concentration and resultant damage. Systems based on stone do not need spillways and they require much less maintenance.

Permeable rock dams are a floodwater farming technique where runoff waters are spread in valley bottoms for improved crop production. The structures are typically long and low dam walls across valleys. Rock dams have been developed mostly in West Africa, and the technique had grown substantially by the end of the 1980s. The technique is labor intensive and needs a group approach, as well as some assistance with transport of stone.

Water spreading bunds are often applied in situations where trapezoidal bunds are not suitable, usually where sudden runoff discharges may be extremely high and would damage trapezoidal bunds or where the crops to be grown are susceptible to the temporary waterlogging, which is a characteristic of trapezoidal bunds. Water spreading bunds are usually used to spread floodwater which has either been diverted from a watercourse or has naturally spilled onto the floodplain. The bunds, which are usually made of earth, slow down the flow of floodwater and spread it over the land to be cultivated, thus allowing it to infiltrate. Water spreading bunds may be combined with the construction of a ground dam, which is a long structure that retains subsurface flow.

Final Remarks

Several ground preparation operations and their uses have been described. Tree growth following different treatments for ground preparation should be monitored and integrated on information systems. Further progress in forestry may be supported by information systems about the results of different treatments for ground preparation under specific field conditions.

Further Reading

Anderson GG (1998) *Site Preparation for Farm Forestry*. Agriculture Note no. AG0770. Victoria, Australia: Australia Forest Growers.

Boden DI (1992) The relationship between soil water status, rainfall and the growth of *Eucalyptus Grandis*. *South African Journal of Forestry* 156: 49–55.

Cunningham L (1994) The effect of site preparation and tending on the growth of *Pinus radiata* in the Southern Cape: five year results. *South African Journal of Forestry* 176: 15–22.

Dharamraj NM, Gaum WG, and Hildebrand A (1900) An investigation into the establishment of indigenous trees on treated mine residue soils in South Africa. *South African Journal of Forestry* 186: 33–40.

FAO (1991) *Water Harvesting: A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production*. Rome: Food and Agriculture Organization.

Mason WL (1999) *Cultivation of Soils for Forestry*. Forestry Commission. Bulletin no. 119. London: HMSO.

Neilson WA (ed.) (1990) *Plantation Handbook*. Tasmania, Australia: Forestry Commission Tasmania.

Schönau APG, Verloren Van Themaat R, and Boden DI (1990) The importance of complete site preparation and fertilising in the establishment of *Eucalyptus grandis*. *South African Journal of Forestry* 116: 1–10.

Schutz CJ (1900) Monitoring the long-term effects of management practices on site productivity in South African forestry. *South African Journal of Forestry* 120: 3–6.

Shumba EM, Mushaka A, and Muchichwa J (1998) A survey of tree-planting practices in the smallholder farming sector of Zimbabwe. *South African Journal of Forestry* 182: 67–74.

Wadsworth FH (1997) *Forest Production for Tropical America*. Agriculture Handbook no. 710. Washington, DC: US Department of Agriculture Forest Service.

Wenger K (ed.) (1984) *Forestry Handbook*. New York: John Wiley.

Zwolinski JB, Donald DGM, and Van Laar A (1992) Regeneration procedures of *Pinus radiata* in the Southern Cape Province. I: Modification of soil physical properties. *South African Journal of Forestry* 167: 1–8.

Zwolinski JB, Donald DGM, Van Laar A, and Groenewald WH (1992) Regeneration procedures of *Pinus radiata* in the Southern Cape Province. V: Post planting mortality and growth of trees in response to the experimental treatments and planting site environment. *South African Journal of Forestry* 168: 7–22.

Stand Establishment, Treatment and Promotion – European Experience

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Introduction and Definitions

There are many aspects to the establishment of forest stands, which are reflected in a number of definitions:

- Reestablishment of existing forests is possible by means of generative or vegetative renewal. Strictly speaking, stands are regenerated only when grown from seed. This may occur through natural or artificial regeneration:
  - Natural regeneration takes place when seed is dispersed without human interference.

Figure 1 High forest in different manifestations: (a) even-aged pure Norway spruce (*Picea abies*) plantation (Riedenburg, south-east Germany), (b) uneven-aged naturally regenerated silver fir (*Abies alba*) and Norway spruce selection forest (Rippoldsau-Sch., south-west Germany).

- ○ Artificial regeneration involves direct seeding, as well as planting.

Both natural and artificial forest regeneration using seed results in high forests (**Figure 1**).

Vegetative renewal is the result of resprouting from the stumps left behind following harvesting. Most broad leaves sprout freely, giving rise to coppice forests (**Figure 2**). Such forests were widespread throughout Europe for centuries, and were an important source of firewood. A tree's ability to resprout from its stump, or to produce root suckers, decreases with age. Coppice forests are normally harvested after two to four decades and form relatively low forests. Vegetative renewal from the stumps is, strictly speaking, not regeneration, as the root systems are not regenerated and continue to age and deteriorate.

A combination of vegetative and generative renewal takes place in coppice forests with standards ('middle forests') (**Figure 3**).

