The Soils of Ireland

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Soil Formation

SOIL formation is the process by which geological parent materials subjected to the action of natural forces and living organisms are transformed over time into soils. In the course of the transformation various chemical, physical and biological changes take place so that the end-product, the soil, is a completely different natural body from the parent material. The nature of the parent materials and the environmental conditions involved are largely responsible for the character of the resultant soil. Five major genetic factors namely, parent material, climate, relief, vegetation and time are usually associated with soil forming processes and man's influence in modifying these natural processes cannot be discounted. The interaction of these factors and the relative impact of each, determine the nature and intensity of the processes by which the inert parent material is developed into a dynamic soil and the character of that soil. A mature soil then possesses both inherited and acquired characteristics.

It may be accepted that the soils of Ireland are more variable than those of most other countries or regions of similar area. A number of factors have contributed to making the soil pattern so complex. The interaction of the major factors of soil formation discussed above are foremost in their influence in this respect. A relationship to the local geology is to be expected in our soils. This relationship is complicated, however, by the fact that most Irish soils have been derived, not from the local rock formations, but from the transported glacial drift which mantles them. Since it is now known that Ireland was subjected to two main glaciations and perhaps a previous one besides (Mitchell, 1957) and since each of these involved a number of advance and retreat stages of the ice sheet, it can be appreciated that the resultant drift deposits that form the parent materials of the majority of our soils are of very mixed origin and of complex geological and physical constitution. Such differences in the drift are reflected in our soils.

Even on a uniform and common parent geological material, our soils display wide variations amongst themselves, due to the other factors that influence them in their genesis, formation and development from the geological parent material. It is now recognised that our post-glacial climate showed distinct variations from time to time (Brooks, 1921) but current and recent-past climate has been operative also. The main climatic factor operative in this country is the rainfall-evaporation regime. With the ratio balance well in favour of rainfall most of our soils tend to occur in the leached to podzolised categories. Apart from those, with our humid climate we have extensive areas of gleyed soils where water movement is retarded in the profile giving surface-water gleys or where high water table gives ground-water gleys. The former may be a function of the physical constitution of the profile, inherited mainly from the parent material, as in our "Drumlin" soils. The latter is most often a function of relief or position of the soil relative to the landscape topography where the relief factor asserts its influence over all others in characterizing the soil profile. Such soils occur in low relief or depressed sites in association with the leached and podzolised groups on the slopes and higher ground. The relief factor toward the opposite extreme is apparent where the tendency toward more severe leaching and podzolisation is increased with elevation.

The vegetation factor has influenced the situation considerably. For instance, on similar parent materials with all other factors being equal, two soils may show variable profile character as a result of vegetation history. Apart from the broad distinctive influence of forest versus grassland on soil profile character, there is the general difference between coniferous and deciduous species in this respect. It is now apparent that the majority of Irish soils were formed initially under a forest cover (Erdtman (1927), Mitchell (1951), Mitchell (1956), Murray (1957)) which in most areas was superseded by a gramineous cover with the usual modification of soil profile.

The influence of time or age is not so apparent in our soils, except in extreme cases of young alluvium in comparison with more mature soils, but nevertheless it has played its part too. The greater portion of Irish soils however, are relatively young. Finally, in thinking of variable soils, we can never discount man's interference over the years with the "natural" trends of soil development which was more pronounced probably from the early clearance of the virgin forests by Neolithic farmers commencing about 3,000 B.C.

Classification of Irish Soils

Prior to the establishment of the National Soil Survey by the Agricultural Institute in 1959, little attempt had been made to survey, classify and map the soils of Ireland in a systematic manner. However, as early as 1848 Sir Robert Kane, a pioneer in this field, described to the Royal Irish Academy a system of classification of land, based on detailed physical and chemical analyses and the agricultural capabilities of the soils, whereby he divided land into types ranging from "waste" land to "superior" land (Simington and Wheeler, 1945). Through some misadventure Kane's maps and reports were unfortunately lost. The work of Gallagher and Walsh (1942) set the basis for the overall classification of the soils of the country. A number of surveys of a more local and specific character (Brickley (1941), Walsh & Clarke (1943), Spain (1948) Walsh et al. (1953), Walsh & Ryan (1954)) were carried out but nothing in the way of a systematic and comprehensive classification and mapping of Irish soils in the modern concept (Ryan, 1962) was embarked upon prior to 1959.

As a result of the prevailing humid temperate climate the soils of Ireland, like those of North West Europe in general, have been subjected to a leaching process, leading to different degrees of podzolisation, depending on parent material and other modifying factors. For the most part then, in terms of soils on a world scale, our soils fall into the broad division of Pedalfers or more specifically into the zone of light-coloured podzolised soils of the cool-temperate, humid regions. As is to be expected extensive areas of so-called intrazonal soils may be interspersed with the above zonal group. Zonal soils are those with well-developed profile characteristics that reflect the dominating influence of climate and vegetation in the course of their development, whereas the intrazonal groups comprise for most part, soils that reflect the dominating, direct, or indirect influence of some *local factors,* usually topography or parent material, over the normal influence of climate and vegetation. Into these intrazonal groups fall our extensive poorly-drained or *gley* soils, the result of impeded drainage due to impermeability within the soil or high water-table. Our soils, at least our mineral soils, then can be considered to fall into two broad groups —the zonal podzolised soils and the intrazonal gleyed soils. We must also consider our organic soils or peats both zonal and intrazonal and our azonal alluvial soils.

The dominant process taking place more particularly in our better drained soils is one of leaching or downward removal of constituents both chemical and physical from upper to lower soil horizons. As one would expect then, most of our free draining soils have A/B/C/ profiles where the constitutents leached from the surface A horizons become deposited in the underlying B horizons. In all cases C refers to the underlying parent material of the soil.

The present systematic survey, classification and mapping of Irish soils is being done on a county by county basis and with three counties completed to date, it is not possible at present to provide a detailed overall picture, say at *soil series* level, of the soil pattern for the entire country. The present contribution therefore, will attempt to provide a more general picture by outlining the *Great Soil Groups* or major soils that we possess. These major groups are comprised of soils that have many important properties in common and that therefore, tend to behave in similar manner when subjected to defined cultural and management practices. In general terms also soils within a major group should have similar use range or use suitability. This level of classification however, is not sufficient to take account of differences at a local level which are significant in determining a soil's best use and true potential. The *soil series* is used for more detailed definition at a local level and conists of soils with similar profile characteristics and derived from a single parent material. A *Great Soil Group* may comprise several series of closely similar character.

