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Colloidal Content and Related Soil Factors as Indicators of Site Quality

Irvine T. Haig

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COLLOIDAL CONTENT AND RELATED SOIL FACTORS AS INDICATORS OF SITE QUALITY

BY

IRVINE T. HAIG, B.S., M.F.

Research Fellow, Yale University

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FOREWORD

THIS study was carried on during the school year 1927-1928 which the author spent as a graduate student at Yale. The author wishes to acknowledge the aid and supervision of Ralph C. Hawley, Professor of Forestry, Yale University, and of M. Francis Morgan, of the Connecticut Agricultural Experiment Station, and Research Associate in Soils, Yale University, under whose joint supervision the study was conducted. The author also wishes to thank various other members of the staff of the Agricultural Experiment Station for aid in the laboratory analyses, and particularly Mr. Henry W. Hicock, Assistant Forester, for his advice in selecting a problem.

The basic data for this study were secured principally in red pine plantations located on the properties of the New Haven Water Company, which are used for investigative and instructional purposes by the School of Forestry. Some data were obtained on the Rainbow Forest Plantations of the Connecticut Agricultural Experiment Station. The soil analyses and tests were made in the laboratories of the latter institution.

COLLOIDAL CONTENT AND RELATED SOIL FACTORS AS INDICATORS OF SITE QUALITY

PURPOSE AND SCOPE

DDRING recent years forest soil problems have occupied a place of increasing importance in the field of forest research. Among the outstanding problems in which foresters have become interested[1] has been the possibility of using some easily determined soil factor in the evaluating of forest sites. This paper presents a study of the correlation between soil colloidal content and soil productiveness and hence a measure of the value of colloidal content in determining site quality. The character of this investigation also permitted incidental observation and comment on the relative value of organic matter, soil acidity, and soil type and class as similar measures. The findings are directly applicable to the forest soils of southern Connecticut and, more particularly, to such of these soils as occur commonly in the vicinity of New Haven. Since these soils are typical of the brown, weakly podsolized forest soils of southern New England and parts of adjacent New York and New Jersey,[2] the results of the investigation are considered applicable throughout this general region.

COLLOIDAL CONTENT

Up to the beginning of the present century the greater portion of the soil was regarded as a mass of inert rock fragments with simple, clear-cut physical and chemical relationships.[3] Advances in colloidal chemistry applied to soil problems soon showed that all inorganic soil particles were not inert" but that, on the contrary, the finest soil fractions, whether of inorganic or organic origin, possessed certain physical and chemical proper-

1 Weis, Fr., The Study of Forest Soils, *Soil Science,* 25 : 75-81, 1928.

2 Marbut, C. F., Classification, Nomenclature and Mapping of the Soils of the United States, *Soil Science,* 25 : 61-70, 1928.

3 Keen, B. A., Soil Mechanics and Physics, *Soil Science,* 25 : 9-20, 1928.

ties peculiar to matter in a colloidal state.[4,5] These very fine soil particles (usually under one micron in diameter) alternately swelled and shrunk on wetting and drying, they possessed great affinity for water,[6] and they readily absorbed and held various plant foods. It was found that the total amount of such fine particles, the soil colloidal content, was associated with moisture-holding capacity, determined to a large extent the character of soil tilth, and controlled in large measure such important soil phenomena as base exchange and absorption.[7,8] The degree to which soil colloids affect these soil phenomena is influenced by the chemical composition as well as by the total amount of colloids present. Since the recent work of Robinson and Holmes[9] indicates that the chemical composition of soil colloids varies little within anyone soil region, this disturbing influence will be at a minimum within an area of the character studied.

The total colloidal content of the soil seemed to offer a particularly promising lead as a single value measure of soil conditions, that is, a measure that might be in itself a good criterion of the complex of conditions on which soil productiveness depends. The important rôle played by the colloidal fraction is widely recognized. One investigator has gone so far as to state that "knowledge of the total amount of colloids present is the most important single physical determination that can be made."[7] It was with this soil measure and the relationship between it and soil productivity that the present study was chiefly concerned.