- Reestablishment of forests is often referred to as reforestation and takes place shortly after the previous stand has been harvested, at which point the soil still predominantly exhibits characteristic forest soil properties.

Figure 2 Beech (*Fagus orientalis*) coppice stand shortly before next harvesting (Akcakoca, north Turkey).

Figure 3 Coppice with standards (mainly *Quercus petraea*) shortly after harvesting of the coppice shoots (Neuf-Brisach, France).

Figure 4 Norway spruce (*Picea abies*) plantation following afforestation of an old meadow (Hinterzarten, south-west Germany).

- Afforestation, on the other hand, takes place when areas have been used for purposes other than forestry for more than 50 years, according to a Food and Agricultural Organization definition (**Figure 4**). From a less precisely defined ecological viewpoint, afforestation is the restocking of sites which have lost their forest soil characteristics. This may arise as a result of various land-use types, such as agriculture, or degradation caused by erosion, and may occur over much shorter periods, depending on the local climatic and soil conditions.
- Stand establishment – depending on silvicultural systems – may take place under the canopy of old trees (**Figure 5a**) alongside forest stands (**Figure 5b**) or on large open areas resulting from clearcuts or other land uses (**Figure 4**). One of the main objectives of each of the silvicultural systems is to create microclimatic conditions appropriate to the ecological demands of the young plants of the different tree species.

  The larger the open areas, the greater the climatic stress conditions may become and the more tolerant the young regenerated plants have to be of such stress, for example, drought, heat, and early and late frosts (**Figure 6**). Usually a sheltering effect can be observed extending a distance across the regenerated area equivalent to the height of the neighboring stand. Generally, bare land conditions develop in areas larger than 0.5–1 ha. Large open areas (clearcuts) may be >5 ha, and very large ones >50 ha.
- The regeneration period largely depends on the type of regeneration and the silvicultural system employed. At one extreme it may require only 1 day to plant a small clearcut area, provided no beating-up is necessary in the succeeding years. The other extreme can be found in selection forests, where regeneration is a continuous process.

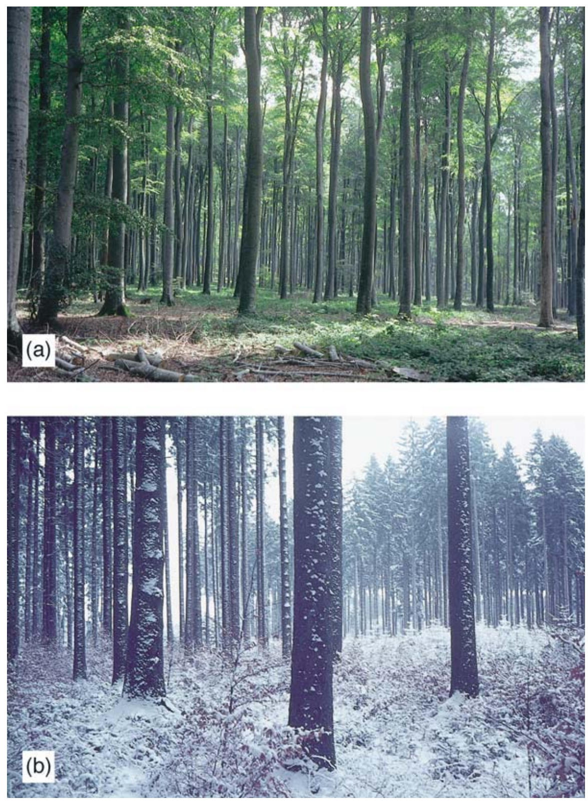

Figure 5 Natural regeneration with shelter for regrowth: (a) beech regeneration (*Fagus sylvatica*) under a shelterwood system (Bourbonnaies, France); (b) Norway spruce (*Picea abies*) regeneration under a strip-cutting system (Zeil, south-west Germany).

- The terms regeneration, planting, restocking, and afforestation denote processes, the results of which are seedlings, saplings, regrowth, plantations, and restocked forests, to mention but a few. In forestry practice, however, strict application of these definitions is seldom observed.

Figure 6 Norway spruce (*Picea abies*) although not very sensitive to frost, often suffers from late frost on large bare land areas (Pforzheim, south-west Germany).

Tree Species Selection

The tree species selected for restocking an area depends on several preconditions, such as the prevailing ecological conditions on the one hand, and the objectives of the forest owner and society on the other. These are illustrated in **Figure 7** and are explained in the following text.

Site Classification

The success of restocking an area is highly dependent on the site conditions. Sites are characterized by their climatic conditions and soil properties. Climate is the dominant site factor in mountainous as well as high mountain regions, and often negates the soil characteristics. Soil characteristics exert a greater influence on forest growth at lower elevations where the climatic conditions are relatively favorable.

Site classification systems, therefore, include two steps:

1. The demarcation of regional landscape units to characterize the predominant climatic influences.
2. The delineation and mapping of local forest site units within regional units, representing similar growing conditions for the tree species and including comparable risks.

