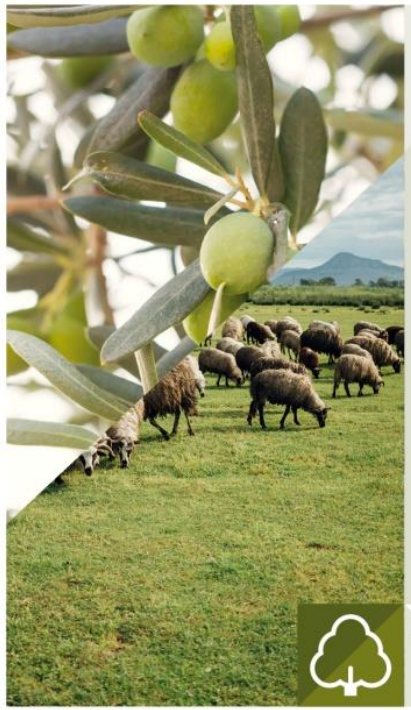
ENI CBCMED
Cooperating across borders in the Mediterranean

Project funded by the EUROPEAN UNION

REGIONE AUTÒNOMA DE SARDIGNA
REGIONE AUTONOMA DELLA SARDEGNA

LIVINGAGRO



Module 2 for LL2, Agroforestry for Grazed Woodlands
Course 3 – Advantages of agroforestry for grazed woodlands

Chapter 1 - Agroforestry for soil and water conservation in grazed woodlands

By Marie Therese Abi Saab, PhD
Lebanese Agricultural Research Institute

Forestas
Agentzia forestale regionale pro s'isviluppu de su territòriu e de s'ambiente de sa Sardigna
Agenzia forestale regionale per lo sviluppo del territorio e dell'ambiente della Sardegna
SardegnaForeste

Consiglio Nazionale delle Ricerche

NARC
National Agricultural Research Center

LARI

CIHEAM
MAI CHANIA

ATM CONSULTING sas

Course Contents

1. Introduction
2. Beneficial effects of agroforestry on soil and water
3. Agroforestry for maintenance of soil fertility
4. Agroforestry for control of soil erosion
5. Agroforestry for carbon sequestration
6. Water conservation through agroforestry: Improving soil water quality
7. Practices used in combination with agroforestry systems for soil and water conservation
8. Conclusion
9. References

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

1. Introduction

Soil and **water** degradation are global concerns. Therefore, **sustainable soil and water conservation practices** such as **agroforestry** are needed. Agroforestry systems that combine trees with crops or pastures have been widely used to reduce water, soil, and nutrient loss, thus reducing water pollution from agricultural lands.

Agroforestry is a land-use system in which woody perennials are grown in association with herbaceous plants or livestock in a spatial arrangement, a rotation or both. Agroforestry is a combination of agricultural and forestry technologies to create combined, diverse and productive land-use systems.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

1. Introduction

Agro-forestry

Productive functions

fuel wood, fodder and fruit, construction wood, gums, resins, medicines, fibres, etc.

Service functions

soil and water conservation, carbon sequestration, improvement of soil fertility, control of erosion and runoff, reduction in wind speed, shading effect, etc.

Objective of this chapter: To provide an overview of soil and water conservation practices through agroforestry

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

2. Beneficial effects of agroforestry on soil and water

Increases nutrient input from the atmosphere and deep soil layers

Controls erosion and reduces loss of soil organic matter

Closed nutrient cycling and efficient use of nutrients

Improvement of the physical condition of the soil

Nitrogen fixation through trees and shrubs

Increases soil water availability to crops

Improvement of acidic and alkaline soils

Reclamation of degraded lands

Soil carbon sequestration

Improves water quality

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

- **Soil fertility** is the capacity of soil to **support the growth of plants on a sustained basis**, under given climatic conditions and other relevant properties of the land.

- Some initially productive soils have unprotected stores of nutrients and rapidly lose their fertility if transferred from natural vegetation to managed ecosystems. Other soils, notably nitosols on basic rocks, possess natural recuperative powers, enabling them to restore nutrients from rock weathering.

