Agroforestry systems for adaptation to and mitigation of climate change: effects on soil fertility

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ABSTRACT. – Agroforestry (AF) systems are gaining pace as good examples of sustainable cropping systems with also a role in climate change mitigation/adaptation. This is mainly because of their huge C sequestration potential and the diversification of the agroecosystem implying high resilience in respect to stressful conditions. At the Centre for Agri-environmental Research "Enrico Avanzi" of the University of Pisa, Italy, a new long-term field experiment has been started in 2018 on 40 ha of arable land with the aim to assess the performances of different cropping systems at different levels of integration between herbaceous crops and trees. Soil organic carbon storage will be one of the main parameters that will be assessed in the long term at different depths and at different distances from the tree rows to assess the importance of the interaction between the system components in terms of soil fertility. The long-term experiment is expected to provide solid data on the contribution of innovative AF systems to climate change mitigation in Mediterranean areas.

AGROFORESTRY SYSTEMS AND CLIMATE CHANGE. – Agroforestry (AF), "the deliberate integration of woody vegetation (trees and/or shrubs) as an upper storey on land, with pasture (consumed by animals) or an agricultural crop in the lower storey", is pointed as a sustainable land-use strategy to cope with climate change and provide environmental, economic, and social benefits (Kay *et al.* 2019). Historically, in Italy and many other countries the combination of tree and herbaceous crops was widely spread until the so called "green revolution", when the sepa-

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ration between science and practice in agriculture and in forestry has left many opportunities for a functional use of trees in the agroecosystem unexploited (Duguma *et al.* 2018). Traditionally, AF systems had been a source of fruits, crops, fodder, building materials, biomass for energy, fiber, crafting materials, all kinds of animal products, etc.

From an agroecological point of view, trees may play an important role in agricultural landscapes through the delivery of important ecosystem services with an impact on crop productivity and reduction of agri-environmental risks (Wezel *et al.* 2014). What really makes a difference between pure stands of arable crops and AF systems is clearly the higher level of planned agrobiodiversity in AF systems, which translates into enhanced symbiotic connectivity between all the agroecosystem biota (*i.e.*, crops, weeds, soil microrganisms, micro-, meso- and macro-fauna) to improve the use of the local resources (EIP-AGRI 2017).

Under the lens of climate change mitigation and adaptation, AF systems are increasingly gaining pace as one of the most effective agricultural solutions as they are able to (EIP-AGRI 2017): i) stabilize the productivity of the land thanks to the integration of different crops/animals that are able to provide different productions; ii) enhance cropping system resistance and resilience to climate change because of the high planned (crops, livestocks) and unplanned (*e.g.*, wild flora, beneficial arthropods and microrganisms) biodiversity level; iii) contrast soil desertification by increasing soil organic matter content through root and litter decomposition and by contrasting soil erosion; iv) improve water storage capacity of soils thanks to their deep root systems able to utilize underground water; v) reduce water evaporation from the soils thanks to their shade and to the litter cover on the ground; vi) compensate for greenhouse gas emissions by increased CO_2 sequestration from the atmosphere through photosynthesis and reduced N excess in topsoil due to high N intake of tree root systems; vii) increase fertiliser use efficiency thanks to reduction in nitrate leaching and P availability (through the release of root exudates and interactions with soil microrganisms as mycorrhizas); viii) reduce pesticide use by enhancing the presence of antagonists and predators of pests and diseases that may find food, shelter and nesting spaces on the trees and in other ecological corridors.

THE IMPORTANCE OF SOIL FERTILITY IN A CHANGING CLIMATE. – Soils play an essential role in the global carbon budget (Houghton 2007). Recent studies estimate the carbon (C) sink capacity of soil and vegetation in about one third of the C emitted to the atmosphere through the burning of fossil fuel and cement production (Le Quéré *et al.* 2014). On the other hand, land use changes and agricultural management occurred in the last two centuries has led to a depletion in soil organic C (SOC) of around 70 Gt (Lal 2004a). There is a huge potential in European agricultural soils to store much more C from the atmosphere if proper management practices are applied. These practices should be aimed, on one hand, to increase SOC inputs (*e.g.*, by using cover crops, intercropping, organic amendments, biochar), and to reduce SOC mineralization (*e.g.*, by keeping the soil covered as much as possible, reducing the soil disturbance adopting reduced tillage techniques, modulating soil moisture), on the other. Increasing SOC stocks is often seen as a win-win strategy (Lal 2004a) as it allows decreasing the CO_2 concentration in the atmosphere while improving at the same time soil quality and fertility, thus enabling the crops to grow much better and to sequester more C from the atmosphere (Lal 2004b).

Studying the effect of AF systems on SOC and soil fertility. – Soil fertility dynamics, and especially SOC dynamics, require long term monitoring in order to be able to detect any significant changes affected by specific agricultural management options. This is because of the chemical nature of the soil organic matter, which is characterized by stable compounds that make its turnover normally taking decades (Dignac *et al.* 2019). These transformation processes are mediated by soil microorganisms, which are in turn affected by any modification in their living habitat.

