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Contents

Species Choice

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Introduction

Species choice is not a new problem. In 1665 John Evelyn wrote in his book *Sylva*:

> First it will be requisite to agree upon the species: as what species are likely to be of greatest use, and the fittest to be cultivated and then to consider how planting may be best effected.

When the Food and Agriculture Organization produced a book on *Choice of Tree Species* in 1958, the importance of first identifying the purpose of tree planting was still recognized. Over 130 pages of the book deal with ecological principles to assist selecting trees for use in different parts of the world. This includes descriptions of various climate, soil, and vegetation classifications. These systems are now mainly of historical interest. But before the widespread availability of computers, information on environmental conditions was often represented as classes, and areas suitable for particular species were frequently shown as zones on maps.

In terms of introducing exotic species, the work of Golfari was some of the most practically important. Golfari and his colleagues produced maps dividing Brazil into 26 regions on the basis of altitude, vegetation types, mean annual temperature, rainfall and its distribution, water deficit, and frost occurrence. They indicated species, mainly eucalypts and pines, suitable for particular regions.

Information of this sort is developed on the basis of knowledge of conditions within a species natural distribution, as well as its success or failure when evaluated in trials outside its natural distribution. For example, two volumes written by Poynton, published in 1979, describe the introduction of eucalypts and pines to southern Africa. These books provide some of the most detailed descriptions of tree species trials ever prepared. The volume on eucalypts includes information on the introduction of 134 species. Details of natural occurrence, characteristics and uses, silviculture, utilization, and potential are presented for each species and results from trials are summarized. Details for specific trial sites are also tabulated for each species. Information is provided on country, plantation name and plot number, silvicultural zone, altitude, annual rainfall, aspect, soil depth and texture, age, stocking, mean diameter at breast height (dbh), mean height, mean volume, and mean annual increment as well as general comments on health and form. Information on the latitude, longitude, and elevation of 271 sites is provided in an appendix along with mean maximum temperature of the warmest month, mean minimum temperature of the coldest month, and mean annual rainfall of each site where available. Another appendix includes recommendations for species suitable for particular climatic zones and a map is included showing these zones.

A Guide to Species Selection for Tropical and Sub-Tropical Plantations, produced at the Commonwealth Forestry Institute in 1980, marked a significant step away from the use of classifications and maps, and towards the use of computer-based methods. The characteristics of 125 species were described in terms of 40 factors grouped within headings, including taxonomy, natural occurrence, climate, soils, silviculture, production, protection planting, timber, utilization, nursery, principal pests and diseases, and principal references. For those users with access to a computer a program was provided to search these data. But as personal computers were not widely available in 1980, instructions were also provided on how to use punched cards to sort through the data manually and select suitable species for particular uses and environments.

Unlike the books prepared by Poynton, the *Guide to Species Selection* only provided summary information for particular species and not site-specific results. In the late 1980s the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Forestry and Forest Products developed a computerized tree crop database called TREDAT. This was designed for the storage and selective retrieval of results from trials. It currently contains information for 411 species, mainly of Australian origin, and for 303 sites, mainly in Australia. It includes information on a total of 90 factors relating to site characteristics, management history, tree performance, botanical identity, and project description. Though this information is useful for assisting species selection, the system contains only raw data for specific sites. It does not contain summary information on the characteristics and requirements of particular species.

Over the years many articles and books have been written to assist species selection for particular countries or regions. These usually contain summary information on factors such as uses, natural occurrence, plantations outside the natural distribution, and environmental requirements. Sometimes these descriptions are complemented by tabular information, which makes it easier to check the uses and environmental requirements of many species quickly. As personal computers became more widely available several programs were developed that enabled tabular data to be searched more efficiently. When selecting tree species for a particular site it is well worth checking to see if a relevant article, book, or computer program exists to assist species choice in a particular region of interest.

Previous reviews have identified some key questions to consider when selecting species for planting. These are:

- What are the environmental characteristics of the site?
- What product or service is the tree species to provide?
- Which species will grow on the sites available?

Site Characterization

It is usually desirable to collate some basic information on site conditions before considering which species are suitable for planting. The location of sample sites can be accurately recorded using global positioning systems (GPS). The location of sites may also be recorded in terms of slope, aspect, and position in the landscape (e.g., hilltop, midslope, or valley bottom).

