Chapter

Basic Theory and Methods of Afforestation

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Abstract

Afforestation is an important practice in silviculture. This chapter outlines the forest site, site preparation, selection of afforestation materials in the process of afforestation. The life cycle of forests is very long, and it is difficult to change them once afforested. Therefore, the forest site must be analyzed in depth before afforestation to maintain the success of afforestation and the healthy growth of forests later. Forest sites are mainly affected by environmental and human activities. To facilitate afforestation, it is necessary to evaluate and classify the forest site factors and achieve a suitable species planted on the right site. Site preparation is also based on site classification. It is usually carried out after determining the type of afforestation land, divided into mechanical land preparation and chemical methods. An essential task of site preparation is to maintain soil moisture and promote seedlings' survival and growth. Afforestation materials are mainly divided into three categories: seed, seedling, and cutting. The choice of these three types of afforestation materials and methods is related to site conditions, tree species, and age.

Keywords: afforestation, forest site, site preparation, afforestation material

1. Introduction

One of the most important afforestation principles is to adapt the trees to the site [1, 2]. In a narrow sense, a forest site refers to afforestation land. In a broad sense, it refers to all factors that affect forest growth, including natural factors such as climate, soil, vegetation, and human activities. These factors constitute the forest site factor. From an ecological point of view, these factors interact with the forest and will change over time. From this perspective, forest factors affect the survival rate of afforestation and affect the forest's entire life cycle. The systematic study of forest sites has a history of over 200 years and is still continuing. Most forest site research objects are mountain forests. With the continuous development of urban forestry, urban forest site research also appears [3]. The forest site conditions of mountain forests (**Figure 1**) are entirely different from urban forests (**Figure 2**).

Forest site factors can have many combinations, each of which determines the corresponding suitable tree species and its afforestation methods, and even subsequent management methods. Therefore, the site factors of the forest should be scrutinized and analyzed before afforestation to avoid afforestation failure. After the type of afforestation land is devised, afforestation tree species and afforestation methods suitable for the type are selected according to the cultivation objectives.

Figure 1.
Pinus tabulaeformis *forest in Song Mountain, Beijing.*

Figure 2.
Pinus tabulaeformis *forest in city plain area, Beijing.*

Another critical factor affecting the success or failure of afforestation is the healthy growth of the root system. Whether it is a seed or a seedling, only rooting or rooting after transplanting can form a forest [4]. Site preparation promotes and ensures that the root system can be closely integrated with the soil through different methods. Furthermore, promote the root system to absorb enough water.

Common afforestation materials include seeds, seedlings, and cuttings. Each material has its advantages and disadvantages. The selection of suitable afforestation materials should fully consider the characteristics of the tree species. Many studies have shown that the age of planting materials, planting season and time, and methods all affect the survival rate [5–7].

In summary, this chapter mainly introduces the concept of forest site, analyzes different site factors, and summarizes forest site evaluation and classification.

Next, the types of afforestation land and standard land preparation methods are introduced. Finally, we outline the three different afforestation materials and their planting characteristics.

2. Forest site

2.1 Concept of forest site

Forest is an important part of the ecosystem, which means silviculture is ecosystem management. Afforestation must be carried out from an ecosystem perspective, specifically light, water, carbon dioxide, and various nutrients. In the traditional sense, forest site refers to the overall environment of an area [8]. Generally speaking, the forest site has two meanings. First, it refers to geographic location; second, it refers to integrating environmental conditions (biology, soil, and climate) in a particular location [1]. The forest site remains unchanged for a certain period, especially climate conditions, and irrelevant with the tree species growing on it. Meantime, some experts refer to the forest site potential and productivity are not constant but change over time [9, 10]. Forest site and its quality should be considered first in afforestation activities.

Forest Site research in various countries around the world mainly focuses on on-site classification and site productivity evaluation. In the late 18th century, European silviculturists tried to classify forestry's productivity by compiling stand yield tables [11, 12]. In 1946, multifactor forest site classification developed into a comprehensive multifactor classification based on climate, geography, soil, and vegetation, namely the Baden-Württemberg forest site classification [13]. Since the 1950s, multifactor site classification methods have been widely used in Canada and the United States [14, 15]. Skovsgaadr and Vanclay's [16] review paper mentioned that there are two methods to assess forest site productivity include geocentric (earth-based) or phytocentric (plant-based) methods.

