



Agroforestry folder for farmers and advisors

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AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This [Deliverable 9.30 \(9.6\)](#) contributes to the fourth objective. It describes the creation of dissemination material providing guidance on agroforestry innovation and agroforestry best practices in a user-friendly format for farmers and advisors.

2 Brief description of the agroforestry innovation leaflets

A total of 46 “Agroforestry Innovation leaflets” and 10 “Agroforestry Best Practice” leaflets have been produced and presented with other innovation and best practice leaflets in a folder (Balaguer et al. 2017) (Figure 1; Table 1).

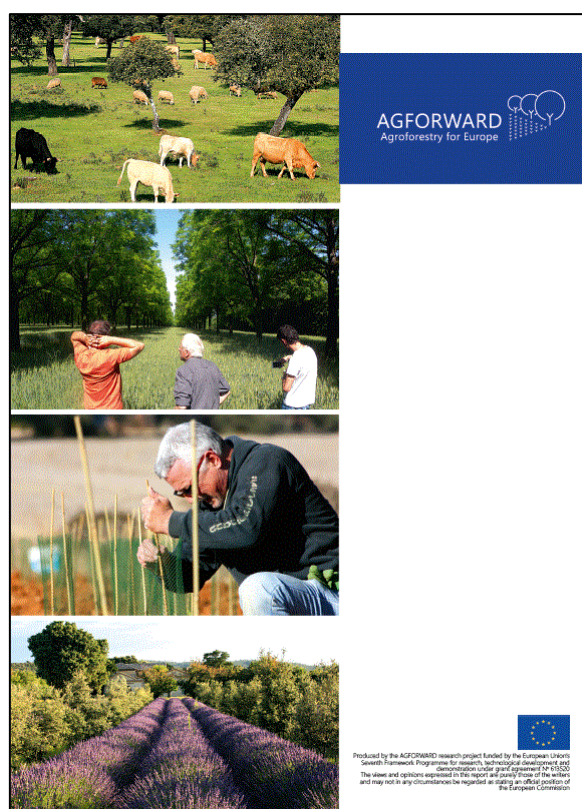


Figure 1. The folder included 46 innovation leaflets and 10 best practice leaflets (Balaguer et al. 2017)

Table 1. Titles and authors of the 46 Agroforestry Innovation leaflets (See Annex A for references)

No	Title for Agroforestry Innovation leaflet	Author
1	Establishing pastures rich in legumes	Hernández-Esteban and Moreno (2017)
2	Triticale in Iberian dehesas	Santamaría et al. (2017)
3	Fast rotational intensive grazing	Catalán et al. (2017)
4	Tree regeneration in grazed wood pastures	Cáceres et al. (2017)
5	Managing shrub encroachment in cork oak montado	Paulo et al. (2017)
6	Modelling livestock carrying capacity in montados	Palma et al. (2017)
7	Rediscovering valonia oak acorns	Papadopoulos (2017)
8	Shade tolerant legumes.	Franca et al. (2017)
9	Multi-functional hedgerows in the bocage systems of France	Thenail et al. (2017)
10	Invisible fencing in wood pastures	Burgess et al. (2017a)
11	Trees and the restoration of waterways in the Spreewald floodplain	Tsonkova and Mirck (2017)
12	Restoration of abandoned wood pasture	Varga (2017)
13	Protecting large old trees in wood-pastures	Hartel (2017a)
14	Grazing and biodiversity in Transylvanian wood-pastures	Hartel (2017b)
15	Enhancing reindeer husbandry in boreal Sweden.	Berg et al. (2017)
16	Grazing sheep under walnut trees	Moreno and Lopez (2017)
17	Protecting trees in chestnut stands grazed with Celtic pigs	Mosquera Losada et al. (2017)
18	New approaches to producing selected varieties of chestnut	Fernandez-Lorenzo et al. (2017)
19	Wild asparagus in olive orchards	Rosati (2017)
20	Olive trees intercropped with chickpeas	Pantera (2017a)
21	Olive trees intercropped with cereals and legumes	Mantzanas (2017)
22	Orange trees intercropped with legumes	Pantera 2017b
23	Apple orchards grazed in France	Corroyer (2017)
24	Economic benefits of grazed apple orchards in England	Burgess et al. (2017b)
25	Key challenges of orchard grazing	McAdam (2017)
26	Farming with pollards	Colin et al. (2017)
27	Cropping cereals among timber trees	Moreno and Arenas (2017)
28	Productivity and quality of maize under cherry trees	Feirreiro-Dominguez et al. (2017)
29	Intercropping medicinal plants under cherry timber trees	Mosquera Losada et al. (2017)
30	Organic crops in olive orchards	Panozzo and Desclaux (2017)
31	Understorey management in alley cropping systems in France	Mézière et al. (2017)
32	Hybrid poplar and oak along drainage ditches	Paris and Dalla Valle (2017)
33	Walnut and cherry trees with cereals in Greece	Mantzanas (2017)
34	Agroforestry and decentralised food and energy production	Wolfe (2017)
35	Trees and crops: making the most of the space	Westaway and Smith (2017)
36	Yield and climate change adaptation using alley cropping	Mirck (2017)
37	Agroforestry with standard fruit trees in Switzerland	Jäger and Herzog (2017)
38	Weed suppression in alley cropping in Hungary	Vityi et al. (2017)
39	Commercial apple orchards in poultry free-range areas	Bestman and Timmermans (2017)
40	Silvopoultry: establishing a sward under the trees	Westaway (2017)
41	Lactating sows integrated with energy crops	Kongsted et al. (2017)
42	Pigs and poplars	Bondesan (2017)
43	Mulberry (<i>Morus</i> spp.) for livestock feeding	Mosquera-Losada et al. (2017)
44	Fodder trees for micronutrient supply in grass-based dairy systems	Luske et al. (2017)
45	Fodder trees on dairy farms	Novak (2017)
46	Combining organic livestock and bioenergy production	Smith (2017)

The contents of the Agroforestry Innovation leaflets have been summarised in four reports which form deliverables for the AGFORWARD project: one focused on agroforestry of high nature and cultural value (Moreno et al. 2018), one on agroforestry for high value tree systems (Pantera et al. 2018), one on agroforestry for arable systems (Kanzler et al. 2018), and one on agroforestry for livestock systems (Hermansen et al. 2018). Because these results have already been summarised (Table 2), they are not repeated here.

Table 2. Titles and references of four reports summarising the contents of the innovation leaflets

Title	Reference
Agroforestry of high nature and cultural value: guidelines for farmers	Moreno et al. (2018)
Agroforestry for high value tree systems: guidelines for farmers	Pantera et al. (2018)
Agroforestry for arable farmers: guidelines	Kanzler et al. (2018)
Guidelines for improved agroforestry systems for livestock production	Hermansen et al. (2018)

3 Brief description of the best practice leaflets

The AGFORWARD project also produced a series of best practice leaflets to provide guidance to farmers on how to plan, create and manage an agroforestry system. The leaflets were produced by Philippe Van Lerberghe from the Institute of Forestry Development (IDF) in France. The leaflets were reviewed by various member of the AGFORWARD team with particular support provided by Tim Pagella (World Agroforestry Centre) and Fabien Balaguer (French Agroforestry Association; AFAF).

Leaflet 1 of the best practice leaflet series focuses on the objectives for developing an agroforestry system, using alley cropping as an example (Table 3). Leaflets 2 to 4 focus on site selection, the selection of tree species and planting material, and planning the layout and spacing of the trees. Leaflets 5 to 9 cover tree protection, land preparation, and tree planting. Lastly, Leaflet 10 covers tree pruning and management to maximise revenue.

Table 3. Titles and reference for the 10 Agroforestry Best Practice leaflets (See Annex B for references)

Number	Title	Reference
01	Alley cropping systems: key objectives	Van Lerberghe (2017a)
02	Analysing the site and choosing tree species	Van Lerberghe (2017b)
03	Choosing quality-planting material	Van Lerberghe (2017c)
04	Planning an agroforestry project	Van Lerberghe (2017d)
05	Protecting trees against wildlife damage: assessing the options	Van Lerberghe (2017e)
06	Preparing the land	Van Lerberghe (2017f)
07	Planting the trees	Van Lerberghe (2017g)
08	Fitting tree protection to prevent deer damage	Van Lerberghe (2017h)
09	Mulching for healthy tree seedling	Van Lerberghe (2017i)
10	Shaping the trees	Van Lerberghe (2017j)

4 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

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Annex B: References for “Agroforestry Best Practice” leaflets

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- Van Lerberghe P (2017j). Agroforestry Best Practice leaflet 10: Shaping the trees. AGFORWARD project. 4 pp. <http://www.agforward.eu/index.php/en/best-practices-leaflets.html>

Annex C: The “Agroforestry Best Practice” leaflets

- Agroforestry Best Practice leaflet 01: Alley cropping systems: key objectives (Van Lerberghe 2017a).
- Agroforestry Best Practice leaflet 02: Analysing the site and choosing tree species (Van Lerberghe 2017b).
- Agroforestry Best Practice leaflet 03: Choosing quality planting material (Van Lerberghe 2017c).
- Agroforestry Best Practice leaflet 04: Planning an agroforestry project (Van Lerberghe 2017d).
- Agroforestry Best Practice leaflet 05: Protecting trees against wildlife damage (Van Lerberghe 2017e).
- Agroforestry Best Practice leaflet 06: Preparing the land (Van Lerberghe 2017f).
- Agroforestry Best Practice leaflet 07: Planting the trees (Van Lerberghe 2017g).
- Agroforestry Best Practice leaflet 08: Fitting tree protection to prevent deer damage (Van Lerberghe 2017h).
- Agroforestry Best Practice leaflet 09: Mulching for healthy tree seedlings (Van Lerberghe 2017i).
- Agroforestry best Practice leaflet 10: Shaping the trees (Van Lerberghe 2017j).



Alley cropping systems: key objectives

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In an alley cropping system, trees are multi-functional: the aim is to provide a range of ecosystem services alongside wood and fruits. These include shelter for crops, host beneficial organisms, increase soil fertility and carbon storage, mitigate climate change, and provide protection against soil erosion.

Alley cropping systems seek to increase the productivity and profitability of the farming system and help create resilient landscapes.

Developing alley cropping systems needs careful thought in terms of motivations and constraints for adoption and thinking carefully about the goals and information needed to achieve success.

Introducing trees into arable systems results in long term land use change (generally between 20-80 years). Care should be taken to ensure that the initial diagnostics and technical planning are appropriate to ensure success.