The Great Soil Groups of most common occurrence in Ireland are briefly described in the following paragraphs. Others occur less extensively or in more scattered areas. Also within these major groups there is a considerable number of related sub-groups.

Alluvial Soils.

Sometimes referred to as Regosols these are immature soils with weakly developed(A/C) soil profiles. In texture and drainage they vary considerably even within one location. Being associated with river and estuarine basins mostly, these are naturally quite a scattered group. These and the soils from lacustrine, marine and raised beach deposits are potentially productive but in many cases poor drainage and temporary annual inundation create serious problems.

Brown Earths.

These well drained soils of medium textures known as *braunerden* or *sols bruns* in Continental Europe were also known as "brown forest soils" to distinguish their comparatively uniform, brownish profile with absence of a bleached sub-surface horizon, depleted of iron, from the podzolised soils associated with coniferous forests and heaths. The brown earths then are essentially soils of relative maturity but with uniform profiles where weathering has more or less kept pace with leaching. A limited degree of leaching however, is allowable within the group. The B horizon is not too pronounced in these soils and usually if present, takes the form of a structure or colour B so that the profile may be designated an A/(B)/C profile. The humus layer is normally of the mull type except in the more sandy types or where the soils tend toward the podzol group when a moder type humus occurs.

Recent evidence suggests that the brown earths may represent the natural soil climax under deciduous forest, on lighter textured materials in the lowland areas especially, with the podzols forming where the forest was removed and reversion to heath took place (Dimbleby and Gill, 1955). Unlimed soils have a moderately acid to neutral reaction coupled with a range in base saturation from low to moderately high and it is on this basis that two sub-groups of the brown earths are distinguished in this country viz. (a) acid brown earth or brown earths of low base status (b) brown earths of medium-high base status.

The former occur predominantly on the more acid parent materials such as non-calcareous shales sandstones, granites, mica-schists and glacial drift derived from these sources but may also be found on glacial drift, originally base-rich and of dominantly limestone composition, that has been decalcified and base depleted through weathering and leaching. The latter subgroup is associated with base-rich parent materials such as limestone and limestone-dominant glacial drift that has undergone less leaching.

The brown earths are amongst the most extensively cultivated soils in the country due to their desirable drainage conditions and their well-developed structure and although of relatively low natural fertility they are responsive to manurial treatments. These in their natural state are excellent forest soils also for hardwoods, Douglas fir and a wide range of conifers.

Rendzina-like Soils.

An important group of soils agriculturally and occurring in scattered relatively extensive areas forms a notable exception amongst our free-draining "Pedalfer" soils. These soils resemble the Continental Rendzina soils and even under our climate possess but an A/C profile or in other words have a rather shallow surface soil resting on the parent material—mostly a Carboniferous limestone or limestone glacial drift. These soils under our climatic conditions have been decalcified to the extent that in many cases they no longer retain any free carbonates in the profile. However, their base status and pH is mostly high. The organic matter content in the surface is high relative to other mineral soils and the humus is a mull type. The surface soil in particular, is dark coloured (dark brown to black). Where more excessive base depletion has occurred, soils with A/(B)/C profiles are found. These rendzina-like soils have many features in common with the shallower members of the brown earths of high base status.

Under the rainfall conditions prevailing these free-draining shallow soils are productive especially under grassland. In certain areas the parent rock comes too close to the surface to allow cultivation and in places too, extensive rock outcrop occurs. Hazel scrub is common on these soils which are suitable for *Pinus radiata,* Silver fir, ash, beech and sycamore.

With the widespread distribution of Carboniferous limestone formations and predominantly limestone drifts in Ireland one might expect more of these rendzina-like soils but this is not so. Our climate is not typical of that associated with the true Rendzina so only where the parent material has a sufficiently strong modifying influence do we find our Rendzina-like soils.

Grey-Brown Podzolics.

Associated with the Pedalfers in that there is a leaching process operative in the profile are those soils in which the main constituent shifted downward is the finely divided clay fraction. Where a defiinite B horizon occurs with significantly greater clay content than in the A or C horizons then these are known as Grey-Brown Podzolics. In Ireland on our vast areas of deep limestone or mixed limestone drift the most common soil at normal elevations in a deep, arable soil of grey-brown colour. This soil, depending on the degree of leaching, resembles in some cases the Continental brown earth already discussed where the profile is relatively uniform in character and in others the Grey Brown Podzolics mentioned above.

The latter group usually possess a heavier texture generally than the brown earths and are characterised by the distinct clay increase (with associated clay-skins) in the textural B horizon (Bt). Thus these profiles are designated A/Bt/C profiles. They are well to moderately well-drained soils of medium base status and moderate to neutral reaction. The organic matter content in the surface is moderate to high and the humus a mull-type.

The lighter-textured members are good all-purpose agricultural soils when adequately manured and well-managed but the heavier textured members do not compare favourably in this regard with the brown earths but make more desirable grassland soils where under proper manurial and management practices they can be highly productive. Very little of these soils are available to forestry but they should constitute highly productive forest soils.

Modified Grey-Brown Podzolics.

This peculiar group occurs on the dominantly limestone fluvio-glacial eskers and glacial outwash materials of Weichsel Age across the Midlands. These in many cases display well expressed podzol characters but under rather unconventional conditions for podzolisation. (See Gallagher and Walsh (1942)—Athy Series). It is now considered, as a result of more recent investigations, that these soils are polygenetic soils where due to vegetational change from a forest to a heath or gramineous cover the original profiles have been modified. In the case of heath, podzol development has proceeded within an original grey-brown podzolic profile and in the case of gramineous cover the surface horizons of the original profile have been homogenized.

These are a very mixed group of soils in terms of profile depth, degree of development and extent of modification. In general they still retain a high base status and reaction is about neutral to slightly alkaline, although numerous exceptions occur where both pH and base status are both in the moderate to low category. In the latter instance the surface organic matter content may be above normal levels and approaching a moder-mor type but about normal or sometimes low organic matter levels with a mull-type humus are most common.

