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ABSTRACT

The importance of soil factors to the establishment of tree crops is well recognized by forest soil scientists and foresters. It has, however, been overlooked by far too many foresters responsible for major forestation projects.

The soil factors found to be significant in the establishment of both planted stock and seedlings from natural or artificial seedfall are: texture and structure characteristics of the soil profile as they affect moisture and aeration; depth to the ground water table; content of soil organic matter; chemical properties, including soil fertility and the occurrence of layers high in soluble salts and toxic substances.

The importance of producing nutritionally balanced or physiologically balanced planting stock has been recognized, and more attention is being paid to nursery soil management practices in an effort to improve the survival qualities of seedlings. The importance of mycorrhizal fungi as related to seedling survival has also been well established.

These relationships are well recognized in the east where foresters have been at grips with the problems for some time. In the west, foresters are just beginning to see the significance of soil factors; the specific soil-site relationships affecting the survival and growth of a tree crop need to be established for western conditions.

ONE of the most significant site factors affecting the successful establishment of tree crops is the edaphic factor. Forest soil scientists and many foresters have been well aware of this fact, and in the planning for reforestation programs a thorough evaluation of soil conditions has been included. These evaluations have ranged from preplanting soil surveys to on-the-spot analyses of certain soil properties known to be significant to seedling survival.

Many foresters who are responsible for seeding and planting programs still disregard the all-important basic resource in planning reforestation operations. Chapter 5 of the "Reports of the Pacific Northwest Seeding and Planting Committee on Various Recommended Reforestation Practices" is a case in point. This chapter, in dealing with factors affecting plantation survival, discusses the natural hazards having a bearing on plantation success. Weather, animal damage, vegetative competition, and insects and disease are discussed, but no mention is made of the quality of the soil on the planting site. The chapters on direct seeding and on reforestation surveys in this same report give only a superficial discussion of soil factors. It is obvious then, that forest soils research workers and teachers still have a big job in educating the practicing forester and convincing him of the importance of a thorough knowledge of soils to forest management.

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Literature Review

Most of the investigations on the effect of soil on the establishment of seedlings have dealt with soil moisture relationships as affected by seedbed conditions. In fact, the majority of work has been concerned with seedbed conditions as related to logging practices or seedbed preparation. In many instances the soil moisture factor was not directly studied; drought was assumed to be the principal cause of seedling mortality. Although there have been conflicting data reported, the general conclusions have been that bare mineral soil is the most favorable seedbed for germination and survival of seedlings.

Observations as to the favorableness of mineral soil seedbeds were reported in America early in the present century. Knechtel (14) observed in 1903, that eastern white pine seedlings were abundant only where bare mineral soil had been exposed. In 1906, Blumer (4) concluded from his studies of reproduction of Engelmann spruce in the Rocky Mountains that mineral soil was essential for the establishment of seedlings. Murphy (26) declared that the distribution of spruce on various soils in the northeast was influenced largely by moisture, a plentiful supply being essential both for germination and establishment. Moore (25), studying spruce reproduction in the same region, concluded that germination and survival was better on mineral soil than on raw humus. He attributed the poor survival on raw humus to the inability of the seedlings to get their roots down into mineral soil before the humus dried out. Larson (15), after investigating natural reproduction following logging in Northern Idaho, stated that surfaces of ash and loose bare mineral soil offer the optimum conditions for rapid germination and establishment of coniferous seedlings. He found fluctuations in moisture to be greater in duff than in mineral soil. Lowdermilk (18) also concluded that mineral soil favored regeneration of Engelmann spruce. He stated, however, that ultimate success was dependent upon the management of the stand to conserve moisture.