Planting the right tree at the right place



A planting density of 50-100 trees per hectare is often recommended when talking about timber trees (*Arbre et paysage* 32)

How to combine trees and crops?

Alley cropping systems are a way of combining crop and tree production on the same plot, with both an economic and environmental objective. Generally they consist of:

- Tree rows (usually a mix of valuable hardwood species) established on cropland.
- Interstitial space between the trees is cropped with a range of species: cereals (for example, wheat, corn, barley), oilseed/protein crops (rapeseed, soya, faba beans, lupin, vetch, peas, sunflower), vegetables or vines.
- This type of system maintains the agricultural potential whilst generating new incomes, which makes it an appropriate option even on high-value agricultural lands.
- Tree rows are arranged in wide spaced parallel lines (28 to 40 m) in order to limit competition for light with agricultural crops and to allow mechanization of farm operations. Trees are established on grass strips of at least 2 m width, which allows cultivation up to 1 m from the trunk on both sides.
- With only 5 % of the area occupied by the rows (tree density changes from 50-250/ha initially to 30-50/ha in mature systems) the loss of crop productivity is low and the production of quality timber can provide substantial extra income over time.
- The large spacing between trees accelerates their radial growth. They develop larger crowns but, due to low density, they do not compete with each other (the average distance between two trees is 6 to 8 m).

In order to produce high quality timber on an alley cropping system, it is necessary to 1) plant the right tree stock, 2) protect each tree from game, 3) mulch the trees and 4) carry out planned pruning operations.

Why plant trees?

Trees protect soil against erosion and improve soil fertility. Intercropped trees develop deeper root systems and, as such, are more resistant to drought and strong winds. Trees also preserve groundwater quality by limiting the water-pollution caused by nitrate leaching and help decrease water runoff by improving water infiltration in soil. Trees store carbon in their wood and in the soil.



A great cultivated plain without trees... Land desertification on the way? (*Arbre et Paysage 32*)



Autumn rains on bare ground: water degrades the soil... and the soil degrades the water (*Arbre et Paysage 32*)



Trees can generate income for farmers



The buffer strip established on the planting line is a refuge for the crop beneficial organisms and a biodiversity tank

Trees diversify landscapes and stimulate biodiversity, especially when associated to a grass strip: usually present mainly on field boundaries, bird populations and beneficial insects are brought closer to the crops, at the centre of the field. The diversification of habitats also improves the game potential.

Maintain farm income

An agroforestry system generates continued income unlike forest plantations. This allows diversification of farm activities that maintain or increase its capital value without significantly decreasing the current income. High value crops can be intercropped until tree harvest if the final tree density is maintained between 40 and 80 trees/ha and if tree line spacing is at least equal to 2 times the adult trees height.

Strengths of the system

Profitable: researchers use the Land Equivalent Ratio (LER) to evaluate the productivity of alley cropping systems; essentially exploring the efficiency of the tree-crop association in different systems. The ratio compares the areas of monocrop systems with those that integrate trees to produce equal yields of biomass.

An LER above 1 means that the productivity of the agroforestry system is higher than the separate crop and tree systems. A large number of studies show LERs of between 1.2 and 1.6 for alley cropping systems. More concretely, an LER of 1.3 means that a 100 ha agroforestry farm will produce as much wood and grains as a 130 ha farm growing trees and crops separately.

Suitable for tenant farming: agroforestry plots are considered agricultural plots. The owner has the right to plant and let the farmer use the land. If the tenant wants to plant during the lease period, he/she must obtain a signed agreement from the owner. A contract specifies the responsibilities of each party and can include a way of eventually sharing between them the value added to the land.

Encouraged by public authorities: alley cropping systems are, under the right conditions, eligible to the support payments under the Common Agricultural Policy (CAP). Additional support mechanisms for agroforestry are available to farmers in several European regions. Under Measure 8.2 from the Rural Development Programme 2015-2020 it is possible to finance the costs of tree establishment and, in some cases, to tree monitoring over the first few years. The trees species must be largely forest species and planted at a maximum density of 250 trees/ha.

Adaptable and reversible: trees on farms have to be considered an additional crop, and managed in such a way that the whole system can evolve and adapt to its changing environment. After the main objectives of the agroforestry project have been defined, trees can be planted regularly over a 10-15 years period.

Monitoring strategy and harvest cycles will be determined according to the farmer's constraints and opportunities. After harvesting trees for timber, the stumps can be easily grubbed out using a shovel crawler or crushing jaws mounted on an excavator.



Planting trees in row arrangements makes field operations easier



Correct pruning ensures high-quality timber production – see the large and regular tree rings and absence of knots



Pollards can produce between 1 and 4 m³ of fuelwood per harvest

Making money with trees

Well selected agroforestry trees grow faster and more regularly than forest trees when selected carefully and planted in the appropriate location and managed well. A diversity of tree species are available such as wild cherry, maples, ashes, walnuts, oaks, service tree, apple, pear, etc.). Agroforestry trees are stimulated by crops and co-benefit from fertilisers and irrigation.



Training days are a powerful way of finding about the benefits of agroforestry systems

Think before acting

Short- and medium-term objectives

An analysis of the project has to be done before planting. The farmer should prioritize the possible roles played by the trees in the system and the expected productions in various types of system:

- **Sustainable ecological farming:** the main aim is for the trees to provide regulating benefits. The trees protect the soil against the erosion, improve water quality by intercepting pesticides, moderate local climate and for improving biodiversity.
- **Crop diversification:** trees provide products (hardwood, fuelwood, fruits, honey, cork) that increase the farm profitability while diversifying its activities and outcome sources.
- **Heritage and capital creation:** the trees will generate an additional income for the next generation or during retirement. If possible farmers should include the next generation into the planning process to ensure the continuity of tree management.
- **Tourism and societal-related value:** trees have a positive impact on landscapes, which enhance the value of the rural countryside and the attractiveness of the farm.

Human constraints

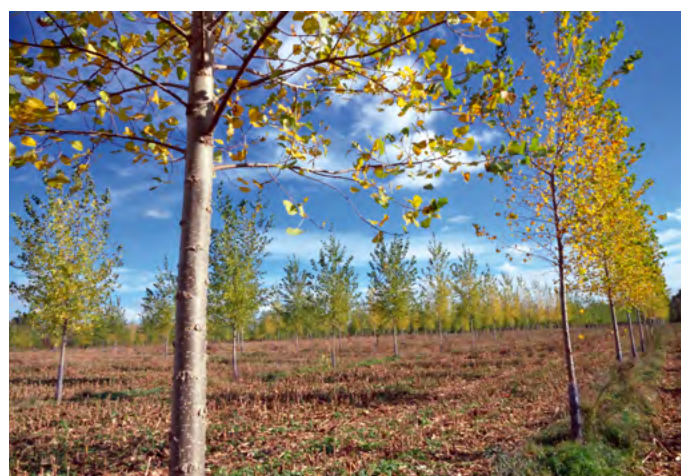
Appropriate training is important to get the most out of the different types of agroforestry system. It is essential to anticipate the time required and the level of monitoring required.

The human and financial investments are not limited to establishment. Tree management continues over the 10-15 years after planting and these need to be incorporated carefully into the management plans.

Environmental constraints

Land preparation is important before establishment. The previous crop can affect the development of the young trees. Unlike unmanaged land cultivated plots are generally easy to plant.

An environmental analysis (considering both climatic conditions and soil) is critical and should be conducted with an agroforestry expert. The ground has to be prepared by subsoiling to a depth of more than 30 cm, especially if a plough pan is present. Additionally, any game pressure has to be evaluated and steps taken to mitigate any potential damage.



Poplar is a fast growing specie providing income within 20 years

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Analysing the site and choosing tree species

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Not every tree will be suitable for a given area of agricultural land. An important first step is to conduct a biophysical assessment to identify the potential suitability of a site for agroforestry.

This should include a detailed analysis of the environmental conditions (climate, soil, topography, surrounding vegetation and game presence) carried out with a technical advisor familiar with the project area. This enables the best choice of tree species and identifies the best soil preparation possible before planting.

Investing in unsuitable tree species is likely to lead to low tree growth (vigor and productivity loss), sanitary problems and potentially dieback - all of which will reduce return from investment.



Using an auger to collect soil cores as part of an agroforestry assessment (Ph. Gaudry – CNPF)



Looking at remainders of hydromorphy in a wet soil is essential (S. Gaudin - CNPF)

Meeting the needs of trees

As with crops, **tree species have specific ecological requirements** in relation to the soil (rooting depth, acidity, water holding capacity, etc.), climate (average temperature, rainfall requirements, tolerance of exposure to frost or droughts) and topography (wind and sunlight exposure, slope). Understanding and meeting these requirements is essential for successful establishment.

These variables can often change over the area of the farm. **Being aware of your chosen trees species requirements and identifying the climate and soil limiting factors** across the farm are important to enable **the best growth conditions possible for the selected trees**.

Environmental factors

Temperature and rainfall are the two critical variables that strongly influence trees growth.

Air temperature moderates trees' biochemical reactions and is important in some life stages (germination, budburst and bud development, flowering, fruits and seeds maturation). Rapid increases or decreases can cause the death of the tree. Therefore, it is important to assess the occurrence of frost (in winter or in spring) and droughts risks.

Rainfall is important for trees metabolism and regeneration. Trees can be big water users and some species are vulnerable to intense droughts. Too much water may also lead to tree death or slow growth when the roots suffocate due to a lack of oxygen in the soil.

Potential evapotranspiration is the evaporative power of the atmosphere, which is important for understanding **the water balance**. If the water balance is negative then this indicates a depletion of soil water reserves. When it is positive, we are seeing a recharge of groundwater. Trees can impact on the water balance.

Why call an agroforestry advisor?

An agroforestry advisor helps farmers to undertake their development projects. Their role consists of:

- identifying farmer's goals, needs and technical skills;
- identifying regulatory issues, fiscal policy and potential grant schemes that will influence farmer choices around implementation and maintenance of their agroforestry schemes;
- producing a diagnosis about the bio-physical characteristics of the plot to determine the potential for agroforestry;
- assisting with the development of agroforestry schemes with the farmer.

In a practical way, he is able to:

- identify suitable locations;
- propose a list of trees species and assist with the planting design;
- identify potential problems and propose solutions;
- advise on ground preparation and materials for maintenance and tree protection;
- teach farmers tree pruning techniques.

For the visit of the advisor, the farmer can help by:

- gathering the deeds for the farms (to confirm ownership);
- identify potentially suitable locations areas;
- dig soil observation pits.