The soils being well-drained, relatively light-textured and of favourable structure are extensively cultivated. The land form in certain cases however, makes cultural practices difficult. Pasture adequately manured and well managed can be very productive on these soils but water deficit in drier seasons, in particular on the lighter-textured and more shallow members, can be a distinct problem.

Brown Podzolics.

These soils are more intensely leached than the acid brown earths as a result of which they have been more depleted of bases and other constituents in the upper horizons. A characteristic feature of these soils is the presence of a subsurface horizon of strong red-brown or yellowish-brown colour due to enrichment principally by iron leached from the upper horizons. These soils therefore, with A/B/C profiles are more degraded generally and of more acid nature than the brown earths. However, they still retain an acid mull or in more degraded forms a moder-type humus.

The brown podzolics occur in many areas in close association with the acid brown earths where local conditions of parent material, topography or past vegetation cover have been more conducive to their formation. They are the dominant soil of medium elevations on acid parent materials such as non-calcareous shales, sandstones, granites, mica-schists and glacial drift of such sources. In such instances they usually occur as an intergrade group from the acid brown earths of the lowlands to the podzols which occupy the higher elevations.

The brown podzolics have usually a somewhat lower level of natural fertility than the brown earths. However, as well-drained soils of favourable structure, they are useful tillage and all-purpose farming soils, provided they are adequately limed and manured and well managed when they resemble the brown earths in behaviour. In their natural state these soils carried the primeval oak forests of Counties Wicklow, Wexford and Waterford, some of which were planted with larch and Douglas fir on private estates. These are considered excellent forest soils.

Podzols.

These soils are still more intensely leached than any of the foregoing, and as such they may be considered as degraded soils. They are usually developed on parent materials of very low base reserves or under conditions that tend to deplete the base reserves to this low level. The hills and mountains of acid geological materials—acid shales, sandstones, quartzites, granites, mica-schists—provide situations where both these factors are operative in soil development. The acid nature of the parent materials and high rainfall with low evapotranspiration losses in these areas, combine to allow a considerable downward leaching of soil constituents foremost amongst which are bases, iron and aluminium oxides and humus. In cases of further deterioration the surface becomes very acid, conditions for decomposition by micro-organisms become unfavourable, with the result that a peat-like, raw humus layer accumulates in the surface, on which a characteristic heath vegetation is found. These soils then, have very distinct profile differentiation or A/B/C profiles. In the more extreme forms the B horizon contains a thin iron-pan rather than a diffuse B as in the less extreme forms.

These are poor soils with high lime and nutrient requirements. Where they occur in lowland areas they have been successfully reclaimed for cultivation and other purposes in many cases. The more extreme forms that occupy extensive areas of hill and mountain throughout the country have not been ameliorated to any extent. In most cases the land forms and nature of the terrain associated with these soils are such that mechanical means of reclamation and cultivation are not feasible but considerable improvement in productivity is possible by surface regeneration including manurial amendments. The presence of iron-pan is a hindrance to root penetration (important in forestry as well as in the agricultural use of these soils) and to water percolation. For the latter reason the surface horizons of these podzols may develop very poorly drained conditions—a further drawback. Besides the low level of major nutrients in these soils they are generally very deficient also in trace elements vital in the nutrition of plants and animals.

These are the principal mineral soils available for afforestation and are usually planted with pines but with deep ploughing and phosphorus application they are suitable for Sitka spruce.

Skeletal Soils.

Throughout the hill and mountain regions in particular, thin, skeletal soils (comprising Rankers and Lithosols) occur intermixed with extensive areas of outcropping rock. The ranker group are composed of a thin moder-mor type humus layer overlying unweathered stones and shattered rock of an acid nature. The lithosols are stony soils with little of finer materials within the profile. These are very poor soils, of very low base reserves and natural fertility and with physical characteristics that strictly limit their development. Some surface treatment can improve their productive capacity for extensive grazing.

Gleys.

Gleys are those soils, of extensive occurrence in Ireland, in which the effects of drainage impedance dominate. These have developed under conditions of intermittent or permanent waterlogging. The impeded condition in these soils may be due to high watertable level or to perched watertable as a result of the relatively impervious nature of the soils or their parent materials or in certain cases to a combination of both factors. Gley soils therefore, can occur in depressions or on elevated sites on the landscape. Run-off of surface water from higher ground is also a major contributing factor.

The mineral soil horizons of gley profiles usually display distinct features associated with the drainage-aeration conditions prevailing such as drab grey colours with prominent ochreous mottling much in evidence. In cases of extreme conditions of waterlogging the greater part of the profile is characterised by grey and blue-grey colours with little or no mottling. Texture in general in these soils is heavy, especially in the surface-water gleys but gleying is not by any means confined to heavy textured soils. Relative to the foregoing soils depletion of bases and other constituents in general is not so pronounced in these soils. However, rooting area in them is limited, structure is very weak, aeration is poor, decomposition rate of organic matter is slow, leading to undesirable surface accumulations of a raw humus in more extreme cases, and they possess many other unfavourable features (Quinn and Ryan, 1962).

The majority of gleys are not very friable and when wet become very sticky. Due to their poor physical conditions, these soils, except in very favourable seasons, present difficulties in cultivation especially in the development of a desirable tilth. Besides, due to their poor drainage, growth is slow early in the season and this factor together with their weak structure, render these soils very susceptible to poaching damage by grazing stock. Consequently the grazing season on them is short. Nevertheless the potential of these soils for pasture production is very high in many cases, provided manurial and management practices are at an adequate level. They can be quite productive under trees also especially for Sitka spruce which however is liable to windthrow due to shallow rooting.

Peats.

Peats or organic soils are widespread in Ireland. These can on a broad basis be divided into two subgroups (a) Basin Peats (b) Climatic or Blanket Peats.

The basin peats were formed by the long-term accumulation of plant remains in post-glacial lake areas due to conditions for decomposition being unfavourable. The lower peat layers are composed of the remains of swamp species principally and are soligenous whilst the uppermost layers are associated more with ombrogenous *Sphagnum* species mostly. Whereas the underlying deposits in these lake beds are predominantly calcareous and of limestone origin the surface layers of the bogs are very acid.

The climatic peats are associated principally with the hill and mountain areas in the country where they form a surface blanket or mantle over the landscape. As such they are not confined to basin areas. Associated factors are chiefly the acid nature of the geological parent materials of low base and nutrient supplying power and the cool-temperate, humid climate.