SEEDBED PREPARATION

A number of investigators have studied the effects of seedbed preparation upon regeneration. Shirley (32) found that disking improved seedbed conditions in mature Norway pine stands by breaking up the mat of litter and decreasing vegetative competition, thus allowing seedlings to start in fresh mineral soil. Osborne and Harper (27) concluded that burning and spading gave the best results in first year establishment of longleaf pine. Burning one year before seeding and disking gave intermediate results, while a 3- to 4-year accumulation of "rough" gave the poorest. It was their opinion that exposed mineral soil offered the most favorable conditions for the establishment of longleaf and slash pines. Gemmer, *et al.* (5) concluded from greenhouse experiments that bare mineral soil and light, well watered humus were the best seedbeds for longleaf pine. In field trials, establishment was found to be better on mulched plots than on bare plots due to more favorable temperature-moisture relationships. Wahlenberg (41) has cited numerous instances where burning prior to seed fall has favored germination of longleaf pine. LeBarron (16) states that bare mineral soil is better for germination of jack pine than burned duff and scarified shaded duff which in turn are superior to the undisturbed forest floor. Recent investigations in southeast Alaska indicate that germination and survival of hemlock, spruce and cedar on cut-over lands is far better on mineral

soil than on the common surface moss that is subject to severe desiccation (7).

Several investigators have made intensive studies of the reproductive habits and environmental conditions favoring the regeneration of individual species. Barr (3), investigating Englemann spruce and white spruce, concluded that germination was poor on undisturbed humus in the forest due to lack of moisture at the time of germination; on the other hand, it took place readily on mineral soil. If, during periods of favorable temperature the humus was watered, conditions were then favorable for germination.

Isaac (13) has pointed out that Douglas-fir seed germinates best on moist mineral soil, but will also germinate on duff provided there is sufficient available moisture; survival, however, is dependent upon the seedling's getting its roots down to mineral soil before the duff layer dries out.

Smith (33), working with eastern white pine, concluded that "the variable influence of seedbed conditions on germination and early survival is confined almost entirely to areas exposed to direct sunlight". He found polytrichum moss and moist mineral soil far less subject to lethal soil temperatures than pine litter, lichens and dry mineral soil. When pine litter is protected from direct sunlight it makes a favorable seedbed.

SOIL MOISTURE AND TEMPERATURE

Although the importance of an adequate supply of soil moisture to germination is well recognized, a number of investigators have pointed out that excessive moisture is detrimental. Barr (3) stated that excessive moisture on north slopes resulted in low soil temperatures, thus inhibiting germination of spruce seed. Baker (2) concluded that in spring, soil temperatures are consistently below optimum for germination and that silvicultural practices that tend to warm up the soil will increase germination.

Soil temperature and moisture have been found to be important factors influencing the early survival of seedlings. Baker (1) pointed out that temperatures are higher on dark colored soils than on light colored soils, and stated that heat injury is a major cause of mortality in young coniferous seedlings. Isaac (13) cites some interesting figures with regard to mortality due to high soil temperatures. He noted a 100% loss of Douglas-fir seedlings in a 5-day period on a soil blackened by burning in contrast to only a 32% loss during the same period on an adjacent yellow soil. Surface temperatures on the black soil were much higher than on the yellow soil. Pearson (28) indicated that soil moisture is a critical factor in the early life of ponderosa pine seedlings in the southwest. Pearson and Marsh (29) reported that a content of gravel or stone up to 20% by volume in heavy clay soils is favorable to ponderosa pine reproduction. They concluded that the rock made the heavy clay soils more open and porous, thus favoring moisture relationships and root penetration.

Gemmer, *et al.* (5) have pointed out that surface compaction of heavy soils is detrimental to the establishment of longleaf pine seedlings. The radicle of the young seedling is unable to penetrate the compacted soil. Moisture conditions and aeration in these compacted surface soils are also poor with regard to seedling establishment. Isaac and Hopkins (12) have shown that hot slash fires reduce the moisture holding capacity of surface soils, thus making conditions unfavorable for seeding establishment. According to Stoekler and Sump (34) direct seeding of conifers on sandy soils in northern Wisconsin was only successful where the ground water table was at a depth of from 1.5 to 5 feet. Their conclusions were that the high water table provided adequate capillary moisture to supply moisture requirements as well as ameliorating surface soil temperatures.