With the intervention of mathematical methods such as remote sensing, geographic information system, computer technology, and multivariate statistical analysis, forest site classification has gradually moved from qualitative to quantitative or a combination, from the single-factor to the ecological multifactor classification for multi-purpose forest resource management [17].

2.2 Forest site factors

2.2.1 Environmental factor

Environmental factors include climate, topography, soil, and hydrology factors. Climate factors determine the water and heat conditions that plants depend on, thus forming vegetation types. Meteorologists divided climate into macroclimate and microclimate base on the ecological scale. The macroclimate has often been referred to as that climate resulting from air masses' passage [18]. The microclimate is the suite of climatic conditions measured in the localized areas near the earth's surface [19]. Macroclimate mainly affects tree distribution [20]. For afforestation, the foresters pay more attention to microclimate factors. Light, temperature, rainfall, solar radiation, wind speed, and other factors affect tree growth and forest productivity [21, 22].

The topography factors include elevation, aspect, slope, position, slope type, etc. Elevation and aspect appeared to be fundamental variables in the assessment of forest site quality [20]. In mountainous areas, tree height and forest productivity decreased as elevation increased [23, 24]. The increase in elevation within a specific area can reduce temperature, decrease evaporation, shorten the frost-free period, increase precipitation and atmospheric and soil moisture, increase soil fertility, dense vegetation, or change vegetation types [23–25]. The light of different aspect is usually different, which can indirectly influence the soil moisture content; the south has more soil moisture than the north [14]. Furthermore, sites with lower slopes have better soil quality and higher nutrients and soil moisture than sites with steep slopes [14].

Soil is the substrate for tree growth and the forest site's essential factor, and it can influence root distribution and the ability to take up water and nutrients exchange [26]. Before afforestation, it is essential to assess the soil factors, mainly soil type, soil layer depth, soil texture, soil structure, soil nutrients, pH, and soil erosion [27]. South African forest site classification system has six soil variables (parent material, soil classification, effective soil depth, depth limiting material, topsoil organic matter, and topsoil texture), and these variables are dynamically changing [28]. It is necessary to collect many soil samples to represent the actual site situation despite this is very expensive.

Hydrology factors include groundwater depth and seasonal changes, groundwater salinity and salt composition, the presence or absence of seasonal stagnant water, and its duration. For some forests in plain areas, hydrology plays a significant role. Such as Ningxia, China, has a high groundwater level and heavy soil salinization [29]. Controlling the rise of the groundwater level is the key to forest site improvement in the irrigation area. When afforestation in mountainous areas, generally does not consider the groundwater level because it is difficult for the tree roots to reach the groundwater layer, and more consideration is streamflow. Moisture tends to increase with elevation and gets wetter on the northern aspects [30].

At present, there are many monitoring instruments that can monitor forest meteorological factors, including radiation, temperature, humidity, wind speed, wind direction, etc. (**Figure 3**). It provides an important data source for afforestation and future forest management.

Figure 3.
A weather station that can monitor a variety of climate factors.

2.2.2 Vegetation factor

Forest vegetation types and the distribution comprehensively reflect different site conditions, especially for soil conditions. Many studies indicated that vegetation factors could refect soil fertility, soil moisture, soil nutrient, and indirectly site quality [31, 32]. In the cold-temperate forests of Russia, Northern Europe, Canada, plant species or plant communities are widely used to evaluate sites [33–35]. Zhang Wanru [36] researched the use of vegetation types as the basis for forest site classification systems in China. However, in China, many plantations are damaged, and it is not easy to use indicator plants to evaluate these forest sites.

2.2.3 Human activity factor

Human activity can affect the forest; some are negative, such as removing litter from forest land and mining groundwater seriously, which will deteriorate the site, cause soil erosion, and lower groundwater levels. Some human activities can severely impact forests, such as the destruction of forests caused by the slashing and burning of agricultural activities in Europe [37]. From an ecological perspective, forest management is also a disturbance to forest growth, but most of them are positive effects, such as afforestation and reforestation [38] (**Figure 4**). Human activity factors are generally analyzed in forest site assessment as one of the driving forces for forming or changing other site factors, not as a constituent factor of site condition types.