The high organic content gives peat some unique chemical and physical properties and makes reclamation and cultivation difficult. Virgin peat has an exceptionally high moisture content, low ash in the dry matter and a massive structure with poor aggregate formation. As a result peat has low hydraulic conductivity, poor porosity and unfavourable aeration conditions. Other problems are inherent in the drainage and amelioration of peat and in the manurial and management practices required in attaining optimum output. (Burke and O'Hare, 1962). Nevertheless success has been attained in the reclamation of peats and in the production of pasture, arable crops and forestry on them at both a local individual level and on a more extensive scale in certain cases. The vast majority of peats in the country however, are still unreclaimed.

Distribution of the Soils

With the present state of knowledge and until such time as the survey, classification and mapping of our soils is more advanced it is not possible to delineate accurately the distribution of our very complex soil pattern. The geographic distribution of our soils is associated with climatic, relief and biotic factors as well as with the nature of the parent materials and these factors are in themselves very variable.

In a generalized manner the dominant great soil groups (already discussed) occurring in different areas or regions are outlined on the accompanying schematic soil map. The delineation of the different soil areas, and the composition of these areas in terms of the most commonly occurring great soil groups within them, are based mostly on spot checks and not complete surveys and the map must be interpreted as such. Likewise the soil boundaries shown are not by any means absolute in most cases. In reality what are shown are associations of dominant great soil groups but no account is taken of more minor inclusions or sub-groups that are interspersed with the dominant major groups.

The legend accompanying the map (Appendix) gives the great soil groups that are dominant in each area and the most commonly occurring geological parent materials associated with these soils. More detail is available in certain regions than in others as a result of more precise observations in these areas. A much more complete picture of the distribution of our soils will become available with the progress of soil survey in the immediate years ahead.

Acknowledgement.

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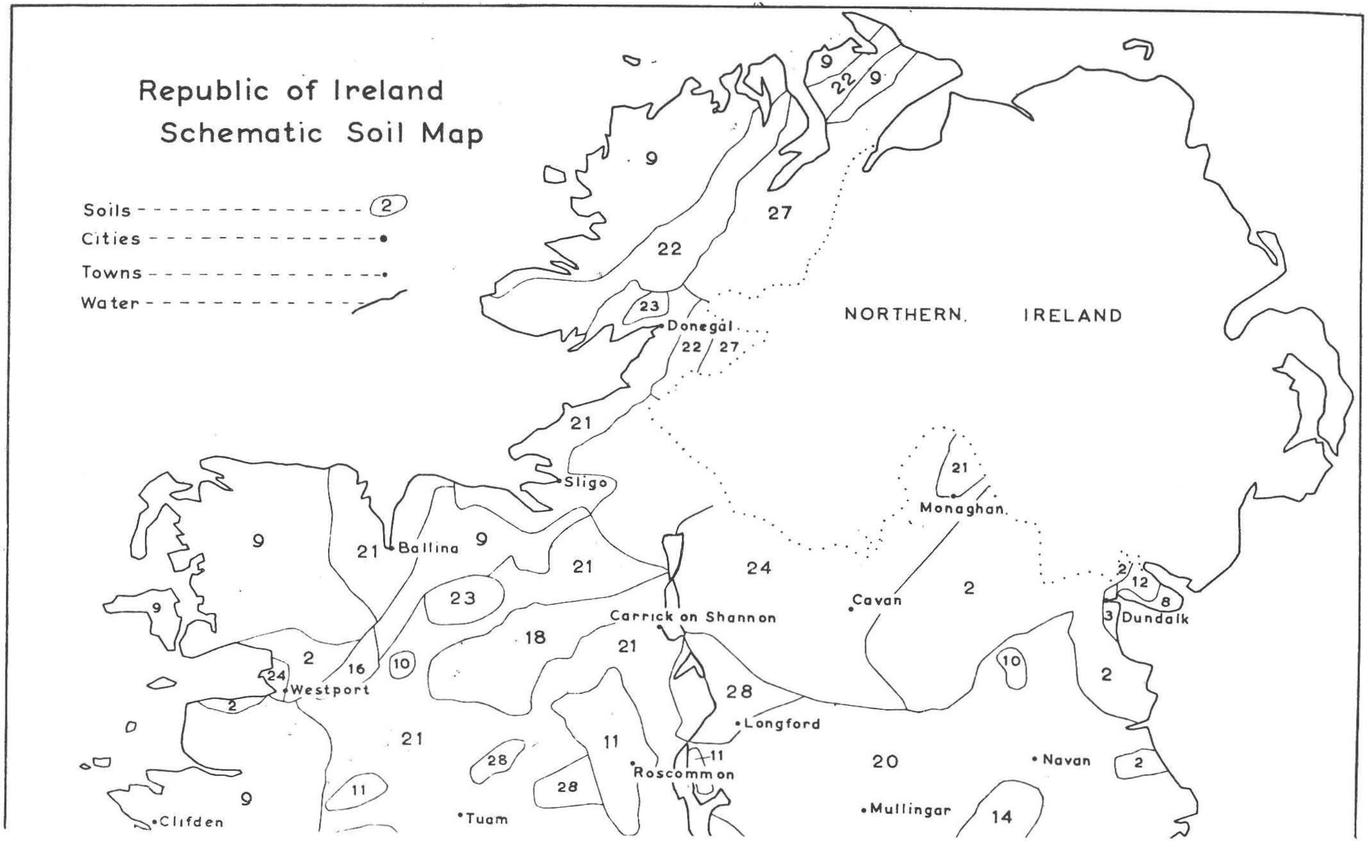
Appendix.

