nature sustainability

Perspective

https://doi.org/10.1038/s41893-024-01483-8

Tailored policies for perennial woody crops are crucial to advance sustainable development

Received: 26 February 2024

Accepted: 1 November 2024

Published online: 19 December 2024

Check for updates

Carlos Martinez-Nuñez[1] ✉, Elena Velado-Alonso[1,2], Jacques Avelino[3,4], Pedro J. Rey[5], G. Martijn ten Hoopen[3], Guy Pe'er[6,7], Yi Zou[8], Yunhui Liu[9], Philip Antwi-Agyei[10], Adrien Rusch[11], Charles Staver[12], Tharaka S. Priyadarshana[13], Denis J. Sonwa[14,15], Damayanti Buchori[16], Lucas A. Garibaldi[17,18], Elena D. Concepción[19], Owen T. Lewis[20], Ivette Perfecto[21] & Ignasi Bartomeus[1]

Perennial woody crops, which are crucial to our diets and global economies, have the potential to play a major role in achieving multiple UN Sustainable Development Goals pertaining to biodiversity conservation, socio-economic development and climate change mitigation. However, this potential is hindered by insufficient scientific and policy attention on perennial woody crops, and by the intensification of perennial crop cultivation in the form of monocropping with high external inputs. In this Perspective, we highlight the potential of properly managed and incentivized perennial woody crops to support holistic sustainable development and urge scientists and policymakers to develop an effective agenda to better harness their benefits.

Most current agricultural models prioritize immediate economic profitability and increased productivity at the expense of long-term sustainability[1]. This has led to severe environmental challenges, such as habitat loss and fragmentation, water and air pollution and soil degradation. These issues are primary drivers of the ongoing biodiversity crisis[2] and have major impacts on human health[3]. The biodiversity decline caused by unsustainable agriculture limits nature's contributions to people[4], increases the dependence of farmers on agrochemicals and threatens food security worldwide[5]. Finding solutions that minimize the adverse ecological impacts of agriculture is therefore key to reducing biodiversity loss[6,7], mitigating climate change and adapting to its adverse effects[8], ensuring food sovereignty[9] and safeguarding the long-term viability of agriculture[5]. Among the environmental targets set at the UN Biodiversity Conference of the Convention on Biological Diversity in Kunming–Montreal 2022 under the Kunming–Montreal Global Biodiversity Framework (https://www.cbd.int/gbf), eight are closely related to the management of agricultural landscapes, including target 10 for the sustainable use of agricultural lands and target 18 for identifying and removing harmful agricultural subsidies. Addressing these issues is a multifaceted, high-priority challenge at the interface of ecology and economics that intersects with social issues such as human rights, equity (including access to land) and the fair distribution of wealth.

The design and management of cropping systems will play a key role in reaching post-2020 global biodiversity targets[10,11]. Perennial woody crops (hereafter referred to as perennial crops for brevity) offer great potential for progress towards achieving the UN Sustainable Development Goals (SDGs) through reconciling agricultural production and biodiversity conservation. Although agriculture has been a key driver of recent and ongoing land-use change and perennial crops have contributed to these changes (for example, through tropical deforestation[12–14]), some perennial crops, if managed under sustainable principles, could promote biodiversity conservation. Furthermore, as perennial cropping systems tend to be less mechanized and often require substantial human labour, there are opportunities to reduce unemployment and support rural livelihoods[15,16], especially in the developing countries where many of these crops are grown. Unfortunately, these potential benefits are often undermined by low wages, seasonal labour demands, worker exploitation and immigration[16]—problems

A full list of affiliations appears at the end of the paper. ✉e-mail: cmnunez@ujaen.es

https://doi.org/10.1038/s41893-024-01483-8

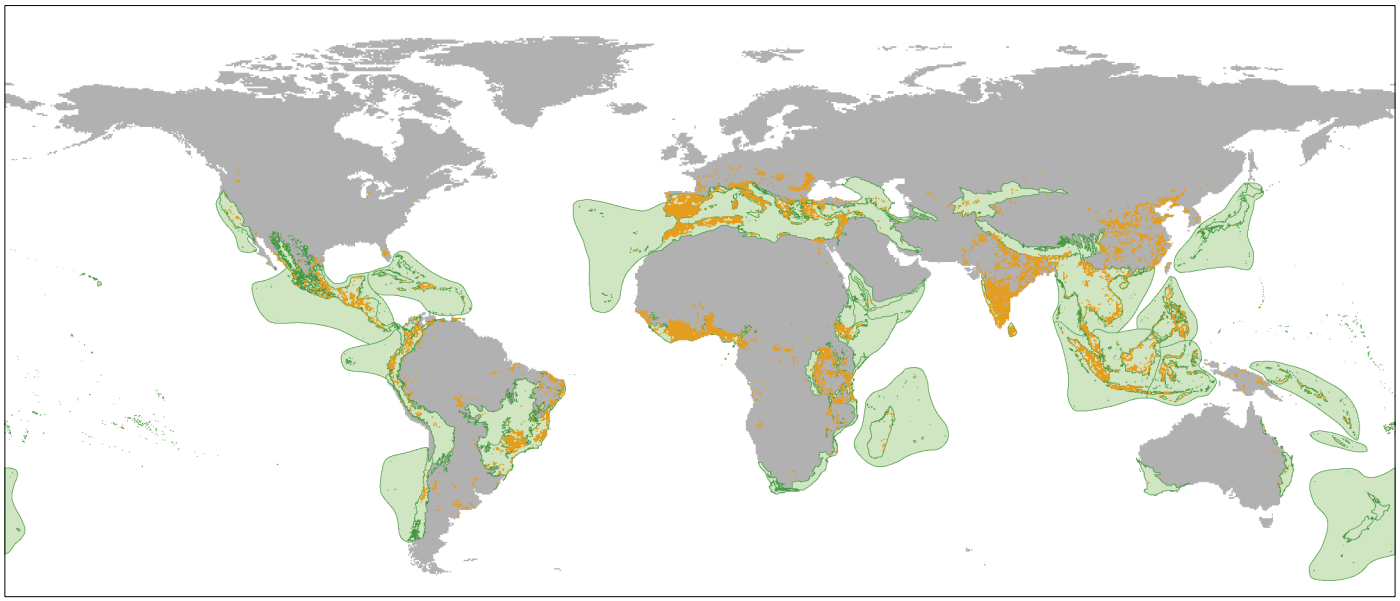

Fig. 1 | Overlap between the main perennial crops and hotspots of biodiversity. Orange shading indicates areas where any of the following perennial crops are grown: oil palm, bananas and plantains, cocoa, coffee, coconut, olives, grapevine, cashews, mangoes, apples and oranges[71]. Green shading indicates the main biodiversity hotspots according to Myers et al.[27] (revised version[72]).

that are exacerbated as perennial crop production intensifies. This intensification partly reflects a lack of recognition of the ecological and social importance of perennial crops, as well as a lack of incentives to promote sustainable practices. Most agricultural policies that are aimed at improving environmental and economic sustainability emphasize annual crop management (arable land); very few specifically target perennial crops[17]. A focus on annual crops is clearly important to improve agricultural sustainability, and associated actions (such as agri-environmental schemes[18,19]) are proving successful overall (albeit with scope for improvement[20]). However, we argue that leveraging the potential of perennial crops to contribute to the SDGs for environmental and economic sustainability requires more research, legislative support and the implementation of tailored policies[21,22].

