Agrobiodiversity as a tool for a better climate

di Francesco Sottile

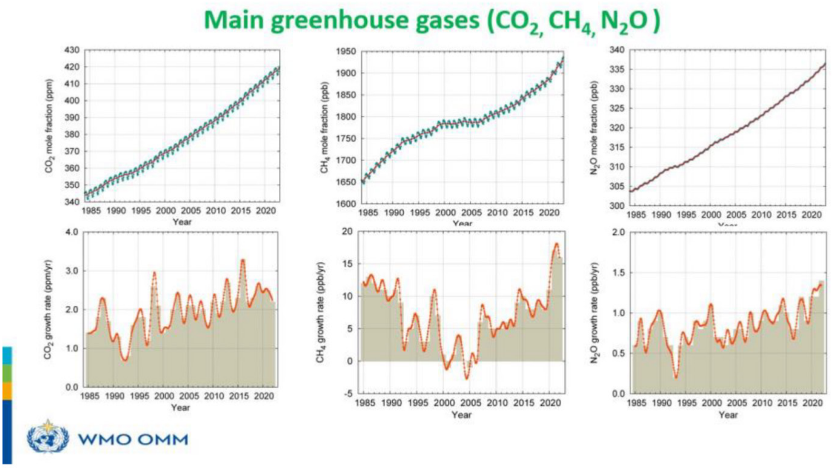
1. *Where we are*

We live in an era in which the coexistence between man and nature has reached a turning point. Every agricultural decision, every energy choice and every environmental protection policy contribute to designing the future of the planet. This is no longer a monologue: it is a chorus in which a multitude of communities, with their stories, their cultures and their biodiversity, may offer contributions of ideas and concrete paths to reconcile economic growth and the protection of ecosystems. If we look at the data, the trajectory is clear: the planet is warming, glaciers are melting and agricultural productive cycles, once marked by well defined seasons and by the wisdom of farmers, are being disrupted by heat waves, droughts and floods.

Emissions of greenhouse gases, mainly carbon dioxide, methane and nitrous oxide, have now exceeded all records of the industrial era. The data recorded at Mauna Loa, with CO_2 concentrations never reached before and now up to 417 ppm, is not just a hard number – it tells a story about what lies ahead: increasingly unstable agriculture, crops at risk, and seasons changing in unpredictable ways. [1,2]. When summers become stifling, as is now being reported in many places, and winters swing between sudden downpours, out-of-season frosts, and other unexpected events, it's the entire global food system that ends up paying the heaviest price. Our food, the daily harvest, are strongly affected by climate change effects.

[1] R. Sánta, L. Garbai. *Investigation of the dynamic equilibrium of atmospheric CO2 concentrations. Air Quality, Atmosphere & Health*, 2025, 1-13.

[2] WMO – World Meterological Organization – *State of the Global Climate 2024*. https://library.wmo.int/viewer/69455/download?file=WMO-1368-2024_en.pdf&type=pdf&navigator=1



Main greenhouse gases emission in the atmosphere (data from World Meteorological Organization, 2023)

Yet, intensive agriculture, while feeding billions of people, has a very high ecological cost[3]. Amazonian deforestation and the unregulated exploitation of the land of Northern Italy are two of the most striking examples that demonstrate the devastating effects of the anthropocentric vision. The incessant use of chemical fertilizers and pesticides have reduced soil fertility and impoverished biodiversity so as to make this model unsustainable in the long term. Only by looking at the paradox – record of production on one hand, and habitat loss, water contamination, soil erosion on the other hand – we can begin to think of the need for alternative paths. There is no longer any need to chase the myth of the indefinite increase in yield per hectare: we need to restore vitality to the soil, recreate a biological fabric capable of self-production and regenerate, restore balance among the living

[3] A. S. MacDougall, E. H Esch, Dolezal, A. J., Kamm, C., Carroll, O. H., Tosi, M., ... & Campbell, M. M. *Ecosystem services on restored marginal farmland*. Frontiers in Ecology and the Environment, e2866, 2025.

beings present in nature without necessarily imagining a dominance of the human being[4].

2. *Soil at the basis of the life*

Soil regeneration is based on ancient gestures and scientific innovations, but its imperativeness depends on the awareness that more than 70% of the planet's arable soils are in an advanced degree of desertification which results from a substantial and increasingly rapid process of soil degradation[5]. It is a slow and often irreversible process, which is not due to phenomena of loss of natural fertility but is supported by agricultural models that push for the breakdown of the microbial balances that underlie the ability of soils to guarantee food production. So, paradoxically, while we have tried to produce food in large quantities, we have caused the progressive loss of the ability of soils to produce food in the future. Hence the need to regenerate the soil, where possible, drastically stop land consumption, look at the reckless use of synthetic chemicals as a fearsome enemy and proceed towards production models that respect the ecosystem balance. Techniques such as crop rotation, mixed and/or intercropping crops, as well as respect for cover crops are not a return to the past, but the synthesis between peasant experience and soil microbiology that today are supported by scientific knowledge[6]. These practices stimulate microbial life, promote nitrogen fixation and reduce compaction by ensuring drainage capacity: each layer of soil starts breathing again, storing water and nutrients. When the soil regains its balance, it can plays a role against climate crises, mitigating heat peaks and retaining moisture in periods of drought. The mitigation of heat peaks, in particular, can be effectively achieved in regenerated soils through increases in organic mat-

[4] WWF. *Living Planet Report 2022* – Building a Nature- Positive Society. Gland, Switzerland: WWF, 2022.

[5] L. Olsson, H. Barbosa, S. Bhadwal, A. Cowie, K. Delusca, et al. 2019.. *Land degradation*. In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, 345–436. Cambridge, UK.