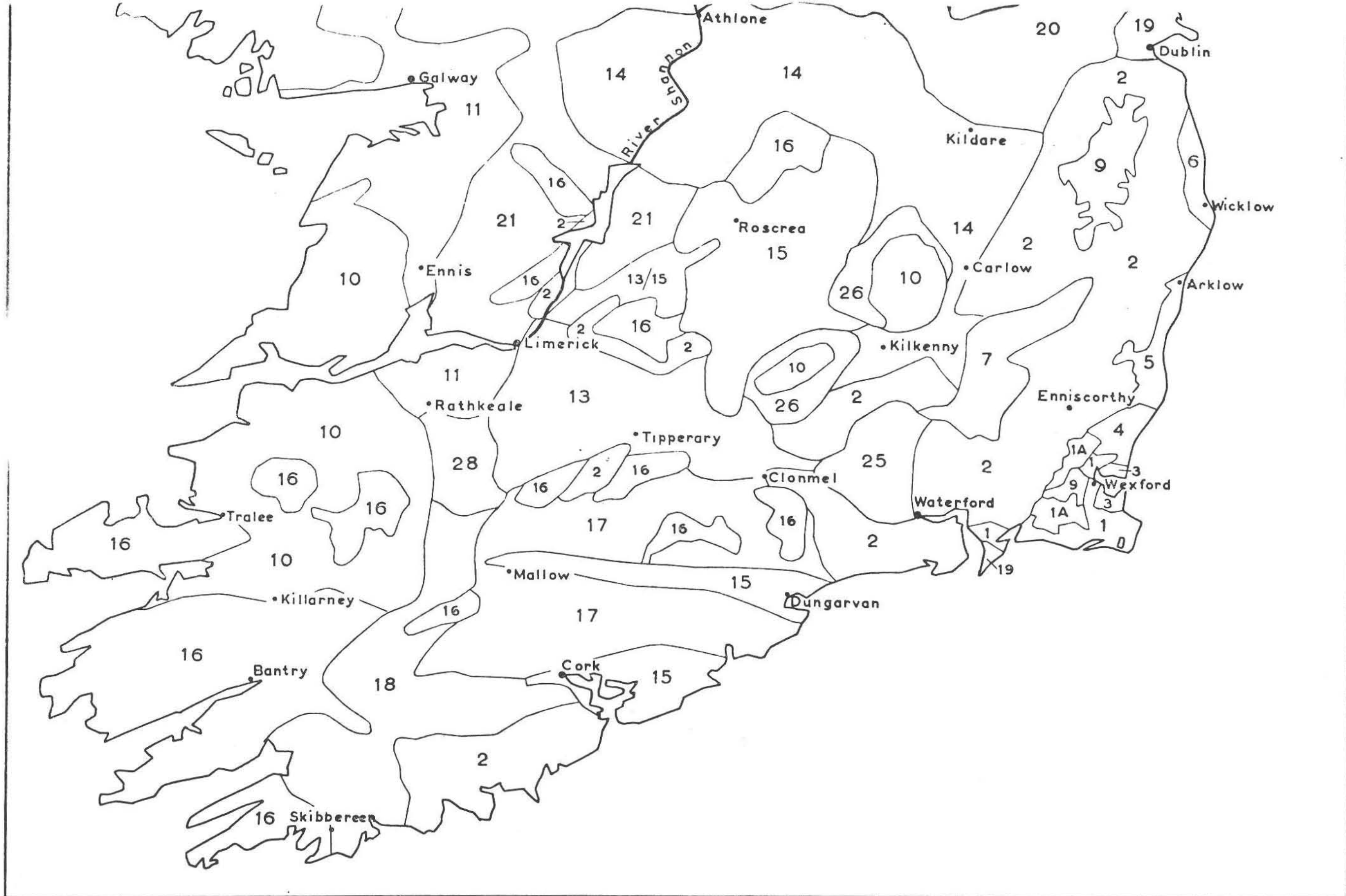
Legend.

1. Acid Brown Earths and Grey Brown Podzolics with some Gleys derived from Ordovician—Cambrian—Quartzite parent materials, mostly as glacial drift cover.

1a. Surface-water Gleys and slightly gleyed Acid Brown Earths derived from Cambrian-Ordovician-Quartzite parent materials mainly as a dense glacial drift cover.

2. Acid Brown Earths and related Brown Podzolics derived from Ordovician and Cambrian shales (igneous intrusions in places) or from Silurian or Avonian shales, with thin mixed glacial drift cover.
3. Deep ground water Gleys of alluvial origin.
4. Acid Brown Earths and Brown Podzolics and some Podzols derived from coarse-textured glacial morainic deposits.
5. Deep surface-water Gleys with some slightly gleyed Brown Earths derived from dense, mixed glacial drift of marine origin.
6. Grey Brown Podzolics and mixed Brown Earths derived from mixed coarse-textured glacial drift.
7. Acid Brown Earths and Brown Podzolics derived from Granite and granitic glacial drift.
8. Mixed Brown Earths and Grey-Brown Podzolics derived from a mixed Limestone—Dolerite—Diorite glacial drift.
9. Climatic Peats, Podzols, Skeletal Soils and Brown Podzolics, on acid igneous and metamorphic formations with mixed glacial drift cover in places.
10. Acid Brown Earths (many with gleying), Gleys, podzolised Gleys and Climatic Peats on Coal Measure and Yoredale shale formations with mixed glacial drift cover in most places.
11. Rendzina-like soils and Brown Earths of high base status derived from Carboniferous Limestone with dominantly limestone glacial drift cover (usually thin). Also some Basin Peats.
12. Grey-Brown Podzolics, Acid Brown Earths and surface-water Gleys derived from glacial drift mainly of Silurian—Felsite—Dolerite —Granite source.
13. Brown Earths (mostly medium base status) and Grey-Brown Podzolics derived from Limestone—Old Red Sandstone glacial drift with igneous influence in parts. Also some Gleys and Basin Peats.
14. Podzolised Grey-Brown Podzolics, Brown Earths of high base status and Grey-Brown Podzolics derived from mixed coarse, fluvio-glacial drift mostly of Limestone origin. Extensive Basin Peats also.
15. Brown Earths (medum-high base status) and Grey Brown Podzolics derived from mixed, mostly Limestone, glacial drift. Some Basin Peats and Gleys also.
16. Climatic Peats, Podzols, Skeletal soils, Gley-Podzols and Brown Podzolics mostly on Old Red Sandstone rock and glacial drift.
17. Acid Brown Earths, Brown Podzolics and some Gley-Podzols derived from mixed, mostly Old Red Sandstone, glacial drift.
18. Acid Brown Earths, Brown Podzolics, Podzols, Gley-Podzols,


Republic of Ireland
Schematic Soil Map
Soils 2
Cities
Towns
Water
NORTHERN IRELAND
Donegal
Sligo
Ballina
Carrick on Shannon
Monaghan
Cavan
Dundalk
Westport
Longford
Roscommon
Navan
Mullingar
Tuam
Clifden



Prepared by National Soil Survey, Soils Division, An Foras Talúntais

Based on the Ordnance Survey by permission of the Government

Gleys and mixed Peats mostly on Old Red Sandstone and Avonian Shale rock and glacial drift.