Only a few Central European countries like Austria, Germany, and Switzerland currently possess area-wide maps providing elaborate site property

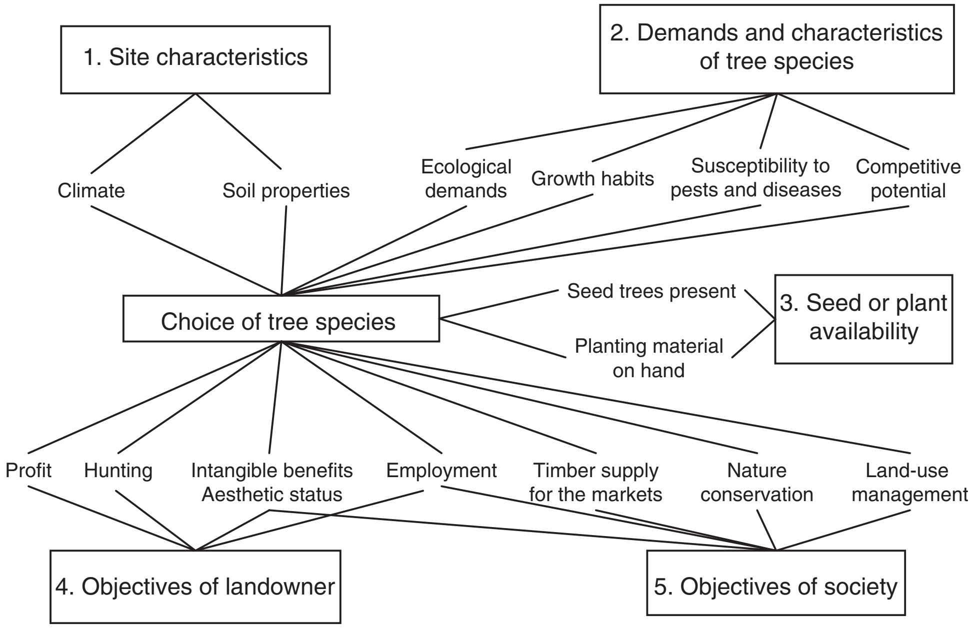

Figure 7 Preconditions and objectives influencing the choice of tree species when restocking forests.

information, enabling detailed planning of the optimum site-adapted stocking. Most European countries, however, possess maps indicating climatic or vegetational zones, which are of some help in the selection of site-adapted tree species.

As the majority of sites are located at lower altitudes and on soils mostly favorable to forest growth, the forest owners are free to select from many tree species for restocking. Other aspects may also be taken into consideration. The more extreme the sites become – high or very exposed elevations, very wet, dry or shallow soils – the fewer the options a landowner has in this regard.

Figure 8 Although clearcuts are diminishing in Scandinavia and Central Europe, an increasing area of bare ground has resulted from hurricanes over the last two decades (south-west Denmark).

Demands and Growth Characteristics of the Tree Species

The prevailing ecological conditions over an area to be restocked may also influence species choice. A large clear-cut or storm-damaged area (**Figure 8**) with a harsh climate, for instance, may be suitable for light-demanding yet stress-tolerant pioneers such as birch (*Betula verrucosa*, *B. pendula*), aspen (*Populus tremula*), or rowan (*Sorbus aucuparia*), whereas late successional species like beech (*Fagus sylvatica*) or silver fir (*Abies alba*) require the protection of a canopy of old trees against late frosts, drought, and high temperatures. Late successional tree species, therefore, cannot be regenerated on bare ground susceptible to the afore-mentioned stress factors unless a nurse crop is established to act in the same way as the old trees.

In order to reduce the microclimatic stress for young regrowth it proved effective to establish nurse crops through natural or artificial regeneration of pioneers (**Figure 9**).

All European forest tree species thrive best on relatively well drained soils, facilitating root growth, and with a sufficient nutrient supply in a moderately temperate climate. On these optimal sites, all species will exhibit their highest production rates. Which species dominates in the long run, however, is determined by the competitive strength of the tree species. Pioneer species, both long- and short-lived, are less competitive than the late successional species. Growing in mixtures, they usually have to be actively favored by management if they are to survive against the more competitive species.

Figure 9 Nurse crops as a means of overcoming adverse bare-ground conditions: birch (*Betula pendula*) planted in a storm-damaged forest acting as a nurse for young oak (*Quercus petraea*) planted shortly afterwards (Kirchberg, south-west Germany).

Seed or Plant Availability

The choice of tree species is highly dependent on the presence of seed trees, which may also provide shelter against microclimatic stress conditions, in the event that natural regeneration is desired, or on the availability of adequate plant material from nurseries.

Objectives of the Forest Owner

Only a minority of forest owners can use their forests exclusively for hunting or pleasure. Most regard their forests as major sources of income and employment, but may take into consideration other functions and objectives in the management of their properties. Therefore, they choose productive species promising good prices in the market. Additionally, the costs of establishing a new stand are of great importance. The greater the emphasis placed on calculating the return on their investment, the more likely they are to choose the species that are easiest to plant and clean.