Minimum climatic information includes mean monthly values for maximum temperature, minimum temperature, and precipitation. Key factors such as mean annual temperature, mean maximum temperature of the hottest month, mean minimum temperature of the coldest month, rainfall seasonality, and dry-season length can be simply calculated from these monthly values. In frost-prone areas, information on absolute (i.e., record) minimum temperature is also useful. Monthly mean temperature and rainfall data are generally readily available from standard sources, such as summaries published by national meteorological agencies and the Food and Agriculture Organization or from the web. In some cases interpolation relationships may be available that allow more reliable estimates to be made for sites which are some distance from meteorological stations. Monthly mean values for solar radiation and evaporation may also be useful to run models that can estimate potential growth rates. However, they are not generally required for species selection.

Samples for assessing soil conditions can be obtained by using soil augers or digging pits. If large areas are to be sampled, mechanical drilling equipment or backhoes can speed up the sampling process. For species selection purposes only simple information on soil texture as well as reaction (pH) and drainage are usually required. More detailed physical and chemical information may be taken to estimate potential productivity. For example, measurements of soil depth as well as texture allow water-holding capacity to be estimated. Samples for chemical analysis are often taken from the topsoil layer (i.e., *A* horizon) and at a lower depth. Analyses may be carried out for major nutrients, such as nitrogen, phosphorus, and potassium, as well as for exchangeable cations of minor nutrients. If appropriate, other analyses such as soil salinity may also be required.

Information on natural vegetation was widely used to assist species selection in the past. Both overstory and understory species respond to the climatic and soil conditions of the site and can provide an indication of its potential for other species. However, as potential sites for plantations have often been previously disturbed, the value of natural vegetation as an indicator of site potential has declined.

The CAB International Forestry Compendium

Having collected information on site conditions, the questions of which species are suitable for particular uses and which species will grow on particular sites can be considered.

The Forestry Compendium developed by CAB International (CABI) is probably the most impressive tool that has been developed to assist tree species choice. The Forestry Compendium aims to provide global coverage and was prepared using contributions from hundreds of experts around the world. It includes a taxonomic database for 22 000 species, with detailed descriptions for 1200 species. The first CD-ROM version of the global module was released in 2000 and a revised version was issued in 2003. It is planned to release improved CD-ROM versions every 2–3 years and a version including the latest amendments can also be accessed via the internet (www.cabicompendium.org/fc).

A particular advantage of the CABI system over other tree selection systems is that it allows access to the research literature by providing over 50 000 references with abstracts. For example, the reference browser in the 2003 CD-ROM version provides access to abstracts of 67 references mentioning species choice and 128 references referring to species selection.

Though the Forestry Compendium has many potential applications, tree species selection is one of its main purposes and it includes a detailed species selection module, which can be entered from the main menu. The user can select from scores of options listed under four main headings: uses, distribution, environment, and silviculture.

Uses

Determining the ultimate use of trees is a vitally important step in species selection. Modern forest processing facilities generally require raw materials of consistent quality. So, if the aim is to grow trees to supply an existing processing plant then the species selection process may be easy. The existing plantations or forests supplying a particular facility may already indicate the only acceptable species.

However, if opportunities to use different species are more open, the Forestry Compendium can assist selection within three main usage categories: land/environment, wood, and nonwood, that together include a total of more than 110 subcategories (**Figure 1**).