Photo credit: Dr. Milad El Riachy

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Soil fertility depletion is a fundamental cause of food insecurity and low income for farmers. **The loss of nutrients due to continuous cropping gradually renders the soil less fertile, resulting in poor yields.**

Agroforestry can help enhance and maintain long-term soil productivity. The **incorporation of trees and crops** that are able to biologically fix nitrogen (N) is fairly common in agroforestry systems. Non N-fixing trees can also enhance the soil's physical, chemical and biological properties by adding a significant amount of above and belowground organic matter and releasing and recycling nutrients in agroforestry systems.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

- In **agroforestry**, both **gains and losses in crop** or pasture **production** could occur **as a result of the presence of trees**.
- Everything depends on the environmental conditions where agroforestry is being practiced.
- In some spatial agroforestry practices, such as **boundary planting**, the tree component occupies unproductive land. In this case, **food-crop production would not be affected**.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

- In other types of agroforestry, for example in **hedgerow intercropping**, there is an **inevitable reduction in the area available for crops**. Also, a **fall-off in crop yield close to the tree/crop interface** is commonly observed.

- **However**, when adopting agroforestry practices, growers can expect to have an **increased yield per unit of area occupied by crops as a result of the erosion-control and fertility enhancement effects of the trees.** This would compensate for the loss of land used for crops and for any reduction in yield of the crops planted close to the interface with trees.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

Trees maintain or improve soils by processes which

- Increase additions of organic matter and nutrients to the soil
- Reduce losses from the soil, leading to more closed cycling of organic matter and nutrients
- Improve the soil's physical conditions
- Improve the soil's chemical conditions
- Affect the soil's biological processes and conditions

Trees provide valuable products
such as fuel wood, charcoal, construction materials and fodder for livestock.

The **service functions of trees** include
improving soil fertility, **conserving soil moisture** and **improving the micro-climate,** resulting in increased crop yields.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

How are organic matter and nutrients mobilized from the trees to the soil?

- Maintenance or **increase of soil organic matter** through carbon fixation in photosynthesis and its transfer via plant litter (dead plant material) and root decay
- **Nitrogen fixation** by some leguminous and a few non leguminous trees
- **Nutrient uptake**: the taking up of nutrients released by **rock weathering (breaking down or dissolving of rocks) in deeper layers** of the soil
- **Atmospheric input**: trees create favorable conditions for input of nutrients by rainfall and dust, including through leaf fall and stemflow.
- Exudation of **growth-promoting substances** by the rhizosphere (soil surrounding the roots).

In hydrology, stemflow is the flow of intercepted water down the trunk or stem of a plant. It is responsible for the transferral of precipitation and nutrients from the canopy to the soil.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

How do trees reduce losses from the soil?

- **Protection from erosion** and thereby from loss of organic matter and nutrients
- Nutrient retrieval: **trapping and recycling nutrients which would otherwise be lost by leaching,** for example through root exudation and through the action of mycorrhizal systems associated with tree roots
- **Reduction of the rate of organic matter decomposition** by shading

Photo credit: Dr. Peter Moubarak

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

How can trees help maintain the physical and chemical conditions of soil?

- Maintenance or improvement of the soil's physical properties (structure, porosity, moisture retention capacity and permeability) **through a combination of maintenance of organic matter and the effects of roots**
- Breaking up of compact or indurated layers by **roots**
- Modification of extremes of soil temperature through a **combination of shading by canopy and plant litter cover**
- Reduction of acidity through the **addition of bases in tree litter**

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

Agroforestry can involve either protecting and managing the **trees that are already in the field, or** planting **new trees**.

These trees are usually grown to **provide a product of commercial or subsistence value**, such as food, fuel, building poles, and/or fodder.

They also **provide nutrients and organic matter for the soil**, as well as shade for crops and livestock.

In semi-arid climates, it is common to find higher soil organic matter and nutrient content under tree canopies than in adjacent open land.

The **service functions of trees** include improving soil fertility, conserving soil moisture and improving the micro-climate, resulting in **increased crop yields**.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Effects of trees on soils

The best trees for agroforestry

- The best trees to grow with crops are **those with deep roots,** so they do not compete with crops for water and nutrients.
- They should **allow light to penetrate through their leaves** to allow crops to grow.
- They should **survive regular pruning** and cutting back.
- They should **add nutrients to the soil**.
- Their **leaves** should provide either **animal fodder or soil mulch**.
- They should have additional **uses that help the farm family**.