METHOD OF INVESTIGATION

A CORRELATION study of this type required as essential data a series of "paired" measures of the factors involved.[10] The field procedure

4 Ashley, H. A., *The Colloidal Matter of Clay and Its Measurement,* Bulletin 388, Geological Survey, 1909.

5 Bradfield, R., *The Chemical Nature of a Colloidal Clay,* Dissertation, Ohio State University, 1922.

6 Mitscherlich, E. A., and Floess, R., The Determination of Hydroscopicity, *Intern. Mitt. Bodenkunde,* 1 : 463, 1912.

7 McCool, M. M., The Rôle of Colloids in Soil Productivity, *Abstracts of Proceedings, 1st International Congress Soil Science,* 1927.

8 Powers, W. L.,. A Study of the Colloidal Fraction of Certain Soils Having Restricted Drainage, *Soil Science,* 23 : 487-491, 1927.

9 Robinson and Holmes, *The Chemical Composition of Soil Colloids,* Bulletin 1311, Department of Agriculture, 1928.

10 Wallace and Swedecor, *Multiple Correlation and Machine Calculation,* Official Publication, Iowa State College, 23 : 25, 1925.

consisted in digging a number of soil pits at which were secured joint measures of soil values and site conditions. Each pit was made approximately thirty-six inches deep and wide enough to permit extraction of clean samples of the major soil profile divisions.

Samples of each of the major soil profile divisions, the A, B, and C horizons, were sacked, labeled, and held for laboratory examination. The A horizon or surface layer, usually six to eight inches thick, is defined as the region from which material has been relnoved by percolating waters. The B horizon or subsoil, from six to thirty inches deep, is characterized as the region in which material has been deposited by percolating waters. It is a region of accumulation. In mature soils this accumulation becomes very marked and results in a compact, semicemented layer of highly colloidal material, but in the relatively immature soils of southern Connecticut the effects of deposition are not yet marked. Horizon C, occurring beneath the subsoil, usually below thirty inches, is a layer of unweathered or practically unweathered material, the substratum. This is the material from which the A and B layers have been derived. These soil divisions are differentiated chiefly on the basis of color and texture.

Height measurements were taken of trees in the immediate vicinity of each soil pit. Usually sixteen trees were measured at each pit, this number being sufficient to give desirable accuracy.[11] In accordance with general practice these trees were of the dominant and codominant classes, that is, trees with the upper portion of their crowns exposed to direct sunlight. The average height of these trees was used as an index of site conditions. Height growth has been found a reliable and easily measured indicator of the wood-producing power of forested areas and its use in this manner is now a firmly established practice among foresters.[12, 13]

In order to assure especial accuracy in site classification, soil pits were established only in red pine plantations. This permitted the use of the height growth of one species as a measure of site conditions. It is true that in this way soil productivity is measured only in the response of red pine. This procedure will only introduce error if other species fail to respond in an essentially similar manner. By using only red pine plantations, the study is confined to soil areas of very similar economic history. In general all of

11 See Appendix.

12 Frothingham, E. H., Classifying Forest Sites by Height Growth, *Journal of Forestry)* 19: 374, 1921.

13 Munns, E. N., and others, Report of Committee on Methods of Preparing Volume and Yield Tables, *Journal of Forestry)* 24: 653-666, 1926.

these red pine plantation sites have been cleared, pastured, in a few cases tilled, and then left to revert to forest. In many cases planting of red pine took place when the area was still in pasture; in others, when the area had reached a brush or old field stage. It is well known that the past treatment of a soil may influence profoundly its productiveness. The similar treatment of the areas studied largely eliminates any chance of error from this cause, while the inclusion only of plantations within the same general climatic and topographic region permits variations in productivity to be attributed largely to soil differences.

A total of ninety-five soil pits were excavated. These are well distributed over the region in twenty-six forest plantations.