The advisor is at the service of the farmer and gives him agronomical and agroforestry knowledge (B. Petit – CNPF)

Farmers have to take into account the topography of fields, which strongly modifies the effects of the local climate on the surface of the soil. South facing hillsides are sunnier and are often warmer and drier than fields with northerly aspects. Similarly cold air is more likely to accumulate in valley bottoms and frosts are more frequent in these areas.

The movement of water downslopes is another important factor to consider. Water travels downslope it will often bring soil with it (including soil minerals). As such up slope areas tend to have shallower drier soils and where the soil settles at the bottom of slopes we find both richer soils but also areas with wetter conditions (prone to water logging).



Last spring frosts can burn the newly formed leaves of oaks planted in valleys bottom (S. Gaudin – CNPF)



Overexposed sites can have a detrimental impact on tree architecture

Do trees and crops have different needs?

Trees generally require a deeper soils with a good water supply (i.e. wet soil conditions). However, soil with too much nitrogen can lead to a massive branching. Crops can be satisfied with a topsoil, about 30 to 40 cm deep and easy to work with (excluding for example a high content of flint or heavy clay).

Analysis of the soil

A number of soil attributes have a significant impact on tree root development. These include soil depth, the amount of stones present, soil type and texture (clay, silt and sand proportion) and potential for waterlogging. The factors need to be assessed prior to establishment to ensure successful planting. These factors can be assessed either by digging soil pits or by using augers.

Identify restricting factors

Shallow topsoil: the soil is a reservoir of water, nutrients and air. The deeper is the soil, the greater the availability of these three elements. A soil with a depth of 80 cm or more has good potential for tree growth. Shallower soils (>40 cm) are only suitable to certain trees species that are adapted to restricted conditions and with powerful rooting. In soils of less than 40 cm the potential for establishment is limited.

Dry soil: the risk of reduced water availability is greater on shallow porous soils (e.g. sandy soils, fissured lime stone, or stony soils), soils without any clay layer to retain water (i.e. low water holding capacity), or in conditions where groundwater is not easily accessible by the roots during summer. This risk is also greater on sloped fields, particularly those with southerly aspects.

Waterlogging: waterlogging creates anaerobic conditions and can reduce the tree rooting depth. All tree roots need oxygen to respire and the more extensive and shallower the waterlogging is, the greater the constraint on root development.

Excess water is traceable in the field through observation of the soil profile. A soil prone to temporary waterlogging (a pseudogley soil) will usually be dry and compact during summer and starved of oxygen during winter and spring; which is problematic for tree growth.

Waterlogging is characterized by the presence of a whitish-gray layer dotted with oxidized iron rust. A layer saturated with water all the time (a gley soil) is anaerobic and unavailable to all but the most flood tolerant tree species; gley soils are greenish-grey or bluish.



The presence of rust spots is characteristic of a temporary congested soil with water (S.Gaudin – CNPF)

Compact soil: compacted soils limit root development. The compactness of the soil can be estimated in the soil pit by assessing resistance to the pull of a pocket knife through the soil horizons. The soil is compact if, in the first 40 cm, a knife encounters resistance. Compaction will sometimes manifest as a single layer (for example, plow pans on soil with a silty-clayey or clayey texture which will be broken by subsoiling).

Calcareous soil: a big quantity of active limestone content in soil can block the uptake of other nutrients essential for trees. This can cause leaf discolouration, tree branches to dry out, or even tree mortality. The presence of limestone can be detected in the field by using a simple chemical test with diluted hydrochloric acid (looking for effervescence in the first 40 cm of soil).

Soil profile analysis

Digging a soil pit enables the technician to evaluate the physical and chemical properties of the soil. The deeper the soil pit, the more complete the soil observations. Ideally you will need a pit of 80-100 cm. Soil pits provide valuable information on the composition of the soil horizons; the homogeneous layers distinguished from each other by their color, texture and structure.

Choose the location: before launching an analysis, you have to dig the soil pit but not anywhere! You need to take into account topographic variations, soil color and your local knowledge to identify the appropriate location for the pit. Avoid idiosyncratic areas of the farm (such as localized depressions) and areas disturbed by human activity (roadsides or field edges where vehicles have left tire tracks).



Soil core samples are collected by auger from the surface down. The whole soil is reconstituted by juxtaposing the successive soil core samples



The soil pit enables a carefully observation of soil horizons and makes possible soil sampling for laboratory analysis, both chemical and physical

Auger: an auger is a useful tool to check how variable the soil is across the farm (and can help in seeing if more than one pit is required). This tool extracts a 20 cm soil core sample. However, many critical parameters cannot be evaluated with soil core samples alone (such as the structure and soil horizons, rootedness, abundance and empty spaces nature, etc.), all of which can be assessed with a soil pit.

Function of the soil pit: the main parameters to be evaluated are soil depth and horizon thickness, humidity, color, signs of waterlogging, fine earth texture, presence of coarse materials (like rocks, gravel...), structure and soil compactness, abundance of the roots, limestone presence, acidity (pH measure), type and distribution of organic matter in the soil, signs of biological and human activities. A soil analysis in laboratory can be done to supplement information gathered in the field.



On the field the soil acidity is measured with a colorimetric pH-meter. If the soil is too acidic, it will be more difficult for the trees to capture the minerals. A high pH value usually indicates the presence of active limestone content

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Choosing quality planting material

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The plant quality determines success in agroforestry establishment; particularly in relation to root development. Once the farmer has selected which tree species to use it is then important to select seedlings that are best suited to the farm conditions but also ensure that the seed stock is healthy (i.e. it comes without pests or diseases).

Ideally trees seedlings should be sourced from a certified supplier (even if there is capacity to produce seedlings direct from seeds on the farm). The forest seedlings quality is regulated from 2003 (directive 1999/105/CE) in the European Union. This regulation protects the buyers of seedlings.



Seedlings packing: seedling in container (1) bare-rooted seedlings (2) - IDF©CNPF



Pedunculate oak plants in rootballs

Origin of the seedlings

When the tree variety is decided care has to be taken to select seedlings from the appropriate **regions of provenance**. These are defined areas within which similar ecological and climatic characteristics are found. They provide a framework for specifying sources of Forest Reproductive Material (FRM). Seedlings must have **tags** which provide information on both the genetic quality of the seedlings and their requirements. The seedlings have to be conform with quality standards (health, shape, etc.). The main tree species used in agroforestry systems are covered by this policy.

Which region of origin?

Within any country there a defined area (based on ecological characteristics) where seeds are collected for sale – this determines the provenance of the seed. Seed from a specified **region of provenance** will be adapted to the broad climate conditions found in this region and is better adapted to local soil conditions. Using seed from outside of your area of provenance can result in poor tree growth. FOREMATIS - the Forest Reproductive Material Information System - provides a list of provenances adapted to each European region (and for specific tree species). It's necessary to use a regional origin for the one without alternatives documented. Securing the correct provenance will positively affect the future wood production (volume production between 10 and 30 %) and quality (straighter trunks, smaller and more manageable branches), the biological rhythm (early or late budburst, lowest frequency of head fork, better resistance to pests). A superior quality of the plant enables higher levels of establishment and reduced mortality rates.

Genetic quality

In the European Union, all Forest Reproductive Material (FRM) including seeds (fruits, cones), parts of seedlings (cuttings, grafts, roots and marcots) and seedling themselves allowed onto the market are divided into four **categories**. Every category provides information on the genetic quality.

The availability of material will vary with location but the **tags** enable you to make informed choices when purchasing.

Yellow tag – source-identified basic material: only one origin or region of provenance is known. The material is collected in non-appraised forests: seeds come from non-selected trees. The collection area is left to the judgement of the suppliers who have to inform the location and the collection date to the government services in case of control. Collecting seeds on isolated trees, hedges or band of trees for a forestry purpose is forbidden. The most common regulated species on the market are distributed in the yellow tag category.

Green tag – selected basic material: seeds are collected on seed-producing forest stands allocated to wood production and selected by the forestry organization in each region of provenance. Seeds are collected from vigorous trees with good shape and health. The green tag corresponds to the best forest stands in the origin region whose adaptation to the local conditions is recognized. Green tag seedlings do not have any genetic testing.

Pink tag – qualified basic material: seeds are coming from seed orchards; artificial forest stands implemented for high quality seed production. The superior quality of the seedlings has not been tested yet. The individual trees have been selected according to several criteria: vigor, shape, wood quality, disease resistance.

Blue tag – tested basic material: seedlings with a superior quality for at least one indicator (straightness, growth, wood quality, pest resistance, branching) and at least one specific use area. The quality is tested through a test of origin comparing these seedlings with indicator origins or through genetic evaluations. This tends to be the rarest category on the market.



Beech seeds

What type of plants are on the market?

- **Bare-rooted seedlings:** nurseries plant the seeds in open ground. After one or two years, the seedlings are transplanted to provide more space to the seedlings and to improve root development. For deciduous species the transplanting step can be replaced by uplifting the seedlings, using a sharp blade at 10-20 cm deep to cut the taproots and encourage root proliferation. Ready after 2 or 4 years, the seedlings are mechanically removed, sorted out by size and conditioned in bunches.
- **Seedlings in container or in rootballs:** these seedlings are planted and raised off ground in an individual container in plastic. The substrate is a mix of breeding soil and trace elements, well aerated to obtain a high porosity. The shape of the container limits roots windings. Seedlings are delivered in the container and taken out before planting with the substrate.
- **Cuttings:** a cutting from the branch or stem from certain tree species can be planted directly into the ground for rooting. Poplar and willows, for example, are difficult to reproduce by seed and are propagated using young cuttings of living branches or stump sprouts.



Sessile oak acorns (J. Rosa – CNPF)

Seedlings quality

The seedling quality is determined by the seedling's ability to survive and to grow up right from the first year after establishment. A poor-quality seedling will have few leaves, a high die-back or crown dieback and should be replaced.

The quality of seedlings can be broken down into two aspects (a) the **morphological quality** which is related to the seedling dimensions at the plantation date (i.e. height, stump diameter, volume of the roots) and (b) its **physiological quality** which is the capacity to extract water and nutritive elements in the soil and to create new roots after plantation. The physiological quality is determined by what happens to the plant between the delivery date to the plantation date (cf. Leaflet n°7).

Age and dimensions

Nursery catalogs will provide details on the **age**, minimum and maximum **height** and minimum stump **diameter** of the root. Where possible try and inspect the quality of the seedlings prior to purchase by visiting stockists (or by reading reviews). Where possible purchasing seedlings that meet the European quality **standards** tend to result in more secure purchases. In some cases national standards are even stricter and may be preferred. There are a simple set of rules for seedlings selection: select the seedlings as young as possible, ideally with a high regeneration capacity producing new roots after plantation, prefer the vigorous seedlings or with the latest subculturing date. If the height of the seedlings is the same, choose the youngest one.