[6] A. Kumar, G. Antoniella, E. Blasi, T. Chiti (2025). *Recent advances in regenerative sustainable agricultural strategies for managing soil carbon and mitigating climate change consequences*. Catena, 2025, 258, 109208.

ter content, microbial biodiversity, and structural stability, which enhance water retention capacity and promote evaporative cooling processes, thereby contributing to the reduction of surface temperatures and their greater temporal stability.

Moreover, the presence of vegetation cover limits direct solar radiation and heat accumulation in the soil, ensuring effective natural microclimatic regulation and increasing ecosystem resilience to extreme thermal stress events.

Healthy soil is also a powerful ally in the fight against climate change: international estimates show that regenerated and well managed agricultural land can sequester a range of 4-14 tonnes of CO_2 eq per hectare each year (depending on the climate and soil usage)[7,8], acting as complementary 'carbon sinks' to forests. If the soil becomes naturally fertile and rich in organic matter, extreme temperature variations are mitigated and water retention capacity is improved, while also protecting crops from heat waves and prolonged droughts. But to achieve these results, it is first of all necessary to listen to the indications coming from the soil itself: regular analyses (pH, organic matter, nutrient content) make it possible to calibrate targeted interventions and to avoid overdoses which, over time, threaten the balance of the system again[9].

Hearing about soil as a living organism may seem poetic, yet it is the truest image to describe the complexity that is hidden a few centimeters under our feet. A healthy soil is a complex system where bacteria, mycorrhizal fungi and countless small invertebrates transform organic matter into available nutrients, retain water and store carbon instead of releasing it into the atmosphere. Every ounce of healthy soil contains more living organisms than all the people on the planet[10], and this invisible community regulates vital processes for the entire ecosystem, from the water cycle to the control of plant diseases.

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[7] R. Lal,. *Regenerative agriculture for food and climate. Journal of Soil and Water Conservation*, 2020, 75(5), 123A–124A.

[8] K. Paustian, E. Larson, J. Kent, E. Marx, A. Swan. *Soil carbon sequestration as a biological negative emission strategy. Frontiers in Climate*, 2019, 1, Article 8.

[9] A. Shukla, N. Rai, R. Mohapatra, V. Thriveni, K.K. Yadav, L. Upadhyay, S. Ghosh. *Assessing the Role of Regenerative Practices in Enhancing Soil Carbon Sequestration in Farmlands: A Review. Journal of Scientific Research and Reports*, 1015, 31(7), 231-246.

[10] R.D. Bardgett, W.H. van der Putten. *Belowground biodiversity and ecosystem functioning*. Nature, 2014, 515(7528), 505–511.

The state of soil health is therefore not a technical issue confined to specialized magazines: it is the material basis of our eating habits, the quality of the water we drink and the climatic stability of entire regions. Every agricultural choice – from the density of sowing to the introduction of organic substances – has repercussions in an intertwining of processes that involve the planet and future generations. Protecting and regenerating soils means investing in resilience, well-being and environmental justice, always keeping in mind that a handful of living soil is worth more than an entire deposit of chemical fertilizers.

3. *Food issues ant the centrality of agricultural biodiversity*

Meanwhile, the paradox of food security is getting worse. Statistics speak of a constantly increasing world food production, but also of a growing number of people suffering from hunger or malnutrition. It is a problem of distribution and waste: estimates of approximately 91 million tons of food discarded annually in China and 19 million tons in the United States reveal a food system that prioritizes the quantity produced and accumulated, while equity in access to food remains marginal. If the surplus of foodstuffs is not transformed into nourishment for those who need it, then abundance becomes an ethical and ecological issue. We need to redefine the concept of efficiency, including social justice in the final calculation.

Agricultural biodiversity lies at the core of a potential shift. Time teaches us that local varieties, shaped by centuries of natural and cultural selection, are our insurance against sudden changes. Today, 75% of cultivated varieties are extinct, but smallholder farmers continue to safeguard the vast majority of traditional seeds worldwide[11]. Each seed is a baggage of adaptations: resistance to pathogens, drought tolerance, unique flavors. Protecting this genetic wealth means filling a vulnerable void: diversity is the most subtle form of climate insurance.

Agricultural biodiversity is much more than a simple inventory of cultivated plants and animals: it is the living testimony of millennia of dia-

[11] U.L.C. Baldos, A. Cisneros-Pineda, K.O. Fuglie, T.W. Hertel. *Adoption of improved crop varieties limited biodiversity losses, terrestrial carbon emissions, and cropland expansion in the tropics. Proceedings of the National Academy of Sciences,* 2025, 122(6), e2404839122.

logue between man and the landscape he cultivates. A traditional wheat field in Sicily or a cassava bed in the indigenous communities of the Amazon are both cases evidencing there is an intertwining of genetic varieties, different species and cropping systems capable of adapting to local challenges. This richness, which is expressed in the thousands of cultivars, varieties, ecotypes selected over time and in the breeds bred according to centuries-old traditions, constitutes the connective tissue of a resilient agriculture, capable of responding to climate change, field diseases and market fluctuations[12].

The functional value of this diversity becomes particularly evident under conditions of stress and crisis. During prolonged drought events, locally adapted varieties frequently exhibit enhanced tolerance to water scarcity compared to uniform commercial cultivars. Moreover, the diversity of flavors and nutrients associated with diversified cropping systems and multi-crop diets constitutes a critical buffer against malnutrition, ensuring a more balanced intake of essential vitamins, minerals, and bioactive compounds. In addition, structurally heterogeneous agricultural landscapes, characterized by the presence of hedgerows, flowering grasslands, aquatic features, and fruit trees, provide key ecosystem services by supporting pollinator communities, enhancing biological pest regulation, and safeguarding groundwater quality.

Yet this wealth is increasingly endangered. Extensive monocultures have converted vast territories into biological deserts, in which reliance on a single, highly productive variety becomes a latent risk in the face of epidemics[13]. Markets reward uniformity and aesthetic standards, pushing growers to abandon "imperfect" strains that are perfectly suited to their environments. At the same time, the abandonment of the countryside and the aging of generations of farmers erode traditional skills on the collection, selection and conservation of seeds, dramatically reducing the available genetic heritage.