Photo credit: Dr. Milad El Riachy

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Nitrogen fixation and nutrient cycling

Nitrogen fixing trees can substantially increase nitrogen inputs in agroforestry systems.

Agroforestry systems are commonly credited with more efficient nutrient cycling than many other systems because of the presence of woody perennials in the system. These **woody perennials theoretically have more extensive and deeper root systems and have the potential to capture and recycle a larger quantity of nutrients.** Their litter contribution to the soil surface is also greater than that of herbaceous plants.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility
Nitrogen fixation and nutrient cycling

About 20 to 30% of the total living biomass of trees is in their roots. There is a **constant addition of organic matter to the soil through dead and decaying roots.**

The deep rooting ability of trees helps trees absorb nutrients from the soil depths that crop roots cannot reach, and then recycle them to the surface soil layers through the addition of litter.

Photo credit: Dr. Peter Moubarak

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility – nutrient buildup

- Higher total content of Nitrogen in top-soil (0-15 cm)
- Narrow C:N ratio
- More retrieval of exchangeable Ca, Mg, K and available P in agroforestry system in the subsurface through roots and recycled litter

C: Carbon
N: Nitrogen

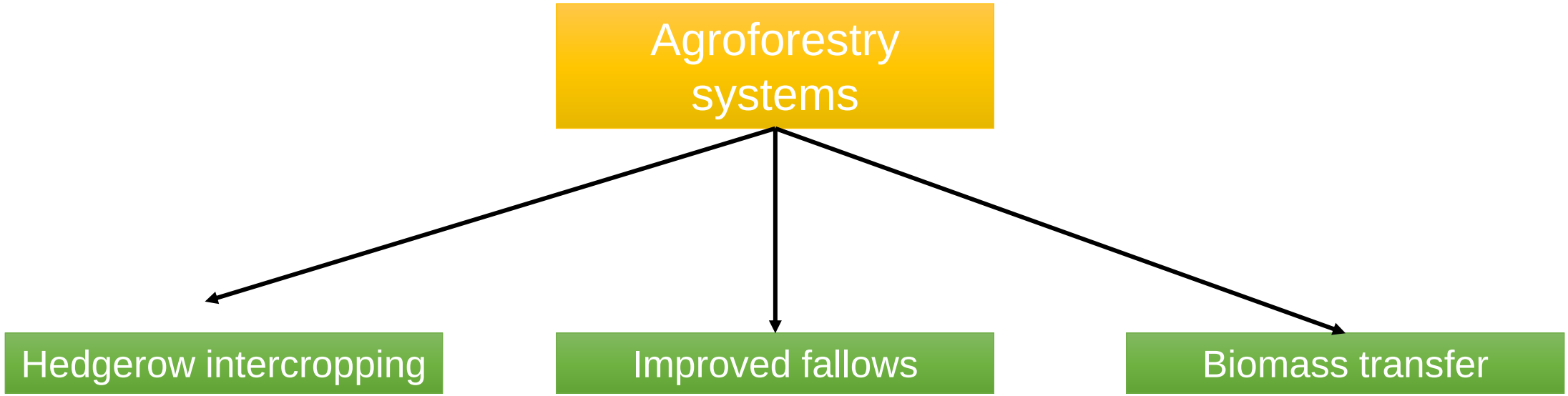
Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

LIVINGAGRO

3. Agroforestry for maintenance of soil fertility

Commonly used systems

In the following slides, we evaluate three different agroforestry systems which include **trees grown** either **in spatial mixtures** or **in temporal sequences with crops.**



Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Commonly used systems:

Hedgerow intercropping

In hedgerow intercropping (or alley cropping), trees are grown in rows that form hedges. Crops are grown in the alleys between the hedges. Tree remnants obtained when pruning during the cropping period can be shredded, then added to the soil to serve as green manure.

Hedgerow intercropping will be most successful under the following conditions:

- ✓ Soils of moderate pH (greater than 5.5) to promote nutrient recycling
- ✓ Declining soil fertility (recognized as a serious problem by farmers)
- ✓ Scarcity of trees in the landscape (creating an interest in tree products)
- ✓ Well adapted tree species for high biomass production
- ✓ Timely pruning, efficient utilization of prunings, and sustained hedge growth

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Commonly used systems:

Improved fallow

Trees are a component of naturally regenerating fallows in many traditional shifting cultivation systems. Farmers in many humid tropical regions have recognized certain tree species as being associated with improved soil fertility and therefore deliberately promote such species in fallows.