19. Very deep black and brown calcareous soils derived from Limestone glacial drift.
20. Deep Brown Earths (medium and high base status) and Grey Brown Podzolics derived from mixed, mostly Limestone glacial drift. Also extensive areas of Basin Peats and Gleys.
21. Brown Earths (medium-high base status), Grey-Brown Podzolics and some Peats on impure Limestone and mixed, mostly Limestone, glacial drift.
22. Brown Podzolics, Podzols and Climatic Peats with some Gley-podzols on Mica-Schist and Gneiss materials.
23. Gleys and mixed Peats on mixed glacial drift.
24. Extensive areas of Gleys with Acid Brown Earths and Grey-Brown Podzolics (with and without gleying) and some Basin Peats on mixed glacial drift (mostly dense boulder-clay) associated with the Drumlins.
25. Grey-Brown Podzolics and Brown Earths (medium base status) on Limestone—Old Red Sandstone—Silurian glacial drift with some igneous influence.
26. Acid Brown Earths, Brown Podzolics and Gleys on mixed shales and glacial drift of similar origin.
27. Brown Podzolics and Acid Brown Earths on mixed predominantly Mica-schist and Gneiss materials.
28. Grey-Brown Podzolics, Gleys and some Basin Peats on mixed sandstone limestone drift and on glacial lake deposits.

The Improvement of Forest Trees by Selection and Breeding

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THE first step in establishing a plantation is to select the species which is most suitable for the site and the future requirements of produce. Until recently selection ended at this stage.

Seed of the species decided upon was obtained from wherever it was cheapest or most convenient. Exotic species with very wide geographical and altitudinal ranges were planted on a large scale during the eighteenth and nineteenth centuries, but it was only towards the end of the nineteenth century that the importance of the actual area of origin began to be realised. For example European larch from high altitudes was recommended because of the northern latitude of Scotland where it was to be planted. Later still it was found that trees raised from these areas failed badly due to the late spring frosts, and lowland larch from farther east was found to grow better. Similarly the inland provenances of Douglas fir, the Blue or Colorado Douglas, were clearly inferior to the green or Coastal Douglas fir. It was realised that choice of species alone was insufficient; there must be a choice also of provenance of the species for the conditions where it was to be planted.

Within areas of similar climate there are tree populations which differ in quality and vigour. This is most marked where the trees occur in scattered groups too far apart to interbreed. A noted example is the Polish larch. The choice of provenance must then be narrowed down to the best stands within the chosen climatic or altitudinal zone, and the survey of populations to assess their quality is the first step in tree-breeding. This can be taken a stage further in certain cases, by removing all the inferior trees from the selected areas when the remaining high quality trees interpollinate. They also then have room to develop bigger crowns and carry more flowers, male and female, and so produce more and better seed.

The stage beyond that of selecting and thinning seed-sources is the selection of the finest individual trees, wherever they may be, and breeding from these alone. This requires the special techniques of vegetative propagation and the formation of seed-orchards.

Natural Selection.

The species and individual trees now growing in natural forests are the survivors of very long periods of natural selection. Any tree possessing an heritable difference rendering it capable of producing more offspring than the others will be represented in the succeeding generations by a greater number of offspring, until this favourable character is to be found throughout the population. Conversely an heritable disability to produce offspring is progressively swamped and disappears—in one generation, in the extreme case of sterility. Hence natural populations are composed of individuals inheriting primarily the ability to survive and flower in their environment. The features most important in a timber-tree may have been selected incidentally —a single straight stem is the most efficient way of carrying a crown high among other trees, for example—or they may, in other circumstances, have been selected against. For example, in an open stand, more flowers can be carried early in life on a low, spreading crown with strongly developed branches.

Artificial Selection.

The breeding of many plants and animals has been carried on almost unconsciously since man settled into pastoral ways. Cattle, dogs and horses were bred for different uses and conditions. Food crops have been gradually selected for increased production of the edible parts. The effects of selection are very powerful and even this unplanned selection has changed the food plants until they bear small resemblance to their wild ancestors. The same changes could have been made in very much fewer generations had they been planned. The first requirement is to decide the aim of the breeding programme. In each generation only the plants which are nearest the ideal are used to raise the next generation. Each generation is thus one step nearer the ideal. Carefully planned selection can have rapid and startling results as is shown for example, in Russell lupins, Excelsior foxgloves and Ballard Michaelmas daisies.

The response to selection depends on the amount of variation occurring in the original population and on the intensity of selection. Most forest tree species are very variable and cross-pollinate freely which maintains this variability. Thus selection can be an effective method of producing improved varieties.

Selection may be operating in undesired directions. One example is the way pests subjected to poisonous sprays produce varieties which are resistant to the poison, by the intense selection against susceptible individuals and in favour of any degree of resistance. A more subtle example is provided by the accidental production of Flax Darnel in the Netherlands. Darnel is a weed-grass growing in the flax fields. When the flax is cut for seed the flower-heads of darnel are normally below the level of the flax and unripe. An early individual plant occurred once, however, and at the flax harvesting time, its seeds were ripe and high enough to be cut. The seeds were mixed with the flax seed and were sown with it, and the process was repeated until this new variety of darnel became a regular contaminant of flax over a wide area.

It is evident that if the best individuals of any crop are removed before they have produced as many offspring as those left behind, a selection will operate in favour of the less desirable types. This is what happens in forests which are exploited in a primitive manner and it has degraded the natural forests of large parts of the world. In the course of time the better inherent factors or genes have been lost and such stands can no longer produce trees of good quality. Tree-breeding aims to reverse this process and raise stands possessing only the best factors.

The Objects of Tree-Breeding.

Broadly, the object of tree-breeding is to produce varieties of trees which are the most desirable for both grower and user. Fortunately the qualities required by silviculturists and timber-merchants are largely compatible.

The silviculturist or forester requires rapid germination and growth in the nursery; rapid establishment of a crop of disease-free trees and rapid growth to timber-size. The trees should also have compact crowns with dense foliage and small, nearly horizontal branches which prune easily or fall naturally.