To react to this erosion, it is necessary to activate strategies both in the field and in germplasm deposits. *In situ* conservation requires incentives for those who cultivate local varieties, preserving traditional cultivation systems and their intertwining with rural culture. At the same time, seed banks –

[12] C. Prins, D. Sreekumar, V. Sejian, V. *Climate change and wildlife biodiversity: Impact and mitigation strategies*. *Arch. Life Sci. Res*, 2025, 1, 6-22.

[13] N. Estrada-Carmona, A.C. Sánchez, R. Remans, S.K. Jones,*Complex agricultural landscapes host more biodiversity, ecosystem resilience, and human well-being*. *Proceedings of the National Academy of Sciences*, 2022, 119(34), e2203385119.

most notably the Svalbard Global Seed Vault – safeguard thousands of species, acting as a global backup for the world's agricultural heritage. In parallel, networks of farmer-custodians and participatory breeding initiatives empower growers as active agents, encouraging the exchange of seeds and knowledge to develop varieties able to thrive in an ever-evolving environment.

It is precisely within smallholder farming that the true capital of agricultural biodiversity is concentrated. These farmers are the ones who know every nuance of the soil, the growing model of a variety, the best seasons for sowing. They often work in marginal territories where large agricultural industries find little incentive to invest, and their practice unfolds as a mosaic of observation, experimentation, and choice – blending scientific reasoning with empirical intuition to create place-specific solutions for every corner of the planet.

Today, scientific research and digital technologies can amplify this ancient knowledge. Genomic analyses identify genes that confer resistance to water or biological stress, while sensors and drones monitor moisture, nutrients and pests in real time. Online platforms network farmers, technicians and researchers, making it possible to exchange data, seeds and field test results. This continuous dialogue between tradition and innovation is the key to developing solutions that are truly effective and sustainable.

On the policy level, instruments such as the International Treaty on Plant Genetic Resources and the Convention on Biological Diversity recognize the value of agricultural resources and define guidelines for equitable access and benefit-sharing. They also recognize the rights of growers to traditional seeds, promoting practices that ensure the conservation and sustainable use of food plants. These regulations are crucial, but we also need concrete national and local measures that translate international commitments into action on the ground.

4. *Does the relation to climate crisis mitigation exist?*

The conservation and promotion of agricultural biodiversity should not be regarded as a nostalgic endeavor, but rather as a forward-looking investment in sustainable food systems. The preservation of genetic resources, the intergenerational transmission of traditional and local knowledge, and the effective implementation of international legal and policy frameworks at the field level collectively contribute to the development of resilient and inclusive agricultural systems capable of ensuring global food security while remaining within planetary boundaries. Addressing this challenge requires coordinated action, institutional commitment, and long-term strategic vision, grounded in the recognition that diversity, at all the levels (genetic, species, and agroecosystem levels) constitutes a fundamental risk-mitigation mechanism in the face of increasing environmental and socio-economic uncertainty.

In this sense, agrobiodiversity is a natural ally in the fight against climate change[14]. When we talk about agrobiodiversity, we generally imagine a medley of plant varieties and cultivated animal breeds, but its meaning goes far beyond a catalog of genetic entities. Rather, it is the set of relationships and practices that have shaped agricultural landscapes around the world, interweaving seeds, soils, climate and human knowledge. At a time when weather anomalies are the norm and agricultural yields are faltering under the wave of extreme droughts or heatwaves, agrobiodiversity emerges as a resilience, survival and mitigation strategy with multiple benefits.

First of all, an agricultural system rich in local species and varieties functions as a large carbon sink. Trees integrated into agroforestry systems, perennial crops and deep roots of subsoil legumes increase the soil's ability to sequester carbon dioxide[15,16]. In Brazil, indigenous communities combine cassava, banana trees, fruit trees and medicinal plants in agroforestry facilities that, in addition to feeding families, sequester and stock CO_2 in biomass and soils. In Tuscany and Sicily, hedges between vineyard rows and terraced olive groves slow soil erosion and promote the accumulation of organic matter, turning slopes into effective carbon sinks[17,18].

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[14] F. Hailu, (2025). *The role of agrobiodiversity and diverse causes of its losses and methods of conservation: A review.* In *Food and Humanity*, 100500.

[15] J. Pan, S. Chen, D. He, H. Zhou, K. Ning, N., Ma, Z. Dong, Z. (2025). *Agroforestry increases soil carbon sequestration, especially in arid areas: A global meta-analysis*. Catena, 249, 108667.

[16] R.K. Srivastava, A. Yetgin, S. Srivastava. *The role of legume roots in carbon sequestration, soil health enhancement, and salinity mitigation under climate change: a comprehensive review.* Soil Tillage Res, 2025, 253.

[17] F. Scandellari, G. Caruso, G., Liguori, F. Meggio, A.M. Palese, D. Zanotelli, M., Tagliavini. *A survey of carbon sequestration potential of orchards and vineyards in Italy.* In *European Journal of Horticultural Science*, 2016, 81(2), 106–114.

[18] S. Drexler and A. Don. *Carbon sequestration potential of hedgerow soils.* In *Geoderma*, 2024, 445, 116878.

But agrobiodiversity is not only used to mitigate and stock greenhouse gases: its multiple plant and animal forms constitute a natural defense mechanism. In fields where cereals, legumes and cover crops alternate, the microbial community of the soil – mycorrhizal fungi, rhizobacteria, actinomycetes – thrives and plays a significant monitoring role. These microorganisms fix nitrogen, break down organic matter, and suppress pathogens, dramatically reducing the need for chemical fertilizers and herbicides. Fewer synthetic inputs mean less pollution, less dependence on oil for their production and, consequently, a further reduction in emissions along the entire agricultural supply chain.