2.2.4 Forest site dominant factor

Many factors affect the forest site and tree growth; see 2.2.1, 2.2.2, and 2.2.3. However, some factors have little effect on the growth and development of trees, and some factors play a decisive role. These decisive factors are called dominant factors. Generally, the climate is the dominant factor at the regional scale, and landform and soil are the dominant factors at the management unit scale [39]. There are two methods to determine the dominant factors. One is to analyze the relationship between each environmental factor and the essential living factors (light, heat, air,

Figure 4.
Reforestation site after clearcutting.

water, and nutrition) of trees to determine the most significant impact on living factors. On the other hand, it is to find out those environmental factors in extreme conditions and restrict plant growth [1]. Generally, the most restrictive factors play a leading role, such as drought, severe cold, strong wind, and extreme weather. For example, in Saihanba Forest farm, some afforestation area has very thin soil; the dominant factor is water (**Figure 5**).

2.3 Forest site classification

The forest site classification refers to a traditionally used method to determine the suited tree species in the right site and perform macro-classification and micro-classification [1, 40]. The system generally consists of multiple (level) taxa depend on the scale. The climate is the primary effect factor at the landscape and regional scale, whereas topography and soil at the local scale [27]. Usually, afforestation always tends to pay more attention to micro-forest sites because it directly relates them to the tree survival rate and have similar management properties. As climate change is concerned, afforestation is increasingly considering the macro-regional scales and the forest life cycle.

Figure 5.
Young Pinus sylvestris *forest of Saihanba Forest farm is planted on a thin site.*

Site classification methods are divided into two groups, single factor and multifactor methods [41]. Single factors classification systems depend on one factor to express a forest site, such as soil, indicator plant, or climate. The soil classification system was wildly used in many countries, like the United States and Ireland, to quantify site quality and determine its suitability for afforestation or timber yields [42–44]. Indicator plants or plant communities could also indicate a forest site's fertility and moisture status, especially in some humid climate regions or coastal countries, such as Scotland, Britain, Ireland, Finland, and British Columbia in Canada [31, 33, 34, 45].

Recently, with the rise of sustainable forest management, multifactor forest site classifications system has developed rapidly. The biogeoclimatic ecosystem classification in British Columbia has combined the climate, vegetation, and soil factors to assess the site productivity and guide the afforestation and forest management [46, 47]. The Finland upland forest site classification system consists of six clusters depend on the vegetation types and the site water conditions [34]. In Germany, the Baden-Wurttemberg silviculture forest site classification has three levels, landscape level, regional level, and local level. The landscape level contains subunit called growth districts, divided into smaller areas at the regional level depending on the climate and topographic; the basic ecological units are called site units according to soil and vegetation [48].

In China, the research group of "China Forest Site Classification," headed by Zhan Zhaoning, proposed a site classification system in 1989 [49]. Zhang Wanru formally established a site classification system based on timber forests [36]. The Chinese Forest Site Classification and Chinese Forest Site are national classification systems. Forest Site Classification system in China can be divided into six levels [49]: site area, site region, site sub-region, site type district, group of site type, and site type. According to this classification system, China divides forest sites into 8 site regions, 50 site areas, 166 site sub-areas, 494 site type communities, 1716 site type groups, and 4463 site types.

2.4 Forest site quality and assessment

Site quality refers to a given forest's production potential on a forest site or forest land's ability to grow trees [1, 42]. Site quality impact factors include climate factors, soil factors, and biological factors, determining forest growth quality and quantity. Generally, forest sites' potential productivity should be predicted and evaluated before afforestation, and the same or similar forest sites should be classified.

Forest site quality evaluation methods can be simplified into direct and indirect methods. The direct evaluation method refers to using the forest's harvest and growth data to evaluate site quality, such as volume, tree height, site index. In 1881, the German forest scientist Von Baur used the stand average tree height to indicate site class; Assmann recommended using top tree height instead later in 1961 [50, 51]. In the United States, from about 1910 to 1925, there were three different site evaluation methods: some people strongly agreed to express by volume; another group of people favored using the "forest site type system", which is based on the plant to indicate site types; the third part support the use of site index [42]. The indirect evaluation method refers to assess site quality with the characteristics of physiographic, climate, edaphic variables, and understory [52].