In most parts of Ireland, for example, oak forests (*Quercus petraea*, *Q. robur*) would be natural and suitably site-adapted. Oak forests are expensive to establish and require intensive weeding, however, and ultimately produce relatively low volumes of timber over long rotations. Planting of Sitka spruce (*Picea sitchensis*), on the other hand, costs much less and the revenue from the fast-growing species is much higher. It is, therefore, easy to understand why most private owners plant Sitka spruce instead of oak.

Objectives of Society

Society is currently seeking to play an active role in influencing the production, appearance, and services provided by forests, as they are an important part of the landscape, and represent comparatively natural ecosystems.

Additionally, an increasing fascination for nature protection ideas to counterbalance modern urban life may favor the reestablishment of 'natural forests.' Employment for rural populations and the supply of a large variety of timber assortments for the markets, on the other hand, is a more general public issue.

Tree species choice is, therefore, a complex decision process and many interest groups may take part in it.

Types of Stand Establishment

Forest stands can be established by means of natural regeneration, direct seeding, or planting. The details, advantages, and risks of each procedure are discussed in the next section.

Natural regeneration is recommended where the following preconditions are met:

- Presence of seed-bearing trees on or in the vicinity of the area to be regenerated
- Existence of site-adapted tree species and provenances
- Seed production reasonably frequent. Some species, such as beech and oak, used to have good seed years at intervals of >5 years. Over the last three decades, however, the frequency of flowering has increased dramatically as a result of more frequent warm summers, which induce the formation of flower buds. Forest practitioners are, therefore, under less pressure to regenerate large areas immediately when the time comes to do so.

  Nevertheless, foresters can to a certain extent increase the intensity of flowering and seed production by promoting crown development of the final crop trees by means of consistent crown thinnings. Early and intensive thinnings ensure that the dominant trees will have developed large crowns decades before seed production becomes essential for regeneration. Some shade-tolerant tree species, however, such as beech, exhibit reactions to increased crown space even at advanced ages
- Soil conditions favorable to germination. Layers of litter, raw humus, and/or ground vegetation may seriously impede natural regeneration. The soil surface conditions may, therefore, require soil treatment in order to expose the mineral soil, thereby providing a favorable seed bed (**Figure 10**)
- Low risk for the development of seedlings. Mice (*Apodemus* spp.), voles (*Microtus* spp.), insects such as the pine weevil (*Hylobius abietis*), and deer (such as *Capreolus capreolus*, *Cervus elaphus*, *C. nippon*, *Dama dama*) may greatly endanger the young seedlings (**Figure 11**). Voles and beetles are less of a problem if the young plants are regenerated in the more moderate microclimate under the shelter of an old stand. Deer, however, can only be effectively excluded by fencing, which is very expensive.

Natural regeneration is only possible if old stands are remaining or have been rehabilitated through afforestation and allowed to reach seed-producing ages. This is the case in most Central and Eastern European, as well as Scandinavian, countries. Therefore, there is a growing tendency to make use of the opportunity to regenerate forests naturally. In these countries, the current aim is to reestablish at least half of the forest area naturally. In Eastern and southern European countries, however, most forests have only been established in the last decades and generally do not as yet produce sufficient seed numbers.

Direct seeding – though considered artificial regeneration – holds an intermediate position between both regeneration types. It combines the advantages of natural regeneration (low cost input; high number of plants per unit area, which is important in the case of broad leaves as it ensures a high rate of natural pruning, a precondition for valuable timber; and undisturbed root development) with those of planting (choice of tree species independent of the presence of seed-bearing trees;

Figure 10 Minor soil preparation to improve germination conditions. (a) Strip ploughing to encourage beech (*Fagus sylvatica*) nuts (Lembeck, west Germany); (b) strip ploughing to help Scots pine (*Pinus sylvestris*) seeds germinate (Bamberg, south-east Germany).

even tree cover over the whole area despite minor site differences caused by the site mosaic).

Direct seeding of acorns (mainly *Q. petraea*) has long been and still is important in forestry practice, as it is difficult to store them over winter. Therefore, the acorns are normally sown in ~5 cm deep furrows and covered with soil for protection (**Figure 12**).

Figure 11 Damage caused by deer and voles. (a) Young oaks (*Quercus petraea*) heavily browsed by red and roe deer (*Cervus elaphus*, *Capreolus capreolus*; Hainich, east Germany); (b) young beech (*Fagus sylvatica*) ring-barked by voles (*Microtus agrestis*) (Zwiefalten, south-west Germany).

Direct seeding of birch (mainly *Betula pendula*) has recently received renewed attention as a means of restocking areas and establishing nurse crops after damage caused by hurricanes and SO_2 emissions (**Figure 13**).

Planting is the general alternative if the preconditions for natural regeneration are not met. The following are some of the advantages of planting over natural regeneration:

- independence with regard to tree species selection (from existing old growth)
- independent of mast years
- even, and calculable, stocking levels across the entire area
- reduction of the vulnerable period for young trees.

The possible objectives of planting are detailed in **Table 1**.

Planting can be carried out under the shelter of existing stands, as well on open areas, thereby resembling natural regeneration in some respects.