On the contrary, in conditions of excessive rain, plants with deeper roots or with different leaf structures spread water better, protecting the soil from erosion and preventing flooding. This "functional" diversity – varieties characterized by different responses to environmental stress – makes it possible not to put all the eggs in the same basket: if one species succumbs, another can continue to guarantee yields and income.

The role of agrobiodiversity then extends to the most subtle but equally vital ecosystem services. An agricultural system that integrates flowering meadows, shrubby borders and mixed rows creates habitats for bees, bumblebees and other pollinators, operating the pollination of more than 75% of food crops[19]. Similarly, natural hedges and irrigation canals covered with vegetation promote the life of microfauna – earthworms, springtails, useful nematodes – by improving aeration and the ability to retain water in the soils. In a context of increasingly unpredictable climate change, these services offer a safety net that intensive monocultures cannot replicate.

Another crucial aspect of agrobiodiversity is the maintenance of traditional knowledge and local techniques. Small farmers, in Italy as in the Amazon, preserve genetic memories and agricultural practices that even concern natural fertilization with algae or the sowing of nitrogen-fixing plants. This knowledge is not a legacy of the past, but a capital of innovation: integrating satellite monitoring with direct observations of the farmer, for example, makes it possible to intervene promptly in the event of an attack by parasites or water stress. Collaborations between universities and

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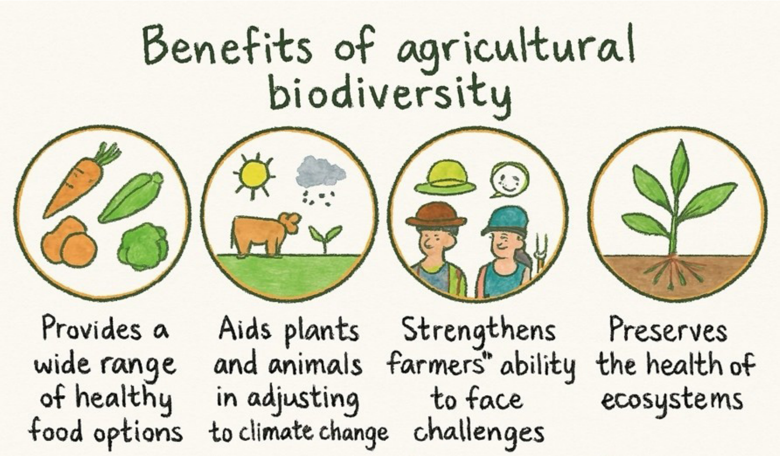
[19] B. Barsola, P. Kumari, S. Yadav, S. Mishra, K. Jaiswa. *Approach to Agrobiodiversity Preservation and Sustainable Agriculture in a Changing World.* In *Biotechnological Innovations for Sustainable Biodiversity and Development*, 2025, 292-304.

rural communities, in this sense, are essential to combine precision farming technologies with the centuries-old experience of local producers.

However, to fully exploit the climate potential of agrobiodiversity, targeted policies are needed. It is necessary to encourage the *in situ* conservation of traditional varieties, to support seed fairs and to strengthen germplasm banks. Regulations should recognize the rights of custodial growers, granting them access to genetic resources and economic compensation when their seeds become raw material for new patents. At the same time, funding for agricultural research must embrace participatory breeding programs, in which scientists and farmers collaborate to select plants that are more adapted to climate change, without sacrificing nutritional qualities and local flavors.



Main benefits derived from agricultural biodiversity

In this direction, agrobiodiversity is not a small detail of the agricultural system but takes on the role of the backbone of an agriculture capable of mitigating the effects of global warming and adapting to its fluctuations through a natural genetic diversification in perfect balance with the surrounding ecosystem. Protecting and increasing this diversity means cultivating food security, preserving life in the soil, combating erosion and reducing emissions. It is a bet on a future in which the recognition of the intrinsic value of every seed and every animal breed translates into concrete practices, courageous policies and a real partnership between science, farmers and institutions. Only in this way will we be able to transform our fields into green shields against the climate crisis.

5. *Communities, territories, diversities*

In Italy, the link with the territory emerges from the heroic cultivations on the terraces in Liguria, Campania, Sicily, or in the small Mediterranean islands: microcosms of resistance and resilience where biodiversity and landscape support each other. Similarly, in Latin America, indigenous communities in the Amazon cultivate agroforestry systems that blend fruit trees, vegetables, and medicinal plants, generating income and preserving the forest. In both cases, agroecology is not a theoretical laboratory, but a daily life of choices where the boundary between forest and field dissolves into a living mosaic. Territory and community are not two separate elements, but the faces of a single living organism: the community gives meaning to the territory, and the territory nourishes the community, opening up paths of sustenance, identity and care. In this intertwining, natural resources – water, soil, forests, pastures, waterways – are not simple assets to be exploited, but heritages to be collectively preserved, shaped by practices sedimented over time and by direct knowledge of one's own land[20]. In the Italian Apennine villages, for example, as well as on the major and minor islands, the maintenance of terraces is not an aesthetic exercise, but a daily pact between men and landscape. Dry-stone structures and steep agricultural furrows play a significant role in soil stabilization, erosion control, and the regulation of surface runoff, thereby enabling the sustained cultivation of vineyards, olive groves, and horticultural crops. This landscape configuration is underpinned by an agricultural community that maintains and transmits traditional agronomic knowledge, including pruning techniques, seasonal crop scheduling, and the systematic observation of local meteorological variables, such as wind regimes and cloud cover. Without this constant presence, the territory would lose its integrity and the ability to generate sustenance.