Site index (SI) is the most commonly used, relatively density-independent quantitative indicator of site productivity [53]. It was defined as the top height of the trees at a specified (index) age [54]. Many countries used site index to evaluate the site quality among different species, like *Picea abies* in Germany, *Quercus suber* in Portugal, *Eucalyptus Grandis* in South Africa, *Pinus tabuliformis* in China [55–58]. Site index established by the multiple regression analysis methods indicates the relationship between the average height of the dominant tree or tallest trees (also called the upper canopy height). We can clearly see the highest height from the site index table that Chinese pine can grow on different sites and at different ages [57] (**Table 1**).

Some scientists used edaphic or physiographic variables in site quality models [59, 60]. In contrast, some scientists have combined the site index with climate data to establish a stable site index that evaluates site quality under climate change [61] (**Table 2**). Using a site index to test the site quality of uneven-aged-mixed forest stands has low accuracy. McNab et al. [62] used the indicator species method combined with the site index to evaluate the hardwood stands' site productivity in Western North Carolina and pointed out that the good quality site's predicting accuracy is higher (85 percent accuracy) than the poorer site (60 percent accuracy).

Tree age/a	**Site index**						
	4	**5**	**6**	**7**	**8**	**9**	**10**
15	2.2 ~ 2.9	3.0 ~ 3.6	3.7 ~ 4.3	4.4 ~ 5.0	5.1 ~ 5.7	5.8 ~ 6.5	6.6 ~ 7.2
20	3.0 ~ 4.0	4.1 ~ 5.0	5.1 ~ 6.0	6.1 ~ 7.0	7.1 ~ 8.0	8.1 ~ 9.0	9.1 ~ 10.0
25	3.5 ~ 4.7	4.8 ~ 5.9	6.0 ~ 7.0	7.1 ~ 8.2	8.3 ~ 9.4	9.5 ~ 10.5	10.6 ~ 11.7
30	3.9 ~ 5.1	5.2 ~ 6.4	6.5 ~ 7.7	7.8 ~ 9.0	9.1 ~ 10.3	10.4 ~ 11.5	11.6 ~ 12.9
35	4.1 ~ 5.5	5.6 ~ 6.8	6.9 ~ 8.2	8.3 ~ 9.6	9.7 ~ 10.9	11.0 ~ 12.3	12.4 ~ 13.7
40	4.3 ~ 5.7	5.8 ~ 7.1	7.2 ~ 8.6	8.7 ~ 10.0	10.1 ~ 11.4	11.5 ~ 12.8	12.9 ~ 14.3
45	4.4 ~ 5.9	6.0 ~ 7.4	7.5 ~ 8.8	8.9 ~ 10.3	10.4 ~ 11.8	11.9 ~ 13.3	13.4 ~ 14.7
50	4.5 ~ 6.0	6.1 ~ 7.6	7.7 ~ 9.1	9.2 ~ 10.6	10.7 ~ 12.1	12.2 ~ 13.6	13.7 ~ 15.1
55	4.6 ~ 6.2	6.3 ~ 7.7	7.8 ~ 9.3	9.4 ~ 10.8	10.9 ~ 12.3	12.4 ~ 13.9	14.0 ~ 15.4

Table 1.
Site index table of Pinus tabulaeformis *Carriese plantation.*

Variables	**Subvariables**
Summer/annual temperature	Mean annual temperature (°C)
	Mean temperature warmest quarter (°C)
	Mean temperature May to Sept. (°C)
	Max. temperature warmest month (°C)
	Mean July temperature (°C)
Winter temperature	Mean January temperature (°C)
	Min. temperature coldest month (°C)
Precipitation	Annual precipitation sum (mm)
	Precipitation sum warmest quarter (mm)
	Precipitation sum May to Sept. (mm)
Continentality	Continentality index
	Tmax_wm-Tmin_cm (°C)
	T_wq-T1 (°C)
Elevation	Elevation (m)

Table 2.
Characterization of the environmental variables for spruce and beech plots used for site index model fitting.

3. Site preparation

Site preparation is a crucial activity affecting the survival rate of afforestation. It is the step after forest classification and before planting. Site preparation is various among afforestation land types. The treatment applied to slash, ground story vegetation, forest floor, and soil to exclude or reduce competing vegetation, pests, fire, and make the site suitable for afforestation or natural regeneration [2]. Site preparation usually includes mechanical and chemical methods, include mounding, scalping, trenching, bedding, chopping, herbicide, prescribed burning, et al.