Smith (32) concluded that eastern white pine is quite resistant to drought, and attributes most of the first year mortality to high soil temperatures. Wilde (48), on the other hand, states that in the Lake States, white pine seedlings are very drought sensitive and that seedling establishment is dependent upon a favorable moisture holding capacity in the soil or a water table at a depth between 2½ to 5 feet. Isaac (13) observed that, although high soil temperatures may be the major factor adversely affecting survival of Douglas-fir seedlings, frequently mortality is due to a combination of causes. Seedlings weakened by heat injury are often more susceptible to drought.

[3]Wright, E. Mycorrhizae and the growth and survival of ponderosa pine seedlings. Proc. Nursery Practice Committee. Western Forestry and Cons. Assoc. Aug. (1952).

[4]Owens, H. E. Certain factors affecting establishment of Douglas-fir seedlings. Unpublished M.S. thesis, Oregon State College, Corvallis. (1953).

EFFECT OF SOIL CHEMICAL PROPERTIES ON SEEDLING ESTABLISHMENT

The literature with regard to the relationship of the physical properties of soil to germination and establishment of seedlings is quite plentiful. There is, on the other hand, a dearth of literature dealing with the effect of the chemical properties of soil on the establishment of reproduction. Most of the literature on this subject treats the growth of the established seedlings.

There are some indications that fertility factors may play an important role in early establishment of seedlings. Baker (2) states that the inability of the young seedling to obtain adequate nitrogen appears to be an important reason for the failure of seedling establishment. He also points out that at this early stage the seedling is at a very critical stage with regard to the formation of mycorrhizae. Taylor (39) concluded that nitrogen in an available form is an important factor in the occurrence of Sitka spruce and western hemlock seedlings in southwestern Alaska. He found that low levels of nitrate-nitrogen were correlated with a scarcity of spruce seedlings. The number of seedlings was greater with an increase of nitrate-nitrogen up to a level of 50 ppm. It was also noted that spruce seedlings were sparse where ammoniacal-nitrogen accumulates, while hemlock seedlings were abundant. Gemmer, *et al.* (5) have pointed out that the alkaline conditions prevalent in heavy ash deposits on severely burned areas inhibit establishment of longleaf pine seedlings.

It is a common observation in the ponderosa pine region where the slash is piled and burned to find no established seedlings in the ash, whereas adjacent unburned areas may support many seedlings. Wilde (48) states than on alkaline soils some coniferous species fail to become established due to their intolerance to excessive carbonates, and to the increased activity of damping-off fungi and other pathogenic organisms.

INFLUENCE OF MYCORRHIZAL FUNGI

Although there appears to be some disagreement as to the specific activities of mycorrhizal fungi (31), most foresters agree that their activities are beneficial to tree seedlings. It is also generally agreed that they are of significance with regard to mineral nutrition (21, 24, 30, 36, 44, 48). The success in afforesting prairie soils has been found to be dependent upon the presence of mycorrhizae on the roots of planting stock or the inoculation of the soils with forest litter (21, 30, 44). Mycorrhizae enable the seedlings to compete favorably with the extensive root systems of prairie grasses and to absorb nutrients that are in relatively unavailable form. White (44) and McComb (21) have also suggested that mycorrhizae produce growth promoting substances that are favorable to tree growth. Wright[3] has reported that survival of 2–0 ponderosa pine on pumice soils was considerably higher for mycorrhizal stock than for non-mycorrhizal.

The above results were obtained on cut-over forest lands. Wright has concluded that differences in survival are only significant during the first year. By the end of the first year the non-mycorrhizal seedlings have been naturally inoculated and differences in second year mortality are small. Preliminary greenhouse trials indicate that mycorrhizal fungi are not present in the soils on some of the natural occurring non-forested openings in the foothills of the Willamette Valley in Oregon. Invasion of Douglas-fir into these areas is confined to the fringes adjacent to the timber or to small areas around clumps of Oregon white oak. Direct seedings in these openings have met with complete failure.[4] Similar results have been noted on prairie soils in Iowa and Wisconsin (21, 44).