With increasing population pressure, the inevitable need to shorten the fallow period and increase cropping intensity has been well recognized. Because of this, a concept of improved fallows is now being pursued which involves planting fast-growing, nitrogen-fixing, and deep-rooting trees to enhance and maintain soil fertility over a shorter span of time.

Unlike spatial mixtures such as hedgerow intercropping, there is no competition between the tree and the crop component in improved fallow systems (except between adjacent fallow and cropland, which could be important on small farms), as they follow one another in temporal sequence.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

3. Agroforestry for maintenance of soil fertility

Commonly used systems:

Biomass transfer

- The transfer of tree or shrub biomass from distant areas to food crop production fields to maintain soil fertility and crop yields is a well-known practice in certain countries.
- Farmers use plant litter directly as green manure, or they dry and store it for later use, especially if the material is collected during the noncropping period, when the demand for labor is low.
- Several factors affect the response of crops to the application of transferred biomass, including the chemical composition of the litter of different species and the method and timing of application.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

4. Agroforestry for controlling soil erosion

Soil conservation

- Different agroforestry systems have the potential to aid in **soil conservation**.
- These include
  - ✓ **barrier hedges** planted on the contour
  - ✓ **tree/shrub combinations** to stabilize existing conservation structures
  - ✓ **multistrata systems** that simulate natural forests and woodlands
- Linear plantings of trees as windbreaks have shown considerable potential to reduce wind erosion, but they fall outside the scope of this review.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

4. Agroforestry for controlling soil erosion

Soil conservation

Barrier hedges

- Barrier hedges planted on the contour line have been widely evaluated. Optimum spacing between hedges depends on the degree of slope, but within-hedge spacing is commonly between 10 and 25 cm.

- Hedges are pruned frequently to minimize competition effects with adjacent crops in a similar manner to hedgerow intercropping.

- Since erosion control is the principal objective, hedgerow prunings are usually applied as a surface mulch to provide added soil protection, a factor which can be critical during the early growth stages of crops.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

4. Agroforestry for controlling soil erosion

Soil conservation

Barrier hedges

The use of barrier hedges involves several mechanisms for soil protection and erosion control. More specifically:

- Hedgerows are semipermeable, allowing the disposal of excess water without ponding and stagnation
- Hedge roots stabilize terraces as they form and improve infiltration rates in the area immediately adjacent to the hedge
- Surface mulch, when applied, reduces rainfall impact and soil erodability, improves soil fertility and soil physical conditions, and conserves moisture by reducing soil evaporative loss during early crop growth.

In conclusion, barrier hedges have proven to be effective in controlling soil erosion on gentle to moderate slopes.

4. Agroforestry for controlling soil erosion

Soil conservation

Trees and Shrubs on Conservation Structures

- Where conservation structures such as earth bunds (ridges or embankments), terraces, or conservation grass strips are already in place, trees and shrubs can play an important role in both stabilizing such structures and increasing the diversity of output from this potential farm niche through the production of fodder, wood, or fruit. Although such niches usually occupy only a small proportion of the land area, they are often fertile due to the accumulation of nutrient-rich soil from terrace washing.

- To fully exploit the productivity of conservation structures, farmers' priorities must be assessed, and potential markets for high-value products ascertained, before trees are selected. In order to identify appropriate tree species, spacing and establishment techniques must also be considered.

- In conclusion, high-value trees and shrubs have an important role to play in both stabilizing conservation structures and increasing their productivity and the diversity of their output. However, this will almost always be at some cost in terms of reduced productivity of associated crops.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

4. Agroforestry for controlling soil erosion

Soil conservation

Multistrata systems

“Project Drawdown defines multistrata agroforestry as a perennial cropping system featuring multiple layers of trees and other perennial crops, with high biosequestration impacts. The system is characterized by having an overstory of taller trees and an understory of one or multiple layers of crops growing in some degree of shade. Their structure and function are similar to those of natural forests, though some are much more simplified” (https://drawdown.org/solutions/multistrata-agroforestry/technical-summary).