In this Perspective we aim to highlight the unexploited potential of properly managed and incentivized perennial crops to contribute to the SDGs. In doing so, we do not aim to diminish the importance of annual crops or to compare the two cropping systems. We instead emphasize that annual and perennial crop systems each have particular risks and advantages that require different management approaches (Supplementary Table 1). Although intensification affects both systems and typically reduces their contributions to the SDGs, annual crops have on average a lower ecological value, even when properly managed, due to their simpler structural complexity and short-term dynamics[23–25]. Perennial crops require a longer-term commitment from growers, which make them less flexible and hence more vulnerable to climate change and new pests and diseases, yet perennial crops managed under agroecological principles with a higher reliance on ecological processes (ecological intensification[26]) could contribute substantially to achieving key SDGs. This results in large part from their greater structural complexity, temporal stability and strategic presence in biodiversity-rich and socio-economically developing regions[10]. We argue that new, complementary agricultural policies should aim to maximize the contribution of perennial crops to the SDGs and counter the current trend towards unsustainable farming in these systems.

Relevance of perennial crops to the SDGs

Perennial crops typically include plantations of fruit trees (such as citrus), nut trees (cashews, walnuts or almonds), berries (blueberries), stimulants (coffee, cocoa (cacao), tea), vine crops and oil palm and olive trees, among others. Although not woody, we include bananas and plantains in this discussion as they are ecologically and socio-economically important tree-like perennial crops. Perennial crops cover approximately 183 Mha worldwide, much of which overlaps with key biodiversity hotspots[27]. For instance, coffee is extensively grown in tropical areas of Mesoamerica, olive trees in the Mediterranean Basin hotspot, cocoa in the Guinean Forests of West Africa and oil palm in Sundaland (Fig. 1 and Supplementary Table 2).

As with any other cropping system, perennial crops inherently conflict with the conservation of the natural habitats they replace. However, some of their characteristics can make them compatible with biodiversity conservation. Their heterogeneous and often forest-like structures, encompassing many vegetation layers, offer a wide range of micro- and macrohabitats that can support high diversity, including native plant species in the herbaceous cover (for example, vineyards, olive or apple groves), overhead shade trees (such as cocoa or coffee) and mixed species associations[28–31]. Consequently, a high number of vertebrate and invertebrate taxa can coexist in these agroecosystems[32–35]. In addition to the inherent structural heterogeneity, perennial crops occupy land over multiple years without replanting, providing relatively stable habitats within and across years. As a result, habitat and species diversity can be more easily maintained in perennial crop systems than in arable crop systems.

Many perennial crops have extensive root structures and provide abundant litter, which means that they can reduce soil erosion, increase soil fertility and soil health, minimize nutrient leaching and offer permanent habitats for many species[36–38] while being highly productive (that is, approximately 1 Gt yr^{-1} worldwide)[39]. Furthermore, woody tree-like perennial crops can help reduce GHG emissions through above- and belowground carbon sequestration[38,40,41]. Perennial crop systems can also act as a permeable matrix through which wildlife can travel between forest patches, enhancing connectivity and contributing to the maintenance of fragmented forest populations as metapopulations[42]. As such, they can buffer protected areas and other natural and seminatural habitats within intensively managed agricultural landscapes[43].

Perennial crops can thus, when correctly managed, support a wide range of plant and animal species alongside the crop, playing a key role in reconciling biodiversity conservation with the needs of people—and