FACTORS IN NURSERY MANAGEMENT

In reviewing the literature with regard to the role of soil factors in the establishment of planted seedlings, it would be well to begin with nursery practice. Perhaps one of the most important factors to be considered in nursery management is the choice of the site. The soil factors of importance have been well outlined (48), but all too often these considerations have been completely ignored. McComb (21) has demonstrated the importance of inoculation of the soil with duff from productive forest stands in order to introduce mycorrhizal fungi when establishing nurseries on prairie soils.

Although there have been many investigations concerned with the nutritional aspects of raising nursery stock, the evaluation of the experiments was largely on the basis of the amount or increase of total dry matter produced; it completely ignored the behavior of the stock when planted on cut-over land. Several

recent publications have strongly emphasized the fallacies of this approach (42, 50).

Wilde (48) has pointed out that a well balanced diet is essential to the production of nursery stock in order for it to have satisfactory survival qualities. Starved seedlings or seedlings that have been overfertilized or have received unbalanced treatments are not satisfactory planting stock. Wilde (48) developed fertility standards for raising both conifers and hardwoods in forest nurseries by analyzing soils from productive stands of the species under consideration. Practical nursery and reforestation experience and specific experiments have proved this approach to be sound. Similar standards have been developed for Douglas-fir and preliminary field planting trials have given positive results.[5]

Wakeley (42) has recently advanced the hypothesis that the morphological grade of seedlings is not necessarily the true grade, or what he chooses to call the physiological grade. He cites cases where differences in mineral nutrition caused by different fertility treatments influenced the physiological grade independent of morphological grade. White[6] and Voigt[7] have demonstrated that jack pine seedlings having had different fertilizer treatments show marked differences in their internal physiology even though they may not exhibit any morphological variation.

The production of physiologically balanced planting stock is dependent in part upon the methods of soil management practiced. The importance of soil organic matter maintenance to tilth and the fertility status of nursery soils has been stressed (40, 48). The use of organic matter applications for control of pathogenic organisms has been treated recently by Maki and Henry (20), Mikola (22) and Wright.[8] Some investigators feel that the use of organic matter amendments to control pathogens in the soil is more profitable than direct control with fungicides, because beneficial organisms are not deleteriously affected.

It is safe to conclude that soil management practices in the nursery directly influence the survival properties of field-planted stock. Here again is an education problem, for unfortunately too many nurserymen are still concerned only with morphological properties of the stock they produce, completely ignoring or being unaware of the significance of physiological grades.

EFFECTS OF SOIL TEXTURE

The majority of the research work dealing with the effect of soil on the establishment of plantations has been, as in the case of the effects on natural regeneration, concerned largely with soil moisture and the properties affecting it. Soil texture has been used extensively as a guide to choice of species and planting sites. Wilde,[9] using a combination of soil texture and drainage factors, subdivided the soils of Monroe County, Wis., into six classes with regard to reforestation possibilities. The upland soils of the Lake States have also been subdivided into six textural classes for reforestation purposes. Wilde (45) stresses the importance of a complete profile examination since the textural properties of the subsoil may warrant planting species having different moisture requirements than might be assumed from surface texture alone. Stoekler and Limstrom (35) have also used soil texture as a means of choosing species and planting sites in northern Wisconsin and upper Michigan. They, as well as Wilde (46), have given considerable attention to moisture relations as affected by depth to the ground water table. A favorable ground water situation warrants planting of more demanding species than would ordinarily be chosen on the basis of texture. Limstrom (17) concluded that the ratio of soil to stone in the spoil materials from strip mines in the central states is important in considering the choice of species for planting, due to its effect on available moisture, drainage and aeration. He found initial survival and growth of plantations to be directly related to the amount of fine material in the spoil surfaces. A tentative planting guide was established, using the percentage of soil material present as one of the criteria for species choice.