LABORATORY WORK

THE colloidal content of each soil sample was determined by the hydrometer method described by Bouyoucos.[14] The details of the method and the proof of its accuracy are set forth in the above and subsequent papers.[15] It is sufficient to say here that the hydrolneter method is an exceedingly simple and rapid one and that the results obtained closely approximate those secured with the accurate and \videly accepted heat of wetting method. The heat of wetting method is undoubtedly the more reliable, but it is also far more laborious. The close approximation of colloidal material secured with the hydrometer method was found sufficiently accurate for the purposes of this study.

In the hydrometer method a soil sample, usually fifty grams, is placed in water and stirred vigorously in a mixing machine very similar to the type employed at modem soda fountains. The turbid liquid resulting is decanted and allowed to settle for fifteen minutes. A single hydrometer reading at the end of that period, corrected for temperature conditions, gives the amount of colloidal material present in per cent of the total sample. Colloidal values thus determined are listed in the Appendix.

In addition laboratory determinations were made of silt-plus-clay content, percentage of organic matter, and soil reaction. The silt-pIus-clay content refers to the percentage of material below 0.05 mm. in size. It includes both the silt material, between 0.05 mm. and .005 mm., and the clay

14 Bouyoucos, G. J., The Hydrometer as a New and Rapid Method for Determining the Colloidal Content of Soils, *Soil Science,* 23: 319-321, illus., 1926.

15 Bouyoucos, G. J., The Hydrometer Method of Studying Soils, *Soil Science,* 25: 265-369, 1928.

material, .005 mm. and less in size. It is, therefore, a measure of the amount of fine material present and a soil value similar in nature to that of total colloidal content. Colloidal material is regarded ordinarily as including chiefly particles .001 mm. or less in diameter. However, empirical measurements of colloidal content of soils give values usually equaling the clay content and perhaps as much as 10 per cent of the silt content, as determined by mechanical analysis.

The silt-plus-clay content was determined very rapidly with the hydrometer method[16] by stirring the soil, as described under determination of colloidal content, and reading the hydrometer one minute after the turbid liquid began to settle. Organic matter was measured rapidly by Schollenberger's titration method.[17] Soil reaction, in pH values, was determined electrometrically by the quinhydrone electrode method.[18] These values are listed in the Appendix. All determinations were based on air dry soil, which had been passed through a sieve with openings two millimeters in diameter.

SITE CLASSIFICATION

As already stated, height growth was accepted as the most accurate, practical measure of the productive capacity of the soil. The methods employed here in site classification are outlined in detail in articles by Bruce[19] and Reinecke.[20] Height is influenced even more by the age of the stand than by site conditions. For this reason the average height of a stand must be converted, by comparison with the average trend of height growth, to the height it normally would have had or will have at some selected classification age. The figure thus obtained is called the site index. It is independent of the age of stand and furnishes a direct numerical measure of soil productivity. A chart for converting average height to site index is shown in Figure I. The mechanics of preparing a chart of this type are explained in detail in Reinecke's article.[20]

16 Bouyoucos, G. J., Making a Correct Mechanical Analysis of Soils in Fifteen Minutes, *Journal American Society of Agronomy,* 20: 305-306, 1928.

17 Schollenberger, C. J., A Rapid Approximate Method for Determining Soil Organic Matter, *Soil Science,* 24: 65-68, 1927.