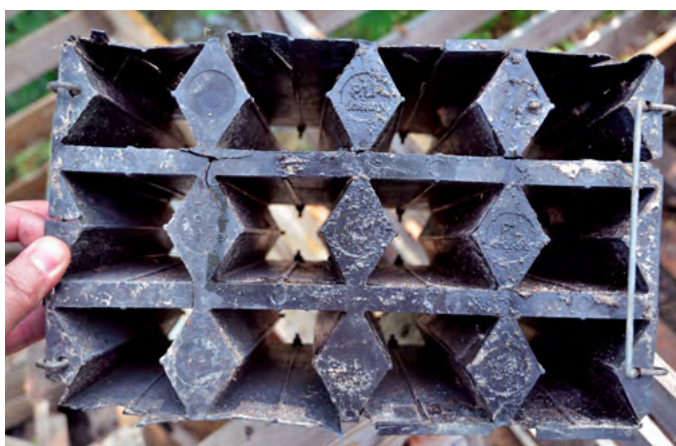
Bunches of bare-rooted seedlings from sessile oak



Crates of hazel seedlings in bucket



Bunches of poplar sets (F. Barbotin - CNPF)



The presence of rust spots is characteristic of a temporary congested soil with water (S.Gaudin - CNPF)



Sorbus torminalis seedlings in clod

Physical state

A farmer should not only look at the stem dimensions of the seedling but also look at the architecture of the root system, at the stem shape and at the balance between root volume and stem volume.

The seedlings capacity to overcome the “transplantation crisis” depends on root quality (abundance and how concentrated the roots are to the collar – see the associated figures here).

Naked-rooted seedlings with apparent defects should not be selected. Look for: a damaged collar, a weak root system, cases where the primary root is tightly wound or twisted, damaged or absent rootlets. Seedlings in bucket with wounded side roots or roots rooting in the wrong direction (i.e. upwards) should not be selected.



Norway maple with an abundant and compliant root system

The seedlings should have a smooth, straight and regular shaped stem without necrosis and cankers with a final bud in good condition. Do not purchase seedlings showing traces of fermentation, heat discoloration, with a stem with pronounced curvature or with a fork or a poor or absent branching, or moldy, dry or part-dry seedlings.



Norway maple with damaged collar: refused



Red oak with roots displaying a hunting horn shape: refused



Atlas cedar seedlings in bucket with upgoing roots: refused

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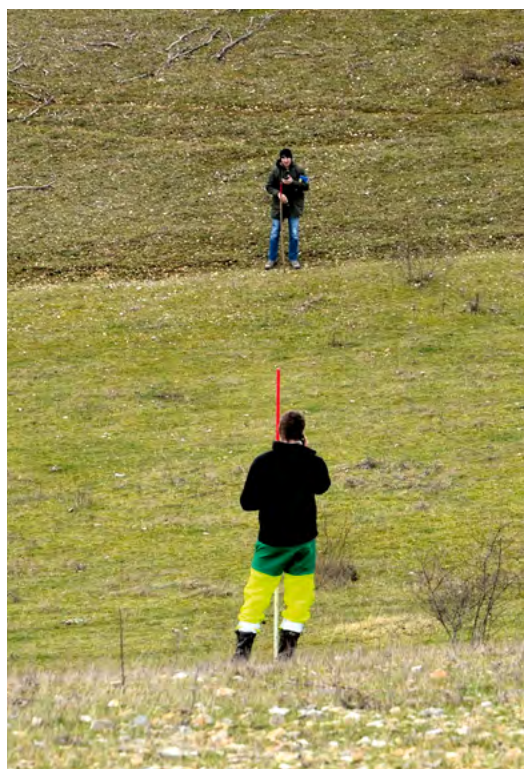
Planning an agroforestry project

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A lot of silvoarable systems exist, with a broad range of varying tree densities and tree spacings. Almost all combinations are viable if the appropriate tree species and the crops are selected to match the environmental conditions.

Before planting, farmers have to decide on the tree density, orientation, spacing between the tree lines and between the trees located in the same line.

Critically the trees should not hamper mechanisation of crop operations between the lines or at the edges of the plot.



A tractor GPS can be used for line staking. Otherwise, this can be done directly from the ground.



The distance between the tree lines is a multiple of the largest engine working width, this to avoid the overlaps.

Project design

Tree density

Silvoarable systems imply interactions and sharing of resources between the trees and the associated crops, both above and below ground.

In a well-managed silvoarable system, the competition between plants is exploited to improve the overall use of resources. For instance, deeper tree roots are able to utilize excess nitrogen fertiliser, thereby increasing efficiency and minimizing waste. They can also decrease crop evapotranspiration by providing shelter, or improve the water holding capacity of the soil.

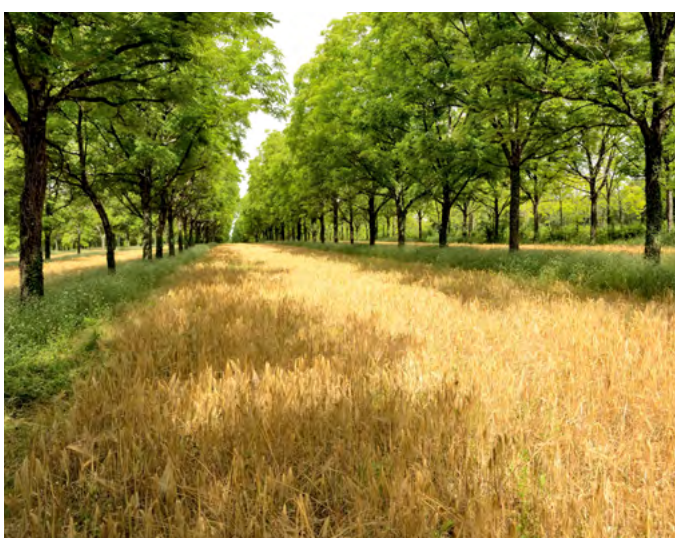
Over the years, however, the competition between crops and trees will often increase in favour of the trees. Crop yields usually start being negatively affected by the presence of mature trees after 20 or 30 years.

Therefore, farmers have to manage the tree density carefully, bearing in mind that the higher the density the stronger the competition.

Research suggests that:

- well-managed silvoarable systems are profitable at densities of between 50-100 trees/ha;
- crop yields will start decreasing halfway through the tree rotation. However, in a well-designed system the overall profitability can be maintained if trees are managed in the proper way. For example, it is possible to have 20-50 timber trees per hectare providing appropriate tree monitoring is carried out in the first ten years of establishment.

It is recommended to have a tree density of at least 100-150 trees/ha at planting so as to be able to select appropriate trees for thinning.



Poor silvopastoral design: 38 year-old black walnuts on 14 m wide apart lines. An example where alleys have been designed much too narrowly to allow comfortable crop operations (especially harvesting). In addition, crop yield has been shown to stand 60 % below the open landscape average, due to lack of sunlight reaching the lower storey

Planting distance

Trees are planted in lines to not interfere with the machinery during crop operations. The distance between the lines has to be chosen in accordance with the width required for operations.

Line spacing should:

- allow the use of the biggest machine/tool (a tractor mounted boom sprayer for example);
- be a multiple of the working width of the narrowest machines to avoid overlapping;
- be at least equal to two times the average of the mature height of the trees; e.g. a distance between 25 m and 40 m for 15 m high deciduous species.

The initial distance between the trees varies between 4 m and 10 m, and can be adjusted (by thinning) later on. The non-cultivated grass strip located at the base of trees is usually 2-4 m wide.

Planting distance

In temperate systems tree lines should ideally run North – South, so the crops will be less affected by the shade and any shading will be equal on both sides of the runs. Of course this will be influenced by other factors such as the orientation of the field and the slope. On steeper ground trees should be planted along contour lines to reduce erosion. The tree rows should not interfere with drainage ditches. In windy areas it is better to arrange tree rows in parallel with the main wind direction. An area with no trees should be maintained at the end of each line (head-lines) to allow machines turning around them. In addition, trees should not be planted under an electric or telephone wires crossing the plot.



Planting a mix of species on contour lines has a great impact at the landscape level

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Protecting trees against wildlife damage: assessing the options

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Wildlife is integral to the life of fields. As they seek to satisfy their natural needs (food and reproduction), animals can cause damage to trees and shrubs.

Farmers need to be well acquainted with the different types of guards in order to use them properly and make the right choice for protecting their trees.



Give preference to mesh guards for protection of trees



There are a number of ways to provide protection for individual young trees

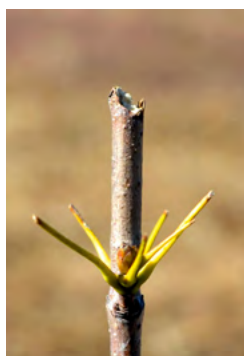
Wildlife damage to trees

Roe and red deer, rabbits and hares damage trees in various ways. Damage may be related to feeding and/or behaviour and its appearance provides clues as to the species responsible.

Browsing: this refers to the removal and consumption of seedlings, buds, leaves or needles, vertical shoots or lateral branches. Animals use their teeth to detach the palatable parts of plants within their reach. Deer, rabbits and hares all cause this type of damage, as they seek to supplement their usual diet of herbaceous and semi-woody vegetation.

Rubbing: rubs are wounds on the bark of trunk. Trunks can be stripped to varying degrees and sometimes even snapped. This type of damage mainly affects trees of less than 10 years old, and often leads to the death of the tree. The causes of rubbing are essentially behavioural. Male deer use tree trunks to rub off the velvet from their newly acquired antler growth when it starts to shed. During the rutting period, deer search for mates and engage in mock combat against young trees to release their aggression and also mark their territory with scent signals.

Bark gnawing: this type of damage is caused by rabbits and hares. It is closely correlated with food scarcity and with the animals' need to wear down their incisors. It consists of bark nibbling and is often characterised by oblique teeth marks at the collar or base of the trunk of young trees.



Browsing (rabbit)



Rubbing (roe deer)



Bark girdling (rabbit)



Mesh tree guard (left), ventilated (centre) and unventilated (right) tree shelters

Types of device

There are several ways of providing protection for individual young trees. It is useful to differentiate between tree shelters and mesh tree guards.

Tree shelters are rigid translucent polypropylene green tubes with anti-U.V. treatment. They have a lifetime of 5 to 7 years after planting. Most shelters produced have a diameter between 8 and 12 cm. Their twin walled construction modifies the microclimate around single trees in ways that enhance height growth rates while offering protection from mammal damage [1].