https://doi.org/10.1038/s41893-024-01483-8

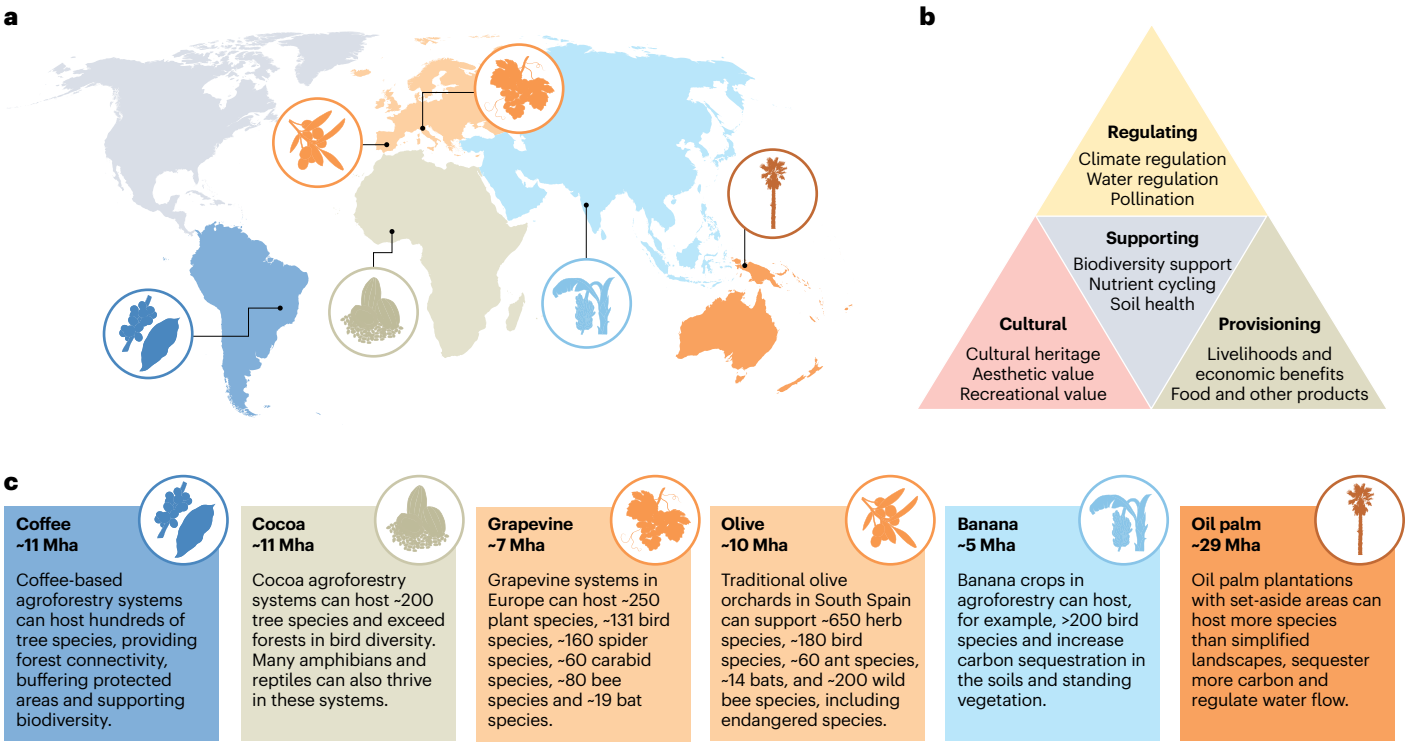

Fig. 2 | The importance of perennial crops worldwide. a, World map showing six of the most important perennial crops in terms of area coverage and socio-economic impact. **b**, Main ecosystem services provided by perennial crops worldwide. **c**, Area covered by each crop in 2021 (the production area of bananas, including plantains and cooking bananas, reached 12 Mha) and the potential for biodiversity conservation and provision of ecosystem services by key perennial crops worldwide. See Supplementary Fig. 1 for a fully referenced version.

in some cases maximizing nature's contribution to people (Fig. 2 and Supplementary Fig. 1). However, leveraging these opportunities will require greater representation of perennial crops in the scientific literature (Fig. 3) and in agricultural policies.

Most potential gains discussed here pertain to diversified woody or tree-like perennial crops because of their high biomass and complex structures. However, it is worth noting that perennial herbaceous crops, such as alfalfa, also cover extensive areas and are highly relevant to biodiversity and soil health[44]. Given the substantial advantages of perennial herbaceous crops over their annual counterparts[23,45,46], notable effort is underway to develop and cultivate perennial varieties of key herbaceous species (such as grains)[25,47]. Developing new and improved crop varieties while preserving the genetic diversity of crops could be crucial, particularly in marginal landscapes, resource-constrained settings and regions facing increased drought from climate change[45,46].

Legislation gaps harm conservation efforts

With a few exceptions[48], perennial cropping systems have received limited attention within the global agricultural policy framework. For example, there is no explicit mention of perennial crops in the latest agricultural policy monitoring and evaluation report compiled by the Organization for Economic Co-operation and Development, which encompasses agricultural legislation from 54 countries worldwide[17]. This is surprising, given the overarching theme of the report, which is titled *Reforming Agricultural Policies for Climate Change Mitigation*[17]. Another example is the EU, known for its wide-ranging agricultural policies and a substantial budget to implement them (for example, €387 billion for the period 2023–2027)[49]. In the EU, perennial crops have historically been considered 'green' by definition, and it is only in the most recent reform of the Common Agricultural Policy (2023–2027) that guidelines specific to them have been introduced, such as the conservation of living or inert ground cover[49]. Although these guidelines represent a step forwards, they fall short of fully realizing the potential of perennial crops for conserving agrobiodiversity and promoting sustainability. Furthermore, long-term unsustainable incentives persist, such as the promotion of inefficient irrigation systems that deplete groundwater in semi-arid rain-fed Mediterranean crops or the exemption of perennial crops from some environmental requirements. For instance, according to the EU's Common Agricultural Policy, establishing seminatural areas of non-production for nature (formerly known as set-aside, now a component of 'Good agricultural and environmental conditions') is a requirement that applies only to arable crops, with perennial crops and grasslands essentially exempt. Moreover, payments for specific sectors—such as fruit trees, olives and wine—are not attached to environmental standards, meaning that opportunities to secure their environmental value are missed. More worryingly, it is precisely in perennial crops that, in Europe, contamination by the so-called candidates for substitution (that is, pesticides listed as hazardous to humans) has seen a steep rise in recent years, reaching extremely high levels in fruits such as cherries, apples, pears, peaches and kiwi[50].

Specific environmental legislation regarding the long-term sustainability of perennial crop landscapes is virtually absent worldwide[17]. This limited focus and the absence of proactive measures have contributed to the ongoing rapid trend towards deforestation[12–14] and extreme intensification of many perennial crops around the world, especially in tropical areas. For instance, Jha et al.[51] found that the area of traditional shaded coffee decreased from 43% to 24% in 19 countries between 1996 and 2010, resulting in high biodiversity loss[51]. This general trend, also seen for other perennial crops and areas, poses an important threat to biodiversity and sustainability across millions of hectares worldwide[52] (Fig. 4).

Some of the most frequent and environmentally damaging practices within perennial crop production include: (1) the loss of forest- or savannah-like structure as traditional low-density orchards are replaced by hyperdense planting lines (that is, hedge-like plantations)[53,54]; (2) the loss of soil and declines in soil quality through frequent tillage and the use of pre- and post-emergence herbicides that leave bare soils by

https://doi.org/10.1038/s41893-024-01483-8

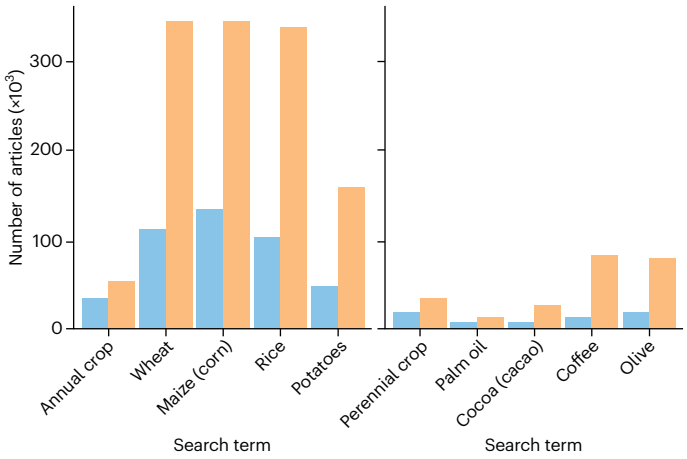

Fig. 3 | Scientific attention received by perennial crops and annual crops. Left: annual crops. Right: perennial crops. The total numbers of publications indexed in the Web of Science (orange) and the subset of publications within the field of environmental sciences (blue) that are related to specific keywords such as 'annual crop' or 'wheat' are shown. The search was performed in June 2024. Note that high scientific attention does not necessarily imply that effective measures are properly deployed.

persistently removing herbaceous cover[55]; (3) the loss of crop diversity and genetic/varieties diversity[56,57]; and (4) the loss of landscape complexity through the removal of field margins and patches of semi-natural vegetation and reductions in native flora in agroecosystems[6]. These negative practices can often co-occur, as in super-intensive olive, apple or even coffee/cocoa farming systems, turning traditional (often smallholder) forest-like agroecosystems into high-input, hyperdense monocultures (Fig. 5 and Supplementary Table 3).