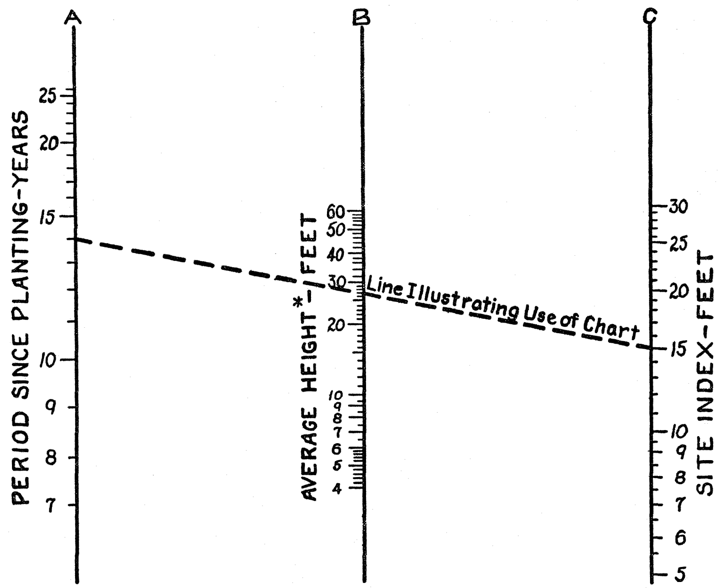
18 Baver, L. D., The Use of the Quinhydrone Electrode for Measuring the Hydrogen-ion Concentration of Soils, *Soil Science,* 21: 167-179, 1926.

19 Bruce, D., A Method of Preparing Timber-Yield Tables, *Journal of Agricultural Research,* 32: 543-557, 1926.

20 Reinecke, L. H., A Modification of Bruce's Method of Preparing Timber-Yield Tables, *Journal of Agricultural Research,* 35: 843-855, 1927.

Figure I.

Site Classification Chart
for
Red Pine Plantations
New Haven, Conn. and Vicinity



* BASED ON DOMINANT AND CO-DOMINANT TREES

The classification age for this chart was set arbitrarily at ten years. This was a mere matter of convenience and any other age within the limits of the data would have served. The height over age curve, on which the chart is based, was carefully compared with the height over age curves obtained in the remeasurements of several red pine sample plots in the same locality[21] and its trend found satisfactory. To use the chart, pass a straight line between the age of plantation (years since planting) on A and the average height on B. Read site index where this line crosses C. For example, a plantation fourteen years old in which the dominant heights averaged twenty-seven feet would be given a site index of fifteen feet, since a straight

[21] Hawley, R. C., *File Records*, New Haven Water Company Plantations.

line between fourteen on A and twenty-seven on B crosses scale C at the fifteen-foot division. (See broken line, Figure I.)

The site index values obtained in this manner are listed in the Appendix. The range of these values, from six to sixteen feet at ten years, clearly indicates the sampling of a wide range of site conditions.