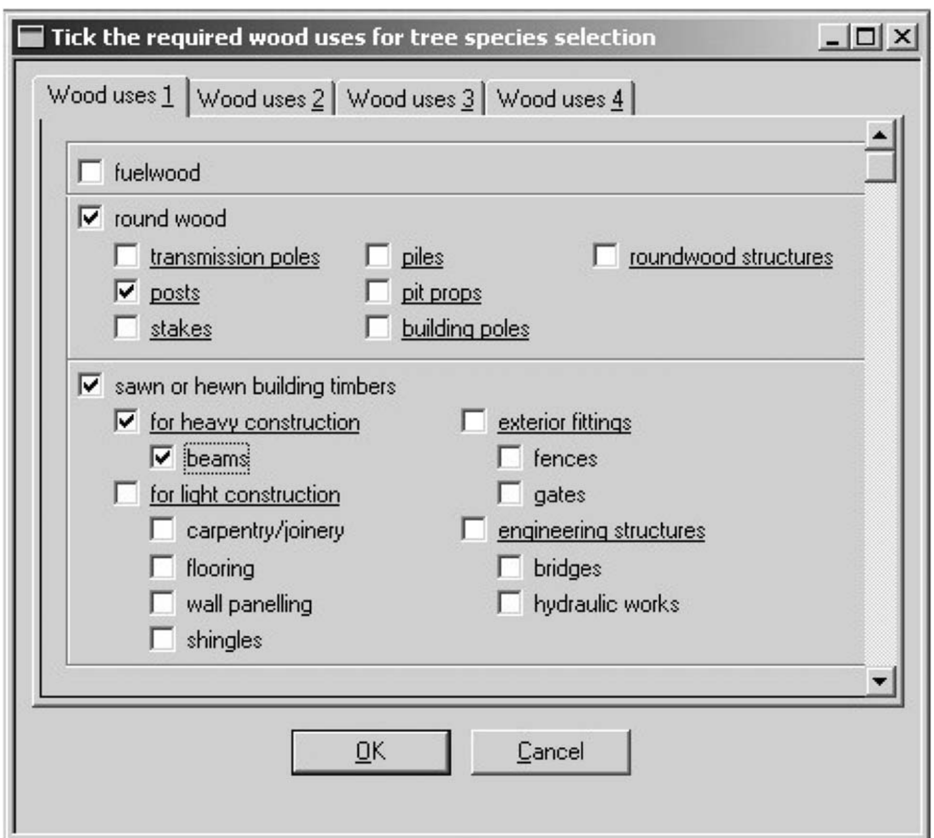

Figure 1 CABI *Forestry Compendium* – wood uses, menu 1 of 4. Reproduced with permission from CAB International (2003) *Forestry Compendium*. CAB International, Wallingford, UK. Available as CD-ROM or online at: www.cabicompendium.org/fc.

Distribution

The Forestry Compendium's Tree Species Selection Module provides the option to select a species on the basis of its country or region, or on latitudinal limits. It is possible to select species that are native or have been introduced to more than 650 countries or regions.

Environment

Altitude, rainfall, temperature, and soil properties are the main environmental categories used in the Tree Species Selection Module to determine which species can grow on particular sites. Altitude, rainfall, and temperature data can be entered as single numbers or ranges.

Soil properties can be selected under four main headings. Soil texture includes light (sands and sandy loams), medium (loams and sandy clay loams), and heavy (clays, clay loams, and sandy clays) options. Soil drainage includes free, impeded, and seasonally waterlogged. Soil reaction includes very acid (pH <4.0), acid (pH 4.0–6.0), neutral (pH 6.1–7.4), and alkaline (pH>7.4). Special soil tolerances include shallow, saline, sodic, and infertile.

Silviculture

Various silvicultural characteristics can be selected within the Tree Species Selection Module. For example, an ability to tolerate any or all of nine factors, including drought and termites, can be selected. Similarly, ability to coppice or fix nitrogen can be selected from six silvicultural characteristics. Options are also provided to select from three categories of seed storage, five categories of vegetative propagation, and five methods of stand establishment.

Species Selection

The user can select a wide variety of options within the four main headings of uses, distribution, environment, and silviculture. The database can then be searched for species that satisfy any or all of these characteristics. **Figure 2** shows the results of a simple search carried out using the Forestry Compendium.