3.1 Types of afforestation lands

The types of afforestation land are different in each country. Some countries have diverse terrains, such as China and the United States, and some countries have a few terrain types, such as some European countries [1]. This is the primary reason that affects the type of afforestation land. There are five types of afforestation land in china, namely barren mountains and wasteland, farmland, logging, and burning land, and secondary forest land [1]. The site quality of farmland is high, and the site quality of other afforestation sites is poor. In Ireland, the country's afforestable land was divided into four types based on biophysical factors, biological factors, national and EU designations and policies, and potential afforestation, respectively [63]. Kadam et al. [17] used the Land Suitability Analysis (LSA) method to divide the afforestation land types of Western Ghat in India into four classes (highly, moderately, marginally, and not suitable); the main dividing factors are topographical factors, soil factors, and meteorological factors.

3.2 Mechanical methods

The primary purpose of mechanical methods is to remove undesirable plants, reduce their growth, protect the surface soils, and improve site quality [2]. Mechanical methods can redistribute the dead vegetation, like slashing or chopping; they also can reshape the soil surface, like bedding, plowing, and mounding.

Mechanical site preparation can influence the species diversity, quantity, composition of underground vegetation. Sebesta et al's research showed that mechanical site preparation decreased the species richness of the understorey and increased the number of non-native species coursed by soil disturbance [64]. Newmaster et al. revealed no differences in the frequency of native species and composition in mechanical site preparation [65].

Proper site preparation methods, either mechanical or chemical methods, can improve both conifers and hardwoods' survival rate and growth [66–68]. However, in coniferous and broad-leaved mixed forests, different site preparation methods lead to different effects. Cain et al's research showed that mechanical or chemical site preparation methods reduced the density and stocking of Oak in a pine-hardwood mixed forest [69]. Mohler et al's study also mentioned that red Oak trees had benefited most from the larger gaps without site preparation [70]. Therefore, mechanical methods should be applied carefully and adapted to site conditions.

The cost of mechanical site preparation should be a consideration. Such as slash can be expensive or course diseases, but it can reduce forest fires' risk, protect the seedlings, and provide organic and inorganic nutrients [71–73]. The equipment and the labor cost is expensive for afforestation (**Figure 6**).

Figure 6.
Use a tractor for site preparation.

3.3 Chemical methods

Chemical methods usually refer to herbicides, pesticides, and fertilization. Chemical site preparation, like herbicides or pesticides, are both harmful and beneficial to site quality. The herbicide can promote trees' early survival rate and have a long-term effect on maintaining forest growth. However, people are also concerned about the environmental effect and cost [74]. It should be noted that herbicide use is related to the length of time of different research. Much long-term research of longleaf pine showed that herbicide applied for site preparation increased seedling growth and had a lasting improvement effect. However, some short time studies reported that the longleaf pine seedling survival was unaffected or reduced by herbicide [68, 75, 76]. Compared with the mechanical methods, herbicides' cost looks more efficient; it was wildly used in South American, especially in pine plantations [66]. Callaghan et al's study showed that herbicide could reduce the hardwood competition and improve the *Pinus taeda* growth, as it costs less [77].

Fertilization can supplement the nutrient loss of the soil caused by logging and increase the seedlings' survival rate. Nitrogen, phosphorus, and potassium (NPK) are the main nutrient elements in fertilizers [78]. Although the fertilization costs a lot, it can improve either hardwood or conifer seedling growth [79, 80]. Fertilization is also used for larger trees. A fertilization study for conifers in Finland showed that after ten years of fertilization if harvested as sawlogs or pulpwood, the additional volume increment was 25% and 75%, respectively, higher than non-fertilized forests [81].

3.4 Site water management

Site water management also plays an essential role in site preparation in certain areas. If drainage is not considered in some low-lying afforestation lands, the afforestation will fail (**Figure 7**). Flooding is a treatment that use channel or dikes to guide the water from afforestation site with high moisture, like coastal and riparian lands, shrimp ponds, swamps. Flooding or irrigation also can reduce the salt and alkali content of saline soil [82]. Irrigation is an essential way in improving site water conditions in water-deficient areas, such as the Middle East, South Africa, China, India, especially for the cultivation of timber forests [83–85].