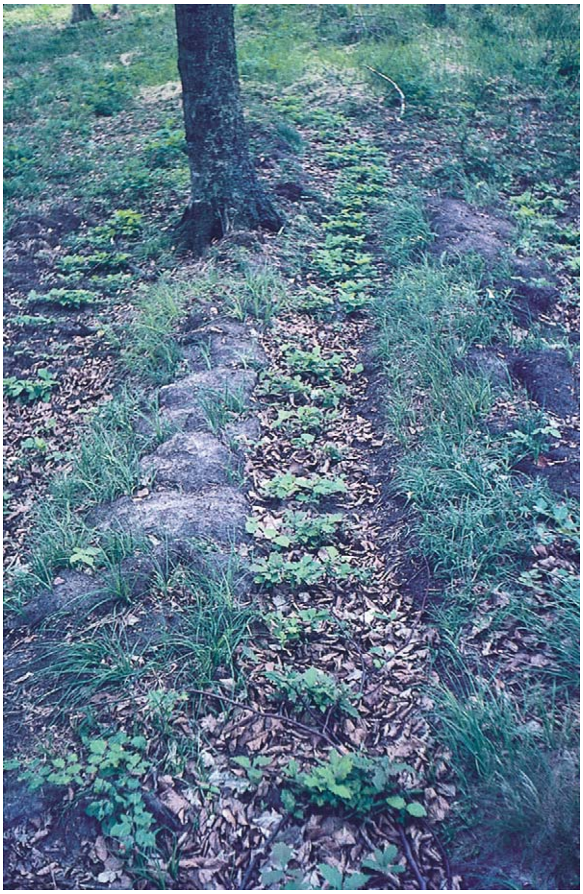

Figure 12 Successful direct seeding of acorns (*Quercus petraea*) (Rohrbrunn, south-east Germany).

Figure 13 Rehabilitation of forests following emissions. (a) Dead stand as a result of SO_2 emission (Ore Mountain, east Germany); (b) birch (*Betula pendula*) established by direct seeding on snow as a nurse crop. Beech (*Fagus sylvatica*) to be planted shortly afterwards under its shelter (east Germany).

Plant Types

A large variety of forests plants varying in their stage of development, size, sturdiness, source of origin, and type of production (bare-rooted or container plants) are available according to the different needs of the forester (**Table 2**).

Generally, small plants can be used when the subsoil texture is similar to that found in agriculture. In the past, soil preparation was commonly undertaken to reproduce similar conditions.

The increased vigor of ground vegetation species in the last three decades has meant an increase in the loss of young trees through competition. Additionally, deer browsing has become a serious problem regionally because of higher deer populations. Consequently, there has been a shift towards taller and sturdier plants (**Figure 16**).

Transplants and container plants are predominantly produced by large private nurseries (**Figure 18**).

In the EU the collection of seeds, plant production and distribution are organized according to legal regulations and special laws in several countries, in order to ensure that the origin of the seeds is documented through all stages of production down to the receipt by the consumer. In spite of these regulations, grave cases of willful deceit have occurred, resulting in the closure of several nursery enterprises.

The globalization of plant production in different countries has generated increased problems in ensuring

Table 1 Objectives of different planting types and planting procedure

Planting objective	*Procedure*
Production forest	Mainly planting across the entire area with one species only
Protection forest	Great differences according to the protection objectives, for instance: • erosion control • nature protection: reintroduction of rare species by planting single trees at varying distances or on special sites, increasing biological diversity
Recreation forest	Concentrating on forest edges: favoring esthetic values, avoiding straight lines, increasing visual diversity
Nurse crop	Planting of a pioneer species on large exposed open areas in order to create favorable ecological conditions under the shelter of which the final crop is later established
Underplanting	Planting shade-tolerant trees with a silvicultural function (shading the valuable trunks of dominant trees against epicormics, shading the forest floor to prevent the development of ground vegetation, an obstacle to later natural regeneration)
Enrichment planting	Introduction of additional tree species into incompletely regenerated regrowth (mainly after natural regeneration; **Figure 14**)
Filling-in	Stocking areas of unevenly developed naturally regenerated regrowth with plants of the same species
Beating-up	Replacement of dead plants 1 or 2 years after establishing the original plantation

Figure 14 Norway spruce (*Picea abies*) enrichment planting in a gap naturally regenerated by beech (*Fagus sylvatica*) (Donaueschingen, south-west Germany).

an appropriate control over the genetic quality of the plant material. Some forest enterprises, have, therefore, intensified natural regeneration and the collection of wildlings on their own property.

Planting Techniques

Although a great number of tools and machines have been developed during the last 200 years, hoes that produce narrow slits are still dominating (**Figure 19a**). New techniques even for steep terrain are under construction (**Figure 19b**).

Plant Density

The number of plants per unit area may vary between 6000 (beech) and 500 (poplar) plants per ha depending on the tree species and on several preconditions and characteristics of the plant material and the restocking area (**Table 3**).

Spacing

Row or quadrangular spacing is common on large areas. Common spacings are 3×1 m or 3×1.5 m and 2×2 m or 2.5×2.5 m. Row spacing involves lower planting costs, as well as savings later during tending operations, such as weeding, and has, therefore, increased importance.