Similarly, in the indigenous communities of the Brazilian Amazon,

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[20] E. C. da Silva, M.A. Guerrero-Moreno, F.A. Oliveira, L. Juen, F.G. de Carvalho, J.M. Barbosa Oliveira-Junior, (2025). *The importance of traditional communities in biodiversity conservation*. In *Biodiversity and Conservation*, 34(2), 685-714.

the boundary between sacred forest and food garden is blurred. Far from being a "wild" area, each forest is crossed by harvesting paths, associated with native fruit species, enriched with medicinal plants. The elders tell of the curves of the river, of the seasons of fruit, of the herbs that cure fevers. It is thanks to this network of social and cultural ties that the forest preserves its biodiversity: the practices of minimal and regenerative cutting, rotation of harvesting sites and spontaneous sowing ensure that no species disappear[21,22].

These experiences show that conservation is not the exclusive task of biologists or public bodies, but a shared responsibility. Communities guard "living zones", spaces in which they regulate access, and they establish rules for fishing, hunting, and grazing. Through informal control systems – assemblies, agricultural festivals, rituals of thanksgiving to the territory – monitoring and sanctioning mechanisms are established that keep the ecosystem in balance. It is what experts call "governance of the commons": a model in which collective ownership or use becomes the key to preserving precious resources. Another example comes from Sicilian fishing cooperatives, where fishing boats and nets are managed together, with limited fishing hours, bans on endangered species and the regeneration of small coral reefs. Here the maritime community recognizes that the sea produces wealth if the shoals of fish have time to repopulate and imposes on itself more stringent rules than those of the law. The result is quality products and a relationship of respect for the environment, which in turn supports the life of every fisherman.

This deep bond between community and territory becomes even more crucial in times of climate change. When prolonged droughts or torrential rains put crops and pastures at risk, it is precisely social networks and traditional practices – knowledge of diversified planting times, favorable winds, hidden water sources – that offer the timeliest solutions. Communities that are well rooted in their territory are able to reorganize, share supplies, protect wells and secure the edges of the fields[23]. To

[21] S.W. Miller, (2025). *The Environmental History of Latin America. A Companion to Global Environmental History*, 93-108

[22] J. Douda, K. Boublík, J. Doudová, M. Kyncl. *Traditional forest management practices stop forest succession and bring back rare plant species*. In *Journal of Applied Ecology*, 2017, 54(3), 761–771.

[23] D. Kalfas, S. Kalogiannidis, O. Papaevangelou, F. Chatzitheodoridis, (2024). *Assessing the connection between land use planning, water resources, and global climate change*. *Water*, 16(2), 333.

strengthen this link, it is essential to recognize and enhance the rights of communities in the territory: from access to land to the protection of traditional knowledge on seeds and cultivation techniques. Legal instruments such as Community Conserved Areas or regulations on the rights of indigenous peoples are stages of a path that must lead to participatory and inclusive management[24]. Governments and international organizations can provide technical support, economic incentives and exchange platforms, but the real innovative force is in the hands of communities. The link between territory and community is the lifeblood that nourishes the conservation of natural resources. Where this link is broken – due to rural abandonment, building speculation or intensive exploitation – chasms of ecological degradation open up. On the contrary, every time a community organizes itself to safeguard a forest, a stream, a centuries-old olive grove, it builds a bulwark of resistance that is good not only for its members, but for the whole planet. Protecting this link means recognizing that territory and community are accomplices in a common project: transforming conservation into a daily act of care, rooted in history and looking to the future.

6. *Technology and innovation: tool or enemy*?

In such a context of complexity, the idea that increasingly advanced technology can be the solution to all critical issues has become increasingly concrete. In any way, the anthropocentric approach has always been present, and it took shape after the Second World War as technological innovation through the development of synthetic chemistry. The same today happens in the form of precision agriculture and genetic modifications. The growing interaction between technology, biodiversity and the agricultural landscape is now part of a context that does not provide real answers to the climate crisis, also requiring a deep reflection on social development models and the use of so-called innovations. Industrial agriculture, as has already been widely discussed, has been substantially supported by mechanical, chemical and digital technologies, carving out a significant role for contributing to the emission of greenhouse gases,

[24] H. Pham, M. Saner, (2024). *Framework and proposed indicators for the comprehensive evaluation of inclusiveness: the case of climate change adaptation*. *FACETS*, 9, 1-15.

deforestation and the loss of fertile soils, aggravating the effects of climate change. The technological response is not functional to the modification of the paradigm and the reversal of the process, and therefore to a real mitigation of the climate crisis. It is probably a way to distract society and make people believe that there are anthropocentric solutions that would require less commitment from human beings on the planet. This applies to precision agriculture, which has aspects of interest but often cannot be shared with most small-scale agriculture, assuming, on the contrary, a very elitist positioning[25]. And it is also true for genetics that thinks of 'building' varieties for use and consumption in different agricultural contexts, creating new organisms that propose a series of critical issues on an ecological, social and cultural level of considerable depth. Over the last fifty years we have gone from technological support for genetically modified organisms (GMOs) to technological support for new GMOs, plant varieties made by 'switching off' or 'turning on' the expression of certain genes without considering a multitude of factors that lead to insecurity for farmers and risks to the environment and agrobiodiversity. All supported by a demagogic narrative that claims that these bodies, in any way modified, make a substantial contribution to the direction of sustainability.

Barry Commoner, father of modern ecology since the early 70s, emphasized these issues by emphasizing how nature is perfectly capable of providing solutions to manage the alterations that derive from the anthropocentric model[26]. In this way he became the precursor of that cultural and scientific approach that today is enclosed by the framework of the so-called *nature-based solutions* (NbS).

NbS represent an innovative and multifunctional approach to the management of environmental and climate challenges, based on the sustainable use of natural processes and elements. In agriculture, NbS are deeply intertwined with the concept of agrobiodiversity, which is a fundamental resource for climate resilience, food security and ecological sustainability. The integration between NbS and agrobiodiversity is manifested through practices such as agroforestry, crop rotation, the use of local varieties and participatory management of the agricultural landscape,

[25] M. Sanyaolu, A.Sadowski *The Role of Precision Agriculture Technologies in Enhancing Sustainable Agriculture*. *Sustainability*. 2024; 16(15):6668.