Figure 7.
After a rain, the accumulation of water in afforestation land caused the death of seedlings.

4. Afforestation materials

4.1 Afforestation with seeds

Direct seeding is a widely used afforestation method. Compared with the seedling method, it has the merits of simple operation, high efficiency, low cost, and can be used over hard to reach areas. Direct seeding was considered the 'best practice' for producing seedlings, regeneration, and afforestation [8]. Sowing seeds directly to forest land without lifting seedlings, packaging, transportation, and planting, the root system of seedlings will not be damaged. Therefore, direct seeding is more "close-to-nature." It can keep intact natural distribution and expansion of the root system, especially of the pivot root the tree species. The seeds that germinate and grow on the forested land are better adapted to the climate and soil conditions [86]. However, it has strict requirements on the water, heat, and vegetation conditions. Compared with seedling afforestation, seedlings formed by direct seeding grow slowly at the initial stage, so it takes a longer time to reach crown closure [86]. Sometimes, the seeds after sowing are easily damaged by birds and animals, trampled by livestock, and human destruction, so it is necessary to strengthen the management and protection.

Generally, before sowing, the seeds should be disinfected, soaked, sprouted, dressed, coating, and gluing [1]. The purpose of pre-sowing treatment is to shorten the time of seeds in the soil before germination, ensure the emergence of seedlings orderly, and prevent the harm of birds, mammals, and diseases. The germination rate after sowing is related to seed size and weight. Moreover, the establishment rate is accord to the timing of seeding, planting practices, microsite environment, competitive vegetation, and seed predation [87–90].

Seed afforestation methods include seed burial, spot, and broadcast [91–93]. Seed burial refers to put the seeds under the soil to store water, preserve moisture, create conditions for germination, and protect seeds. Some seeding experiments conducted in the nursery show that the suitable spot seeding depth is between one and two times the seed width [94, 95]. Broadcast seeding has the advantages of small workload, simple construction, great flexibility in site selection, and is widely used for barren mountains and wasteland (including desert) and cutting and burning slash site [1]. No matter which seeding method, it is required that the covering soil thickness is appropriate (except for broadcast sowing) [1].

Different sowing season can affect the seed germination rate, which should be determined according to the tree species' characteristics and environmental conditions [96]. Many studies were conducted about the suitable sowing season, such as some pine species in southern US and Finnland (spring seeding), *Pinus palustris* in the US (fall seeding), *Fraxinus excelsior,* and *Acer pseudoplatanus* in the UK (winter seeding) [5, 96, 97]. Some species can be sowed in multiple seasons, like temperate hardwoods in the US [98].

4.2 Afforestation with seedlings

There are two types of seedlings, bare root and containerized. Compared with the direct seeding, seedlings have a complete or partial root system. It can be planted in almost all suitable sites, and site conditions requirements are not high. In general, container seedlings are used for afforestation under difficult site conditions. Furthermore, seedlings are usually grown in nurseries or a controlled greenhouse environment, transplantation more or less damaged the root system, and both bare root seedlings and container seedlings can be produced all year round [6, 99].

Bareroot seedlings have always been promoted for reforestation projects because it can be easily hand-carried by forester and less expensive than containerized seedlings [100]. The survival ratio of bare root seedlings is affected by the seedling vitality, planting time, or season, especially the soil moisture and temperature [101]. The water content in the seedling is the most critical factor affecting the seedling vitality. To maintain the seedlings' water balance, appropriate treatment measures should be taken before planting, such as pruning and partial-root cutting, which can remove most of the seedling leaves, branches, trunk, and roots, reducing water evaporation [102, 103].

Compared with seeding afforestation, container seedlings show better environmental adaptability and stress resistance because of their protected root systems (**Figure 8**). Container seedlings have increased survival rates of or more than other transplant types and show improved growth on adverse sites, though they cost more than bare-root seedlings [104]. Under droughty conditions, container seedlings survived and grew better than bare root seedlings [105]. Furthermore, some researchers mentioned no difference between bare root seedlings and container seedlings when soil moisture was adequate at the planting time [106].