Trials have recently been established to study the effect on saplings of planting in small groups (nest-planting, e.g., 100 nests per ha with 25 plants each, with 1×1 m spacings within the nests), with the spaces between groups left to natural succession, or else either sown or planted. The numbers of plants required, and as a consequence the costs, are lower than for traditional planting designs. Final results are not yet available, however.

Group Mixtures

There is an increasing tendency to establish forests with two or more species in the canopy. Unlike traditional plantings, these mixtures should always be established in groups of at least the size of the crown of a final crop tree (i.e., 50–150 m^2), thereby ensuring that the species which grow more slowly initially will not be overgrown by the faster ones.

Mixtures in rows have mostly proved unsuccessful because one species suppresses the other during a certain phase of development (**Figure 20**).

Plantation as a System

Plantations are in a certain sense a system, based on a combination of many preconditions and procedures. When establishing a new stand, on many sites the forest owner has the following options:

Table 2 Plant types used in forestry practice

Plant type	*Description/suitable for*
Seedlings	Seedlings spend 1 or 2 years in the seed bed; 10–30-cm tall seedlings are planted in the open if no humus layer is present. Litter and ground vegetation impede planting and seedling development. Although attractive for their low prices and planting costs, seedlings may be susceptible to high risks, for example, deer browsing (**Figure 15**)
Transplants	After 1–2 years in the seed bed, the seedlings are transplanted and left for 1–3 years in a new bed ($1+1$ to $2+3$), attaining heights of 30–80 cm. Transplanting reduces height growth, but favors the development of a compact root system with more fine roots, thereby simplifying the planting procedure and improving growth in the field. Undercutting plants in the seed bed also stimulates development of a compact root system. Due to the high costs of transplanting, undercutting has gained popularity. Transplants remain the most commonly used in practice, however (**Figure 15**)
Saplings	Plants of >1 m in height. Mainly broad leaves. Most common in horticulture. Important in earlier centuries for establishing standards in coppice stands and as solitary oaks. Increasing importance today because less susceptible to competition from ground vegetation and deer browsing. New planting techniques may lead to a reduction of the high planting costs (**Figure 16**)
Wildlings	Naturally regenerated young plants, 30–100 cm tall, extracted for the purposes of filling up incomplete young stands, for underplanting and for transplanting in a nursery. Wildlings have a proven site adaptation. A further great advantage is their availability. They often suffer from dieback if transplanted into open land, however, due to poor root development
Container plants	Seedlings grown in blocks of containers under semiindustrial conditions in plastic greenhouses for a few months. Low costs because of integrated lines from production to planting. Highly attractive to large-scale forest enterprises in the boreal zones. Of little importance in temperate zones because they are too small to withstand the intensive competition posed by the ground vegetation (**Figure 17**)

Figure 15 Beech (*Fagus sylvatica*) seedlings and transplants: $1+0$-year-old seedling only reach $\sim$10 cm in height and normally cannot be used in the open; $2+2$-year-old transplants, however, reach $\sim$80 cm in height and are able to withstand most of the dangers in the open.

- In order to save money in the first year the forest owner may choose small plants, which are cheap and easy to plant, but normally require intensive soil preparation. In the following years, however, several clearings of the competing ground vegetation may be necessary, as well as protection by fencing.
- As an alternative, the forest owner may buy saplings, which are much more expensive and difficult to plant, but do not require any further expenditure.

Upon reaching the thicket stage, the sum of the costs may be much lower using the second alternative and, additionally, the stand has reached this stage in a much shorter period of time. Apart from the differing growth rates and requirements of the young plants and the varying intensity of ecological influences, the economic aspects, such as the time of investment, as well as the interest rate, may strongly influence the owner's decision. Unfortunately, little experimental work has been carried out by forest research institutions and forest enterprises in order to obtain reliable data comparing the advantages and disadvantages of all of the factors and procedures influencing the establishment of young forest stands. In fact, this is a very complicated aspect of silvicultural research for the following reasons:

- Experiments of this type require long observation periods (10–20 years).
- There are many factors to be considered, not to mention their interactions.
- Some factors, such as weather conditions, browsing pressure, and ground vegetation competition, may vary from one year to the next.
- The conditions in forest practice are never stable over long periods of time.
- Finally, all these factors may have very long-lasting effects and even influence the final products.

Figure 16 Saplings do not need cleaning and fencing. (a) Beech (*Fagus sylvatica*) saplings planted in a gap caused by storm in a Norway spruce (*Picea abies*) stand (south-east Germany); (b) sycamore (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and wild cherry (*Prunus avium*) saplings planted in a wet area within a young beech stand (Ettenheim, south-west Germany).

