SOIL ANALYSIS IN SERVICE OF NURSERY PRACTICE [1]

S. A. Wilde and H. H. Krause [2]

This paper appraises the relative significance of the results obtained by analysis of various properties of nursery soils, and stresses the limitations of certain analytical data. Soil analysis may serve as a useful tool of soil fertility maintenance and the production of vigorous nursery stock only if unjustified assumptions and misinterpretations are excluded. The value of systematic soil analyses is illustrated by a concrete example presenting a record of changes in the fertility status of a nursery soil during a 7-year period of stock production.

Although soil analysis was brought to life in the cellars of medieval alchemists, it stubbornly refuses to attain maturity and in many of its aspects still remains a "problem child." Reasonably dependable analytical data may be expected only in the determination of some soil characteristics, such as texture, bulk density, some other physical properties, contents of total carbon, nitrogen, and soluble salts, exchange capacity, and the supply of replaceable bases. On the other hand, when an attempt is made to disclose nutrients available to plants, soil analysis at times enters the realm of gross approximations. In such analyses, vitally important for plant production, one frequently encounters unjustified assumptions and misinterpretations. To gain the full benefit provided by analytical data, the manager of a nursery soil must be fully aware of the data's limitations. A review of the relative significance of the numerical expressions of different soil fertility factors is here discussed.

The determination of soil texture of the root-bearing zone and substratum provides one of the most important informations on the productive potential of nursery soils. The content of the fine soil materials, that is silt and clay particles, is responsible for the retention of water and soluble salts. In turn, the fine soil fraction determines in large measure the rate of artificial watering, as well as the kind, the rate, and the manner of applying fertilizers. From the standpoint of nursery practice, simple methods of textural analyses are sufficiently accurate and reliable.

About the same methods may be repeated in the determination of soil organic matter. In many respects organic matter supplements the effect of mineral colloids and, in addition, usually serves as a storehouse of all essential nutrients--nitrogen, phosphorus, bases, and trace elements. The recently developed rapid methods of organic matter determination provide data of unquestionable practical importance.

The effect of mineral colloids and organic matter is conveniently summarized by the data of the adsorbing or exchange capacity of the soil. Again, for the purposes of fertility maintenance of nursery soils, there is no reason to question the reliability of the exchange values provided by modern methods of soil analysis.

As recent investigations have shown, the pH values of soil result from the activity rather than from the concentration of hydrogen ions. Moreover, pH values are only distantly related to the total acidity or total alkalinity of soils. These latter properties are of much greater importance than the pH values in many aspects of soil fertility, such as availability of nutrients, activity of soil microorganisms, incidence of fungus diseases, and the choice of applied fertilizers. The ecological significance of the pH value varies considerably depending upon conditions of climate, content of mineral and organic colloids, and the origin of the soil. An adjustment of soil reaction cannot be made on the basis of pH value alone, for the amount of lime needed to bring a soil from, let us say, pH 4.5 to pH 7 may vary from 2 to 8 tons, depending on the texture and the exchange capacity of the surface soil layer. Just as great a variation in the amount of sulfur or

[1] Soils Department of the University of Wisconsin, in cooperation with the Wisconsin Conservation Department and the Con
solidated Water Power and Paper Co.

[2] Professor of Soils and Project Assistant in Soils, respectively. The authors are indebted to E. S. Hurd, Supervising Forester of the Consolidated Water Power and Paper Co., for his help in several aspects of this study.

aluminum sulfate may be encountered in acidification of a soil from pH 8.0 to pH 5.0. Therefore, in management of nursery soils it is often necessary to determine the total acidity and the content of carbonates besides the pH values (Wilde, 1954).

The determination of the total nitrogen content should be included among other essential and dependable methods of soil analysis (A.O.A.C., 1950). However, such determinations supply information on the total supply of nitrogen, but not on the content of this element available to plants. Some nursery soils, given a heavy application of peat, may show as much as 0.2 percent or about 4,000 pounds per acre of the total nitrogen. Yet, seedlings on such soils often experience an acute nitrogen starvation, for the entire content of this element is in the form of high molecular compounds unavailable to plants. -

In recent years attempts are being made to devise a method for the determination of hydrolysable nitrogen fraction that should be available to plants. However, analyses of this kind, as well as periodic determinations of ammonia and nitrate nitrogen, reveal only approximate potentialities. In a way they resemble electrocardiograms that require an interpretation by a specialist, who may or may not establish a correct diagnosis. Ordinarily, the nursery soil manager must be satisfied with the empirical appraisal of the microbiological activity of the soil and corresponding estimate of the fraction of the total nitrogen that is released in available form. In nursery soils with uninhibited activity of ammonifying and nitrate-forming microorganisms, the annual release of available nitrogen fluctuates between 1 and 2 percent of the total nitrogen. Under conditions of conservative irrigation, the nitrogen requirement of even exacting nursery stock is usually met if the soil analyzes 0.2 percent of the total nitrogen providing annually between 40 and 50 pounds of this element per acre in available form. Otherwise, the nitrogen deficiency must be estimated on the basis of the color of nursery stock, which serves as a very sensitive gage of the supply of nitrogen released in the form of nitrates, ammonia, and amino acids.

