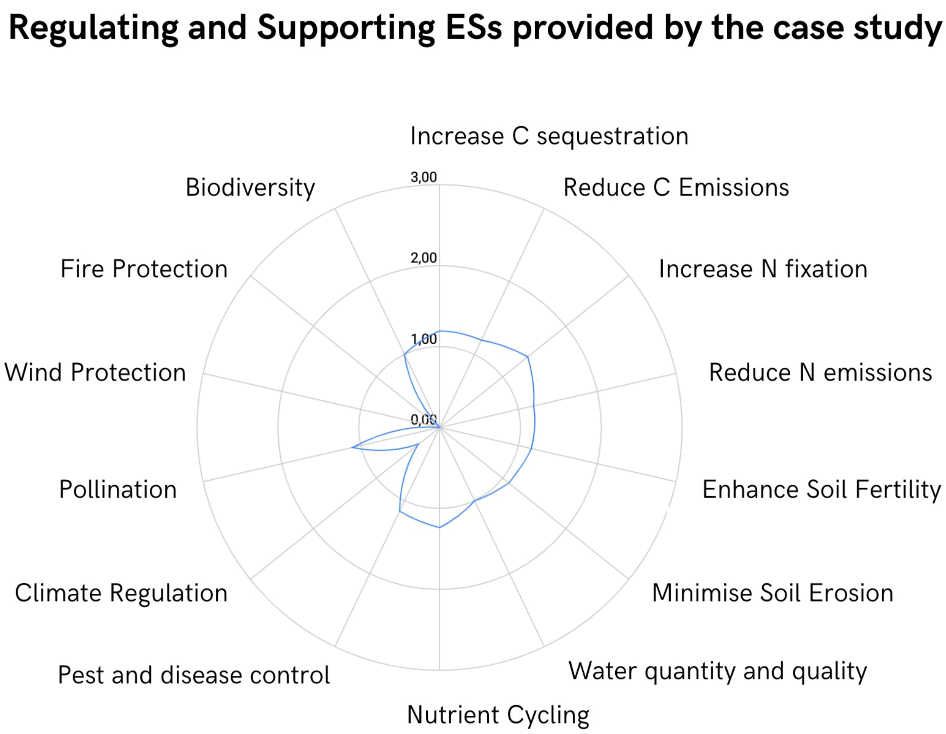

FIGURE 4
Regulating and supporting ecosystem services (ESs) assessed through practice-based indicators and implementation scoring. Scores range from 0 (no implementation) to 3 (high implementation intensity).

issue, but APES represents a step toward reconciling scientific rigor with contextual relevance in the assessment of ecosystem services.

Agroecological transition and agroecological food system transformations are very complex paths. Different strategy options (Röös et al., 2022) and key entry points (Wezel et al., 2020) domains and principles (Billen et al., 2024) have been identified: responsible governance, circular and solidarity economy, diversity, and co-creation and sharing of knowledge, relationship building and inclusivity.

APES through agroecological practices identification, helps to support multifunctional agricultural systems, which consider ecological relationships, resource recycling, and biodiversity management.

3.4 Limitations of the framework and future prospects

While APES demonstrates strong potential for informing sustainability assessments and agri-environmental monitoring schemes, it should currently be understood as a prototype tool. Its application to a single illustrative case study highlights its practical relevance and usability, but broader validation across farming systems, regions, is needed to assess its generalizability and scalability.

The perception-based indicators for assessing provisioning Ess are inherently subjective and may be influenced by biases or limited comparability across farms and regions. To address this, future versions of the APES framework could complement perception-based indicators with more objective measures, such as yield data, nutrient content, or resource-use efficiency, when available.

Moreover, socio-cultural ecosystem services were excluded from the current version of the APES framework due to the inherent complexity in capturing these dimensions through standardized and broadly applicable indicators. While for some practices, such as agroforestry maintained in traditional landscapes, the link to socio-cultural values is well documented, for many others the connection is far more nuanced, context-dependent, and difficult to generalize. This made it challenging to develop evidence-based indicators that could be applied across diverse farming systems without oversimplifying or misrepresenting these impacts.

4 Conclusions

This study introduced the APES (Agroecological Practices for Ecosystem Services) framework as a novel, practice-based tool to assess 22 ecosystem services in farming systems, grounded in both scientific literature and participatory input. By linking specific agroecological practices to provisioning, regulating, and supporting services, APES makes ecological functions visible and actionable at farm scale, while remaining adaptable to diverse agricultural contexts. Its application in a Northern Italian case study demonstrated its capacity to identify both strengths and gaps in ecosystem service provision, offering valuable insights for agroecological transitions. The framework shows strong potential for broader implementation in agri-environmental monitoring, sustainability assessments, and policy instruments such as eco-schemes or payment for ecosystem services. Further research could test APES across a wider range of farming systems and socio-ecological contexts, to validate and refine the practice-service linkages, and develop context-specific weighting systems.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by University of Gastronomic Sciences of Pollenzo. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CB: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. VB: Data curation, Formal Analysis, Methodology, Writing – review & editing. PM: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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