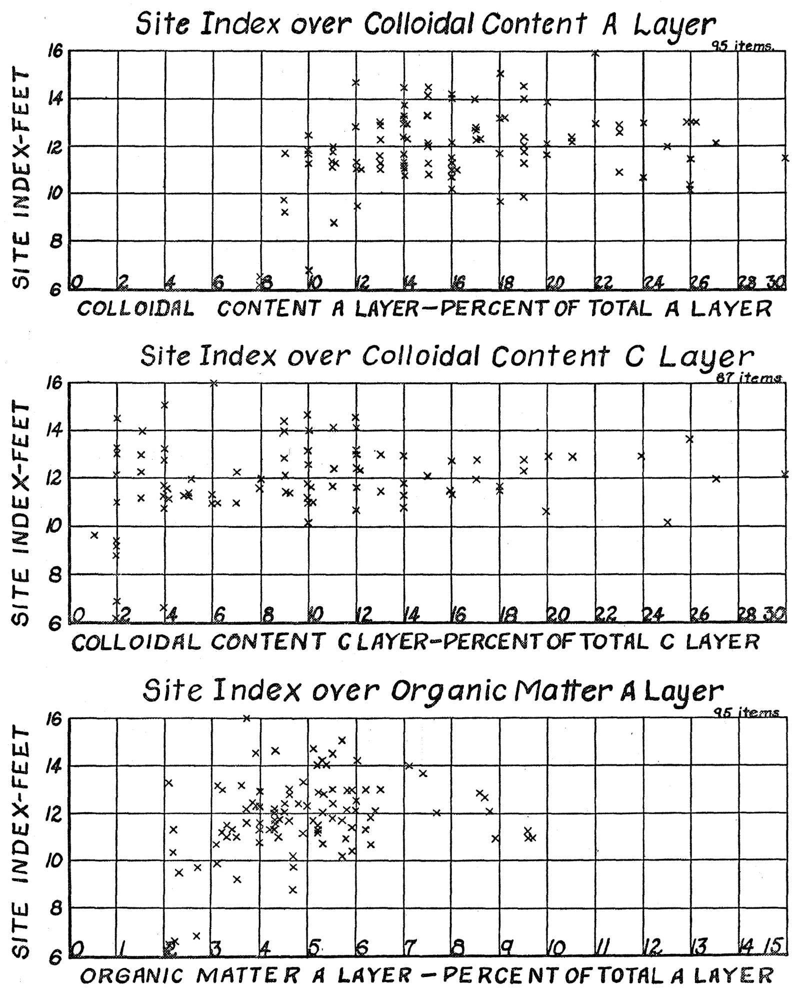
GRAPHIC ANALYSIS

THE next step was the preparation of scatter diagrams designed to show the relationship between site index and the various soil measures. In these charts the vertical scale was invariably in site index units, and the horizontal scale, in terms of the soil value. Each dot represents the site index value at a given soil pit plotted over the associated soil value. Any correlation between site index and soil measure would be indicated by a banding of points, other than horizontal banding, as opposed to their random scatter. Diagrams of this nature were constructed for site index over the following soil values:

(1) Colloidal content of the A layer.
(2) Colloidal content of the B layer.
(3) Colloidal content of the C layer.
(4) Average colloidal content of the A and B layers.
(5) Average colloidal content of the A, B, and C layers.
(6) Silt-plus-clay content of the A layer.
(7) Soil reaction in pH values.
(8) Organic matter.

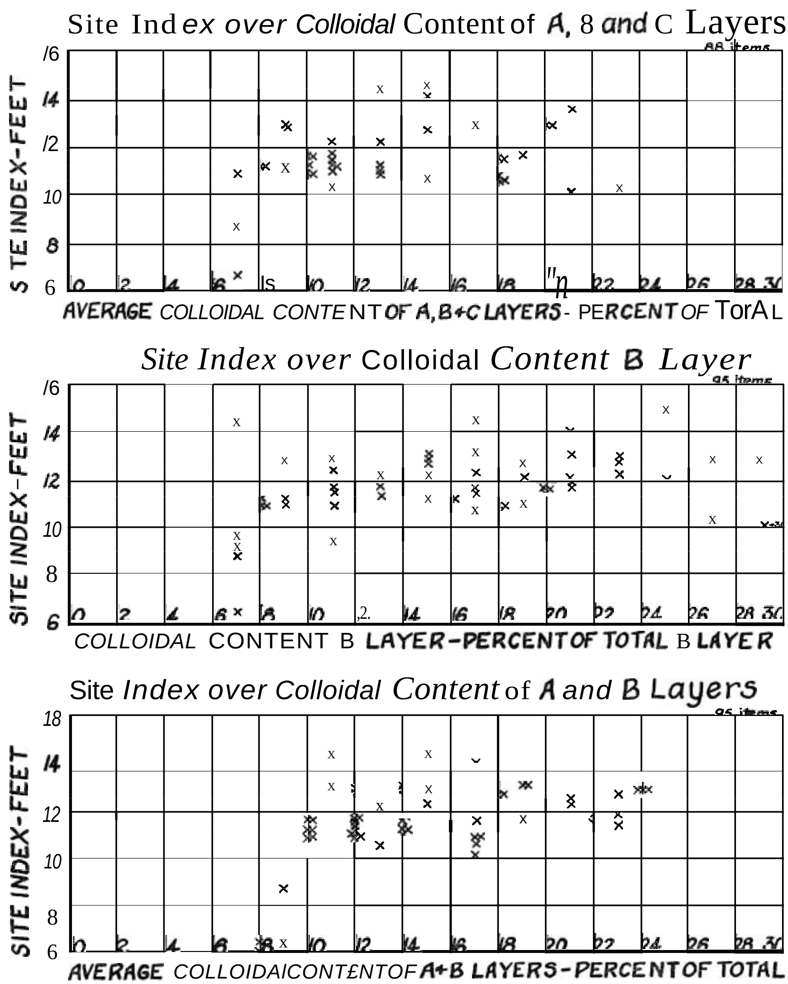
These diagrams are shown in Figures II, III, and IV. Three typical diagrams are grouped in Figure II. In this group of diagrams site index over the colloidal content of the A layer displays a very definite trend, which is shown more clearly by a curve through the average points. (See Figure V.) This type of distribution is representative of items 4, 5, and 6 of the above list. Site index over colloidal content of the C layer exhibits little or no trend whatsoever. The band of points is practically horizontal and average site index remains about the same regardless of changes in the colloidal content of the C layer. This distribution is typical of items 2 and 7 of the above list. The last item plotted in Figure II, site index over organic matter, emphasizes the lack of correlation between this measure and site index, not only in the horizontal distribution of the points, but in their

