Umwelt Bundesamt

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Silvoarable agroforestry (including hedgerows)[1]

1 Measure definition

Agroforestry with cropland or silvoarable agroforestry is a system where woody perennials such as trees or hedges and agricultural, usually annual crops are grown on the same cropland in a specific spatial and/or temporal fashion (Cardinael et al. 2017; FAO and ICRAF 2019). This involves tree lines but may also involve the use of hedgerows, woodlots (small parcels of woodland), and scattered trees (Golicz et al. 2021).

In Europe, five main categories of trees occur in agroforestry systems: fruit trees, olive trees, timber trees, oaks and fodder trees (Eichhorn et al 2006). Depending on the systems, cereals, vegetables, sunflowers or fodder crops (e.g., legumes, alfalfa) can be intercropped with trees. Systems can vary in terms of the intensity of management, with some managed extensively and others relying on fertilisation and irrigation. Olive trees (dispersed or in rows), linear systems of hybrid poplars, and oak systems intercropped with cereals are some of the most widely adopted systems. Systems with timber trees may be more promising commercially because they face fewer constraints than fruit trees (fruit trees compete more with crops on the same area of land; market standards for fruit trees) (Eichhorn et al. 2006).

Some systems combine trees with both arable and grassland use (grazing, fodder cultivation) so that the term *agrosilvopastoral* is used. For example, in Spanish *dehesas*, the grazing component is dominant, but a small proportion of land may also be cultivated with crops such as cereals, sunflower or fodder crops (Eichhorn et al. 2006).

Agroforestry covers approximately 8.8% of the EU's utilised agricultural area and is concentrated in the Mediterranean and southeast Europe (Burgess et al. 2018). There is insufficient quality of data to be able to determine the share of silvoarable as opposed to silvopastoral or silvoarable-pastoral systems. However, pure silvoarable systems represent a minor share of agroforestry in the EU.

Geographical and biophysical applicability

- **Suitability to different biophysical conditions:** In Northern Europe silvoarable systems are limited by light availability due to higher latitudes (lower photon flux densities) which reduces the economic viability of crops under tree canopies (Eichhorn et al. 2006). In the Mediterranean, there is a greater diversity of silvoarable systems with the limiting factor here being water availability. Sloping land should not be kept exposed due to risk of soil erosion, so that silvoarable systems should also not be established here unless they use permanent soil cover (reduced or no-till organic systems that do not use herbicides).
- **Suitability in EU/German conditions:** Given the large diversity of potential combinations of trees and crops, silvoarable agroforestry systems can in principle be designed for and applied across Europe. They should not be established on rich organic soils due to emissions occurring

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during the planting phase of the trees and because this would limit rewetting of peatlands, which is a much more effective mitigation option.

Fit with NbS definition

Silvoarable agroforestry serves carbon sequestration objectives and fulfil all aspects of nature-based solutions as in the working definition for this research project as defined by Reise et al. (2022) provided that: the arable components of the system are locally appropriate and protect soils and that agroforestry is not situated on rich organic soils, does not involve conversion from grassland to arable land, and does not rely on intensive fertilisation/agro-chemical inputs or unsustainable irrigation.

2 Mitigation Potential

2.1 Carbon sequestration

Incorporating trees into croplands has the potential to promote soil carbon sinks compared to crop only (and especially monoculture) systems by sequestering more carbon in soils, and additionally through carbon stored by the trees in above ground biomass (Jose, 2009). The sequestration potential will depend on biophysical conditions, land use history, type of management (rates of harvesting/pruning), tree density, and types of tree species (Golicz et al 2021).

Kay et al. (2019) estimate the carbon storage potential of all agroforestry in the EU27 (plus Switzerland) to be between **0.3 - 27 t CO_2e/ha/year** or a total of **7.7 - 234.8 Mt CO_2e/year**. The sequestration potential in particular depends on the type of trees, density of trees, lifespan and final use for the timber. This estimate assumes that agroforestry would be implemented on approximately 8.9% of EU farmland, or so-called “priority areas” in Europe, which face the highest environmental pressure.