The situation is more complicated with the determination of the supply of available phosphorus. It is partly because the deficiency of this element is not readily revealed by the foilage of seedlings. Moreover, the results of analyses for available phosphorus, like those for many other essential nutrients, have only one-sided significance. If the extraction of soil samples is accomplished with the use of a reasonably mild solution, such as 0.002 N sulfuric acid (Truog, 1930), then the presence of about 50 pounds per acre of extractable phosphorus eliminates the possibility of phosphate starvation of nursery stock of most exacting species. With less exacting trees, the adequate phosphate nutrition is assured even if the content of extractable phosphorus is only 10 pounds per acre. On the other hand, analyses showing traces of available phosphorus may or may not be trustworthy. This is because weak solutions fail to extract much of the phosphorus incorporated in organic matter, phosphate minerals, and iron or aluminum compounds. A considerable fraction of this less soluble phosphorus, however, is available to seedlings whose root systems are endowed with mycorrhizal fungi. To a certain extent, the determination of available phosphorus may be facilitated by the use of stronger extracting solutions. Nevertheless, procedures of this kind require participation of an expert, for potent reagents may extract phosphorus that is not available to plants.

Within certain limits, what is said about phosphorus is true of other nutrients that may be deficient in nursery soils, particularly potassium, magnesium, and calcium. The experience of the last quarter of a century has shown beyond a doubt that a reasonably high content of exchangeable bases, as determined by the use of normal ammonium acetate (Chapman and Kelly, 1930; Volk and Truog, 1934), or similar weak extracting solutions, assures adequate nutrition of nursery stock. Contrariwise, the low content of bases, especially potassium, as determined by analysis, does not always identify their deficiency. This is largely because of the enormous nutrient-extracting ability of mycorrhizal fungi and the effect of root sloughings producing chelating compounds that complex iron and release bases from unweathered minerals. In recent time, therefore, the claims are made that the use of more drastic methods for extraction of available bases, such as boiling of soil samples with 1 N_ nitric acid, yields more reliable information (Leaf, 1957). However, there are no sufficiently prolonged observations on nursery soils to make a definite statement on the merits of this procedure.

Another important detail in soil analysis is that no general agreement exists as to the nature and strength of extracting solutions. This is true not only for different countries and States, but even different investigators. Therefore, a statement that a nursery soil has 50 pounds per acre or 25 p.p.m. of available phosphorus in some places indicates plentiful supply of this element and in others an acute deficiency.

Because unification of analytical procedures cannot be expected, it is advisable to relate the results of analyses obtained by different methods to soils supporting stands of different productivity ratings (Wilde, 1938; Wilde and Patzer, 1940; Youngberg and Austin, 1954). For purposes of nursery soil management, particular attention should be given to soils that support a vigorous natural reproduction of species in question, for such soils present prototypes of nursery beds. For example, using methods of soil analysis accepted by the Wisconsin Soils Department, sandy soils of glacial outwash and river terraces supporting healthy reproduction of red pine are characterized by the following statistical averages: Reaction, pH 5.3; total N, 0.12 percent; available P2 05, 25 parts per million; available K2O, 75 parts per million; exchange Ca, 3.0 m.e. per 100 grams; exchange Mg, 0.9 m.e. per 100 grams. The use of other analytical methods may provide a somewhat different set of numerical expressions of soil fertility. Nonetheless, as long as the composition of the nursery soil is maintained at a comparable level with that of natural seedbeds, the seedlings will not undergo malnutrition or an unbalanced nutrient ratio. In other words, as long as forested soils are used as primary standards, the results of soil analyses will preserve their relative significance. The experience in many nurseries demonstrates the value of this approach.

Considering all mentioned precautions and amendments, soil analysis serves as an extremely useful tool in maintenance of nursery soil fertility and production of nursery stock. The value of soil analysis is illustrated by the following concrete example featuring the "life history" of the Monico Industrial Nursery of the Consolidated Water Power and Paper Co.

This nursery was established in 1950 on a level 20-acre area of glacial outwash, located near Rhinelander, Wis. The soil was previously used for raising farm crops and as a grazing ground. Consequently, it was depleted in organic matter and several essential nutrients. Upon initial analysis, the soil was given an application of peat, hardwood-hemlock leaf mold, and commercial fertilizers including ammonium sulfate, ammonium nitrate, superphosphate, and potassium sulfate. The area was then assigned to the production of white and black spruce with some red pine and a few ornamentals.