Besides the conservation threats arising from unsustainable practices, there are also crucial socio-economic consequences to consider. Current models for perennial crop cultivation rely heavily on rapid and extensive automation and mechanization, which contribute to rural unemployment, a major political challenge worldwide[58]. Moreover, the prevalence of corporate farming—large-scale monocultures owned by major companies—fosters a decline in community engagement and leads to income reductions for millions of people worldwide[7]. Given that ensuring a decent job for all is one of the SDGs (SDG 8), avoiding extreme levels of mechanization and promoting fair and stable labour for people seems to offer a viable approach to balancing employment and profit, especially when striving to ensure an equitable redistribution of profits among stakeholders.

In light of the prevailing tendency towards less sustainable agricultural practices, it is timely to stress the need for national and international agricultural policies that strategically allocate targeted and tailored incentives to foster socially responsible and sustainable perennial crop cultivation. Measures in this direction (for example, the minimum social and labour standards required to receive subsidies implemented in the last EU Common Agricultural Policy) have the potential to safeguard the long-term sustainability and ecological value of these agricultural systems while ensuring equitable incomes for farm households and labourers. This would also support progress towards other SDGs, such as providing decent jobs and economic development.

Policies for perennial crop sustainability

Solutions that offer a favourable balance between production and sustainability exist, but agricultural policies are still inadequate to encourage farmers to adopt them.

The viability of sustainable agricultural practices largely depends on economic benefits for farmers and wider society[59,60]. The payment of incentives for ecosystem service provision has been highly effective at promoting sustainable practices in some contexts[7,61]. Nevertheless, the complex nature of agroecosystems, influenced by diverse socio-political circumstances, means that there is no one-size-fits-all solution that can be applied in all ecological and socio-economic contexts. Therefore, we share our vision of the status and threats to key perennial crops worldwide (Fig. 5 and Supplementary Table 3) and propose the incentivization of specific practices to promote more sustainable agriculture in key agroecosystems—oil palm, cocoa, coffee, olive, grapevine, banana, citrus and apple (Fig. 6, Supplementary Table 4 and further discussion in Supplementary Notes 1–8)—to increase their sustainability and support progress towards the SDGs[62].

We identify three priorities. First, most perennial crops will benefit from within-field and landscape-level management practices that foster biodiversity (that is, ecological intensification)[26] and those good practices often require both regulation and economic incentives[59]. Second, for some perennial crops grown in tropical biodiversity hotspots (for example cocoa, coffee or oil palm) there is a need for stricter regional land-use planning together with international trade regulation efforts to adjust offer and demand[63]. Such regulations should target the whole food chain and are necessary to ensure that deforestation is halted and reversed. Finally, transitioning towards agricultural sustainability demands a holistic and multidimensional approach. This involves integrating a variety of tools across the entire food chain into policy design, creating targeted campaigns for technology adoption and providing comprehensive support to farmers through training, extension programmes, financial aid, fair prices (that is, living income reference prices) and incentives. Addressing market access, certification standards, consumer awareness and fostering participatory approaches are equally crucial. A combination of incentives, such as subsidies for biodiversity-friendly farming practices, payments for ecosystem services or results-based payments, could substantially enhance conservation outcomes. Measures such as tax reductions, insurance support for farmers willing to sacrifice some yield in favour of more sustainable practices, assistance with certification processes, promotion of sustainable products, support for implementing adaptive measures against climate change risks and land stewardship programmes can further reinforce these efforts.

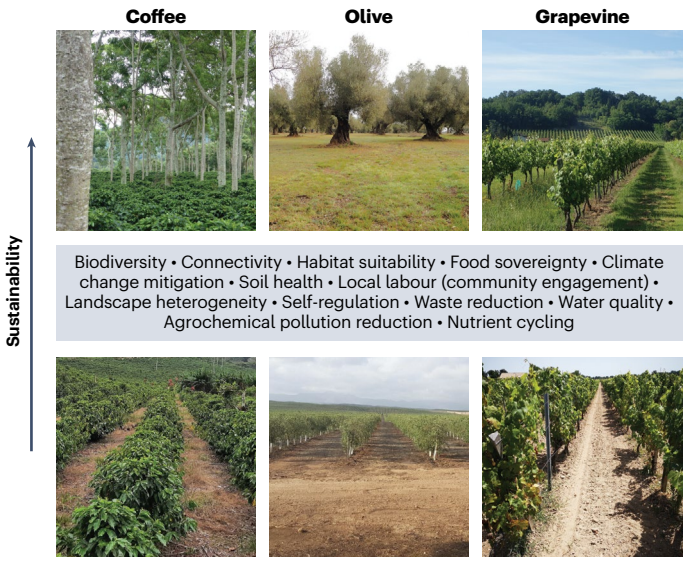

Fig. 4 | Effects of agricultural practices in perennial crops along the sustainability gradient. Negative environmental and socio-economic effects driven by unsustainable production in perennial crops are listed, showcased by extremes of sustainability in three key perennial crops worldwide (coffee, olive and grapevine). Credit: grapevines, Sophie Chamont (top), Sylvie Richart-Cervera (bottom).

https://doi.org/10.1038/s41893-024-01483-8

Crop	Environmentally less sustainable practices					Economically less sustainable practices			Threats to sustainable production			
	Deforestation	High dependence on agrochemicals	Monocropping	Landscape simplification	Removal of ground cover	Low crop value and low income for farmers	Increased cost of inputs and agrochemicals	Price volatility	Vulnerability to climate change	Pests and diseases (emergent species)	Extreme weather	Limited research
Oil palm fruit	✓	✓							✓			✓
Banana		✓	✓			✓	✓	✓		✓	✓	✓
Cocoa	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
Coffee	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
Olive		✓	✓	✓	✓	✓		✓	✓			✓
Grapevine		✓	✓	✓	✓				✓	✓	✓	✓
Citrus		✓			✓				✓	✓	✓	✓
Apple		✓							✓	✓		✓

Fig. 5 | Main threats to the sustainability of key perennial crops worldwide. The principal risks facing specific perennial crops were highlighted by experts on each crop. Environmentally less sustainable practices are actions under the control of farmers, whereas economically less sustainable practices and the broader threats to sustainable production require the involvement of multiple stakeholders, including scientists, society and politicians. This list is not exhaustive; only the priority threats are highlighted for each crop and other secondary threats may also apply.