Multistrata agroforestry systems have evolved primarily to generate income and provide and diversify basic family food needs. Because of their structural resemblance to secondary forests, they exhibit a profound capacity to prevent soil erosion.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

5. Agroforestry for carbon sequestration

- Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, vegetation, or soils) through physical or biological processes.

- The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture. In addition to the significant amount of carbon stored in aboveground biomass, agroforestry systems can also store carbon underground.

- Carbon sequestered in agroforestry systems could be sold in carbon credit markets where such opportunities exist. The largest amount and most permanent form of carbon may be sequestered by increasing the rotation age of trees and/or shrubs and by manufacturing durable products from them upon harvesting.

The rotation age can be defined as the planned number of years between the establishment or regeneration of a tree crop or stand and its final cutting at a specified stage of maturity.

https://www.tariffnumber.com/info/abbreviations/3495

5. Agroforestry for carbon sequestration

- The potential of agroforestry systems to sequester carbon varies depending upon the type of system, species composition, age of component species, geographic location, environmental factors, and management practices.

- Considering the large extent of degraded croplands and pasturelands and the potential to improve them using agroforestry, there is enormous potential to sequester additional carbon in such systems. Compared to degraded systems, agroforestry may hold more carbon.

- Soil organisms are the key engineers in nutrient turnover, organic matter transformation, and the physical architecture of soil structure. The microbial biomass includes both primary and secondary decomposers, represents an important component in the cycling of nutrients in soil, and governs the breakdown of organic matter and the availability of nutrients, particularly nitrogen mineralization, which is indirectly linked to soil conservation.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

5. Agroforestry for carbon sequestration

- In agroforestry systems, the largest concentration of microbes is usually on the soil surface. The dense network of fine roots of trees, with its capacity for abundant mycorrhizal association, increases the availability of nutrients for the understory crops (crops grown beneath trees), as well as increasing the population of microarthropods.

A mycorrhiza is a symbiotic association between a fungus and a plant.

- On the other hand, when a single crop is cultivated, soil degradation due to physical disturbances associated with cultivation, depletion of organic matter, reduced floral diversity, and absence of plant cover for part of the year lead to a reduction of the population of beneficial soil microarthropods.

- Soil and crop techniques employed in agroforestry are believed to favor and enhance the activity of soil fauna, which improves the rates of soil turnover, mineralization and humification of soil organic matter, soil texture and consistency, porosity, infiltration rate and soil-water retention characteristics. This means healthier soil and healthier crops.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

6. Water conservation through Agroforestry
Improving soil water quality

- Agroforestry practices are also proven to help provide clean water. In conventional agricultural systems, less than half of the nitrogen (N) and phosphorous fertilizer applied is taken up by crops. Consequently, excess fertilizer is washed away from agricultural fields via surface runoff, or it leaches into the subsurface water supply, contaminating water sources and decreasing water quality. For example, agricultural surface runoff can result in excess sediment, nutrient, and pesticide delivery to receiving water bodies and is a major contributor to eutrophication (Eutrophication is the process by which an entire body of water, or parts of it, becomes progressively enriched with minerals and nutrients, particularly nitrogen and phosphorus.).
- Agroforestry systems such as riparian buffers (an area adjacent to a stream, lake, or wetland that contains a combination of trees, shrubs, and/or other perennial plants) help clean runoff water by reducing the velocity of runoff, thereby promoting infiltration, sediment deposition, and nutrient retention. Riparian buffers have been proposed as a means to combat non-point source pollution from agricultural fields. Buffers also reduce nutrient movement into ground water by taking up the excess nutrients.
- Trees with deep rooting systems in agroforestry systems can also improve ground water quality, serving as a “safety net” by capturing nutrients.

6. Water conservation through Agroforestry
Improving soil water quality

- The establishment of perennial vegetative buffers along water bodies and upland areas can reduce nutrient losses from row crop and grazing practices and store those nutrients in the crop areas.
- A four-zone buffer system can consist of fast-growing trees next to a water body, slow-growing trees away from the water body in the second zone, shrubs in the third zone and grasses in the fourth zone. Grasses and shrubs help reduce water flow rate and enhance sedimentation. Sediment-bound nutrients are deposited on the soil surface, while the roots of the perennial vegetation use nutrients from the lower soil horizons. Because of their position, riparian zones effectively remove nutrients from the surface and subsurface water flow before surface, subsurface, and ground water enters water bodies. Riparian vegetation intercepts soil solutions as they pass through the rooting zone prior to entering the water bodies.
- The agroforestry buffers enrich the soil with nutrients and improve soil properties in these buffers and in adjacent areas, thereby improving the condition of the land.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

7. Practices used in combination with agroforestry systems for soil and water conservation

- In a semi-arid environment, limited and concentrated precipitation, together with high evapotranspiration, make imperative the use of water conservation strategies to prevent soil erosion and keep the humidity level at an optimum for agricultural crops.