Minkler (23) reported that some of the factors affecting plantation success on old fields in the Great Appalachian Valley are soil type, aspect, first year precipitation, depth of A horizon and the consistency of the A and B horizons including porosity and permeability. Tarrant (38) concluded that soil moisture is the most critical factor affecting plantation survival. He developed a preplanting soil survey for the Yacolt Burn in Washington using soil depth, surface texture, surface consistence, subsoil consistence, surface organic matter conditions, percent slope and aspect as factors for evaluating the quality of planting sites for Douglas-fir. Wakeley (43) has indicated that unfavorable soil texture and soil organic matter deficiencies are important causes of plantation mortality resulting from drought. Site preparation that improves moisture conditions either by minimizing competition or by providing for accumulation of soil moisture has been shown to increase plantation survival (35, 43, 47). This is particularly true on sandy soils and heavy clay soils in which moisture conditions are more apt to be critical.

AERATION, ORGANIC MATTER AND FERTILITY

Satisfactory aeration has been shown to be of significance from the standpoint both of moisture relations and of root development. Tarrant (38) concluded that poorly aerated heavy clay soils are unfavorable for survival of planted Douglas-fir. White and Wilde[10] have pointed out that heavy clay soils and soils with high ground water tables are inadequately aerated and unfavorable for plantation establishment. Wilde (48) has suggested that aeration is an important guide for choice of species. It has also been demonstrated by Wilde (46) and Stoekler and Limstrom (35) that planting on top of a turned over furrow slice improves aeration and survival on poorly drained soils.

Although the exact role of organic matter is not mentioned, foresters are generally agreed that a satisfactory level of organic matter is essential to plantation survival, particularly in the case of more exacting species. Wilde (48) stated that on sandy soils a higher content of organic matter counteracts a deficiency of mineral colloids. He has suggested the use of nitrogen fixing legumes for site improvement on depleted soils (49). Heiberg (8) concluded that in reforesting old fields in New York, only pioneer species should be used if the humus layers are absent or badly depleted. In many cases soil organic matter undoubtedly enhances plantation success by improving both soil moisture and soil fertility conditions and, in the case of heavy clay soils, physical conditions. Minimum allowable levels of soil organic matter for various species have been given by Wilde (48). Minkler (23) has pointed out that the biological activity of the soil, which depends in part on the level of organic matter, is an important factor affecting plantation success. Investigations by Gessel, *et al.* (6), Heiberg and White (8), and Lunt (19) although carried out on older stands, tend to indicate that the role of organic matter in fertility relationships is of utmost importance to the satisfactory growth and establishment of tree seedlings.

Although the role of soil fertility in the successful establishment of planted stock has not been too well defined, it is undoubtedly of great significance. An evaluation of the potential productivity and planting possibilities of soils according to their geologic origin has been presented by Wilde (48). The presence of carbonates, hydrogen sulfide, manganese and aluminum in excessive amounts has been shown to have an adverse effect on certain species and care must be exercised in the choice of species to plant on such areas. Soil reaction has been used as a means of evaluating some planting sites. Some species, such as eastern white pine, are not sensitive to wide variations in pH and can be planted on a variety of sites, other factors being favorable. On the other hand, some species (e.g. red pine) appear to have a narrow range of tolerance to soil reaction (48). Limstrom (17) has used pH as one factor in setting up planting guides for reforesting spoil banks.

This is by no means a complete review of the literature dealing with the effect of soil factors on the establishment of tree seedlings. An attempt has been made, however, to cover the most pertinent points.

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Status of Current Thinking and Pressing Problems Needing Research

It is of interest to note that more emphasis is being placed on soil fertility in current soils research as related to reforestation. Fertility experiments in forest plantations and natural stands have revealed the existence of mineral deficiencies in many forest soils. Thus we are becoming more aware of the importance of soil fertility to forest growth. Tissue analysis is becoming more widely used in forest soil fertility investigations. No doubt these studies will be of great value in helping to evaluate fertility factors for reforestation purposes.

Additional research is needed to ascertain the requirements of various species. The feasibility of forest soil fertilization is a subject in need of thorough investigation. The effects of the destruction of humus layers by burning on soil fertility and seedling development needs to be studied in more detail. The advances being made in forest tree breeding may well give rise to new problems in forest soil fertility. It is possible that vigorous new strains may be more demanding and their production may have to be confined to more fertile sites.