However, this estimate does not include below-ground SOC potential which is shown to be higher under agroforestry than under croplands or grasslands by themselves and can deliver significant additional sequestration (Upson and Burgess 2013). For example, agroforestry using poplar trees increased soil carbon stocks to 60 cm depth by 13% compared to conventional arable croplands in England (Upson and Burgess 2013). In temperate climatic zones, the establishment of hedgerows could increase SOC stocks by 21 - 32% with a SOC sequestration potential of 0.9 - 0.3 Mg C ha-1 over a 20 to 50-year period. The reported increase in SOC stock is in close range to estimates of land use conversion from cropland to forests (Cardinael et al. 2018; Drexler et al. 2021).

Separate estimates for silvoarable systems provided in Kay et al. (2019) vary quite significantly across different biogeographic zones and types of system. They found the highest per ha potential for silvoarable systems in terms of above ground biomass in the Mediterranean mountains zone where lined poplar trees (200 trees per ha density) are interspersed with rotation of wheat, oilseed rape and chickpeas (5.76 - 7.29 C/ha/year). For Atlantic and continental regions the per ha potentials of silvoarable systems were in general lower (e.g. hedgerows as productive boundary for use as woodchips was estimated to have 0.1 - 0.45 t of C/ha/year or alley cropping with coppice in continental lowlands at 0.15 - 0.44 t C/ha/year).

In an assessment for Germany, Golicz et al. (2021) distinguished between three types of small woody landscape features (linear, patchy and additional) and provided an assessment of their additional mitigation potential. They found that cropland has the lowest share of features at

2.8% of total arable area, with south and north-east regions being dominated by cropland and low share of features, and northwest dominated by grasslands and higher share of woody features, and that cropland also has the highest potential through inclusion of additional features. Hedgerows as field boundaries have a higher potential than adding tree lines in cropland due to the structure of the hedges, high stem densities and regrowth capacity after trimming which leads to higher increase in soil organic carbon. In total, Golicz et al. (2021) estimate that increasing agroforestry on 1 – 10% of total agricultural land could potentially sequester 0.2 - 2 Tg C/year in soil and biomass and more than double the amount with the incorporation of hedgerows over the same area.

2.2 Total climate impact

Methods for estimating C stocks and GHG balances e.g., N_2O, CH_4 to monitor the net benefits of agroforestry on atmospheric GHG levels have not been optimized and are difficult and costly (Albrecht and Kandji 2003). Studies that examine the full GHG impact of agroforestry are hardly available. Underlying is the issue that there are no reliable statistical sources on trees located on agricultural land. Based on satellite data, Zomer et al. (2017) estimated that in 2000 more than 40% of the agricultural land area had more than 10% tree coverage with a CO_2 storage of 166 Gt CO_2. Average estimates range from 0.3 Gt CO_2e /year in Bossio et al. (2020) (only considering SOC contribution), 1.1 Gt CO_2e/year in Griscom et al. (2017) to 3.4 ± 1.7 Gt CO_2e/year in Kim et al. (2016). Jia et al. (2019) estimate the potential between 0.1 and 5.7 Gt CO_2e/year and Lal et al. (2018) between 1.6 and 3.5 Gt CO_2e/year (technical potential). Potentials for the enhancement of CO_2 storage by agroforestry vary widely with the type of system, soil types, climate, tree species and tree densities.

Agroforestry can be a source of N_2O emissions, depending also on the level of fertiliser use and intensity of management. Kim et al. (2016) estimated that 7.7 ± 3.3 kg N_2O emissions/ha/year can occur. Thus, a major trade-off might involve choosing between CO_2 sequestration and N_2O emissions.

The total impact also depends on the fate of the timber harvested, with the most significant benefits from long-term timber use, for example, in construction. Timber use for fuelwood reduces the total impact significantly.

2.3 Limitations on the mitigation potential

The amount of carbon sequestered will depend on the agroforestry system such as tree species, and management options (Albrecht and Kandji 2003). Research conducted in France showed that the potential for carbon sequestration by hedges was dependent on the hedgerow characteristics such as location in the landscape, the size and the height of the hedges (Aertsens et al. 2013). For short-rotation coppicing systems, the climate impact is limited since the system is not permanent and when the timber is harvested after a given cycle (at most 15-20 years), there is disruption and loss of carbon sequestered, the scale of which also depends on the final use of the timber harvested.