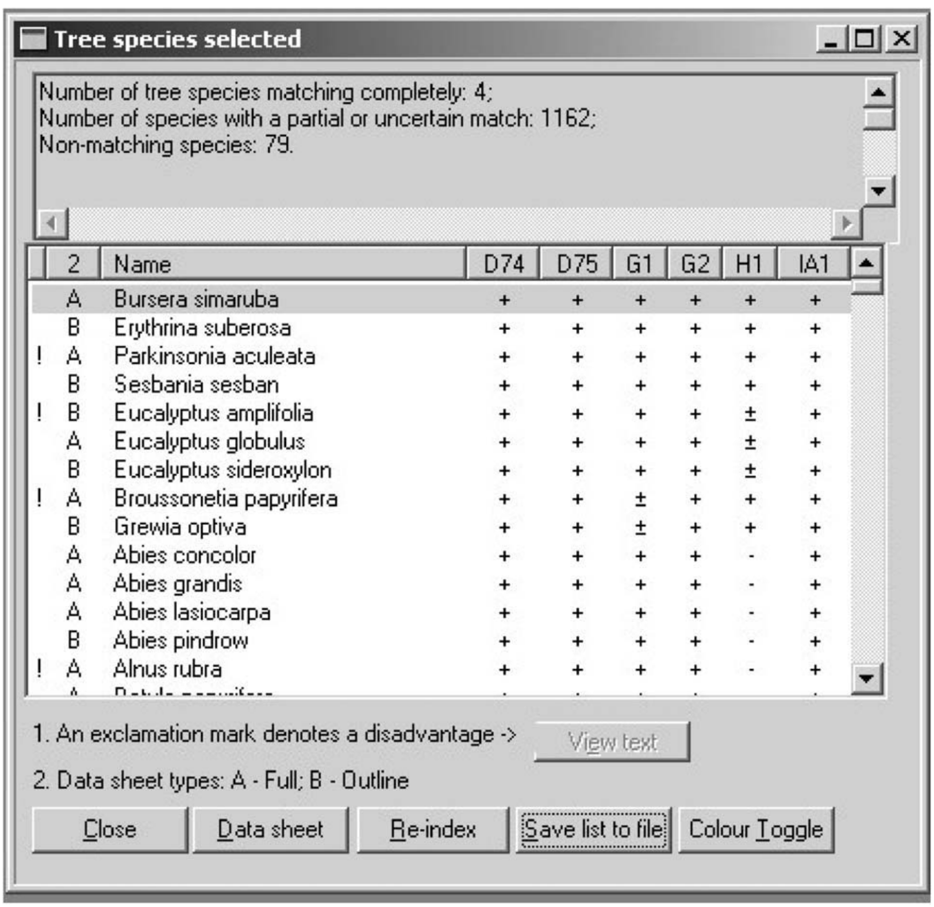

Figure 2 CABI *Forestry Compendium* – tree species selection output. Reproduced with permission from CAB International (2003) *Forestry Compendium*. CAB International, Wallingford, UK. Available as CD-ROM or online at: www.cabicompendium.org/fc.

The features requested were D74 wood pulp, D75 short fiber pulp, G1 mean annual rainfall 500–750 mm, G2 winter rainfall seasonality, H1 mean annual temperature 20–25°C, and IA1 light-texture soil (sands, sandy loams). The output indicates the number of species that completely satisfy the requirements, those that provide a partial match, and those that fail on all counts. Individual species are listed with those that satisfy most criteria at the top of the list.

Exclamation marks in the first column indicate potential problems, such as possible risk as weed species. There is increasing concern about species that can become established outside the areas where they are intended to grow. Particular care should be taken when introducing potentially invasive species, such as *Prosopis juliflora* and *Acacia* spp., into areas where they have not previously been grown.

The second column indicates if full (A) or outline (B) data sheets are available. Full data sheets include sections on name, importance, botanical features, geographic distribution, environmental amplitude, silviculture and management, protection, variation and breeding, uses, disadvantages, and references. The columns following the species name indicate whether it has fully satisfied (+), partially satisfied (+/−), or failed to satisfy (−) the particular criterion.

Checking the data sheets will indicate that some of the species shown in **Figure 2**, such as *Bursera simaruba* and *Erythrina suberosa*, have little current commercial use. Others, such as *Eucalyptus globulus*, have been successful in many countries. Information like this can help select species worth including in trials. However, if it is available, the most useful information may come from practical experience in local and nearby regions.

Pests and Diseases

The Forestry Compendium provides information on insect pests, diseases, and parasitic plants which may cause problems for particular trees within each species description. For example, *Lophodermium pinastri* causes needle cast problems for *Pinus sylvestris* (Scots pine) in nurseries and in young (2–5-year-old) high-density plantations. Highlighting the name of the disease and selecting a 'soft link' button brings information about the disease onto the screen. This often includes maps showing the countries where it has been observed. Where available, control methods for important pests and diseases are described within each tree species description.