Tree guards are commonly used for alley cropping systems. They are rigid cylindrical sheathing (Ø 15-33 cm), made from square or hexagonal mesh (2.5 to 25 mm). Quality products available today are made from high-density black polyethylene (HDPE) stabilised with ultraviolet (U.V.) radiation absorbers. This improves the resistance of the finished product to photo-decomposition and therefore enhances their durability.

Their life span also depends on their weight. Heavyweight ($\geq 400\text{--}450\text{ g/m}^2$) reinforced double-mesh tree guards will last from between 7 to 10 years. They are intended primarily to provide effective protection from mammal damage [2].

Why use mesh guards?

Cheaper and more convenient

The most marketed tubes are nested in each other by five or more, sold rolled up and delivered in boxes. Mesh tree guards are less bulky, and usually sold flat and pre-folded. This makes them easier for storage and carrying. The purchase price of mesh tree guards can be up to 35 % lower than tree shelters.

Unattractive to wasp nests

In the spring, the confined space created by the diameter of small tree shelters favours nesting of the wasps. With the summer, wasp activity and nest size increase. They proliferate and are made aggressive by the heat. During tree pruning, stings are frequent. The microclimate in tree guards is less favorable for wasps and it is rare to observe nests within them.



A wasp nest in a tree shelter

Easier for pruning

Low tree densities optimise initial growth by reducing competition from other trees, but induces the development of numerous defects in shape. Pruning is a means to correct these defects.

The diameter of the tree shelter is critical (≤ 12 cm) because it constrains branches. It can be difficult to insert pruning shears into a narrow tube when removing the unwanted branches. A mesh tree guard of 20 cm in diameter is the ideal device to facilitate the work of tree pruning.



When it is impossible to remove the shelter to prune a tree, the only solution is to damage the tube

Promotes balanced tree growth

Plastic tree shelters can cause physiological modifications in the growth of young tree seedlings by creating a microclimate within the tube. The most visible effect is a substantial elongation of the annual leading shoot (sometimes 2 to 3 fold longer than that of unsheltered tree). However, a reduction in root and stem diameter growth of the trunk has been also observed.

While earlier studies focused on temperature and light modifications to explain the distorted growth of trees inside shelters, more detailed studies have shown that ventilation is crucial. Without good ventilation, resulting from free convection through the top of the shelter, the supply of CO_2 to the tree is too low. This results in a reduced assimilation rate.



Unstable red oak plant grown in ventilated tree shelter: it cannot support their own weight

Shelters have been improved by creating chimney-effect ventilation with holes drilled at the bottom, resulting in unnatural trunk diameter growth. However, the shoot - root ratio remains unbalanced. This abnormal biomass allocation in ventilated tree shelters results from the lack of tree movement within the shelter.

The movement of the tree stem induced by the wind influences the way in which material is allocated to different parts of the growing plant. Repeated swaying leads to a thickening of the lower stem and the rapid development of a structural root stem. This phenomenon is called **thigmomorphogenesis**. The leaves, which are free to move, might also be able to produce a signal (by wind or raindrops) that is sufficient to induce thigmomorphogenetical responses within trunks and roots [3].

Promote the growth of young saplings by:

- Protecting individual trees with mesh guards: potential negative impacts on trees are lower than those of shelters.
- Choosing protectors with a larger diameter promotes foliage development.
- Choosing a mesh with a larger size reduces the microclimatic conditions on trees.
- Avoid using protectors that are taller than necessary.

Quality criteria

Height and diameter

The effectiveness of a mesh tree guard depends on its capacity to protect tree seedlings during their entire period of vulnerability. The minimum height of a tree guard must always be greater than the critical height of possible damage inflicted on trees by an animal.

Maximum height (cm) of wounds to trees caused by animals				
	Rabbit	Hare	Roe deer	Red deer
Browsing	<60	<70	<150	<200
Rubbing	-	-	50-100	100-200
Bark gnawing	<50	<60	-	-

The standard heights of tree guards are **50 cm for rabbits, 60 cm for hares, 120 cm for roe deer, and 180 cm for red deer**. In areas where deer populations are very dense, the attractiveness of newly planted trees often compels farmers to use higher, heavier, and more rigid tree guards. These should be **150 cm high for roe deer** and **200 cm high for red deer**, and supported by reinforced wooden stakes.

The standard diameter of mesh tree guards will depend on the type of tree to be protected: 10 cm to 15 cm for poplar; 14 cm to 15 cm for hardwoods with strong apical dominance (e.g. cherry, ash, maple, red oak); 20 cm to 25 cm for hardwoods with strong lateral development and weak apical dominance (oak, beech, walnut) and 30 cm to 33 cm for conifers.

Weight

Supply catalogues currently give weights in grams per linear meter (lm). However, this is not a reliable indication when choosing between two products of equal height but of different brands and/or diameters. **Weight in grams per m²** is the only realistic criterion for reliable comparisons between types of protection.

Work out the weight in grams per m²

Use the following formula to calculate the weight (W) of a mesh tree guard in grams per square meter: **$W = g/(\pi \cdot \varnothing/100)$** , where:

- g: grams per linear meter (g/lm)
- π : mathematical constant equal to 3.1416
- \varnothing : diameter (cm) of the mesh tree guard

For protecting hardwoods from wildlife damage in agroforestry plantations, **heavyweight ($\pm 400\text{--}450 \text{ g/m}^2$)**, mixed and reinforced mesh tree guards combine the advantages of wide (1-3 cm) and fine (2-3 mm) mesh: thicker horizontal and vertical plastic strands provide rigidity and greater tear resistance, while the fine mesh prevents shoots from growing through the sides.

This reduces the risks of malformation and browsing of the main stems. Four pre-formed folds make the mesh guard easy to open for placing on the tree without injuring the tip, and help to maintain an oval cross-section which ensures the tree can grow easily out of the top.



Close-up of a heavyweight, reinforced double-mesh tree guard (25 x 25 mm/ 2.5 x 2.5 mm). This is suitable for agroforestry

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Lines after stubble ploughing, subsoiling and levelling by shallow tillage

Preparing the land

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A comprehensive diagnosis of the land potential to bear trees (studying the soil, climate, topography, etc.) allow farmers to choose the appropriate species to plant. It also helps identify appropriate soil cultivation operations to be carried out before planting.

This preparatory work aims to reduce or eliminate the crop residues (stubble ploughing), to control the grass development next to the trees to encourage a fast and deep expansion of their root system while improving water supply and soil aeration (subsoiling) and to level the ground before planting. These operations will greatly impact the growth and reduce the mortality of the trees, therefore the increasing overall productivity and profitability of the agroforestry system.



This decompactor with 3 teeth is fissuring the ground to a depth of 40 cm

Preliminary weeding

The young trees have a low tolerance to grass competition which causes a reduction of growth and a high mortality. The soil at the base of each seedling has to remain completely clean on a 1 m² area for a minimum of three years. **It is easier to remove the invasive grasses before planting the trees than afterwards.** Several soil cultivation operations can help with this objective and can be selected according to the context (weed pressure, type of soil, etc.).

Stubble ploughing is the first tillage operation to start with on any soil with abundant grass cover. This is done using a disk or a tooth stubble plough (chisel), preferably during summer time, and will mix up the soil surface without turning it over. It is a solid technique to control grass spread and to clear the surface of the soil before carrying out later steps of the project (planting and mulching of the trees). A 5 to 8 cm deep tillage keeps more residues on the surface compared with a tillage between 10 and 15 cm. The former will carry a lower risk of soil erosion.

The **false seedbed technique** is usually used in arable crops and consists of several surface cultivation operations done before sowing. This will encourage germination of seeds from previous crops and weeds. A second tillage 3 to 4 weeks later will destroy the emerging plants. In general, the seedbed technique decreases the seed density of the main weed species without eliminating them entirely from the soil seedbank. Efficient on annual species (rape, cereals, ray-grass, etc.), it is ineffective on perennials (bindweed, thistles, rumex, quackgrass), making it not appropriate to every context. As with every soil cultivation operation these are costs associated with fuel use and increased risk of soil compaction and these should be assessed prior to use.

Ploughing can be used to deal with contexts where weed pressure is high. Most of the weeds germinate in the first 2 cm of the soil. If buried deeper by ploughing some of them will lose their ability to germinate within one to three years. However, this effect is limited to broadleaf weeds.

Subsoiling

Subsoiling is a deep tillage that does not mix or turn the soil over. Unlike the decompacting tillage that works on the arable layer (from 15 to 40 cm in general, but usually 20 to 30 cm), subsoiling is affecting the deeper layers of the soil, that are rarely cultivated (> 60 cm depth). This operation is carried out using a subsoiler during the dry season on a crumbly or hard soil (except if the soil is a clayey one).

The main goal of the subsoiling is to facilitate the expansion of the trees roots in-depth. The hard, compact and impermeable layer under the arable layer (compact pebbly bed, hardpan, calcareous tufa, plough-sole) cannot be considered as arable layer and limits the root growth, which can impact the strength of the tree. These layers remain a barrier for the air and water circulation causing a clogging by water stagnation in the superficial layers during winter and rainy seasons.

What is a plough pan?

A plough pan is a compacted soil layer created under the ploughshare and located at the bottom of the plough line. Regularly-ploughed soils usually present a plough pan at between 20 cm and 35 cm depth with a thickness of few centimeters.

A plough pan creates anoxic conditions (lack of oxygen), limiting the air circulation and drainage. The soil becomes more prone to waterlogging and root growth is impacted.

An adapted tool going 10 cm-deeper than the plough-pan is necessary to destroy this layer.

Subsoiling is **a fundamental step to guarantee successful establishment of the trees**, leads to soil clumps being moved and creating air pockets that are harmful to root life. Therefore, it is important that subsoiling is done early enough before planting so the soil can sink down again before the trees come.

Soil preparation is completed by a shallow tillage (<15 cm) to level the ground and make the particles thinner, facilitate the plantation, the mulching and setting of the individual tree protections.



Tooth stubble plough (chisel)



Subsoiler with a straight frame and inclined teeth (F. Gallois - CNPF)



The rotary tine harrow levels the ground effectively and makes the particles thinner

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Planting the trees

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Successfully planting a tree in agroforestry does not only mean buying good quality seedlings. Die off after planting is primarily attributable to inadequate management beforehand. Drying out of roots or exposure to excess sun, wind, or frost can substantially hamper the development of young trees.