Figure II. Scatter Diagrams



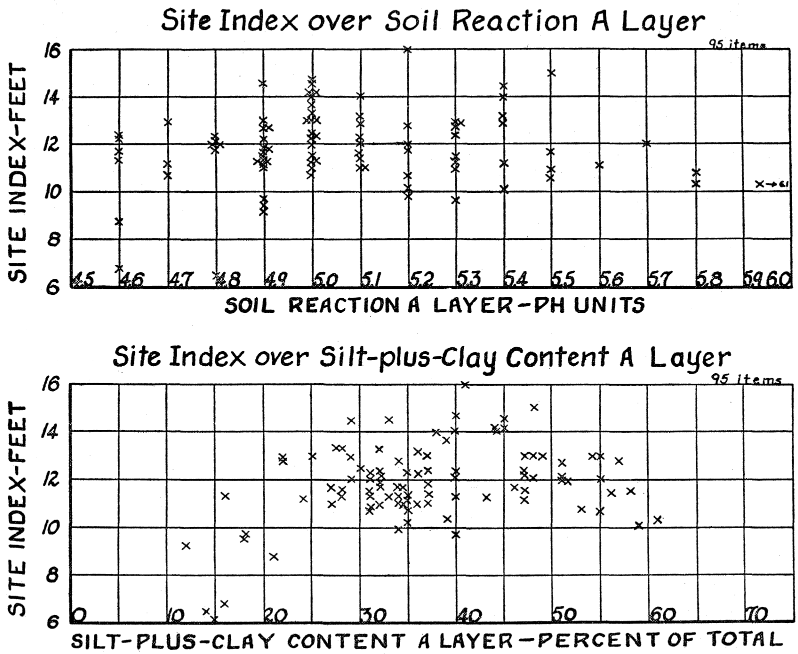
random scatter as well. A careful study of the scatter diagrams, checked in some cases by mathematical analysis, indicated that colloidal content of the A layer, colloidal content of the A and B layer, and silt-plus-clay content of the A layer held the greatest promise as measures of site index. These items were marked for further study.

Figure III. Scatter Diagrams



It is interesting to note the relative importance of the A layer values. In every instance the soil criteria measured in this layer are equal or superior as measures of site quality to the same values in the B and C layers. It is true that this study deals with young stands whose root systems may be imperfectly established. Yet field observations showed that root distribution,