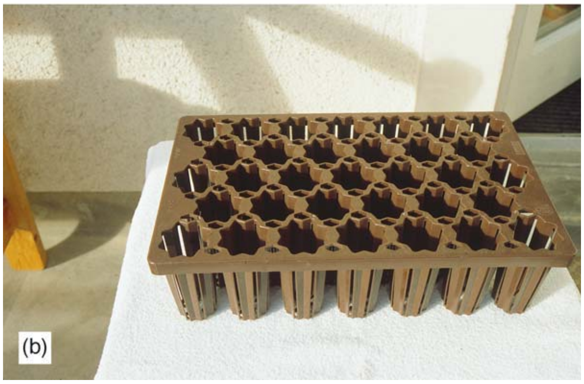

Figure 17 Container types commonly used in Sweden. (a) Container with small root volume for Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) (Kopperfors multi-pots); (b) modern, much larger star pots for rough subsoil conditions.

Treatment and Promotion of the Regrowth

When young plants have reached an average height of ~50 cm, the differences between naturally and artificially established young stands tend to even out, except possibly for differences in density . Therefore, they can be discussed jointly.

Some of the following procedures may be essential in order to achieve the goals mentioned previously.

Regulating the Light Conditions

Young plants growing under the canopy of old trees increasingly need sufficient light, regardless of the type of establishment. A progressive opening of the canopy is an essential silvicultural procedure during the early phases of development. The speed at which the canopy is opened depends on the light requirements of the different tree species, and may take between 5 (oak) and 20 years (beech; **Figure 21**), or possibly even longer (silver fir).

Removal of Damaged Young Plants

The felling of canopy trees over existing regrowth often results in damage to some of the young plants during both harvesting and extraction procedures. These damaged saplings tend to become malformed, and should therefore be removed by cutting them down to the stump. Broad leaves tend to resprout

Figure 18 Private nursery (a) with long machine workable beds (west Germany) and (b) modern fully equipped, automatically managed greenhouse (Sweden).

Figure 19 (a) Various modern planting hoes; (b) modern sapling planting machine.

immediately, replacing the damaged individuals with straight and vigorous sprouts within a few years.

Regulation of Mixtures

Young naturally regenerated stands often contain more than one tree species. This species mixture has to be regulated prior to reaching the thicket stage (2–3 m in height). As has been mentioned already, the most common type of mixture is that of two or more final canopy species. If not planted in groups, the individuals of the different tree species should at this point be arranged into groups of at least the size of a grown crown. This ensures that none of the tree species will be entirely suppressed by the others because of diverging growth dynamics in particular development periods.

Regulation of Density

Naturally regenerated stands often exhibit very high tree densities. Plantations, too, are often naturally enriched by wild seedlings of pioneer species.

Very dense regrowth of certain species, for example, Norway spruce, often requires a long time to differentiate and to start developing. A systematic reduction of the plant numbers, e.g., in the form of line thinnings, or the selection of dominant individuals and the elimination of some of their competitors prior to reaching the thicket stage, therefore, helps to initiate differentiation within the young stand and improves its further development immediately.

Removal of Ground Vegetation and Climbers

Grasses especially may cause fire hazards in dry periods and may have to be cleaned even if they are no longer competitors for the saplings (**Figure 22**). In some areas, moreover, climbers such as *Rubus fruticosus* or *Clematis vitalba* may impede the development of the saplings even when they have already reached a height of some meters.

Negative Selection, Shaping, and Pruning of Saplings

There are several situations which may justify tending measures in the early stages of young stand development, i.e., before they have reached the thicket stage:

1. Some very dominant individuals already display poor form. These young trees will suppress their better-formed, but slightly less competitive

Table 3 Factors affecting the plant density of plantations

Factor	*Influence on plant density and the subsequent procedures*
Natural pruning ability of the tree species	Most broad leaves lose their branches easily when densely planted, thereby ensuring a high-quality lower stem. They are, therefore, maintained at close spacings in their youth. Poor self-pruners, including most conifers, poplars, and wild cherry must be pruned artificially if high-quality timber is desired
Quality of planting stock	Freshly harvested plant material exhibits higher survival rates. Therefore, the plant numbers can be reduced
Weather conditions at time of planting	Rainy weather with low temperatures at planting and for some days after improves successful establishment. The choice of an appropriate planting season will also allow for a reduction in the number of plants
Plant size	Seedlings and small transplants may experience higher losses after planting. Therefore, more plants are required than is the case with taller plant material
Type of restocked area	Young plants growing under the canopy of the old stand are less susceptible to climatic stress, and attacks by insects and mice, and will therefore survive better. Their stem form also benefits from the shade. Consequently, the number of plants can be reduced
Vigor of ground vegetation	Thick layers of grasses, brambles (*Rubus fruticosus*), and bracken (*Pteridium aquilinum*) result in high losses. Therefore, taller and more vigorous plants are necessary
Anticipated browsing pressure by mice and/or deer	Based on experience, damage by deer and mice has to be anticipated and compensated for with greater plant numbers

Figure 20 Line planting normally results in pure stands because one species will always dominate, and should, therefore, be avoided.

neighbors before they reach the thinning stage. Timely elimination of these individuals will raise the quality of the whole stand and improve the selection of potential crop trees at a later stage.
2. Removal of forks of dominant individuals (often called 'formative pruning') may improve their quality, where only a limited number exist.
3. Pruning of big side-branches in groups of naturally regenerated regrowth may also help to improve the quality of the whole stand.