Seedlings have to be handled carefully from the nursery to the field (including transport) to avoid injuries and deterioration of their quality.

Planting has to be done when the vegetation is at rest, this generally means from autumn to the end of the winter. Farmers should avoid planting in periods of frost, when the soil is wet or very dry and during windy periods.



Efficient and fast plantation with a hoe



Bare-root seedlings stocked and protected from the sun and the wind before planting

Seedlings packaging

- Bare-root seedlings are usually packaged in bundles of 25, 50 or 100. The ties should not be too tight to avoid causing injuries to the stems.
- Bundles must be packed in opaque plastic bags (polyethylene). Paper bags are not recommended. In each plastic bag, all bundles of deciduous seedlings should be the right way up (with root systems towards the bottom of the bag) to avoid contact between aerial parts and the roots. Small softwood seedlings can be safely packed head-to-head.
- The seedlings must be packed on the day they are grubbed-up from the nursery. The bags have to be closed tightly to limit water evaporation. The aerial parts must not be wet and must not stick out of the bag (unless it is necessary, for large deciduous seedlings).
- Seedlings in containers and clods have to be transported in boxes or crates that are easy to handle. Their conservation is easier if they are maintained in their growing medium before planting and if the substrate is kept moist by frequent watering.



Bare root oak seedlings conditioned in opaque plastic bags



Seedling of *Sorbus torminalis* in clods. Substrate must be kept moist



Plastic bags must be properly labelled and inform about: customer's name, species, age, number and size of bundles, dates of packaging and expected delivery. The white colour-bags reflect light and reduce risk of heating and fermentation

Seedling transport

Transport of bare root seedlings from the nursery to the planting site is a delicate step.

It is critical to protect the seedlings against:

- the risk of drying out: ask for 1) seedling delivered in opaque and air tight plastic bags, 2) a transport in closed or tarpaulin-covered lorries. If not, protect the plants with a dampened hessian cover;
- frost and sunshine, both of which will damage the seedlings' root systems;
- the risk of overheating and fermentation due to the seedlings being packed in air-tight plastic bags: choose a nursery located near the planting site in order to reduce the transport time as much as possible.



Individual containers placed in wooden crates to facilitate transport and handling at the plantation site (L. Amandier - CNPF)

Taking delivery of the seedlings

In most cases the seedlings from the nursery are sorted before delivery and only the best trees are delivered. However, on delivery it is recommended to check that the seedlings are appropriate. Make sure that they are well balanced, with a single straight stem, a healthy terminal bud and thick collar, abundant and fresh roots.

On delivery the farmer should:

- ask the supplier to provide a properly completed document which has both the seedlings health passport and their certificate of provenance;
- check that the ordered number of seedlings matches the number that is delivered;
- evaluate the age, the quality, sanitary state and size of the seedlings.

This evaluation is useful in case it is necessary to reject a seedling lot (in cases where more than 5 % of the lot is poor quality seedlings) and will avoid any contention with the nursery or the carrier in case of a high die off of the seedlings.

Seedling storage

After delivery, the farmer is responsible for storing the seedlings. He must ensure that the seedlings are protected from the sun, frost, wind and dryness until they are planted.



The storage period should be as short as possible

The seedlings should be stored in a sheltered, dark and sufficiently warm place, for not more than two days. They should be kept in their plastic bags. The roots must be kept moist enough, but not too much to avoid risk of rot.

If there is a need to store them longer than two days, seedling should be heeled into the soil near the planting site, in a place sheltered from the sun and the wind with a soft and well-drained soil. Dig a trench (deep enough to host the roots) to store the seedlings. Ensure the bundles are first loosened and that the seedlings are aligned and their roots are covered with fine soil or sand. The soil should be slightly compacted to remove air pockets. The seedlings can then be dug out as the planting progresses. The seedlings in containers just need to be stored in a safe place with their substrate is always kept moist.



The roots of the seedlings must be in contact with the soil: heeling in of bundles that have not been loosened should be avoided

Planting

A carefully handling of the planting operations is essential to ensure the best survival chance for the seedlings. The planting conditions will heavily impact the hydrological and mineral conditions of the future tree by directly affecting the shape of the root system.

When to plant?

Bare-root seedlings are planted from autumn to spring (end of November to mid-March, approximately) avoiding frost or snow, windy or heavy rainy days. It is recommended to plant on cool but not soaked soil (especially on loamy or clayey soils). Avoid times where there is a need vehicle activity in the fields.

If possible, planting should preferably take place in autumn. This is generally possible where late autumn and winter climates are moderate. In case of harsh winters or short autumns, planting should be planned in the spring.

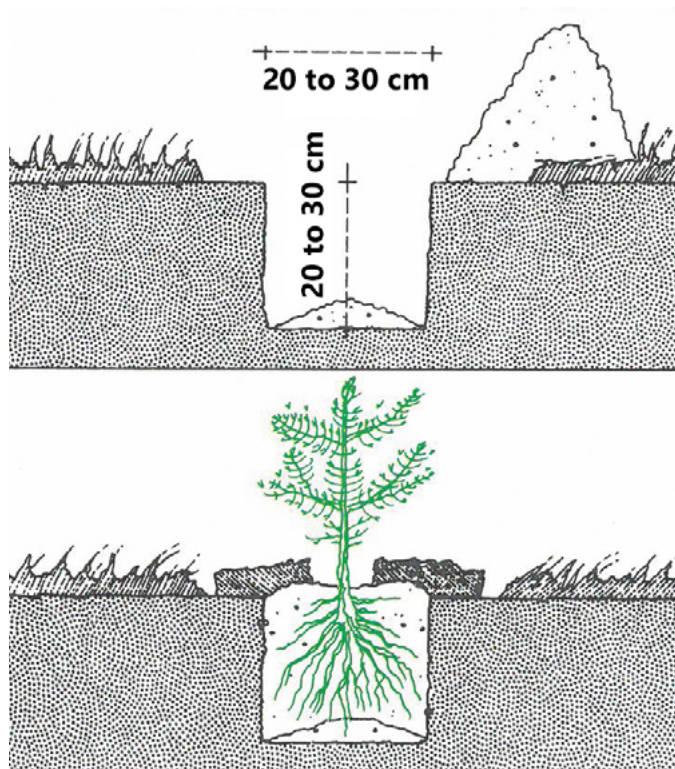
Seedling preparation

In bare root seedlings, injured roots or roots that are too long or dry have to be cut off before planting. This operation helps the seedling recover and should be carried out with sharp pruning shears.

Maintain a tap root of at least 20 cm for those species that need them (especially oaks, walnut and chestnut trees). Above ground the main stem should be kept intact and the forks and lateral branches of large seedling can be cut off.



Pre-planting preparation of a bare-root seedling



Planting

Special precautions should be taken for successful planting:

- planting should be carried out on well-prepared, soft soils, never on wet or frozen soils. If a tillage has been carried out beforehand wait for a few days until the soil has settled down;
- if a superficial vegetation layer is present, remove it on a 1 m² area and dig with a spade a square hole between 20 and 30 cm width.
- each seedling should be placed vertically with its collar placed at ground level. The roots should be well spread in the planting hole to avoid any risk of deformation which could hamper the growth and future stability of the tree. Then the roots can be covered with fine earth;
- after planting, the soil around the seedling is lightly tamped down with the foot without hurting the collar. Seedlings should be kept packed whilst on site

and only taken them out their bags as the planting progresses.

- for seedlings in clods or containers, a hole is dug in the same way with a spade or a forest hoe. Once the container has been removed, the clod is placed vertically and covered with 3-5 cm of fine earth to prevent the substrate from drying out. The clods must be rewetted a few minutes before planting.

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Fitting tree protection to prevent deer damage

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The effectiveness of a mesh tree guard in protecting individual trees from wildlife damage depends not only on careful selection of the device itself and the stakes supporting it, but also on the care taken during installation.

Some simple rules need to be followed to install a tree guard properly, and to ensure that it does its job until it wears out and has to be removed.



Some supplies needed to protect a young tree against roe deer damage



Protect the seedlings when they are planted: after that it will be too late

Three essential steps

Three steps are required to protect trees from wildlife damage.

Before planting, the farmer must choose the right type of protection. The required specifications will depend on identification of the animal species responsible the damage observed on nearby trees or in neighbouring plant populations.

The height, the diameter and the weight of UV-treated, high-density polyethylene (HDPE) mesh tree guards are key factors to consider (cf. Leaflet n°5). For protecting hardwoods from deer damage in agroforestry plantations, heavyweight ($\geq 400\text{--}450\text{ g/m}^2$) reinforced double mesh ($25 \times 25\text{ m} / 2.5 \times 2.5\text{ mm}$) and ultra-heavyweight ($> 700\text{ g/m}^2$) wide-meshed ($5 \times 5\text{ mm}$) guard are the most suitable solutions.

During planting, it is essential to protect the trees on the day they are planted. If the installation of tree guards is postponed, there is an immediate risk of animal damage to some of the newly planted trees. Particular care must be taken when positioning the stakes to ensure that they will remain upright (a point which is all too often neglected).

After planting, regular inspections of the trees are essential to check the stability and effectiveness of plastic mesh tree guards.

Positioning a mesh tree guard

For roe deer

To install a heavyweight ($\geq 400\text{--}450\text{ g/m}^2$) reinforced double mesh deer guard, the farmer will need a wooden stake, a lump hammer or sledgehammer, a staple gun, staples and possibly, a pair of gloves.

The stake (split, pointed chestnut stake - L 150 cm - C 18-22 cm or Ø 5.5/7 cm) must be driven in straight, and to a depth of 30 cm to prevent it from leaning, and deeper if the soil is gravelly or was ploughed with a subsoiler.



Drive the post in straight with a lump hammer or sledgehammer to a sufficient depth to keep it upright



Press down on the outer folds of a tree guard (that has been delivered flat before installing it) to open it into an oval section



Pressing on the outer folds places them in a central position, with the centre folds on the outside. The mesh can now be rolled up lengthways



Rolling a reinforced double-mesh tree guard lengthways before opening it up will help to maintain an oval section



After pressing and rolling, open up the tree guard to form an oval section

When positioning the stake, the following must be checked.