Figure 8.
Container seedlings of Larix principis-*rupprechtii in a greenhouse.*

Afforestation with seedlings requires a series of practices include lifting, storage, transport to the site, and planting. All of these operations can affect seedling performance [107]. The protection of seedling roots during those operations is critical to maintaining the water content and seedlings' vitality. To this end, it is advantageous to shorten the operation time of each process; grading and packaging should be carried out in a shady, wet, and cold environment. Some studies have shown that exposing the seedlings' roots to air can limit their growth [108, 109]. The seedling's roots should be closely contacted with the surrounding soil during planting. The planting depth of each seedling should be the same in the nursery; sometimes, a little deeper is more favorable. After planting, the bare root seedlings generally have a process of root restoration and adaptation.

Hole planting is a common method that is suitable for all kinds of bare root seedlings. Digging tools can be large machinery, shovel, mattock, spade (**Figure 9**). The depth and width of the hole are determined according to the seedling root's length and width [110]. Generally, the planting depth should be about 3 cm above the original soil seal at the seedling's ground path [1]. The planting method can also be divided into a single plant and cluster plant according to one or more plants per hole. Recently, seedlings with root-ball were widely used in afforestation, especially in urban afforestation; it can maintain a relatively complete root system, and the planting survival rate is high, but the weight is massive, so the afforestation cost is relatively high.

To ensure planting seedlings, it is necessary to select the appropriate season and time according to the climate and soil conditions. Bareroot seedlings and container seedlings are produced in one to four growing seasons or one to two years [6, 111]. Theoretically, the appropriate planting time should be when the physiological activity of the aboveground part of the seedling is weak (deciduous broadleaf tree species are in the deciduous stage), and the physiological activity of the root is vital, so the root healing ability is strong [112]. Generally, hardwood seedlings must be planted in late winter or early spring, when the seedlings are dormant and the ground has thawed [113].

4.3 Afforestation with cutting

Seeds and seedlings are sexual afforestation method, and many trees also have asexual reproduction ability. Cutting is a piece of a plant that can be used in

Figure 9.
Use excavators to dig a hole for the afforestation.

Figure 10.
Root sprouting of black locust.

afforestation. It can be taken from stems, branches, leaves, roots and directly plant on forest land. Cuttings can maintain the parent tree's target characteristics, such as high yield, fast growth, and stress resistance ability [114, 115]. Some research showed that cuttings' behavior varies with age, genotypes, the parent plant's physiological status, cutting position, and temperature [116, 117]. Besides, sprouting is another afforestation method that can produce a new forest. Sprouts are more resistant to disturbance than seed-origin seedlings and grow fast [7, 118]. Compared with the plant with seed and seedling, cutting afforestation is labor-saving, time-saving, and low-cost.

Stump or root adventitious sprouts are commonly used sprouting materials, and it can rapidly produce many adventitious roots with strong water-absorbing ability, such species include *Populus*, *Robinia pseudoacacia*, *Salix*, *Cunninghamia lanceolata*, *Ziziphus jujuba*, *Paulownia tomentosa*, and *Toxicodendron vernicifluum* [119–121] (**Figure 10**). It is believed that the sprouting ability is related to species, stem size, age, management intensity [7, 122–125]. It was reported that different damage treatments on beech roots could cause different sprouting results [126]. Some sproutings come from the stump after cutting, like *Cercidiphyllum japonicum* and some tropical species [127, 128]. Recently, sprouting has been widely used in coppice forest cultivation. In China, Europe, and the Americas, this method is used to develop short rotation energy forests to get biomass raw materials [129, 130].

The cutting plant or sprouting harvest season varies with the tree species and region. Generally, the most suitable time is the same as planting seedlings, like fall, winter, and early spring [127, 131]. However, some studies showed that harvest season had no effect on sprout number but can affect the dominant sprout height in the first year [132, 133].

5. Conclusion

Afforestation and reforestation activities must be considered systematically and integrally. More and more studies have shown that making afforestation plans from the perspective of forest ecosystems is the future trend. Using multi-factor methods to analyze forest site characteristics will become the primary site evaluation and classification method. Although the cost is high, with the continuous advancement of technology, afforestation machinery will be popularized in the afforestation process, such as land preparation and planting. At the same time, many future afforestation activities will fully consider climate change dynamics on the forest site and the forest itself and determine afforestation tree species, materials and methods.

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