[26] B. Commoner. *The Closing Circle: Nature, Man, and Technology*. New York, 1971.

which not only contribute to climate change mitigation and adaptation, but also promote the restoration of degraded ecosystems and the conservation of natural capital[27]. According to the Intergovernmental Panel for Climate Change (IPCC) and the EU Biodiversity Strategy to 2030, NbS offer an effective and flexible response to bring nature back to health in the face of the climate crisis, generating environmental, social and economic benefits. In this context, agrobiodiversity, therefore, is not only a heritage to be preserved, but a dynamic element to be enhanced through territorial policies and agricultural practices that recognize the central role of biological diversity in the construction of resilient systems. The experiences documented by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) of the Italian Ministry of the Environment highlight how the application of NbS in the agroecological field can reduce emissions, improve soil and water quality, and strengthen the adaptive capacity of rural communities. Ultimately, the synergy between nature-based solutions and agrobiodiversity represents a crucial frontier for the ecological transition of agriculture, capable of combining innovation, tradition and sustainability in response to the challenges posed by climate change.

7. *Agroecology as an innovative tool for the future*

Agroecology can be understood both as a scientific discipline and as an agricultural practice, as it goes beyond the mere application of ecological principles to food production and integrates the cultural, economic, and political dimensions of rural systems. From a social science perspective, it investigates the interactions between farmers, local communities, and the environment, promoting participatory and inclusive models of natural resource governance as well as forms of social and food justice. As an agricultural practice, agroecology translates into sustainable management strategies that enhance crop diversification, integration of crops and livestock, reduction of external inputs, and the revitalization of traditional knowledge, generating resilient systems capable of addressing the challenges posed by climate change and biodiversity loss.

In this dual perspective, agroecology assumes a transformative role,

[27] A. Kumar, S. Singh, R. Kumar, M. Kumar, K. Rani, J. James. *Balancing conservation and development for achieving land degradation neutrality. Horizon*, *2*(4), 17-24, 2024.

contributing to the redefinition of rural landscapes as multifunctional spaces capable of reconciling production, conservation, and social cohesion. It also represents a strategic tool for climate change mitigation, integrating ecological principles into agricultural systems and promoting the reduction of greenhouse gas emissions, the increase of carbon sequestration capacity, and the resilience of rural landscapes. Through practices such as agroforestry, crop diversification, cover cropping, and reduced tillage, agroecology contributes to enriching soil organic matter and enhancing soil fertility, with direct effects on carbon storage and the reduction of dependency on high-energy external inputs.

This approach also promotes the conservation and enhancement of both agricultural and wild biodiversity through the creation of mosaic landscapes, ecological corridors, and multifunctional habitats that strengthen essential ecosystem services, such as pollination, natural pest control, and nutrient cycling. Moreover, the connection between agroecology and biodiversity has a social dimension, as it values the traditional knowledge of rural communities, preserves cultural landscapes, and strengthens the bonds between society and nature. In this context, agroecological rural landscapes serve a multifunctional role, functioning not only as sites of food production but also as spaces for climate regulation, environmental conservation, and the safeguarding of cultural heritage. Agroecology therefore emerges as an integrated strategy capable of addressing the global challenges of climate change, promoting biodiversity, and redesigning rural landscapes from a sustainable, resilient perspective that prioritizes the well-being of local communities.

The conceptual development of agroecology has been progressively shaped by international and regional organizations, which have elaborated principles and frameworks to guide the transition toward sustainable agri-food systems. The FAO, in particular, has identified ten fundamental elements that serve as methodological and strategic pillars[28]: diversity, knowledge creation and sharing, synergies, efficiency, recycling, resilience, human and social values, food culture and traditions, responsible governance, and circular and solidarity-based economy. These elements aim to guide governments, communities, and institutions in rethinking agricultu-

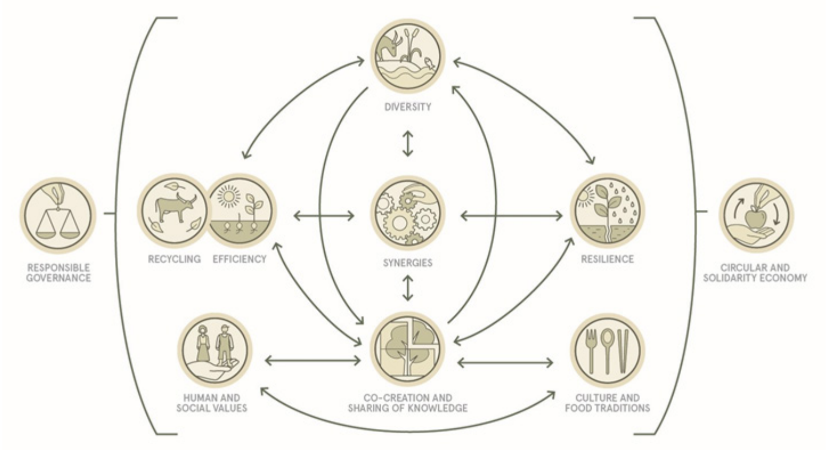
[28] F.A. Murriel Gonzales, J. Dessein, J. Adriaensens. *Knowledge on agroecology disseminated by the FAO: assessment from a human-nature relationship perspective. International Journal Of Sociology Of Agriculture And Food*, 2025, 31(1), 15-52.

ral models and reorganizing production practices according to ecological, social, and cultural criteria.