- Diameter of the tree guard (Ø 15 cm, or better 20 cm): the distance from the stake to the tree must be equal to half the diameter of the tree guard (on average 7 cm for a deer guard protecting a broadleaved tree) to ensure that the sapling is centred and will grow properly inside the guard.
- Slope of the planting site: the stake should be placed on the uphill side of the tree and driven in 10 to 20 cm deeper than usual.
- The pre-folded (2-4 folds) mesh should be pressed by hand to form an oval section so that it will slip easily over the plant. This is done by pressing on the outer folds of mesh guards that have been delivered flat. Reinforced double mesh tree guards may also need to be rolled lengthways to help maintain an oval section once they are opened and installed.
- Slide the mesh down around both plant and wooden stake. This must be done gently so as not to damage the terminal and lateral buds by rubbing or tearing. To keep rodents out, always make sure that the base of the tree guard is in close contact with the ground.
- Staple the mesh to the stake with three wide, 10 - or 12 mm staples placed at an equal distance along the length of the guard (in the middle and at each end). Position the guard so that one of its folds is in contact with the stake. Stapling along one of the outer (main) folds will help to keep the guard open.



The stake must be driven in at a distance from the tree equal to half the diameter of the tree guard, so that the tree is at the centre and will grow properly inside the mesh



Slide the mesh sleeve gently down around both tree and wooden stake



Staple the mesh to the wooden stake

For red deer

For red deer mesh tree guards are fixed to 2 sawn pointed round chestnut or treated pine posts (L 250 cm - Ø 6/8, or better 8/10 cm) to support an ultra-heavyweight (>700 g/m²) wide-meshed (H 180 cm, Ø 20-30 cm). Avoid ultra-wide mesh guards.

The trickiest phase when installing a mesh tree guard for protection against red deer damage is the positioning of the wooden posts.

- The posts must be equidistant from either side of the sapling. The distance between them will correspond to the diameter of the tree guard.
- Using a crowbar or an auger, make starter holes (at least as deep as a quarter of the length of the wooden posts) to ensure better long-term stability. A simpler method would be to drive the posts directly into the ground using a front-end bucket on a farm tractor. However, this is not recommended as there is a much greater risk of damaging the wood.
- Drive each post into its starter hole to a depth of 40 to 50 cm. A high (H 180 cm) wide-diameter (Ø 20-30 cm) mesh tree guard is placed by sliding it gently down around the tree and the wooden supports.
- Attach the tree guard to its wooden support with fence staples 20 to 30 cm apart.

After planting

Regular maintenance

It would be a mistake to think that mesh tree guards will last for a long time without any maintenance. After planting, the farmers are strongly advised to make regular site inspections in order to straighten, repair or replace tree guards damaged by animals or high winds.

During the winter following the first growing season, all the stakes should be reinforced. In sites ploughed with a subsoiler, stakes will often sink by a further 10 to 15 cm. Stapling should also be reinforced at the same time, if necessary.

The top edges of heavyweight reinforced double-mesh tree guards can be abrasive and should be folded over, like a sock, or slit around the top, to prevent damage to trees with thin bark in windy sites especially.

Preventing health problems

Some health problems affecting young trees are directly attributable to mesh tree guards. The main potential problem is overheating of the trunks. The trunks of thin-barked species, such as beech, cherry, maple and poplars, are particularly susceptible to overheating when the plastic mesh is too tight. Black plastic mesh will cause the most severe damage. High temperatures and exposure to sunlight will promote bark lesions inside the mesh guard, which consistently develop on the southwest side. 3 to 8 year-old plantings are often the most affected.

Other symptoms of damage are peeling bark and calluses forming around the lesions. The wood becomes exposed and these fragile areas may be colonised by wood-rotting fungi.

Mesh tree guards must be removed when they become tight against the trunks because the risk of overheating is greatest at this point. If they are not removed in time, the stake to which the mesh is attached can become embedded in the trunk.



The edges of heavy reinforced double-mesh tree guards are potentially abrasive and should be folded over like a sock

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Mulching for healthy tree seedlings

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Successful tree establishment depends on minimising competition from other vegetation for water and nutrients.

Mulching is one of the most beneficial practices a farmer can use to establish healthy tree plants.



The closer the grass is to the tree seedling, the slower the tree grows



Using sawdust for mulch can be an economical choice



Gravel mulch becomes a permanent element in landscaping



Straw mulch prevents the germination of weeds only for the first year after planting

Weeding requirement for young trees

Trees and grass compete for water and nutrients. The majority of feeder roots of both trees and grass occur in the top 30 cm (12 in), and the high root density of grass species means that they are particularly competitive until the tree is fully established [1, 2].

- The closer the grass is to the tree seedling, the slower the tree grows [3].
- Controlling competitive herbaceous species within 1-2 m around newly established tree seedlings, and then for 2-3 years after planting, enhance tree survival and growth.

What is mulch?

Mulching consists of laying on the soil surface an organic or inorganic material (called mulch) which forms a barrier to weed growth. Some mulches can be used to enhance soil conditions and improve tree growth.

Organic mulches are made of natural substances such as leaves, pine needles, straw, hay, tree bark, wood chips, sawdust, and compost. They decompose over time, more or less rapidly, according to their lignin content. They improve soil structure and nutrient availability.

Inorganic mulches, such as crushed stone, gravel, pebbles, plastic films and landscape fabrics (geotextiles), offer the advantage of low maintenance. Typically, however, they do not decompose and do not improve soil properties.

Available mulches on farms

Plastic films

Black polyethylene-based (PE) plastic film is commonly used because it is relatively cheap, and is readily available. It reduces weed growth, conserves soil moisture and increases soil temperature.



Disposing of used plastic films, which cause pollution, has led to development of biodegradable mulches

Despite these benefits, PE films can create a considerable waste problem. If not properly collected, treated and recycled, plastic materials can pollute rural areas and release harmful substances into the environment. Dumping, open-air burning, burying, stockpiling and abandonment are prohibited.

The non-polluting, but time consuming, solution is to use hand labour to collect the film. Because PE mulch films become dirty during use, they cannot be recycled. Their removal and disposal is therefore an economic and environmental constraint and, consequently, encourages the illegal disposal methods [5].

Biodegradable plastic mulch films

Developed successfully over the last few years for the organic sector, biodegradable films can function in a similar way as conventional PE, but without the environmental drawbacks. The main advantage is that, after a period of time, they degrade into the soil [6] where microflora transforms them into carbon dioxide, water, and non-toxic biomass.

Bioplastic sheet is typically accredited (*) with the «OK Biodegradable Soil» conformity mark by Vinçotte (an international certification organisation). This verifies that the film will completely biodegrade without adversely affecting the environment.

A biodegradable plastic mulch film of 0.08 to 0.10 mm thickness can save on maintenance work for up to 18-24 months, depending on the climate and soil conditions.



This logo indicates the film can be left to break down in situ after used
(*) The finished product and all its raw materials

Other Traditional weeding techniques

Chemical and manual weeding can be considered but they have drawbacks that limit their use.

Chemical weeding allows localised intervention before competition starts. However, this approach requires knowledge of the weeds and of the activity, selectivity, and conditions of herbicide use. Herbicides often give the best weed control relative to costs, but some people are wary of their use [7] [8] [9]. Repeated application is usually required, and appropriate operator training is also needed.

Manual weeding consists of uprooting grasses and other weeds mechanically (typically with a hoe). As with chemical weeding, the process may need to be repeated. Operators need to be skilled to avoid damage to the seedlings, and unless limited to very small areas, it is likely to be costly and laborious.



Pre-cut 1 m² bioplastic sheet squares are flexible, lightweight and resistant for easy placing as required



Mechanizing the mulch film laying saves working time

Wood chips

Wood chips represent one of the best biodegradable mulch choices for trees and shrubs. Raw materials can come from sources such as hedgerow and farm woodland biomass, or even recycled wood pallets. A wood chipper can reduce branches and trunks to small loose pieces. The materials vary in their size (a typical thickness: 3 mm; width: 15 mm, length: 35 mm).

Wood chips are slow decomposers (if they do not contain leaves), as their tissues are rich in lignin and tannins. If possible, aged material should be used so that the chips decay slowly thereby releasing nutrients over a long period; at the same time the chips can absorb significant amount of rainwater that is slowly released to the soil.

Straw

Straw is one of the most economical mulches. Unweathered, unchopped wheat, oat or barley straw is best. It can be obtained loose (40-50 kg/m³), or in round (50-70 kg/m³) or compressed rectangular bales (140-170 kg/m³). Straw decomposes more rapidly than wood chips, so an annual replenishment will be needed to control weeds. For optimal protection, wheat straw from compressed rectangular bales is preferred (higher density and lignin rate) because it does not decompose as rapidly as loose oat straw.

Comparative benefits of organic mulches

When applied correctly, coarse textured mulches have many beneficial effects on saplings and soil [10] :

- Moderate the temperature of the root zone: by providing insulation, mulches keep the soil warmer during winter and cooler during summer. This helps protect fine tree roots from drying and temperature extremes.
- Prevent loss of water from soil surface by evaporation: by acting as a protective blanket over the ground area, mulch can increase water availability and decrease moisture fluctuation in the root zone.
- Help control weeds: mulch prevents light penetra-



Wood chips mulch is one of the best performers in term of weed control, soil moisture retention and temperature moderation



Straw mulch prevents the germination of weeds just the first year after planting

tion to the soil and this can reduce the germination of weeds. Weeds that do germinate are smothered, and the lack of weed growth minimises the loss of soil water through transpiration.

- Prevent soil surface splashing and crusting: mulch restrains raindrop erosion, allowing rainwater to penetrate into the soil.
- Improve soil structure: as the mulch decays and moves down into the soil, it improves the fertility of the topsoil.
- Enhance tree establishment: roots grow whenever and wherever environment conditions are favourable. Conservation of soil moisture and moderation of soil temperature under the mulched zone maximize initial tree root and shoot growth.

How to apply organic mulch ?

- Begin mulch application just after planting, as weeds are best controlled when they are small. Bare soil should be mulched as soon as practical, especially in the spring and autumn when weed seed germination is at its peak.
- Apply organic mulch to the desired depth: weed control and tree performance are directly linked to organic mulch depth. Shallow mulch layers [5-7 cm (2-3 in) or less] can promote weed growth. A layer of 10-15 cm (4-6 in) thickness is recommended. An excessive depth [>15 cm (6 in)] can decrease water penetration in soil and increase plant stress.
- Mulch is not typically recommended on heavy soils, where drainage is a problem: it may prevent the adequate drying of the soil (especially during spring). This may create anaerobic (without air) conditions which promotes root rot diseases.
- Keep mulch away from tree stems: placing organic mulch up against a tree stem creates a moist, low oxygen environment which can promote fungal or insect damage, such as collar rot. Aim for a distance of at least 5-10 cm (2-4 in).
- Replace mulch as needed to maintain the desired depth: the replacement rate will depend on decomposition rate.

