Agroforestry and the environment

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Abstract Agroforestry is a traditional land use system that may contribute to the solution of environmental problems in agriculture. Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crops and/or animal systems to benefit from the resulting ecological and economic interactions. Recent research indicates that a wider adoption of agroforestry principles and practices is a key means by which the global agri-food sector might achieve more sustainable methods of food and fiber production by producing both economic benefits for farmers and environmental benefits for society. Agroforestry provides numerous provisioning, regulating, cultural and supporting ecosystem services and environmental benefits while promoting eco-intensification based on a more efficient use of the resources. Nevertheless, there is only little published recent information on the contribution of agroforestry to the environment in general and on climate change, carbon

sequestration and forest fires in particular. In this special issue a number of articles are included that provide a kaleidoscope of the environmental benefits that agroforestry provides to the environment.

Keywords Biodiversity · Forest fires · Policy · Carbon sequestration

Introduction

Agroforestry is a traditional land use system that may contribute to the solution of many present and future environmental problems. Agroforestry is a sustainable land management practice that includes the deliberate integration of a woody component with an agricultural production in the lower storey (Santiago-Freijanes et al 2021). This definition covers a diverse range of agroforestry systems such as silvopastoral, silvoarable, forest farming, home gardens, and hedge, windbreak and riparian buffer strip systems. However, many farmers who practice agroforestry do not identify it as a distinctive and specific land use nor even accept such identification (Mosquera-Losada et al. 2020). This was also shown in the pan-European study by Rois-Diaz et al. (2017) who recognize that “*in society, agroforestry is a new word for something extremely old and large*”. Yet, framing it under the more recent term of “agroforestry” goes along with a new and broader perspective on this land use system,

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encompassing not only productivity but also other ecosystem services and environmental benefits (Jose 2009, 2019). The same authors indicate that the concept of agroforestry was not clear for many conventional farmers while it was evidenced that there was a lack of awareness among the agroforestry farmers. Education must represent the “alpha” and “omega” to confront this issue in order to enhance the uptake of agroforestry. Actually, it was one of the issues claimed by farmers from nine countries within the HORIZON 2020 (H2020) project Agroforestry Innovation Network (AFINET) (Mosquera-Losada et al. 2019).

Aiming to gather the experience and knowledge developed by different research teams dealing with ecosystem services and environmental benefits, this special issue brings together various contributions built on a multidisciplinary, science-based evaluation of these practices and systems and their contribution to the environment. The identification and diffusion of such knowledge may help to better target public policies for these systems, and also support land managers in their everyday decisions, helping to clarify pathways for the maintenance of a sustainable system. The novelty of this special issue is the contribution for the understanding of how agroforestry systems and practices will become a path for sustainable management, and as such help link science to practice.

Agroforestry to enhance biodiversity

Less than two centuries have passed since the dawn of the new era of intensive agriculture and the initial cheers have been replaced by the worrying voices accompanying the realization that plant and animal species are disappearing by hundreds and even more are threatened. Based on the IUCN Red List (2021), more than 37,400 species are threatened with extinction. Biodiversity preservation is addressed by several actions aiming to conserving biological diversity, to sustainably using the components of biological diversity and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (Mosquera-Losada et al. 2020). The European Union under the *Green Deal*, has adopted a roadmap for a sustainable economy, striving to be the first climate-neutral continent (EU 2021). Agroforestry represents

one of the most important tools to meet this challenge while fulfilling the European and Global Biodiversity Targets (Rankoth et al., 2019; Mosquera-Losada et al. 2020).

Akese-Ransford et al. (2021) demonstrated that insects can be used as bioindicators of ecosystem health and changes in the environment. Their number and presence is affected by management and, subsequently, informs about agro-ecosystem management priorities and actions. This holds an even more important position when it comes on the management of agricultural crops such as cocoa. Cocoa is a major crop and income source for many parts of the world holding an outstanding role in local economies, especially in many African countries such as Cameroon and Ghana. Insect pests remain a major constrain to cocoa production in Ghana causing huge economic losses. Akese-Ransford et al. (2021) evaluated the influence of organic and conventional management systems on abundance of insects, including both pest and beneficial species. In the conventional farms, a higher number of insect pests to cocoa were recorded, while the organic farming systems support many predatory insect species that could act as natural enemies, emphasizing the importance of the management system to sustaining high biodiversity for a sound ecosystem. Pollinators represent one of the most important insect groups, as they are irreplaceable agents for many crop and plant species to fructify, generate yield and propagate. Kay et al. (2020) analysed the implications of agroforestry in terms of nesting and flowering potential provided to wild bee species in relation to the pollination service potential in landscapes with traditional cherry orchards in north-western Switzerland. The results indicate that agroforestry provides important additional food and nesting resources for wild bees. A higher pollination service is expected for landscapes with a higher proportion of cherry tree agroforestry. Mainly cavity nesting species might potentially benefit from the nesting opportunities offered by agroforestry trees. The results by Kay et al. (2020) highlight the importance of traditional flowering fruit trees in combination with agroforestry in sustaining wild bee populations and the associated delivery of pollination services in agricultural landscapes.