The timber users require a straight, nearly cylindrical stem, free from fluting and spiral grain, and wood of uniform quality and of the necessary density, fibre-dimensions and so on, with few or small knots, perpendicular to the grain.

The two qualities of rate of growth and size of branches can be altered by silvicultural practice, but only within the limits inherent in the population. If the crop is inherently very vigorous, growth can be retarded if necessary by close spacing or delayed thinning but if the population is not inherently vigorous, no silvicultural treatment can make it grow very fast should this be required. Hence selection of the parents should be in favour of maximum vigour. Again, it is difficult to foresee the requirements of the timber-trade sixty years ahead of the date of planting so the safest plan is the production of the maximum possible yield of wood per unit area of land.

Thus the aim is to produce trees of great potential vigour, healthy, with straight, persistent stems which are as nearly cylindrical as possible and possess regular, numerous, small and level branches cleanly set in the stem.

The Selection of Parent Trees.

It will be evident that only those characters which are inherited can be improved by breeding. It is fortunate that the greater number of the important characteristics of trees have been found to be heritable in varying degrees. It would seem simple, therefore, to find trees in the forest which approach the ideal and breed from these. This is the general plan, but there are complications in assessing the trees for use. No characteristics are inherited in the manner of goods—the same entities belonging to successive generations. The most that can be inherited is the ability to show a character given the required environment. For example, although gorse plants are said to inherit spiny leaves, a gorse seedling grown in high humidity will develop trifoliate leaves and not spines. Trees are long-lived and may be conditioned to their environment to a greater degree than other organisms. The tree in the forest is the result of the interaction between the potentials inherited and the effects of the environment. This important concept is expressed in the terms *genotype,* or inherent make up of the tree and the *phenotype,* the actual appearance of the tree modified by its environment. The selection of trees for breeding is dependent on the estimation of the relative importance of genotype and environment in forming the tree. Three methods are used in selecting trees by which this is done. These are:—

(1) For single trees, straightforward assessment of the environmental effects from topography and soil and the condition of other trees and plants in the area.

(2) In plantations the potential plus trees are surrounded by other trees in very nearly the same environment and their relative performance can be seen. If conditions were completely uniform the differences among trees would be solely those due to their genotypes.

(3) On very favourable sites every tree will be almost as good as its genotype is capable of making it i.e. genotype almost equals phenotype. Such sites do in fact produce a great variation among trees of the same species and the outstanding trees can be selected and the rest safely ignored.

Further difficulties arise from trees which would be selected but have some defect which may be due to damage of a random nature i.e. loss of the leader some years previously. This could have been caused by wind, snow, another tree blowing against it or by birds. Sometimes many trees in one area show such damage at similar heights and from the date when it occurred it can be attributed to an ice-storm known to have happened at that time. This kind of defect might occur in any tree, but on the other hand, there may be trees which are more susceptible to it than others and these would not be desirable. The safest course is to discard such trees unless certain desired characteristics are really exceptionally well developed.

Selection of trees in very unfavourable conditions, as for example at high altitudes or severe exposure is a special case. It may be that the best trees selected on favourable sites would produce the best plants for extreme sites too, but this hypothesis needs testing. Meantime trees are selected on such sites and should be used separately because their use may be limited. For example in severe exposure the only trees which can show good stem form and crown-shape are those able to withstand the wind. Any other trees which might on a favourable site, have been of excellent form, will be mis-shapen on the site where it is growing. Plants raised from trees selected on these sites may be the best for growing on such sites but not on others.

The selection of broadleaved trees raises the problem of the lack of persistence of the main stem, which even in the best oak for example is seldom longer than fifty feet. This is so even in plantations, whereas open grown oak frequently fork much lower. Nearly all the value of an oak stem lies in the bottom thirty feet and it might be thought sufficient to select trees which fork at or above this height. But there is no guarantee that progenies of such oak will not fork below thirty feet whereas this is less likely if all the parent trees have grown fifty feet with a single stem. In beech it is possible to select trees with stems persistent through the crown to the top at over 100 feet, although this is rare. Good boles of seventy feet are, however, found less rarely.

Some defects debar a tree from selection completely. These are susceptibility to disease, possession of spiral grain and excessive fluting or bending.

Selection of plus trees along the lines outlined above does, in fact, produce progenies much superior to the normal seed. In Australia, trees raised from normal and selected Loblolly pines have been compared, also those raised by controlled pollination of selected trees as would occur in a seed-orchard. The results, with the trees at 800 to the acre are tabulated below :—

	Good trees/acre	Plus trees/acre
Average seed (normal collection) ...	112	1
Selected parents (open pollination) ...	200	10
Three best selected parents	277	47
Controlled pollination	412	80

Controlled pollination of larches in Britain has shown that at four years of age the progenies are outstanding. At two years assessments showed that vigour is heritable to a small degree and only the most vigorous trees produced progenies significantly more vigorous than normal. Later assessments may well show a greater inheritance of vigour but selection should be very rigorous and only outstanding trees should be selected.

Once sufficient plus trees have been selected to make graphs of the height and girth reached at different ages by this kind of tree, the figures can be used as a basis for selection as far as vigour is concerned. The fastest growing plus trees of larch at various ages lie on curves up to three quality classes above Quality Class I in the Yield Tables.

The Use of Hybrids.

Progress in breeding by selection depends on the natural variation available. One way to increase variation is to cross trees of different species and select among the hybrids. Only species which are closely related will cross, but even so their genotypes are usually very different and the second generation of their hybrids (i.e. F_2 plants raised by crossing the first generation, F_1) will segregate to produce new variants. In other branches of plant-breeding it is possible to work through generations rapidly and great progress is made by this method. In forest trees the time needed for raising and seeding a generation makes it desirable in practice to use the first generation hybrids for planting in the forest. But while these are being raised in quantity, a few of the most desirable are selected and planted together for raising an improved second generation. Selection here must be rigorous, for in raising a second generation from hybrids, there is normally a loss of a phenomenon known as hybrid vigour, or heterosis. Heterosis occurs where plants raised from dissimilar parents are superior for any characteristic to either parent, and is therefore confined to the F_1 cross. Heterosis in some qualities—for example vigour in some western American pines—has been shown to occur only in climates intermediate between those of the parent species. It may have a number of genetic causes but in some cases a simple explanation may be sufficient. For example, natural crosses between Nootka cypress, *Chamaecyparis nootkatensis* and the Monterey Cypress, *Cupressus macrocarpa* arose in Wales in 1888 and 1911. The Nootka cypress inhabits the cool moist regions of western North America and the Monterey Cypress comes from a hotter, drier peninsula in California. The former is of slow growth and the latter is fast. The hybrid, known as Leyland's cypress *x Cupressocyparis leylandii,* on all sites so far used, easily outgrows the Nootka cypress, and on many sites outgrows the Monterey cypress as well. This could be due to inherited ability to grow well in both the cool moist periods in which the Monterey does not do so well, and in hot dry periods, in which the Nootka is slow, so that in our climate with both kinds of weather, the hybrid can grow well at all times.