The European debate, particularly through the High Level Panel of Experts (HLPE) report and contributions from Agroecology Europe, has expanded and deepened this framework, formulating thirteen principles that articulate more comprehensively the complexity of agroecological transitions[29]. These include recycling, reduction of external inputs, soil health, animal health, biodiversity, synergy, economic diversification, co-creation of knowledge, social values and diets, equity, connectivity, land and natural resource governance, and participation. Compared to the FAO elements, the European principles place greater emphasis on specific aspects such as soil and animal health, the ecological foundation of biodiversity, economic diversification as a tool for socioeconomic resilience, and connectivity among actors and territories as a lever of cohesion.

Overall, the ten FAO elements and the thirteen European principles are complementary: the former provide a concise and universal framework to promote agroecology globally, while the latter represent a contextualized refinement for the European setting, characterized by specific ecological, agricultural policy, and social dynamics. From an academic perspective, the comparison of these two approaches highlights how agroecology, beyond being a science and agricultural practice, is also a political and cultural process in evolution, capable of integrating multiple levels of governance and systematically addressing the challenges of climate change, biodiversity loss, and socioeconomic inequalities through increasingly sophisticated analytical and operational tools.

[29] L.L. Vázquez. *Scope of agroecology during the agroecological transition of the local food system. J Appl Biotechnol Bioeng*, 2025, 12(2), 60-65.



The interconnections between the factors that make up the 10 principles of agroecology (Fao, 2018)

Among the organizations most closely linked to food production and the fight against the climate crisis, Slow Food has played a central role at the international level, fostering the development of a global network of activists committed to exploring the cultural and social dimensions of agricultural production, deeply rooted in biodiversity and identity-based traditions. For Slow Food, agroecology represents an integrated approach to food production that combines environmental sustainability, biodiversity conservation, social equity, and the promotion of local food cultures, viewing food not merely as a commodity but as a fundamental cultural and social element.

The Slow Food Farms, recently launched as a program to bring together resilient farmers, constitute tangible expressions of this approach[30]. They function as model farms or farms in active transition, where practices based on agroecological principles are systematically applied through crop diversification, the valorization of local varieties and breeds, sustainable management of soil and water resources, and integration between agriculture and local communities. These farms also promote networks of exchange and cooperation among producers, consumers, and educational institutions.

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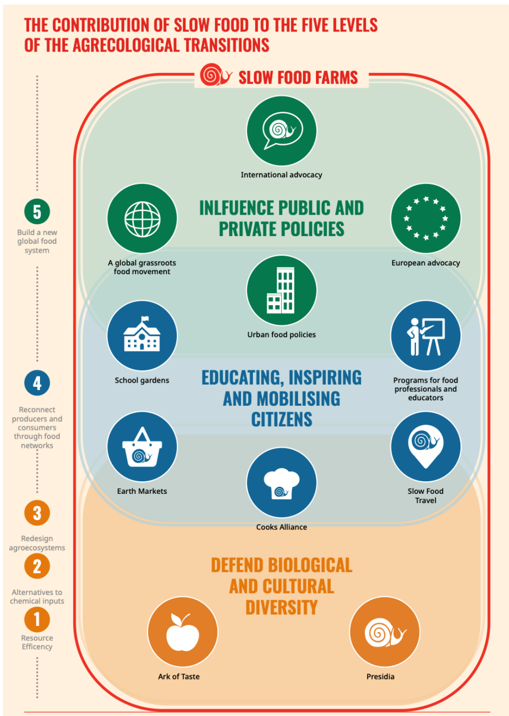
[30] *https://www.slowfood.com/slow-food-farms/* (entered on August 2025)

The relationship with the FAO is evident in the shared objectives and principles, particularly in the promotion of agricultural biodiversity, the dissemination of participatory knowledge, and the construction of resilient and sustainable food systems. Slow Food and the FAO also collaborate on the development of guidelines, capacity-building initiatives, and awareness campaigns aimed at supporting agroecological transitions globally, emphasizing the role of small-scale producers and rural communities in conserving genetic, cultural, and environmental heritage.

Within this framework, agroecology, as envisioned by Slow Food, is not only a set of sustainable agricultural practices but also a platform for inclusive governance and social responsibility, strengthening the connections between food production, biodiversity conservation, and rural development. This approach aligns with the principles and strategies promoted by the FAO for fair, sustainable, and climate-resilient agriculture.



Source: Slow Food International (www.slowfood.com)

8. *Concluding remarks*

Agricultural biodiversity, encompassing locally adapted crop landraces and indigenous livestock breeds shaped by specific agro-ecological and socio-environmental conditions and integral to food and agricultural systems, constitutes a critical strategic asset for enhancing system resilience and addressing contemporary sustainability challenges. Nevertheless, this biodiversity is increasingly undermined by the intensification and homogenization of production systems, as well as by the largely unregulated digitalization and commodification of genetic resources. The agricultural landscape, recognized as a historical and cultural expression of the interaction between man and nature[31], undergoes radical transformations under the pressure of technologies that privilege production efficiency to the detriment of ecological complexity and territorial memory. In this scenario, the climate crisis acts as a vulnerability multiplier, accelerating the degradation of ecosystems and the loss of rural identity. However, technology can also offer solutions if guided by agroecological principles and inclusive governance. Tools such as precision agriculture with a social inclusiveness approach, environmental monitoring systems and digital platforms for knowledge sharing can contribute to reducing environmental impact and strengthening climate resilience, as long as they are integrated with traditional practices and with the active involvement of local communities. The challenge is to overcome the technocratic approach and promote an agricultural paradigm that recognizes biodiversity and the agricultural landscape as central elements for sustainability, environmental justice and food security in a world marked by climate instability

And this is a challenge that can only be faced if we change the agri-environmental approach of the policies that underlie agricultural production, especially in Europe where there is an increasingly evident drift that links agricultural subsidies to agro-industry lobbies. The European Court of Auditors has repeatedly rejected the results of the CAP (Common Agriculture Policy), both because the funds are not fairly distributed (80% of the resources allocated to 20% of companies, always the largest and most agro-industrial with the exclusion of small and medium-sized farms), and because the measures identified have proved to be unsuc-

[31] E. Sereni. *History of the agricultural landscape*. Rome-Bari, 1961.

cessful in achieving agri-environmental goals[32]. Agri-environmental policies represent a crucial tool to address the environmental and climate challenges that threaten global agriculture and European instruments, if well-modulated, could play a decisive role only on condition that it is definitively decided to adopt strict measures that orient the agricultural sector towards sustainable and resilient practices.