Matching Species and Sites

The CABI *Forestry Compendium* can be very helpful in assisting the process of species choice, but there are other useful tools and critical considerations. For example, it may be important to know in more detail where a particular species will grow, how well it will grow, and whether there are any economic, social, or environmental problems with its use.

Climatic Mapping

Climatic factors are important in determining where particular species will grow. Great advances have been made since the mid-1980s in developing interpolation methods to assist estimating mean climatic conditions for any location around the world.

For example, CSIRO's Division of Forestry and Forest Products has used an interpolated climatic database prepared at the University of East Anglia's Climatic Research Unit to develop a world climatic mapping program. This can take in any of the 1200 descriptions of species climatic requirements included in the Forestry Compendium and map which of 67 477 locations in a half-degree grid satisfies the description. For example, **Figure 3** shows climatically suitable areas for *Tectona grandis* (teak) with the description of climatic requirements being used shown below the map.

Climatic mapping programs are very helpful in checking and improving descriptions of species climatic requirements. For example, the description shown in **Figure 3** should probably be slightly modified to include some wetter and warmer areas in India. It is very difficult to appreciate the implications of a written description of climatic requirements, but a map makes these immediately apparent.

Descriptions of species climatic profiles can be developed from analyses of their natural distributions as well as their performance in trials outside their natural distribution. Ideally, geocoded data (i.e., latitude, longitude, and elevation) are collated for both the natural distribution and successful trials and interpolation relationships are used to estimate mean climatic conditions for each location.

In addition to the world climatic mapping program, CSIRO has developed more detailed climatic mapping programs for a wide range of regions, including Africa, mainland South-East Asia, and Latin America, as well as for individual countries, including Australia, Cambodia, China, Indonesia, Laos, Thailand, Philippines, Vietnam, and Zimbabwe.