Intertwined complexities and a way forwards

Legislating agriculture is a complex challenge as there are multiple trade-offs and interconnections between ecological, economic and social components. In this context, solutions are not absolute and universal but need to be implemented progressively and revised to avoid undesired outcomes. In particular, much work remains to be done to understand the interplay between various socio-economic and ecological dimensions in key agroecosystems, particularly perennial crops, and how to maximize benefits in some components (for example, farmer profitability or rural development) without compromising others (such as biodiversity conservation)[59].

The first key aspect is that many biodiversity-friendly measures relate to promoting smallholders. However, it is crucial to recognize that smallholders often lack the capacity to implement efficient and sustainable practices due to limited resources, while some larger producers could transition more easily towards sustainable farming. Therefore, it is important to consider that the type and extent of exploitation are affected by various economic, social and environmental factors that affect farmers' decisions. Accordingly, support should be tailored to farmers' capacities and needs to ensure that larger producers are incentivized to pursue agroecological efforts, while vulnerable farmers receive sufficient help to adopt sustainable practices without compromising their livelihoods[64]. Similarly, regulations can prove ineffective if we do not tackle problems such as the unfair distribution of the income generated by perennial crops across the food chain—decentralizing food chains could help in this context[59]. Regulating crop production cannot be done without integrating the social, economic and ecological dimensions, as well as their interconnections and ramifications. Resolving pressing global issues such as food waste, climate change, food security challenges and biodiversity loss depends heavily on the actions we suggest here.

Second, we need to understand how potential solutions at small scales can work when implemented at larger scales, as we still have little knowledge about the feedback effects (positive or negative) of the large-scale expansion of sustainable practices[65]. For example, imposing a fast transition towards organic agriculture in a generalized manner, without properly facilitating the transition, could have positive results for biodiversity but bring problematic consequences for food production and food security if yields decrease importantly (for example due to elevated pest damage) and products become unavailable or unaffordable for part of the population[66]. In some cases, certifications or labels (for example, organic or fair-trade for coffee or cocoa) have been implemented successfully to distinguish specific products in the market, encouraging more sustainable management in these systems. This assumes that a segment of the public is willing to pay more for certified products. However, predicting market behaviour becomes challenging as the proportion of production achieving certification increases, and certification might only work if certified products are relatively scarce. Hence, while we support the promotion of certified products through economic incentives, international customs duties and national tax differentials to alleviate the certification costs incurred by farmers, this recommendation should be revisited in the medium term once higher market quotas for certified products are reached.

Third, some of the major problems in agriculture are inherent to the current market system and predominant consumption model. Therefore, a deep transformation in the way people purchase and consume agricultural goods and products could be needed to change these dynamics. For instance, many tree crops yield non-essential products from a nutritional standpoint that are consumed far from the production areas, which is often regarded as less sustainable than using local products. Hence, as a society, we should reflect on the biodiversity impacts of consumption of non-local and non-essential products, and on which crops we would like to prioritize to promote healthy and nutritious diets (for example, crops with high protein contents).

Reflecting on these complexities, we argue that the following three points are crucial to achieving SDGs. First, international trade needs international agreements that focus on the entire supply chain. Countries and companies that import products from producing areas (often located in developing countries in Latin America, Africa and Asia) should also take responsibility for the socio-economic and ecological impacts of these transactions (for example, waive customs duties or avoid externalization of environmental damage)[63]. Working on international agreements could have a positive impact on the way we produce food and on people's livelihoods worldwide. Special care must be taken not to shift the burden of environmental protection onto smallholder farmers, who typically have lower incomes and are more vulnerable to both environmental stresses and the economic and social impacts of agricultural policies. Instead, they should be supported and incentivized to adopt sustainable practices while it is also ensured that they receive a fair income. For example, rising temperatures and erratic rainfall patterns driven by climate change are increasingly affecting the production and profitability of some perennial crops (such as cocoa, coffee and citrus). This is particularly critical for smallholder farmers whose livelihoods are closely linked to these crops[67]. Addressing the challenges posed by climate change for such perennial crops requires ingenuity from smallholder farmers and support to implement adaptive measures including shade-planting, establishing cover vegetation to protect the soil (including marketable crops) or rainwater harvesting and the provision of irrigation[68,69]. Smallholder farmers, especially those in dryland farming systems, are also confronted with non-climatic stressors (for example, limited access to markets and inadequate agricultural equipment) that are often exacerbated by existing inequalities in relation to access to land and other productive capital resources[70]. These challenges drive the vulnerability of smallholders to climatic and non-climatic threats, including food insecurity. Therefore, there is an urgent need for holistic policy interventions that could empower smallholders to adopt new, efficient and sustainable practices where possible. Larger commercial growers can also learn from smallholders (for example, about the use of different parts of the plants). The exchange

https://doi.org/10.1038/s41893-024-01483-8

	Agricultural practices to incentivize					Goals and areas of priority policy investment								
Crop	Promote islands and corridors of native vegetation	Enhanced understory vegetation and inter-row vegetation	Diversify planting stock	Reduced reliance on agrochemicals	Reduced nutrient inputs	Landscape planning to avoid deforestation	Restore risk-prone land	Protect water and soil resources	Promote agroforestry	Promote equitable income and tax benefits for smallholders	Promote low-density and rain-fed agriculture	Promote certification	Advertisement campaigns to increase consumer awareness	Promote cultural heritage and traditional practices
Oil palm fruit	✓	✓		✓		✓								
Banana	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		
Cocoa		✓				✓	✓		✓	✓		✓	✓	✓
Coffee		✓				✓	✓		✓	✓		✓	✓	✓
Olive	✓	✓		✓				✓			✓	✓	✓	✓
Grapevine	✓	✓	✓	✓				✓	✓					
Citrus		✓		✓				✓						
Apple		✓		✓				✓						
SDGs enhanced	12, 13, 15	12, 15	1, 10, 12	6, 10, 12, 15	6, 12	12, 13, 15	1, 8, 10	6, 12, 13	12, 13, 15	1, 8, 10	12, 13, 15	12	12, 15	8, 10, 12, 15