Agroforestry and farming systems

Agroforestry is not *per se* related to a particular farming system. Conventional, integrated and organic farmers combine trees with crops and/or animals. Also, agroforestry is not *per se* more intensive or extensive than other types of agricultural land use. But agroforestry is able to eco-intensify production systems through better use of resources (Mosquera-Losada et al. 2020) as shown in the Spanish dehesa system. In tropical regions, where mineral fertilizer and synthetic pesticides are often not readily available, agroforestry is analogous to organic farming. Rosati et al. (2021) reviewed how the adoption of agroforestry practices could contribute to increase the sustainability of organic farming and discussed the challenges and opportunities of this adoption. They stress that contemporary agroforestry systems need to be designed to combine environmental benefits with modern requirements such as mechanization and labour efficiency in order to make the production system economically sustainable. During the past years research has greatly progressed in assessing interactions, both positive and negative, between trees, crops and/or livestock and this knowledge was used to propose and study several innovative agroforestry systems. As the authors conclude, until new products, markets, knowledge, social attitude and policy are established, subsidies for the ecosystem services agroforestry systems provide will be of critical importance to encourage a wider adoption of agroforestry.

Trees as tools for environmental management

As mentioned above, woody perennials represent valuable tools in the management of natural resources. Tree species selection and establishment methods are important points of consideration before starting agroforestry. Some of the tree species used can be easily characterized as “wonder-trees” by their multiple environmental role and products. For example, *Moringa oleifera* (Lam) (Boumenjel et al. 2021) represents a promising choice in arid zones where water is a limiting growth factor. Based on the results from greenhouse and field research conducted in Tunisia, it appears that *Moringa oleifera* can withstand severe water stress while maintaining sufficient root

and foliar growth, rendering this species a valuable candidate to rehabilitate and enhance soil quality in arid zones. Similarly, gliricidia (*Gliricidia sepium* Jacq.) offers generously services to the environment while supporting agricultural production. As Kaba and Abunyewa (2021) mention, it could be enough to prune young gliricidia trees at 4 months and old gliricidia trees at 8 months as source of green manure to meet the N need of a cocoa plantation without any external N fertilizer. So, pruning this leguminous tree represents an important management tool to enhance N levels in an agroforestry system, as in the cocoa one investigated, reducing the need of external inputs and, subsequently, increasing farmers’ net profit. This is of major importance in agroforestry systems that support local economies, such as mentioned above for Ghana and also for Cameroon. Cocoa-based agroforestry systems are very typical in regions of south and southwest Cameroon and have undergone multiple changes, following developments in natural, economic and socio-political conditions (Essouma et al. 2021). In this part of West and Central Africa, many people’s livelihoods depend on cocoa as a main income source. In the study area in Cameroon, the farmers had developed a diverse range of cocoa-based agroforestry practices. From a structural point of view, most of the cocoa-based agroforestry farms had a similar multi-layered vertical structure with a high level of tree species diversity in each stratum. The importance of farmers’ training is pointed out in this work since, as the authors mention, this could enhance their knowledge on new techniques while pinpointing the financial and ecological benefits of these systems.

Windbreaks have been an indispensable part of agricultural landscapes in time. Their multiple roles include, among others, crop protection from winds, biodiversity habitats, soil protection from erosion and microclimate formation that mitigates extreme weather events which are becoming more frequent with ongoing climate change. Ukraine has more than 200 years of history in protective afforestation and windbreak systems (Yukhnovskiy et al 2021) as well as in Bulgaria (Kachova et al. 2016). However, there is limited information on the effect of various designs on windbreaks’ aerodynamic properties. This has been the major research goal of the work compiled by Yukhnovskiy et al. (2021) who evaluated the structural features of windbreaks and various windbreak designs while analyzing their aerodynamic properties

based on their phenological phase. Their results demonstrated that windbreaks with some degree of porosity were more effective in reducing wind speed compared to dense windbreak designs. The windbreaks of blown and sieve-looking designs in the aphyllous state with an average porosity between trunks of 40–50% and in the crowns of 20–30%, regulate more effectively the wind regime in comparison with windbreaks of dense design. Additionally, the windbreaks of blown design with porosity 40–50% between the trunks and 0–10% in crowns and sieve-looking design have the best ameliorative properties in the region.