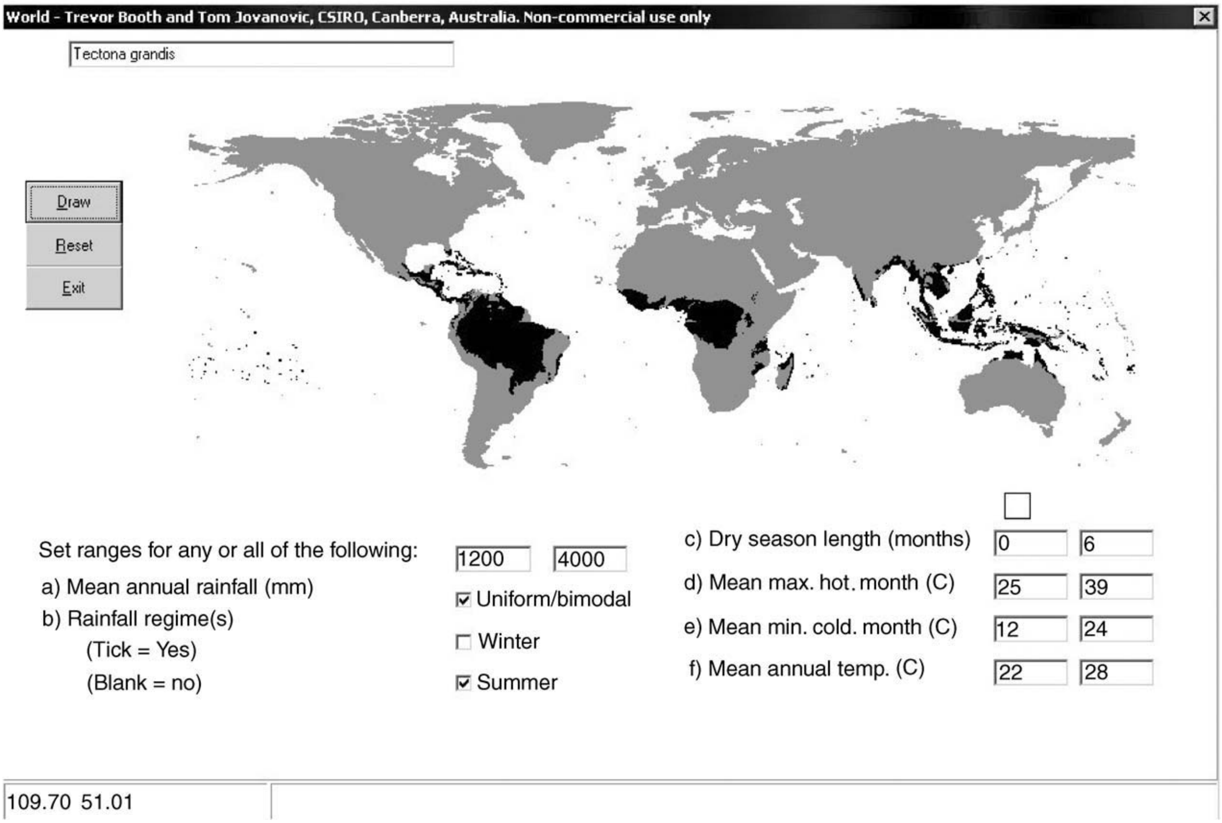

Figure 3 World climatic mapping program – black areas are climatically suitable for *Tectona grandis* according to description in CAB International (2003) *Forestry Compendium*. Wallingford, UK: CAB International. Available as CD-ROM or online at: www.cabicompendium.org/fc.

Tree Growth Models

When choosing species for planting it is useful to know not only where a particular species will grow, but also how well it is likely to grow at selected locations. Considerable progress has been made in recent years in developing simple tree growth models, such as 3-PG and ProMod. These take in simple information on climatic and soil conditions and predict likely growth rates for particular species. Models of this sort can be used to estimate potential productivity at individual sites or run for many hundreds or thousands of gridded sites to produce an indication of potential productivity across broad regions.

Economic, Social, and Environmental Suitability

In addition to local testing a consideration of the social and environmental implications of introductions should also be part of the tree selection process. This is particularly important if the species is an exotic. In the past, economic considerations have tended to dominate the choice of tree species. Economic considerations remain important, but social and environmental issues should also be assessed.

Social issues should involve a consideration of the likely impacts of tree species introductions into a particular region. Many social issues, such as the replacement of agricultural land by forestry plantations, may not be related to species choice, but visual impact is an example where species selection may be important.

Environmental issues include questions such as the decision whether to use native or exotic species. Biodiversity is an important environmental issue and use of native species may be preferred for this reason. However, use of highly productive plantations of exotic species may allow larger areas of native forest to be used as nature conservation reserves.

Water use is emerging as a major issue in many countries, so the efficiency with which different species use water may need consideration.

Opportunities for Future Developments

In the past the emphasis on tree selection has been at the species level. Some information about important hybrids and provenances is provided in the Forestry Compendium, but generally existing tree species selection systems provide little or no information at the provenance or clonal levels. In the future more information will be included in selection systems about requirements of particular genotypes, including provenances, hybrids, clones, and genetically modified material. For the present, field trials are essential before embarking on any large-scale afforestation program. Improved genetic material developed for another region may not necessarily perform any better than the best natural provenances when introduced into a different environment.

Improved genotype–site matching will require more detailed information on both tree growth and site conditions. Comparing the results of trials in many different countries and areas would be assisted by the development of an internationally agreed minimum dataset for evaluating tree growth and environmental conditions at trial sites. This dataset will need to include information about soil physical and chemical status to assist predictions of potential productivity and sustainability. If an agreed minimum dataset could be established it would be logical to develop an international database, similar to TREDAT, which contains information on observations from individual sites, as well as summary data of the type in the Forestry Compendium database. It would also be desirable to collect minimum dataset information on growth and environment for sample locations within existing plantations, so that production level performance could be more reliably compared with results from small-scale trials.

Improvements in remote sensing will allow more reliable growth predictions to be made for different genotypes over broad areas. Remote sensing is already beginning to provide some useful information on important soil properties such as water-holding capacity and nutrient conditions. However, validating remote sensing observations by selective on-ground sampling is likely to be required for the foreseeable future.

Though great improvements have been made in estimating mean climatic conditions over broad areas, more could be done to evaluate climatic variability. Improved climatic data are becoming available for factors such as rainfall variability and frost risk. Greater use of this information should be made in species selection systems.

In the past climatic databases have typically used monthly mean data. Data storage and transmission speeds have increased so greatly that access to actual time series data of hourly rainfall and temperature data for many years is now becoming practical. These datasets will allow factors such as insect development and leaf wetness to be estimated for potential planting sites. This will allow pest and disease risks to be more reliably estimated.