Fig. 6 | Agricultural practices and farming models that could be incentivized by new agricultural policies. These actions could help to increase the ecological and socio-economic long-term sustainability of key perennial crops worldwide. The proposed solutions are based on expert knowledge and scientific literature (see the Supplementary Information for extended commentary on each one, with supporting citations). The agricultural practices to incentivize are actions under the control of farmers, whereas the goals and areas of priority policy investment require the involvement of multiple stakeholders (including scientists, civil society and politicians). The SDGs enhanced are the environmental and socio-economic realms that each action would improve: no poverty (SDG 1); clean water and sanitation (SDG 6); decent work and economic growth (SDG 8); reduced inequality (SDG 10); responsible production and consumption (SDG 12); climate (SDG 13); and life on land (SDG 15).

of knowledge and practices should be mutual, ensuring that different types of farmer benefit both environmentally and economically. Second, each agricultural system has its own particular problems and needs, and one policy will not fit them all. While some regions should focus on the protection and conservation of natural areas (for example, palm oil production) using regulatory policies and land-use planning, others should concentrate on restoring already degraded lands, seminatural habitats under exploitation and the surrounding landscape through incentives (for example, olive farms, vineyards or apple orchards). Third, the multiple socio-political feedbacks and interactions in place mean that policies cannot work in isolation from society and local communities. Instead, a socio-cultural and economic context that facilitates the evolution and development of green and equitable policies should be fostered. There is a need to work from the bottom up with local communities to incentivize and encourage local sustainable crops and ensure the uptake of such policies by local communities, instead of enforcing market needs on them.

In conclusion, perennial crops can play a crucial role in harmonizing agriculture and the achievement of the SDGs if correctly managed. However, their importance warrants increased attention in scientific research and agricultural policies. Neglecting the value of perennial crops could lead to increased unsustainability, accelerating a myriad of environmental and social issues that are compounded by climate change. To secure the future of agriculture and biodiversity, and make progress towards the achievement of the SDGs, governments should consider legislative support and tailored policies for perennial crops. A variety of actions proposed here could promote sustainable practices in perennial crop cultivation globally by reducing biodiversity loss, supporting livelihoods and rural development, addressing climate change concerns, building the resilience of farmers (especially smallholders) and enhancing food security in the years ahead. The ultimate goal of this Perspective is to bring attention to this issue, stimulate debate involving as many actors as possible and motivate policymakers and scientists to place this important matter on their agendas.

References

1. Clough, Y. et al. Land-use choices follow profitability at the expense of ecological functions in Indonesian smallholder landscapes. *Nat. Commun.* **7**, 13137 (2016).
2. Newbold, T. et al. Global effects of land use on local terrestrial biodiversity. *Nature* **520**, 45–50 (2015).
3. Rohr, J. R. et al. Emerging human infectious diseases and the links to global food production. *Nat. Sustain.* **2**, 445–456 (2019).
4. Díaz, S. et al. Assessing nature's contributions to people. *Science* **359**, 270–272 (2018).
5. *Tool for Agroecology Performance Evaluation (TAPE)—Test Version: Process of Development and Guidelines for Application* (FAO, 2019); https://www.fao.org/documents/card/en/c/ca7407en/
6. Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C. & Batáry, P. Beyond organic farming—harnessing biodiversity-friendly landscapes. *Trends Ecol. Evol.* **36**, 919–930 (2021).
7. Garibaldi, L. A. et al. Policies for ecological intensification of crop production. *Trends Ecol. Evol.* **34**, 282–286 (2019).
8. Lal, R. et al. Management to mitigate and adapt to climate change. *J. Soil Water Conserv.* **66**, 276–285 (2011).
9. Perfecto, I., Vandermeer, J. & Wright, A. *Nature's Matrix Linking Agriculture, Biodiversity Conservation and Food Sovereignty* (Taylor and Francis, 2019).
10. Bhagwat, S. A., Willis, K. J., Birks, H. J. B. & Whittaker, R. J. Agroforestry: a refuge for tropical biodiversity? *Trends Ecol. Evol.* **23**, 261–267 (2008).
11. Wanger, T. C. et al. Integrating agroecological production in a robust post-2020 Global Biodiversity Framework. *Nat. Ecol. Evol.* **4**, 1150–1152 (2020).
12. Fitzherbert, E. B. et al. How will oil palm expansion affect biodiversity? *Trends Ecol. Evol.* **23**, 538–545 (2008).
13. Li, T. M. Securing oil palm smallholder livelihoods without more deforestation in Indonesia. *Nat. Sustain. 2024 74* **7**, 387–393 (2024).