Agroforestry systems and nutrient and water economy

Silvopasture is a promising agroforestry land use option to combine the advantages of tree soil cover while producing numerous products including high quality wood, meat and dairy products (Jose and Dollinger 2019). However, in the early stages of silvopastoral systems' establishment, competition between trees and pasture for water and nutrients is usually high, limiting both pasture production and tree growth (Jose et al. 2019). A viable solution to address low nutrient availability is the application of sewage sludge as an organic fertilizer. Many countries are adopting the use of sewage sludge as fertilizer due to its organic matter and nutrient contents, particularly N and P, that improve soil chemical and physical properties (Rigueiro-Rodriguez et al. 2021; Ferreiro-Dominquez et al. 2021). However, an excess of elements such as N, P, Cu and Zn due to fertilizer application to the soil can pose a threat to the environment and to human health. Addressing these issues Rigueiro-Rodriguez et al. (2021) and Ferreiro-Dominquez et al. (2021) have investigated the effects from the application of sewage sludge on two different silvopastoral systems. In the first case, the authors investigated the effect of sewage sludge dosage (200 and 400 kg ha⁻¹) and application period on soil chemical properties, tree growth and pasture production in an area afforested by *Pinus radiata* D. Don. The results differed based on the application date and dose, but indicated that the highest dose of sewage sludge applied between January and February represents the best option for adequate sewage sludge application

that increases nutrient availability and, subsequently, improves pasture production and tree height. Likewise, Ferreiro-Dominquez et al. (2021) stress the importance of sewage sludge type (anaerobic, composted and pelletized) on the concentration of total and available Zn on tree growth and pasture production. Based on their results, pelletized sewage sludge increased soil Zn levels without affecting tree growth. As an overall conclusion, the effects of sewage sludge on soil fertility and heavy metal concentration should be evaluated on the long-term since this is an attractive and inexpensive fertilization option.

From soil to plant biomass, water availability and nutrient cycling are the starting and ending points of primary biomass production and life on our planet. This is even more important in dry environments where water may be the limiting and detrimental factor to plant growth. The work by Mantzanas et al (2021) contributes to our knowledge on growth characteristics of annual crops and trees under an intercropping system. In particular, the authors demonstrated that intercropping olive trees with cereal crops, such as barley and mixtures of barley and leguminous species such as common vetch, is a very promising practice for Mediterranean areas with traditional olive agroforestry systems. However, information was missing on the actual processes taking place in water economy in intercropping systems. The work of Guo and Zhao (2021) adds a piece to this puzzle by investigating root water uptake in an alley cropping system by using isotopic labelling. They proved that different plants use water from different depth in soil layers, based on the plant species involved in the intercropping system. This actually reflects the importance of a well-designed agroforestry system where all the cropping parameters are carefully examined and measured. For example, by understanding the route of water utilization in an alley system it contributes to develop successful water management systems in arid ecosystems such as in oases. Poplars, the tree species used in this work, absorbed water from the deeper soil layers even if the soil was dry on the top layers. The system included walnut trees that acted as windbreaks which is another important use of trees in agroforestry systems such as was also evaluated in the study of Yukhnovskiy et al (2021).

Agroforestry as a tool to reduce wildfires incidents

Wildfires have been an integral part of many terrestrial ecosystems such as the European Mediterranean basin. However, during the past decades, increasing temperatures and dry summers have been accompanied by an increasing risk of wildfires with devastating effects on the environment and human lives (Damiánidis et al. 2021). This may be partly due to large-scale rural abandonment and moving of people to big cities combined with changes in land use (Kaloudis et al. 2021). The first has resulted in an increase of flammable biomass (fuel) in forests that can then be easily ignited by anthropic activities and sometimes by natural events such as thunderstorms. In their work Damiánidis et al. (2021) investigated and analyzed the spatial relationship between fire incidences and different land uses (agroforestry, forests, shrublands and grasslands) in the European Mediterranean countries Cyprus, France, Greece, Italy, Portugal and Spain). Based on the average fire incidents for all the countries, the lowest incidents of fire were recorded for grasslands (11.2%) and agroforestry (20.2%) while the highest average was recorded in forests (31.9%) and shrublands (36.7%). These findings are of even higher importance taking into account that due to ongoing climate change, land use management practices such as agroforestry represent a viable and sustainable option.

Agroforestry and carbon sequestration

Soil continually undergoes development through physical, chemical and biological processes, which include both formation and degradation (Mosquera-Losada et al. 2017). Ultimately, soil sustains primary production, which is directly related to land management practices. However, there are several challenges that this natural resource is facing such as water erosion, depositions of air pollutants and nitrogen, natural disturbances such as storms and wildfires, or compacting. Agroforestry could help reverse the adverse effects in many different ways and restore and promote soil health (Dollinger and Jose 2018). Bateni et al. (2021) show how agroforestry could help in this respect. In the Umbria region of Italy, they compared soil carbon in different olive groves, a typical silvopastoral agroforestry system including

conventional and organic management, with an abandoned olive grove and with nearby forest for comparison. Based on their results and irrespective of the management applied, olive groves were characterised by a high level of soil carbon storage compared to those growing in other areas and to forest ecosystems, which indicates that the practices adopted in the area are not negatively affecting soil organic carbon stock. They conclude that olive cultivation contributes to high soil carbon stock in the area, which alternatively would have returned to the atmosphere as a consequence of land use conversion to arable land or to the adoption of different soil management practices such as soil tillage.