If predictions of climatic change are realized, this factor may also need to be considered in species selection. At present regional predictions of climatic change are not sufficiently accurate for forest managers to include this factor when selecting trees for planting.

Great progress has been made in developing methods to fulfill the need identified by John Evelyn in 1665 of identifying the fittest trees to be cultivated on any particular site. However, even better tree selection methods will be required to realize the full benefits of the improved genetic material that is becoming available for planting.

See also: **Mensuration**: Forest Measurements. **Resource Assessment**: GIS and Remote Sensing. **Silviculture**: Silvicultural Systems. **Tree Breeding, Principles**: A Historical Overview of Forest Tree Improvement; Economic Returns from Tree Breeding; Forest Genetics and Tree Breeding; Current and Future Signposts.

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Ground Preparation

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Introduction

Ground preparation is defined as the set of preliminary operations on soil that are required for effective establishment of tree seedlings. The main objective of ground preparation is to assure access to nutrients, air, and water for the seedlings to be planted.

Ground preparation is associated with site preparation. Ground preparation is more focused in soil treatment for plant establishment, considering the simple meaning of ground as 'solid surface of the earth' or 'the upper soil.' Site preparation may be understood as a wider concept referring to a modification of the surrounding environment for plant establishment. In this sense, site preparation may include operations prior to ground preparation.

Thus, site preparation includes clearing, soil cultivation, and also protection operations, such as management of pre-existing vegetation especially weeds, fencing and other animal control systems, protection of plants against frost and wind, etc. Conversely, ground preparation as a normal step leading to plant establishment is concerned with soil cultivation, including either drainage or water storage according to site conditions.

As a major operation for ground preparation in planting sites, soil cultivation frees ground and it facilitates a deeper penetration of water and air into the root zone and therefore, it allows root systems better access to soil nutrients and assists their correct placement, anchorage, and development. Also, draining facilitates aeration for roots in extremely wet and waterlogged fields. Furthermore, water harvesting increases soil water availability in dry zones.

Intensity of the operations for ground preparation may be defined in terms of work or power per unit area, which varies from site to site, depending on constraints of cost, plantation objectives, and site conditions. Ground preparation work may be classified as low intensity operations or high intensity operations. Low intensity operations include basically manual support and simple soil cultivation. High intensity ground preparation includes the use of agricultural machinery and mechanical support for soil cultivation.

Operations for ground preparation may be further classified according to their use of labor or machinery. Thus ground preparation may be implemented through a manual support system, a mechanical or machinery support system, or a combination of both systems. Ground preparation with manual support is normally preferred in low intensity ground preparation and small-scale operations such as the construction of furrows, mounds, bunds, ditches or trenches.

In general terms, field conditions such as slope, deepness, and stoniness are not limiting factors for manual ground preparation, which is performed by using hand tools such as shovels or spades, *azadas*, or a plow drawn by animals. Also, ground preparation with manual support may be used for smoothing and compaction of mounds and bunds, when combined with machinery or mechanical support operations.

Ground preparation with machinery or mechanical support is used for large-scale operations and it cannot be used on steep slopes because its application requires gentle to moderate slopes. Operations of ground preparation with mechanical support involves plowing, disking, or bedding, mounding, also scratch or spoil drain mounding, ditching, ripping, subsoiling or scarifying operations. However, disking and ripping are the most widely used operations of this type.

Machinery used for mechanical support operations consists of tractors or dozers with special attachments, especially blades, disks, rippers, rutters, or excavators, among other devices. Agricultural equipment may be used in most operations for soil cultivation in planting sites, where field conditions are not too rugged or stony. Heavy machinery should be used if there are relatively adverse conditions such as heavy clay soils, moderately steep slopes, or stoniness in the field.

Thus mechanical support to ground preparation can be classified into three categories of equipment: (1) machines for vegetation cutting and stump removal; (2) machines for vegetation cutting plus breaking up the ground up to certain depth; and (3) machinery that breaks ground structure to a deep level (**Table 1**).

For example, bulldozers may be used to remove remaining trees and stumps. A rotovator works over ground vegetation and it turns over the upper soil