In agronomy research, the long term effect of agricultural practices on soil fertility have been traditionally studied by setting up "long term experiments" (LTEs), where the application of experimental treatments (*e.g.*, different fertilization strategies, different farming systems) are applied continuously over years in order to detect any change in the studied parameters. These experiments, considered very expensive and less productive than reductionist studies, have been partially disregarded in the last decades. But now they are attracting an increasing interest from scientists and stakeholders in respect to new societal challenges, climate change mitigation and adaptation above all.

AF systems also require by their nature long term monitoring of their effects on agroecosystem functioning and performances. This is first because of the long life of the tree components, but also because their development and growth pass through different stages with different levels of interactions with the other agroecosystem biotic and abiotic components.

THE ARNINO LTE: A LONG-TERM FIELD EXPERIMENT ON AF AND SOIL FERTILITY. – A multidisciplinary team has designed and established a long-term field experiment to evaluate the transition of a conventional arable system towards AF in Tuscany (*https://www.avanzi.unipi.it/index.php/ricerca/itemlist/category/183-agroforestry-long-term-experiment.html*). The purpose of the LTE is to assess the sustainability and performances of AF compared with conventional arable and forestry systems, as well as the potential transferability to real farm conditions. The research focuses on synergies and trade-offs among the two main components of the agroforestry system, *i.e.*, tree and herbaceous crops in order to evaluate whether the diversification of the cropping system may enhance its resilience to variability of weather conditions. Additionally, the LTE will allow to assess in the long term the potential of climate change mitigation/adaptation of AF systems through the monitoring of carbon storage, soil fertility and biodiversity.

The LTE, started in 2018, is located at the Centre for Agro-Environmental Research "Enrico Avanzi" of the University of Pisa, San Piero a Grado (Pisa) (43.667205 N, 10.313160 E). The field trial was established on Xerofluvent soils classified as Typic Haplustert, with loam to clay-loam textures, sub-alkaline pH and soil organic matter varying from 1.5 to 2%. Two AF systems, Silvo-Arable (SA) and Agro-Silvo-Pastoral (ASP), are being compared with the respective controls, *i.e.*, Arable (AR) and Mixed (MX) systems (Table 1). The crop sequence adopted in AR and SA includes durum wheat (*Triticum turgidum* subsp. *durum* Desf.), sorghum (*Sorghum bicolor* L. Moench) and faba bean (*Vicia faba* var. *minor* Beck). In MX and ASP, the three annual crops are followed by a 4-year meadow of Italian ryegrass (*Lolium multiflorum* Lam. var. *italicum*), orchard-grass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* L.), sulla (*Hedysarum coronarium* L.) and alfalfa (*Medicago sativa* L.). This meadow is exploited both to produce hay and for direct grazing of sheep. In SA and ASP, oak (*Quercus robur* L.) and poplar (*Populus* spp.) have been planted alternate on the row every 5 m, along one side of each field, 2 m away from drainage ditches, corresponding to a density of 60 trees ha^{-1}. The space between tree rows and ditches is managed as semi-permanent buffer strips to support functional biodiversity and to limit nutrient leaching. Forestry control fields are two pure stands of poplar and oak and a polycyclic plantation based on oak, poplar, hazelnut (*Corylus avellana* L.) and alder (*Alnus cordata* L.).

Preliminary and expected results. – Besides data on crop yield and quality, animal production and quality, the experimental protocol of the LTE includes collection of data on soil fertility, weed abundance and composition, soil erosion, nitrate leaching and economic budget. Soil fertility will be assessed at the beginning of the trial (*i.e.*, as soon as all the tree plants will be established) and then periodically (at the end of each crop rotation cycle). The sampling protocol will include monitoring soil parameters (*i.e.*, pH, soil organic carbon, total N, available P, Cation Exchange Capacity, Electrical Conductivity, total and active limestone) at different depths (down to 1 m at least to intercept most of the tree roots) and at different distances from the tree rows in order to assess the effect of interaction between the two plant components of the AF systems.

According to the literature, we should expect a huge effect of the presence of trees in the modification of soil parameters, especially for soil C and N, but with different intensity depending on the state of development of the trees. In this LTE two different kind of tree crops were included (*i.e.*, poplar and oak) in order to provide a sufficient tree biomass along all the lifetime of the AF systems. Poplar trees are expected to grow very quick since the beginning and will be periodically cut to provide wood product regularly. Oppositely, oak plants will be able to deliver ecosystem services and wood products only after some decades.

Potential collaboration. – This LTE is intended as an open-air laboratory open to new collaborations from disciplines other than agronomy and crop/animal production. Given the high complexity of the AF systems and the standard field size of the plots, we foresee potential for future studies, for instance, on mechanization aspects (*e.g.*, how the operational difficulties in field operations caused by the presence of trees could be overcome by innovations in farm machinery), energetic budgets, soil microbiology, water use efficiency, plant and animal genetics, animal biodiversity, social aspects. All these aspects can contribute to enhance the impact of the outcomes by covering most of the sustainability dimensions that need to be considered in the light of climate change adaptation/mitigation.

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TABLE 1 – *Cropping systems tested in the ARNINO LTE. Within brackets, the length of crop rotation is reported.*

Arable systems	**Agroforestry systems**	**Forestry systems**
Arable (AR) (3yr)	Silvo-arable (SA) (3yr)	Poplar (P) (10yr) Oak (O) (45yr)
Mixed (MX) (7yr)	Agro-silvo-pastoral (ASP) (7yr)	Polycyclic plantation (3P) (45yr)