Figure IV. Scatter Diagrams



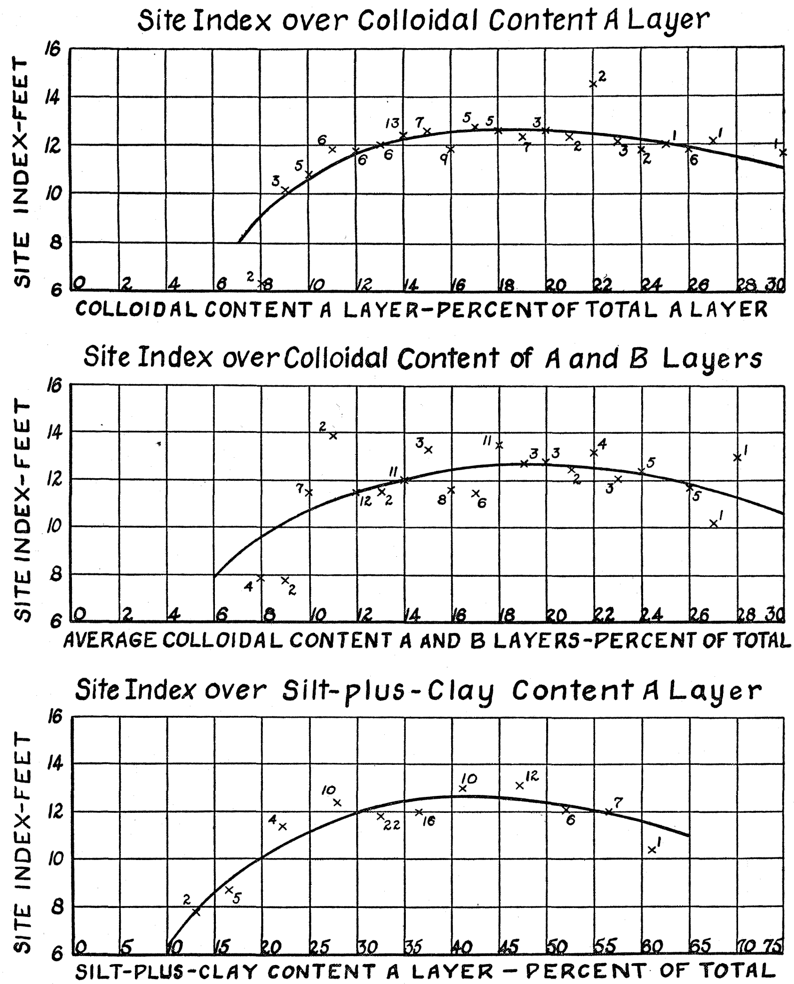
while occasionally concentrated to an abnormal degree in the upper six or eight inches, the A horizon, more commonly extended with normal distribution to at least thirty-six inches or through the entire B and into the C horizon. It is also true that the soils of this region are relatively immature and still in the early stages of development from parent material. In such soils the accumulation of material in the B horizon is not so pronounced as in older soils. Hence there is some possibility that the relative importance of the A layer in the soils sampled may be due partly to this factor.

The scatter diagrams indicate that the amount of organic matter and soil reaction show little or no correlation with the site quality of the soil, as expressed in height growth.

CORRELATION MEASURES

THE curved average values or regression curves for the correlated items illustrated in Figure V indicate very clearly the type of rela-

Figure V Regression Curves



tionship present. These curves show that soils of low colloidal content are relatively less productive, that as the colloidal or silt-plus-clay content increases the site quality increases also until certain optimum conditions are reached, and that beyond this point site quality falls off steadily with any further increase in colloidal material.

Correlation index,[22] a statistical measure of the degree of relationship or association between two variables, offers a good method of weighing mathematically the relative value of these various soil factors. If the association between a soil value and site index were perfect and the correct site index could be predicted invariably from the measured soil value, the correlation index would be 1.0. Total lack of correlation would be expressed by an index of 0.0. In actual statistical work these extreme degrees of association do not occur, but they illustrate that the size of the index is an indication of the degree of association and that the nearer an index approaches 1.0 the stronger the degree of relationship between the variables concerned. In this study, therefore, the larger the correlation indices the better the corresponding soil value as a measure of site quality. The correlation indices for the soil values studied are listed in Table I, column 1. The indices were computed by squaring the individual errors of estimate and not by the less accurate approximation method. The reliability of these indices can best be judged by the size of their standard deviations. (Table I, colulun 2.) The fact that these standard deviations are relatively small fractions of the index proper[10] indicates that, if the correlation indices were recomputed on the basis of a new series of pits equally well distributed throughout the region, the new indices would be very close in. size to these here listed. But, while these indices are undoubtedly reliable and show a real tendency of site quality to vary with the soil values measured, the small size of these indices compared with 1.0 (the value for perfect correlation) indicates that only a relatively small portion of the total variation in site quality is associated with the soil values listed. The proportion of variation thus associated can be derived from the indices of alienation listed in Table I, column 3. These indices,[23] computed from the correlation indices, can be considered as percentages and they show the amount of variation in site quality associated with factors other than the corresponding soil value or values listed. For example, index of alienation for silt-plus-clay content shows that about 81 per cent of the total variation in site quality is associated with factors other than the silt-plus-clay content of the soil.