14. Kalischek, N. et al. Cocoa plantations are associated with deforestation in Côte d'Ivoire and Ghana. *Nat. Food 2023 45* **4**, 384–393 (2023).
15. Garibaldi, L. A. & Pérez-Méndez, N. Positive outcomes between crop diversity and agricultural employment worldwide. *Ecol. Econ.* **164**, 106358 (2019).
16. Seneduangdeth, D., Ounmany, K., Phommavong, S., Phouxay, K. & Hathalong, K. Labor employment opportunities in coffee production in southern Lao People's Democratic Republic. *J. Asian Rural Stud.* **2**, 16–36 (2018).
17. *Agricultural Policy Monitoring and Evaluation 2022: Reforming Agricultural Policies for Climate Change Mitigation* (OECD, 2022); https://doi.org/10.1787/7f4542bf-en
18. Batáry, P., Dicks, L. V., Kleijn, D. & Sutherland, W. J. The role of agri-environment schemes in conservation and environmental management. *Conserv. Biol.* **29**, 1006–1016 (2015).
19. Boetzl, F. A. et al. A multitaxa assessment of the effectiveness of agri-environmental schemes for biodiversity management. *Proc. Natl Acad. Sci. USA* **118**, e2016038118 (2021).
20. Candel, J. J. L., Lakner, S. & Pe'er, G. Europe's reformed agricultural policy disappoints. *Nature* **595**, 650 (2021).
21. Pe'er, G. et al. Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People Nat.* **2**, 305–316 (2020).
22. Nicholson, E. et al. Scientific foundations for an ecosystem goal, milestones and indicators for the post-2020 global biodiversity framework. *Nat. Ecol. Evol.* **5**, 1338–1349 (2021).
23. Pimentel, D. et al. Annual vs. perennial grain production. *Agric. Ecosyst. Environ.* **161**, 1–9 (2012).
24. Batello, C. et al. *Perennial Crops for Food Security: Proceedings of the FAO Expert Workshop* (FAO, 2014).
25. Crews, T. E., Carton, W. & Olsson, L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Glob. Sustain.* **1**, e11 (2018).
26. Kleijn, D. et al. Ecological intensification: bridging the gap between science and practice. *Trends Ecol. Evol.* **34**, 154–166 (2019).
27. Myers, N., Mittermeler, R. A., Mittermeler, C. G., Da Fonseca, G. A. B. & Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858 (2000).
28. Sonwa, D. J., Weise, S. F., Schroth, G., Janssens, M. J. J. & Shapiro, H. Y. Structure of cocoa farming systems in West and Central Africa: a review. *Agrofor. Syst.* **93**, 2009–2025 (2019).
29. Tarifa, R. et al. Agricultural intensification erodes taxonomic and functional diversity in Mediterranean olive groves by filtering out rare species. *J. Appl. Ecol.* **58**, 2266–2276 (2021).
30. Winter, S. et al. Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: a meta-analysis. *J. Appl. Ecol.* https://doi.org/10.1111/1365-2664.13124 (2018).
31. Valencia, V., García-Barrios, L., West, P., Sterling, E. J. & Naeem, S. The role of coffee agroforestry in the conservation of tree diversity and community composition of native forests in a Biosphere Reserve. *Agric. Ecosyst. Environ.* **189**, 154–163 (2014).
32. Schroth, G. & Harvey, C. A. Biodiversity conservation in cocoa production landscapes: an overview. *Biodivers. Conserv.* **16**, 2237–2244 (2007).
33. Rey, P. J. et al. Landscape-moderated biodiversity effects of ground herb cover in olive groves: implications for regional biodiversity conservation. *Agric. Ecosyst. Environ.* **277**, 61–73 (2019).
34. Sonwa, D. J. et al. Diversity of plants in cocoa agroforests in the humid forest zone of Southern Cameroon. *Biodivers. Conserv.* **16**, 2385–2400 (2007).
35. Bruggisser, O. T., Schmidt-Entling, M. H. & Bacher, S. Effects of vineyard management on biodiversity at three trophic levels. *Biol. Conserv.* **143**, 1521–1528 (2010).
36. Clough, Y. et al. Combining high biodiversity with high yields in tropical agroforests. *Proc. Natl Acad. Sci. USA* **108**, 8311–8316 (2011).
37. Kavvadias, V. & Koubouris, G. in *Soil Fertility Management for Sustainable Development* (eds Panpatte, D. & Jhala, Y.) 167–188 (Springer, 2019).
38. Cerda, R. et al. Effects of shade, altitude and management on multiple ecosystem services in coffee agroecosystems. *Eur. J. Agron.* **82**, 308–319 (2017).
39. *FAOSTAT* (FAO, 2021); https://www.fao.org/faostat
40. Ewing, P. M. et al. Smallholder farms have and can store more carbon than previously estimated. *Glob. Change Biol.* **29**, 1471–1483 (2023).
41. Batsi, G., Sonwa, D. J., Mangaza, L., Ebuy, J. & Kahindo, J. M. Preliminary estimation of above-ground carbon storage in cocoa agroforests of Bengamisa-Yangambi forest landscape (Democratic Republic of Congo). *Agrofor. Syst.* **95**, 1505–1517 (2021).
42. Perfecto, I. & Vandermeer, J. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proc. Natl Acad. Sci. USA* **107**, 5786–5791 (2010).
43. Kremen, C. & Merenlender, A. M. Landscapes that work for biodiversity and people. *Science* **362**, eaau6020 (2018).
44. González del Portillo, D., Arroyo, B. & Morales, M. B. The adequacy of alfalfa crops as an agri-environmental scheme: a review of agronomic benefits and effects on biodiversity. *J. Nat. Conserv.* **69**, 126253 (2022).
45. Glover, J. D. et al. Increased food and ecosystem security via perennial grains. *Science* **328**, 1638–1639 (2010).
46. DeHaan, L. R. et al. Discussion: prioritize perennial grain development for sustainable food production and environmental benefits. *Sci. Total Environ.* **895**, 164975 (2023).
47. Zhang, S. et al. Sustained productivity and agronomic potential of perennial rice. *Nat. Sustain.* **6**, 28–38 (2022).
48. *ASEAN Regional Guidelines for Sustainable Agriculture in ASEAN Jakarta* (ASEAN Secretariat, 2023).
49. The common agricultural policy at a glance. *European Commission* https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en (2021).
50. *Forbidden Fruit* (Pesticide Action Network Europe, 2022); https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/ForbiddenFruit_01.pdf
51. Jha, S. et al. Shade coffee: update on a disappearing refuge for biodiversity. *BioScience* **64**, 416–428 (2014).
52. Harvey, C. A. et al. Transformation of coffee-growing landscapes across Latin America: a review. *Agron. Sustain. Dev.* **41**, 1–19 (2021).
53. Guerrero-Casado, J., Carpio, A. J., Tortosa, F. S. & Villanueva, A. J. Environmental challenges of intensive woody crops: the case of super high-density olive groves. *Sci. Total Environ.* **798**, 149212 (2021).
54. Morgado, R. et al. Drivers of irrigated olive grove expansion in Mediterranean landscapes and associated biodiversity impacts. *Landsc. Urban Plan.* **225**, 104429 (2022).
55. Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A. & Lombi, E. Soil and the intensification of agriculture for global food security. *Environ. Int.* **132**, 105078 (2019).
56. Wolkovich, E. M., García De Cortázar-Atauri, I., Morales-Castilla, I., Nicholas, K. A. & Lacombe, T. From Pinot to Xinomavro in the world's future wine-growing regions. *Nat. Clim. Change 2017 81* **8**, 29–37 (2018).