The forest soils group in the Northeast is currently engaged in preparing planting site classifications for eight site areas. The classification is based upon drainage features of the soil profile, available moisture as determined by soil texture, rooting depth and depth to ground water, and special features including lime status, fertility and erosion. Recommendation of species is based on various combinations of these factors.

The important studies dealing with improving the survival qualities of nursery stock are still being given a great deal of attention at the University of Wisconsin. Similar studies are in progress at the Forest Industries Nursery in Washington and the Oregon Forest Nursery.

In the Douglas-fir region much attention is being given to the effects of slash burning on soils. This work is being conducted by the Pacific Northwest Forest Experiment Station with some cooperative laboratory and greenhouse studies by the College of Forestry, University of Washington. Although only portions of the investigation are aimed directly at reforestation problems, it is felt that the basic information obtained from the whole study will be of great value in reforestation research. The study embraces the chemical, physical and biological properties of the soil and is summarized as follows:

1. Effect of burning on the chemical properties of the soil and the relation of those effects to seed germination and seedling growth.

2. Effect of burning on physical properties of the soil. This is a study involving measurements of moisture relationships on soils having been burned at various intensities. The information from this phase will aid in evaluating seeding and planting sites.

3. Effect of burning on occurrence and amount of mycorrhizal development on seedling roots.

Crown Zellerbach's soil scientist is making intensive soil examinations including chemical analysis in plantations where survival and initial growth have been poor. One project that is currently receiving much attention is an evaluation of soil profile features in brushy areas on the coast. An attempt is being made to correlate soil profile characteristics with the occurrence of brush so that areas having a high brush potential may be given immediate attention with regard to reforestation after logging.

Weyerhaeuser Timber Co. research foresters are conducting soil moisture investigations in connection with their seeding and planting research projects. Soil moisture trends are being correlated with soil type, aspect, slope and vegetative cover. A study has also been initiated to evaluate the effects of various logging methods on soils. Infiltration rate, bulk density, and porosity determinations are being made using undisturbed core samples collected from spots exhibiting apparent soil differences in logged areas. Chemical analyses will also be made. Several areas have been chosen for permanent studies on regeneration and soil recovery.

The physical, chemical and biological properties of exposed subsoils and their influence on seedling establishment and growth is worthy of further consideration. Moisture relationships on these soils should be carefully evaluated.

The current research in forest soils with regard to reforestation now being carried on at Oregon State College falls into two main categories: *(1)* The evaluation of soil factors affecting the survival and establishment of seedlings and *(2)* the improvement of the physiological grades of nursery stock by nursery management practices.

The soil studies relating to seedling survival involves the investigation of the soil fertility status, mycorrhizal relationships, physical properties of soils and the soil moisture regime, including the determination of the range of available moisture for different soil types. Soil preliminary work on species adaptation on particular problem soils is also included.

The nursery investigations include further testing of fertility standards recently proposed for Douglas-fir, the establishment of similar standards for other western conifers, and the evaluation of present soil management practices with special emphasis on fertilizer practices and cover crop rotations. These studies are being carried on in cooperation with private, state and federal nurseries.

The work in California is being carried on principally by the California Forest and Range Experiment Station and is concerned with logging methods and site treatment that enhance the regeneration of favored species and with vegetation-soil mapping. A new vegetation-soil specialist position has been set up in the Station. In part, his job will be to help select areas on the basis of soil suitability for tree planting and range revegetation on National forest areas. The soils on these areas will be classified and mapped so that the results obtained can be related to like soils elsewhere. In addition to this the School of Forestry at Berkeley is concerned with the effects of fire upon soil in connection with range improvement work.

In the west one of the most critical needs in forest soils research is in the field of soil genesis, morphology and classification. Very little is known with regard to climatic or zonal features of forest soils. A more thorough knowledge of the clay minerology, organic matter status and other soil genesis features will undoubtedly facilitate the interpretation of many of the results from our forest soils reforestation research.

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