Agrobiodiversity, in this direction, can be central as well as identified and reported in the joint report between the Intergovernmental Panel for Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), presented in 2021, which highlights the interconnection between biodiversity and climate change, emphasizing the need to address both challenges with integrated approaches[33]. This report presents policymakers with a comprehensive scientific assessment of the intricate relationships between biodiversity, water, food, health and climate, which, however, are often overlooked. However, integrating environmental criteria into agricultural subsidies and rural development plans can steer production choices towards greener models.

Moreover, closely connected to the considerations outlined above, rigorous agri-environmental policies foster the resilience of rural communities, strengthen food sovereignty, and safeguard agricultural landscapes – elements that today are not optional but essential.

Addressing this challenge requires an inherently interdisciplinary perspective. Agronomists, ecologists, sociologists, economists, jurists, and anthropologists must engage in dialogue with policymakers and stakeholders to co-design participatory land management models, identify

[32] *https://www.eca.europa.eu/Lists/ECADocuments/SR20_13/SR_Biodiversity_on_farmland_IT.pdf*, 2020

[33] H.O. Pörtner, R.J. Scholes, J. Agard, E. Archer, A. Arneth, X. Bai, D. Barnes, M. Burrows, L. Chan, W.L. Cheung, S. Diamond, C. Donatti, C., Duarte, N. Eisenhauer, W. Foden, M.A. Gasalla, C. Handa, T., Hickler, O., Hoegh-Guldberg, K. Ichii, U. Jacob, G. Insarov, W. Kiessling, P. Leadley, R. Leemans, L. Levin, M. Lim, S. Maharaj, S. Managi, P.A. Marquet, P. McElwee, G. Midgley, T. Oberdorff, D. Obura, E. Osman, R. Pandit, U. Pascual, A.P.F. Pires, A. Popp, V. Reyes-García, M. Sankaran, J. Settele, Y. Shin, D.W. Sintayehu, P. Smith, N. Steiner, B. Strassburg, R. Sukumar, C. Trisos, A.L. Val, J. Wu, E. Aldrian, C. Parmesan, R. Pichs-Madruga, D.C. Roberts, A.D. Rogers, S. Díaz, M. Fischer, M., Hashimoto, S., Lavorel, N. Wu, H.T. Ngo, H.T.. *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change*; IPBES secretariat, Bonn, Germany, 2021.

effective mitigation pathways to confront the ongoing climate crisis, and develop forms of agricultural support capable of driving a genuine paradigm shift.

Within Europe, common agricultural policies should reward farmers who reduce the carbon footprint of their land, reintroduce forgotten species that restore ecological balance and enrich community knowledge, and invest in training the next generation of farmers. At the same time, environmental education must return to schools – through garden-based projects that teach the value of soil and life cycles, and through curricula where the environmental crisis is not treated as an occasional topic of discussion but as a continuous theme for learning and reflection. Without building bridges between traditional knowledge and scientific research, we risk losing an invaluable collective heritage. The peasant grandparents who knew every plant and every season of sowing, the healers who transformed leaves into ancient remedies, and the women who mastered the secrets of food preservation and seed saving, all embody knowledge that remains indispensable. At the same time, digital technologies, satellite monitoring, and genomic analysis can strengthen this heritage by providing real-time insights into soil moisture, nutrients, and biodiversity – without, however, becoming instruments of exploitation, alteration, or mere profit. Only a balanced dialogue between these perspectives can generate genuine innovation.

Looking ahead, we have the chance to build an agricultural model that unites economy and ecology, science and culture, the global North and South. By weaving together with the experiences of communities worldwide – across civil society and academia – we can create a global laboratory of sustainable practices. What is needed is not a sudden revolution, but a gradual process of transformation that engages local communities, markets, and international institutions alike. On this path, every seed preserved, every soil restored, and every piece of knowledge shared will represent a tangible step toward a planet in balance.

Abstract

In the face of accelerating climate change and ecological degradation, agrobiodiversity emerges as a strategic resource for building resilient agricultural systems. This paper explores how traditional knowledge, local crop varieties, and nature-based solutions can mitigate environmental impacts and enhance food security. By analyzing soil regeneration practices, community-led conservation models, and inclusive agricultural policies, the study highlights the role of agrobiodiversity in carbon sequestration, ecosystem restoration, and climate adaptation. Drawing on case studies, it advocates for a paradigm shift that integrates scientific innovation with cultural heritage, promoting a sustainable and equitable future for global agriculture.

Agrobiodiversità: strumento di mitigazione della crisi climatica

Il contributo analizza il ruolo centrale dell'agrobiodiversità nella costruzione di sistemi agricoli resilienti e sostenibili, capaci di rispondere alle sfide poste dal cambiamento climatico. Attraverso un'ampia riflessione che intreccia conoscenze tradizionali, pratiche agroecologiche e politiche territoriali, il testo evidenzia come la diversità biologica – di semi, suoli, paesaggi e comunità – rappresenti una risorsa strategica per la rigenerazione dei suoli, la sicurezza alimentare e la mitigazione degli impatti ambientali. Sono molteplici gli esempi che mostrano come le comunità locali, grazie a pratiche sedimentate nel tempo e a un rapporto profondo con il territorio, possano diventare protagoniste di un cambiamento concreto, capace di coniugare innovazione scientifica e giustizia ambientale.