57. Dempewolf, H., Krishnan, S. & Guarino, L. Our shared global responsibility: safeguarding crop diversity for future generations. *Proc. Natl Acad. Sci. USA* **120**, e2205768119 (2023).
58. Kühn, S. Global employment and social trends. *World Employ. Soc. Outlook* **2018**, 5–10 (2018).
59. Kleijn, D. et al. Bending the curve of biodiversity loss requires rewarding farmers economically for conservation management. *ARPHA Prepr.* **4**, e104881 (2023).
60. Scheper, J. et al. Biodiversity and pollination benefits trade off against profit in an intensive farming system. *Proc. Natl Acad. Sci. USA* **120**, e2212124120 (2023).
61. Hayes, T., Murtinho, F., Wolff, H., López-Sandoval, M. F. & Salazar, J. Effectiveness of payment for ecosystem services after loss and uncertainty of compensation. *Nat. Sustain.* **5**, 81–88 (2021).
62. Malekpour, S. et al. What scientists need to do to accelerate progress on the SDGs. *Nature* **621**, 250–254 (2023).
63. Zinngrebe, Y. et al. Prioritizing partners and products for the sustainability of the EU's agri-food trade. *One Earth* **7**, 674–686 (2024).
64. Waarts, Y. R. et al. Multiple pathways towards achieving a living income for different types of smallholder tree-crop commodity farmers. *Food Secur.* **13**, 1467–1496 (2021).
65. Gaudaré, U. et al. Soil organic carbon stocks potentially at risk of decline with organic farming expansion. *Nat. Clim. Change* **13**, 719–725 (2023).
66. Wijerathna-Yapa, A., Henry, R. J., Dunn, M. & Beveridge, C. A. Science and opinion in decision making: a case study of the food security collapse in Sri Lanka. *Mod. Agric.* **1**, 142–151 (2023).
67. Asitoakor, B. K. et al. Influences of climate variability on cocoa health and productivity in agroforestry systems in Ghana. *Agric. For. Meteorol.* **327**, 109199 (2022).
68. Jamal, A. M. et al. Gendered perceptions and adaptation practices of smallholder cocoa farmers to climate variability in the central region of Ghana. *Environ. Chall.* **5**, 100293 (2021).
69. Afriyie-Kraft, L., Zabel, A. & Damnyag, L. Adaptation strategies of Ghanaian cocoa farmers under a changing climate. *For. Policy Econ.* **113**, 102115 (2020).
70. Antwi-Agyei, P. et al. Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: a participatory approach. *Reg. Environ. Change* **17**, 213–227 (2017).
71. Tang, F. H. M. et al. CROPGRIDS: a global geo-referenced dataset of 173 crops. *Sci. Data* **11**, 1–14 (2024).
72. Noss, R. F. et al. How global biodiversity hotspots may go unrecognized: lessons from the North American Coastal Plain. *Divers. Distrib.* **21**, 236–244 (2015).

Acknowledgements

We acknowledge funding from the project SHOWCASE (SHOWCASing synergies between agriculture, biodiversity and Ecosystem services to help farmers capitalizing on native biodiversity) within the EU's Horizon 2020 research and innovation programme (grant agreement number 862480). C.M.-N. was supported by the 'Juan de la Cierva' programme (reference number FJC2021-046829-I). T.S.P. was supported by a research scholarship awarded by the Nanyang Technological University, Singapore (application number R2004096). P.J.R. acknowledges the projects RECOVECOS (PID2019-108332GB-I00, funded by MICIN/AEI/10.13039/501100011033) and OLIVARES VIVOS+ (LIFE20 AT/ES/001487, European Commission). The contribution of D.J.S. was made possible by financial support from NORAD (grant number QZA-21/0124) for the CIFOR GCS-REDD+ (Global Comparative Study on REDD+) project. A.R. acknowledges support from the French National Research Agency (ANR) under grant number 20-PCPA-0010 and from the National Program PEPR 'Solutions fondées sur la Nature' (SOLU-BIOD) through the Living Lab 'Bacchus'. G.P. acknowledges funding from the strategic project iCAP-BES through the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig (grant number DFG FZT 118), as well as from the EU Horizon Europe project Agroecology-TRANSECT (grant agreement number 101060816). This publication reflects only the authors' opinions.

Author contributions

C.M.-N. conceptualized the study, coordinated the team and wrote the first draft of the paper. E.V.-A. created Fig. 1 and Supplementary Table 2, and helped to structure the study. J.A., P.J.R., G.M.t.H., G.P., Y.Z., Y.L., P.A.-A., A.R., C.S., T.S.P., D.J.S., D.B., L.A.G., E.D.C., O.T.L. and I.P. contributed to writing and improving different sections of the paper. I.B. contributed to structuring and writing the article. All authors contributed importantly to the final version of the paper.

Competing interests

The authors declare no competing interests

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41893-024-01483-8.

Correspondence should be addressed to Carlos Martinez-Nuñez.

Peer review information *Nature Sustainability* thanks Timothy Crews and Kirsten Hannam for their contribution to the peer review of this work.

[1]Department of Ecology and Evolution, Estación Biológica de Doñana EBD (CSIC), Seville, Spain. [2]Functional Agrobiodiversity, George August University of Göttingen, Göttingen, Germany. [3]French Agricultural Research Centre for International Development (CIRAD), UMR PHIM, Montpellier, France. [4]PHIM (Plant Health Institute Montpellier), CIRAD, INRAE, Institut Agro, Université de Montpellier, Montpellier, France. [5]Departamento de Biología Animal, Biología Vegetal y Ecología, Universidad de Jaén & Helmholtz Centre for Environmental Research Leipzig (UFZ), Jaén, Spain. [6]Department of Biodiversity and People, Helmholtz Centre for Environmental Research Leipzig (UFZ), Leipzig, Germany. [7]Department of Biodiversity and People, German Centre for integrative Biodiversity Research (iDiv), Leipzig, Germany. [8]Department of Health and Environmental Sciences, Xi'an Jiaotong-Liverpool University, Suzhou, China. [9]College of Resources and Environment, China Agricultural University, Beijing, China. [10]Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. [11]INRAE, Bordeaux Sciences Agro, ISVV, SAVE, Villenave d'Ornon, France. [12]Universidad Veracruzana, Xalapa, Mexico. [13]Asian School of the Environment, Nanyang Technological University, Singapore City, Singapore. [14]Center for International Forestry Research (CIFOR), Yaoundé, Cameroon. [15]World Resources Institute (WRI), Kinshasa, Democratic Republic of the Congo. [16]Center for

Transdiciplinary and Sustainability Sciences (CCTS), IPB University (Bogor Agricultural University), Bogor, Indonesia. [17]Agroecología y Desarrollo Rural, Instituto de Investigaciones en Recursos Naturales, Universidad Nacional de Río Negro, Río Negro, Argentina. [18]Agroecología y Desarrollo Rural, Instituto de Investigaciones en Recursos Naturales, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Río Negro, Argentina. [19]Museo Nacional de Ciencias Naturales (CSIC), Madrid, Spain. [20]Department of Biology, University of Oxford, Oxford, UK. [21]School for Environment and Sustainability, University of Michigan, Ann Arbor, MI, USA. ✉e-mail: cmnunez@ujaen.es