- A number of strategies that are applicable to semiarid agricultural systems could be implemented. These include
  - row diking
  - conservation tillage
  - strip cropping
  - live barriers
  - terraces

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

7. Practices used in combination with agroforestry systems for soil and water conservation

- In row diking, small catchments or depressions store water so it seeps into the soil before it can drain or evaporate. Compared with conventional tillage, row diking has been reported to yield up to 270% increases in corn and bean production in semiarid environments.
- Non-tillage agriculture in semiarid conditions has been shown to increase and maintain soil humidity, structure, and fertility, resulting in an income up to 74% higher than with common tillage.
- Strip cropping is recommended to cultivate land slopes of 2-15%. Alternating and variable width stripes are used to avoid water/wind erosion, generally along with a crop rotation program.
- The use of terraces is also recommended as an option for moisture retention on slopes in areas of low precipitation.
- Trees can be used as living barriers when forming terraces on steep slopes; in areas with low slopes, trees can be planted at the edges.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

7. Practices used in combination with agroforestry systems for soil and water conservation

Suggested combinations

On land with a low slope

- Tree species at the edges for fruit, fodder, vegetable and wood production
- Associated crops in the middle (at normal density)
- Practices such as row diking and conservation tillage (minimal tillage)

On land with a steep slope

- Forest species forming contour lines and hedgerows
- Associated crops in the middle
- Practices such as strip cropping, row diking and non-tillage

Photo credit: Dr. Peter Moubarak

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

8. Conclusion

Agroforestry is a sustainable land use system that can play a vital role in conserving soil and water.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

9. References

- Ram et al., 2017. Reactive Nitrogen in Agroforestry Systems of India. Chapter 14 in The Indian Nitrogen Assessment. http://dx.doi.org/10.1016/B978-0-12-811836-8.00014-8 207.
- Oros B., 2016. Agroforestry systems and water conservation techniques focused in semiarid areas of Guanajuato, México. Department of plant and environmental sciences.
- Wolde Z., 2015. The role of agroforestry in soil and water conservation. Lambert academic publishing. https://www.researchgate.net/publication/305032193.
- Seiter, S., William, R.D., Hibbs, D.E., 1999. Crop yield and tree-leaf production in three planting patterns of temperate-zone alley cropping in Oregon, USA. Agroforest. Syst. 46, 273–288.

Course co-funded by the EU under the ENI CBC Med Programme and developed in the framework of LIVINGAGRO project activity 3.1.8

9. References

- Udawatta, R.P., Kremer, R.J., Garrett, H.E., Anderson, S.H., 2009. Soil enzyme activities and physical properties in a watershed managed under agroforestry and row-crop system. Agric. Ecosyst. Environ. 131, 98–104.

- Naiman, R.J., Decamps, H., McClain, M.E., 2005. Conservation restoration. In Naiman, R.J. (Ed.), Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier, New York, 269–325.

- Udawatta R.P., Gantzer C.J., Jose S., 2017. Agroforestry Practices and Soil Ecosystem Services. Chapter 14. In Soil Health and Intensification of Agroecosystems. DOI: http://dx.doi.org/10.1016/B978-0-12-805317-1.00014-2. Elsevier Inc.

- Cooper, P.J.M., Leakey, R.R.B., Rao, M.R., Reynolds, L., 1996. Agroforestry and the Mitigation of Land Degradation in the Humid and Sub-Humid Tropics of Africa. Experimental Agriculture, 32, 235-290.

This publication has been produced with the financial assistance of the European Union under the ENI CBC Mediterranean Sea Basin Programme. The contents of this document are the sole responsibility of the Lebanese Agricultural Research Institute (PP3-LARI) and can under no circumstances be regarded as reflecting the position of the European Union or Programme management structures.