The contribution of agroforestry to local economies has been proven in most of the articles presented in this special issue, but a different perspective of this theme is presented in the work of Singh et al. (2021). They feature wood biomass as a renewable and CO₂ neutral source of energy, which, if used sustainably and efficiently, can contribute to a cleaner environment. In their work they estimated fuelwood value supplied from agroforestry systems and suggested policy research and measures to ensure access to affordable, reliable, sustainable energy for cooking in India. They raise important policy questions including the prioritization of Liquefied Petroleum Gas (LPG) subsidy instead of improved, in terms of thermal efficiency, cook stoves. They emphasize the importance of agroforestry systems in terms of sustainable supply of fuelwood for cooking, as a renewable and nearly carbon-neutral fuel, and energy security for financially poor households.

Agroforestry policy and management

Last but not least, policy can play an important role to support or suppress agroforestry sustainability and environmental soundness. As Santiago-Freijanes et al. (2021) and Rodríguez-Rigueiro et al. (2021) mention, agroforestry, even if it is a worldwide recognized sustainable land management system, it has not yet seen a large-scale adoption neither in temperate nor in developed countries. Agroforestry promotion, at least at European level, is of high importance and policy decisions can play an important role in this. In their article, they compiled information from relevant documents at global scale including United Nations,

FAO and European policy bodies, web pages, reports and other papers to evaluate the impact of policies on agroforestry. They found that the promotion of agroforestry is addressed in some countries such as France, USA and India, but still not sufficiently enough by other countries and regions, for instance the European Common Agricultural Policy. The authors conclude that immediate actions need to be taken, such as clear identification of all agroforestry practices including silvopasture, silvoarable, hedgerows and riparian buffer strips, home gardens and forest farming, and these should be recognized by agricultural policy. In addition, drawing up management plans could remove the limitation for expanding agroforestry in arable lands which is currently restricted to a tree density of 100 trees per hectare which does not consider the higher initial tree density needed to ensure adequate tree production. Actually, as Baig et al. (2021) mention in their work on identifying constraints, improvement strategies and extension for agroforestry in Pakistan, it is important to work with individual farmers to identify the most appropriate agroforestry practices for each farm. Policy could stimulate innovation in agroforestry through effective knowledge transfer based on the bottom up involvement of stakeholders and multi-actor approaches. Due to the huge potential benefits that the different agroforestry practices have, it is important that policy makers, farmers and researchers make a common effort to identify the obstacles and knowledge needs, improve knowledge transfer and promote sustainable agroforestry practices. A successful promotion of agroforestry requires the appropriate choice of message, messenger, target audience and communication tools (Baig et al. 2021).

There is still a lot of work to be done until agroforestry systems get the credit they deserve from an environmental, economic and societal point of view. In a work by Vrahnakis et al. (2021) on a Greek silvopastoral system, it became clear that the factors affecting the perception of societal and institutional groups relate to the economic benefits and the interdisciplinary complementarity of livestock management and forestry. In particular, their results reveal that the main factors regulating the attitudes of social groups on habitat type are the threats and risks for habitat degradation, the complementarity of forestry and livestock husbandry professional activities, and the economic benefits for the local community.

Actually human intervention holds a key role in land cover changes (Kaloudis et al. 2021). The same authors point out that the whole process of land cover evolution in an old-growth valonia oak silvopastoral system, is complicated and dynamic and relates to local environmental factors, which, in turn, affect the type and intensity of human activities.

Conclusion

The articles in this special issue collate the latest knowledge on important environmental issues providing evidence on the potential of agroforestry to address and provide viable and sustainable solutions on current environmental issues, and its ability to mitigate and confront climate change and its impacts on our natural environment, our societies and food production systems. Agriculture is currently a major net producer of greenhouse gasses and one of the reasons for the current biodiversity crises. There is little prospect of improvement unless things change dramatically. Agroforestry systems incorporating trees in crop cultivation or livestock systems can help to enhance carbon sequestration and to compensate for ongoing biodiversity loss. This special issue has brought together a range of articles that are useful in the tropics as well as in cooler northern regions. There are suitable crops and trees for most climate types and hopefully this special issue will be a source of inspiration and hope by providing reasoned arguments for integrating more trees in agricultural landscapes to feed people and preserve our natural legacy.

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