Species which have a wide natural distribution may consist of a number of geographic races or even subspecies. Crosses between the geographic races are intra-specific but since their parents are of different non-interbreeding populations, these crosses may show hybrid vigour. Crosses between the Blue or Colorado Douglas fir and the Green or coastal Douglas fir; and between the Polish European larch and Western alpine European larch are such intra-specific hybrids and may prove to be of value.

Tree Seed-Orchards.

The seed-orchard is the means of selective breeding and cross-breeding in trees. The selected "plus" parent trees are propagated by grafting and clones of these grafts are planted in balanced mixtures in such a way that the female flowers of a given clone can be pollinated equally by all the other clones in the orchard. The individual grafts of each clone are separated from each other to prevent self-pollination for this inbreeding causes a loss of vigour and the production of many aberrant forms. The minimum number of clones in any one seed-orchard is usually 20, and 30 is better but a few small orchards of 10 clones are made for special purposes. The higher numbers are preferable for large scale forest use, to avoid the harmful effects of inbreeding among progenies from the stands which will be raised from seed-orchard seed, where natural regeneration may be required.

The seed-orchard is planted on a site isolated by distance from other trees of the same or related species to avoid contamination from unselected trees. The minimum distance from a stand of other related trees is a quarter of a mile. Scattered individual trees at half this distance will have a negligible effect. The best areas are those of a good but light soil of high nutrient status, preferably with a southward slope and in a part of the country receiving much sunlight and high June and July temperatures. These factors increase the flowering and hasten the first crops of seed. Air-drainage is of great importance to minimise damage from late frosts.

Seed-orchards intended for the production of inter-specific hybrids are planted with the grafts of the two species alternately in the column and the rows. Thus each graft of one species has four plants of the other species adjacent to it. Conifers are wind-pollinated and it has been found that all but a small fraction of the pollen comes from adjacent trees. The proportion of hybrid seed produced, however, depends also on the relative flowering times at each orchard of the two species and of the clones of those species being used. The parent trees may be growing in any area of Britain or abroad and their times of flowering observed where they are growing does not show their relative times of flowering when all are in one area in an orchard. These can be found only from the seed-orchards themselves or from the collection of grafts, called "tree-banks" which are built up by the breeder. Tree banks are discussed below.

From observations on flowering times in tree banks, of all plus trees, early and late clones may be used to exercise some control over the output of seed and in hybrid larch orchards the outgoing seed can be sorted at picking, if the right trees are used. The Japanese larch sheds pollen two weeks before most European larch but the cones of the European are receptive when the Japanese pollen is shed. Hence by ensuring that the orchard does not contain any unusually early pollinating or late coning European larches, all the cones collected from the European larch clones will contain hybrid larch seed and the cones from the Japanese larch will produce pure Japanese larch seed. To produce pure European larch from a hybrid orchard, late coning European larches could be used with early pollinating Japanese but in practice it is better to have pure European larch orchards separately. Pure Japanese larch orchards will be unnecessary as this seed will be produced by the Japanese larch cones in a hybrid orchard if there are no early pollinating European larch. From these findings it is also apparent that the output of hybrid larch seed is proportional to the number of European larch grafts. Since the Japanese larch cones used have mostly proved copious pollinators, hybrid larch orchards can now be made with only one Japanese larch graft to every four European larch grafts.

The onset of flowering in grafted plants is usually earlier than in trees of seedling origin, especially in pines, spruces and beech. The flowers are first borne within easy reach of the ground making controlled crossing work easy. The trees may be pruned to increase or encourage early flowering—the shapes of the grafts cannot affect the genotype of the seed they produce. If the grafts are allowed to grow tall, climbing for seed-collection is concentrated and special methods may be developed to make cone-collection easier.

The Tree-Bank.

As has been said above, for observation small numbers of grafts of every plus tree selected are put in tree-banks. These are also used to build up supplies of grafting material. Ideally seed-orchards would be made after these observations in tree-banks had been made, but in order to save time and to have seed-orchards from the earliest possible time, so that their management can be learned, the best of the first plus trees found are put straight into seed-orchards. The grafts in the tree-bank ensure that if the parent tree is blown, or felled, or dies, there is still material available from it to make more grafts. It enables scion-collection to be done rapidly from the ground within a few acres, from parent trees which may be scattered all over the country. The grafting material taken from grafts is frequently much superior to that from the parent tree and makes better grafts.

Botanical and cytological work and small scale experimental crosses can also be carried out in tree-banks and to some extent the forms of growth of the parent trees can be compared under the same conditions of soil and climate etc.

General Conclusions.

Although at first sight, the long time-gap between generations might make tree-breeding seem impracticable, there are now techniques which make possible the production of improved cultivars within a few years. Eight years after establishment, the first larch seed-orchard has produced two crops totalling about ten pounds of seed. More recent seed-orchards are getting established more quickly and have been planted at twice the density. The estimated annual production after ten years should be 10 lbs. of seed per acre and at twenty years perhaps 50 lbs. per acre. Thus 20 acres of larch seed-orchard can contribute substantially to national requirements. Seed-orchards are expensive to establish but even if their products give only a one per cent. increase in the crop value, the outlay yields a big return, for it must be noted that one pound of larch seed for example, of normal germination, provides plants for 15 acres of forest. With the improved germination a good seed-orchard should provide and the wider spacing which may be adopted with high quality plants, one pound of seed may plant 30 acres. A small increase in value of timber on 30 acres of land would allow a very great increase in the economic price of a pound of seed needed to plant it.

The establishment of seed-orchards enables the few really outstanding trees growing in any country to be used as the progenitors of all the crops planted, and provides the material for raising a succession of improved cultivars.