Early tending normally significantly reduces the effort required during the thinning phase.

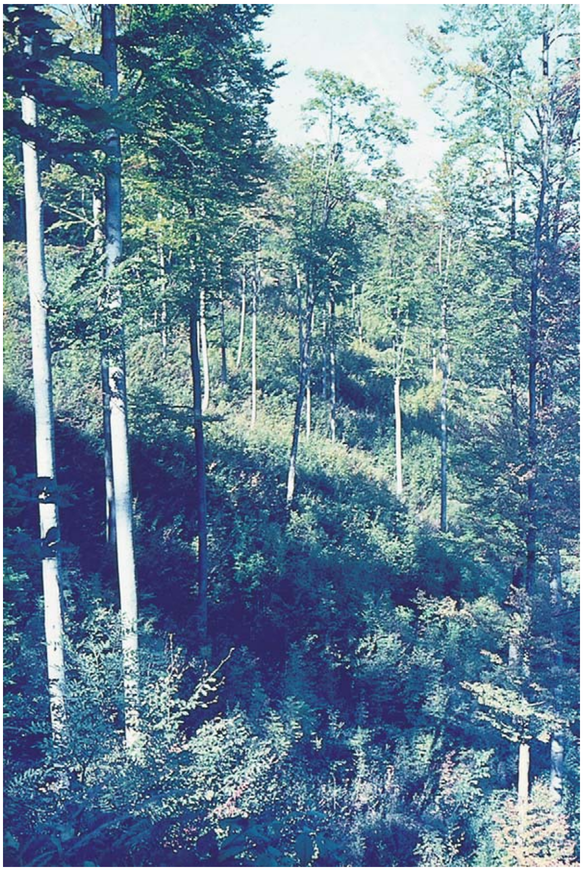

Figure 21 Final stage of beech (*Fagus sylvatica*) shelterwood system (Czech Republic).

Final Considerations

Stand establishment and early treatment procedures have a direct influence on the intensity of the subsequent measures. Carefully established and well-treated young stands will later need little input in terms of the regulation of mixtures, increasing the proportion of valuable timber or aesthetic

Figure 22 Dry grasses often cause fires in young plantations (Kelheim, south-east Germany).

improvements. Initial omissions, on the other hand, may later require a great deal of energy and financial input in order to achieve the original goals. Often it is not possible to compensate for a delay in tending in the early phases of stand development. The stand will never reach the possible optimum in terms of quality or fulfillment of its functions and services.

Apart from these direct interactions between early and later interventions, the intensity of stand establishment procedures has an effect over the whole life of a stand. The species distribution, horizontal texture, and even to some extent vertical structure are largely fixed and adaptation to suit new management concepts is limited – even more so with increased age.

All procedures necessary to establish and treat young stands are investments in a distant future. Many forest owners, and society as a whole, are not willing or able to spend much money and effort on forests which they will never harvest. Furthermore, it is almost impossible to predict the future needs of society with regard to production and services of the forests. For instance, is it possible that today's quality standards for the production of valuable timber will no longer be needed in the future?

Intensive and high-quality stand establishment and treatment, therefore, require a more ethical approach: how much should the current generation invest in the future of its children and their progeny?

See also: **Afforestation**: Species Choice. **Operations**: Nursery Operations. **Plantation Silviculture**: Forest Plantations; Stand Density and Stocking in Plantations; Tending; Coppice Silviculture Practiced in Temperate Regions.

Further Reading

Burschel P and Huss J (1997) *Grundriss des Waldbaus: Ein Leitfaden für Studium und Praxis*, p. 487. Berlin: Parey Buchverlag.

Joyce PM and OCarroll N (2002) *Sitka Spruce in Ireland*, p. 201. Dublin: COFORD.

Joyce PM (ed.) (1998) *Growing Broadleaves: Silvicultural Guidelines for Ash, Sycamore, Wild Cherry, Beech and Oak in Ireland*, p. 144. Dublin: COFORD.

Hunter ML (1990) *Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity*, p. 370. New Jersey: Prentice-Hall.

Piussi P (1994) *Selvicoltura Generale*, p. 421. Torino: UTET.

Savill P, Evans J, Auclair D, and Falck J (1997) *Plantation Silviculture in Europe*, p. 297. Oxford: Oxford University Press.

Schütz J-P (1990) *Silviculture 1: Principes d́éducation des forêts*, pp. 243. Lausanne: Presses polytechniques et universitaires romandes.

Smith DM (1986) *The Practice of Silviculture*, 8th edn, pp. 525. New York: John Wiley & Sons.

AGROFORESTRY

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Introduction and Definition

Agroforestry is a term for practices where trees are combined with farming, as well as for the interdisciplinary subject area embracing land use systems, at a range of scales from that of the field to the planet, that involve interactions amongst trees, people, and agriculture. Put simply, agroforestry is where trees interact with agriculture. There is a long tradition of agroforestry practice in many parts of the world, but it has come to scientific prominence, and has emerged as a major focus in international development, only during the last quarter of a century. The term clearly derives from uniting two subject areas, forestry and agriculture, which for a long time, but not necessarily for good reasons, were