In the course of the following 8 years, the nursery soil was subjected annually to complete analysis. Depending on conditions, two to three samples were collected from each acre block. The pH value of the soil was determined by the use of a glass electrode, texture by Cenco hydrometer, organic matter colorimetrically by oxidation with dichromate, total nitrogen by the Kjeldahl method, phosphorus by the Truog method, exchange capacity and the contents of exchangeable potassium, calcium, and magnesium by leaching with neutral N ammonium acetate and by the use of the Beckman model DU flame spectrophotometer. Occasionally, these analyses were supplemented by the determination of nitrate and ammonium nitrogen by the phenol-disulfonic acid and nesslerisation methods, respectively, and specific conductance by the use of a resistance bridge with a cathode magic eye (Wilde and Voigt, 1959).

The application of fertilizing materials was coordinated with the results of current soil analyses, particular attention being paid to losses of nutrients by leaching during wet years. The gradual change in soil fertility status is illustrated by the average results of analyses for the entire area (table 1).

The improvement in the level of different soil fertility factors and in the ratio of available nutrients was paralleled by the improvement in the quality and survival coefficient of produced nursery stock. Besides these achievements, the fully productive state of the nursery soil was attained with minimum expenditure on natural and commercial fertilizers. According to the records of the nursery superintendent, the expenditures

TABLE 1.--Changes in the state of fertility factors in a nursery soil during the period 1950-58, Monico Industrial Nursery, Consolidated Water Power and Paper Co.

Year of analysis	Reaction pH	Organic matter	Exch. capacity	Total N	Avail. P_2O_5	Avail. K_2O	Exch. Ca	Exch. Mg.
		Percent	*M.e. per 100 g.*	*Percent*	*Pounds per acre*	*Pounds per acre*	*M.e. per 100 g.*	*M.e. per 100 g.*
1950............	5.3	1.3	2.8	0.030	183	107	1.12	0.30
1951............	5.7	1.5	3.0	0.037	133	137	1.30	0.35
1952............	5.4	1.6	4.0	0.039	151	80	2.02	0.58
1953............	5.5	2.0	4.5	0.050	159	112	2.41	0.60
1954............	5.6	2.1	4.4	0.055	184	152	2.38	0.72
1955............	5.5	2.1	4.5	0.052	256	161	2.44	0.59
1956............	5.7	2.4	5.3	0.060	208	157	3.32	0.68
1957............	5.6	2.3	5.8	0.058	149	126	3.59	0.66
1958............	5.0	2.9	5.9	0.074	180	147	3.51	0.73

on soil improvement constituted 7 percent of the total annual cost of producing 4-year-old white and black spruce transplants.

The use of biocides was restricted to occasional light applications of chlordane (10 pounds per acre), made to prevent the building up of white grub population. The negligible losses of seedlings from parasitic organisms or toxic chemicals were an encouraging detail of the established method of nursery soil management.

Although the files of the authors include records of systematic soil analyses for much longer periods and larger nurseries, none of them provide as clear cut a picture of the gradual improvement of soil fertility under planned management as was observed in the Monico Nursery.

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Literature Cited

Association of Official Agricultural Chemists. 1950. Official and tentative methods. 7th ed. Washington, D. C.

Chapman, H. D., and W. P. Kelley. 1930. The determination of the replaceable bases and the base exchange capacity of soils. Soil Sci. 30: 391-406.

Leaf, A. L. 1957. Diagnosis of deficiencies of available potassium, calcium, and magnesium in forested soils. University of Wisconsin Dissertation Abstracts 17 (9) 387 (Pub. 22).

Truog, E. 1930. The determination of the readily available phosphorous of soils. Amer. Soc. Agron. Jour. 22: 874-882.

Volk, N. J., and E. Truog. 1934. A rapid chemical method for determining the readily available potash of soils. Amer. Soc. Agron. Jour. 26: 537-546.

Wilde, S. A. 1938. Soil-fertility standards for growing northern conifers in forest nurseries. Jour. Agr. Res. 57: 945-952.

Wilde, S. A. 1954. Reaction of soils: Facts and fallacies. Ecology 35: 89-92.

Wilde, S. A., and W. E. Patzer. 1940. Soil-fertility standards for growing northern hardwoods in forest nurseries. Jour. Agr. Res. 61: 215-221.

Wilde, S. A., and G. K. Voigt. 1959. Analysis of soils and plants for foresters and horticulturists. Ed. 2. J. W. Edwards, Inc. Ann Arbor, Mich.

Youngberg, C. T., and R. C. Austin. 1954. Fertility standards for raising Douglas fir in forest nurseries. Jour. Forestry 52: 4-6.