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Begin mesh tree guard positioning and mulch application just after planting



A wood chips layer of 10-15 cm (4-6 inch) thickness is recommended



Take care not to pile the mulch around the trunk of trees, as this can encourage rot

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Shaping the trees

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Trees planted at wide spacing naturally develop a shorter trunk, with a greater tendency to a sinuous and forked shape. They often bear many vigorous lateral branches that can hamper the movement of agricultural machinery.

A wide array of factors can lead to defects in shape (high wind, frost, drought, snow, presence of birds and insects, game, changes in soil fertility) or more structural (genetics and quality of seedlings). All defects in shape should be corrected as soon as they appear.

Early, moderate and gradual pruning interventions are necessary to increase the rigor of the trees, straightness of the trunk and produce quality marketable timber. Those interventions have to be undertaken at the right time and with the adequate material.



Shape pruning of a poplar (A. Guerrier - CNPF)



Rapidly growing tree with heavy side branches will benefit from early pruning (H. de Grandmaison - CNPF)

Why prune trees?

Pruning is the action of cutting, living and dead branches growing from the main stem of the tree, with the view of improving its shape as the tree mature and, ultimately, to increase the production of knotless (and therefore higher value) timber wood.

Farmers will need to prune trees for the following main reasons:

- to improve the mechanical resistance of the tree, and therefore its ability to withstand wind. This requires eliminating forks and vigorous vertical branches that compete with the main stem;
- to preserve tree health. This requires removing dead branches, or those that have been broken or carry diseases so as to prevent their spread;
- to lift the tree crown. This requires cutting lower branches and increasing the height of the crown so as to ease farming operations along the tree rows;
- to increase the timber value. Pruning can help produce a quality tree bole (the part of the trunk that is located in between the soil and the first branches) with a high marketable value.



Before



After

Delayed shape pruning on a wild cherry (J. Becquey - CNPF)

What are the characteristics of high value timber wood?

From a farmers' perspective a quality tree bole is one that can be sold easily and at the highest price. For a sawmill manager, however, it is straight, perfectly cylindrical, branchless piece of wood, with enough diameter and length and a minimum amount of knots or other internal defects. These characteristics make wood processing easier, while maximizing the yield in valuable produce and reducing sawing costs.

Shape pruning

Shape pruning consist of the removal of forks, multiple, broken or defective top branches, as well as those that compete with the main stem of the tree and threaten to alter its shape. The objective is two-fold: getting a single, straight, cylindrical trunk that has the longest possible height, while giving the crown a shape that can withstand the wind.

What is a «hazardous branch»?

- **Acute branches:** these are branches that branch away from the main stem at an angle of less than 30°. Acute branches will grow upwards and will tend to grow faster than a more angled branch. The risk with these branches is that they can overtake the apical stem and create a fork-like structure.
- **Over grown branches:** when a branch reaches a diameter that is bigger than the neighboring branches or exceeds half of the diameter of the trunk it may become hazardous.

How to prune properly?

Prune early. Pruning often starts 2-3 years after planting the young seedling, usually by the time the main stem gets out of the tree shelter. If a fork has formed inside the tree shelter it can be removed by using hand pruning shears through the shelter or by lifting it. If the seedling shows difficulties of establishment, remain patient: pruning the young tree would mean depriving it of a part of its foliage that will be essential to enable a fast and healthy growth of its root system.



3 steps here: removing the top fork (red), big branches (blue) and diving branches (green)

Prune from top to bottom. Correct primarily top branch defect (forks, multiple, broken or unclear top branches) that represent a big threat, with long-lasting impacts, for the straightness and cylindricality of the main stem. Cut, as soon as they appear, any hazardous branches, taking care to not damage the branch collar. Lower vigorous branches should be cut as soon as their diameter exceeds 2.5-3 cm.

Prune gradually. It is more efficient to undertake a moderate, gentle pruning just a few hours every year rather than entire days every 2-3 years. Shape pruning is necessary during the first 10 to 25 years of the tree life, until the bole has reached the target height: 4-5 m in walnut, 8 meters in poplar, and around 6 m in other broadleaves.

Prune gently. Avoid removing more than 30 % of the living branches (photosynthetic biomass) annually, in particular if the crown is still little developed. Make sure you maintain the balance of the whole crown.

Prune at the right time. Whereas dead branches can be cut all year round, living branches must never be cut during bud break (from swelling of the buds to the complete development of the first leaves), nor while the sap flow is going downwards (from the end of August till the shedding of leaves). This will avoid depleting the tree's resources. From late June, it is advised to undertake a – moderate – summer pruning on young trees. Summer pruning will allow a better closing of wounds, higher resistance to pathogens, and less vigorous epicormics growth. A winter pruning before bud break is also possible with most species (although avoid this in wild cherry). Pruning without leaves enables the underlying tree architecture much more easily analysed, however epicormics growth can be much more vigorous in the next spring.

How many trees to select for shape pruning? In a wide-spaced agroforestry systems, most if not all trees are usually shape pruned.

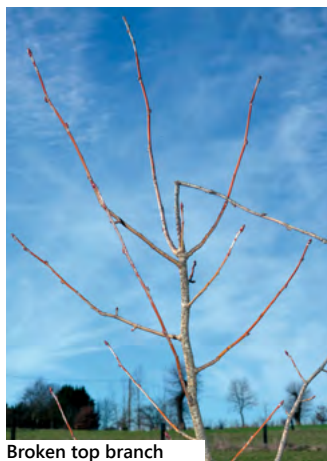
Nevertheless, it is each farmer's job to evaluate the capacity of each tree to produce quality timber, and may decide to leave aside trees that are less promising for this use (e.g. those with a twisted trunk). Such trees would represent a higher labor investment that may not be profitable in the end. They can be managed in a different way, by coppicing or pollarding them.

How to handle a delayed pruning? It is possible to cut rather big branches (diameter between 3 and 6 cm) that were missed in the previous years, however this requires more time and has to be done carefully. In order to allow a clean wound and avoid the bark surrounding the branch to be ripped, this has to be done in two successive steps: a first cut of the branch 30 cm away from the trunk, followed by a second cut level of the trunk. From 7 cm in diameter and above, it is considered too late to prune the branch. This could threaten the tree's health (high risk of decay) and greatly reduce its growth.

Main top branch defects



Fork



Broken top branch



Multiple top branches



Unclear top branch

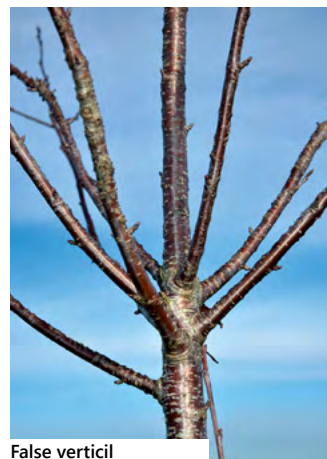
Main branching defects



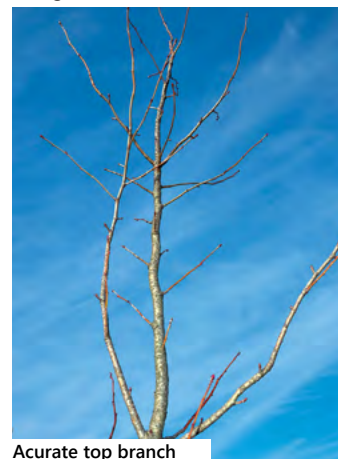
Accurate branch



Overgrown branch

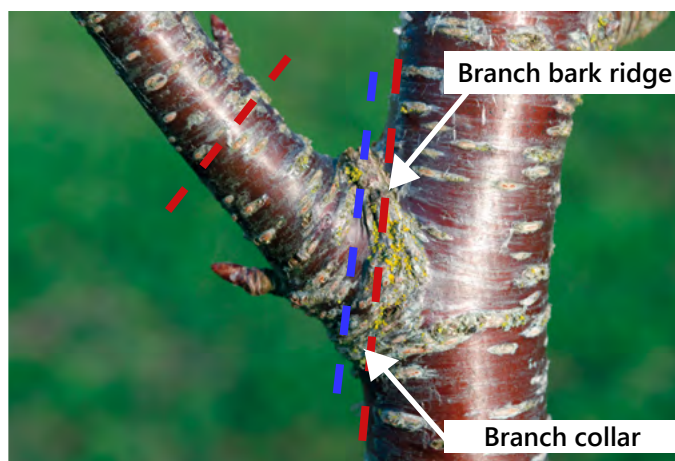


False verticil



Accurate top branch

How to cut a branch? A good cut has to be clear, with no ripped bark around it. Done at a slight angle with the trunk, it has to preserve both the branch bark ridge and the branch collar so as to allow the underlying tissues to allow callus formation. Cuts that are done too far from the trunk will leave a dead stump, while those too close to it will hamper the healing process. In both cases, the risk of infection is high.



Pruning a branch properly (good cut – wrong cuts)

What tools to use? Up to 2.5 m height, it is easy to use common hand tools: hand pruners (branch $\varnothing < 1.5$ cm), lopping shears ($\varnothing < 3$ cm) and pruning saw ($3 \leq \varnothing \leq 10$ cm). From 2.5 through 6 m height, tools fixed on telescopic poles are required to reach the branches from the soil: pole pruners ($3 < \varnothing < 4.5$ cm) or pole saws are available.



Hand pruners (1), lopping shears (2) and pruning saw (3)



Pruning saw (1) and pole pruner (2)

Silvicultural pruning

Silvicultural pruning consist of the removal of lower branches, dead or alive, level of the trunk. It aims at producing a quality bole: as high and cylindrical as possible, and with the greatest proportion of knotless wood. Knots¹ should only be present at the core of the stem (earlier years of tree life), in a cylinder of 10-15 cm in diameter, at the most.

Silvicultural pruning has to be:

- **early:** start after the first few years of shape pruning, once the trees have reached a height of 2.5-3 m (walnuts and oaks) and 4 m (other broadleaf species), but not before the lower branches have reached 2 cm in diameter;
- **frequently:** make sure you check your trees often enough to only deal with small branches, with 3-4 cm in diameter at the most;
- **gradually:** the first time you prune your trunk, the height of the branchless part must not exceed 1/3 of the total height of the tree. At the end of the cycle the branch less part can represent up to half of the total tree height (more if in poplars);
- **from bottom to top:** contrary to shape pruning, silvicultural pruning should go bottom to top. Nevertheless, this rule can be adapted so bigger branches ("hazardous branches") located at higher levels of the tree can be cut before lower ones with a smaller diameter.

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1. A knot is the base of a cut branch that is gradually enclosed in the stem from which it arises during the growth of the tree.