On plot level, the introduction of trees on agricultural fields can lead to competition for space, light or nutrients which may affect food/fodder production (EEA 2021). This can lead to leakage and thus reduced overall positive climate impact. However, this effect is suggested to diminish on a larger scale due to the more efficient use of nutrients in agroforestry systems (Aertsens et al. 2013) and thus a lower emission of total GHGs.

3 Adaptation and co-benefits

- **Air spread diseases:** The reduction of wind speed and temperature buffering in agroforestry systems reduces the dispersal of epidemic spores of airborne diseases (Boudrot et al. 2016) and the higher biodiversity supports pest regulation (Boinot et al. 2019).

- **Soil health:** Agroforestry reduces erosion by improving soil cover and reduces nutrient leaching. Plant root exudation can improve soil quality especially when compared to conventional cropland agriculture and forestry (Harvey et al. 2007, Jose, 2009; Smith et al. 2013; Torralba et al. 2016). Up to 65% reduction in erosion and 28% reduction in nitrogen leaching was observed for soils with the adoption of silvoarable agroforestry system using trees such as pine, oak, walnut, wild cherry and poplar in European regions (Palma et al. 2007).

- **Biodiversity:** Enhancing tree structures across croplands such as in agroforestry systems means to support biodiversity-friendly landscapes by achieving a large-scale mosaic of more natural habitats (Tscharntke et al. 2021). Agroforestry promotes soil biodiversity and ecosystem stability via suitable habitat for species (Harvey et al. 2007). The presence of tree row-associated bacteria in alley-cropping systems with poplar trees altered soil bacteria composition and increased overall microbial diversity of croplands in Germany (Beule and Karlovsky 2021).

- **Addressing societal challenges**: Agroforestry can improve food security, production of commercial products and energy production (e.g., timber) (Smith et al. 2012), thus diversifying income sources for farmers, improving wellbeing and offering economic benefits (Bene et al. 1977; Smith et al. 2014).

- **Yields**: Under drought conditions, agroforestry systems may maintain or enhance yields (Seddon 2020b). Research for Spanish conditions also predicts that crop production can be improved in agroforestry systems compared to open fields when there is an increase in warm springs (Arenas-Corraliza et al. 2018).

4 Trade offs

- **Land use:** Carbon sequestered by the trees can be reversed if the trees die, are harvested or removed due to land use change or fires. Carbon sequestration in above ground tree biomass is reversed if the biomass is used for energy production.

- **Management:** The combination of perennial trees with crops can make the management of agroforests difficult and time consuming (EEA 2021).

- Competition with crop only systems, limits on profitability and efficiency as well as limited market outlets (e.g., for high quality / specialty timber) currently limit their expansion in particular in northern Europe and in most intensified agricultural regions, where traditional agro-forestry systems have largely been abandoned (e.g. *Hauberg* system in North Rhine-Westphalia which combined trees for fuelwood with long rotations of crops and grazing) (Eichhorn et al 2006). Traditional systems in the Mediterranean, including France, have declined more slowly, but tend to remain more limited to marginal soils where cropland intensification was not as viable.

5 Implementation challenges

Until the current programming period, the CAP discouraged the maintenance of landscape features since areas with shrubs or trees were not eligible for payments. This has changed for the 2023-2027 period as the eligibility definition has been extended to include trees and landscape features. However, this only reduces the pressure to convert and remove landscape features, but does not provide an incentive to increase agroforestry coverage per se. Member States, however, can support agroforestry under eco-schemes and agri-environment-climate measures. In the past programming period of the CAP, the funding support for setting up new agroforestry was minimal.

Agroforestry systems are knowledge-intensive; the optimal combinations of trees and crops need to be determined for different biophysical conditions. The mainstream agricultural research activities and interests, however, have a strong bias towards single crop systems. One bottleneck is the development of systems where mechanization can reduce labour costs.

More limited profitability of single crops in agroforestry systems is also a significant barrier (e.g., due to cheaper imports of walnuts) and missing markets for different types of wood products limit commercial viability, so that research and piloting on how to improve efficiency and profitability while supporting climate and environmental objectives is needed. Increasing the economic value of trees through development of markets for high quality tree products is an implementation challenge (Eichhorn et al. 2006).

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