The weakness of the correlations involved is further indicated by the fact that the standard error of estimate, through a knowledge of the silt-

22 Smith, B. B., *Correlation Theory and Method as Applied to Agricultural Research,* Mimeograph Report, Bureau of Agricultural Economics, Department of Agriculture, 1926.

10 Wallace and Swedecor, *op. cit.*

23 Kelley, T. L., *Statistical Method,* 173, 1924.

plus-clay content of the soil, is reduced only from 1.63 feet to 1.32 feet. In other words, a knowledge of average site index for the entire region permits an estimation of site quality within 1.63 feet of actual in about 68 per cent of the cases and within 3.26 feet in about 95 per cent of the cases, while a knowledge of silt-plus-clay content of the soil reduces these maximum errors to 1.32 feet and 2.64 feet, respectively, in similar percentages of cases. This is a very desirable and yet a rather small improvement.

These soil measures do have, in spite of the weakness of the correlations involved, a certain value in estimating site quality.

TABLE I

STATISTICAL MEASURES OF THE DEGREE OF ASSOCIATION BETWEEN SITE INDEX AND VARIOUS SOIL MEASURES

Soil value	*Correlation Index* (1)	*Standard deviation of the correlation Index* (2)	*Index of alienation* (3)	*Standard error of estimate* (4)
Colloidal content—A layer	0.52	± 0.07	0.85	± 1.39
Average colloidal content—A and B layers	0.55	± 0.07	0.84	± 1.36
Silt-plus-clay content—A layer	0.58	± 0.07	0.81	± 1.32
Colloidal content plus organic matter plus soil reaction—A layer	0.65	± 0.06	0.76	± 1.24
Soil type	0.80*		0.60	± 0.98
Soil class	0.70*		0.71	± 1.16

* Determined approximately from standard error of estimate.

The best test of the value of any soil measure is to use it in predicting values of site index and compare these predicted values with actual values based on height measures. Table II shows a comparison of this sort with silt-plus-clay content as the measured soil factor. The estimated site indices were obtained by reading for each silt-plus-clay percentage the corresponding curve value in Figure V. The differences between these· curve values and actual indices are called the errors of estimate. An examination of the size and distribution of the errors of estimate, given in Table II, will show that approximately 68 per cent of the predicted values are within 1.32 feet of the corresponding actual site index. This figure is called the standard error of estimate and can be computed directly from the correlation index and the standard deviation of the actual site indices around their mean. Standard error is a direct measure of the accuracy of prediction that will be obtained with a given soil value.

Just as with silt-plus-clay content, 68 per cent of the site indices predicted with any other soil value will be within the range of the corresponding standard error, and practically all or 95 per cent will be within twice this range. The standard errors of estimate for the various soil factors are listed in Table I, column 4. A study of these standard errors shows that silt-plus-clay content is the best of the soil measures based on percentage of fine material. If the total range of site indices (six to sixteen feet at ten years) is divided into three broad site classes, each covering a range of three to four feet, then a knowledge of silt-plus-clay content of the soil will permit site classification approximately within the range of one such major site class. Silt-plus-clay content is, therefore, a fair measure of site quality.

Even the use of three soil values, colloidal content, percentage of organic matter, and soil reaction of the A layer, through the employment of curvilinear multiple correlation technique only raises the correlation index to 0.65 and reduces the standard error to $\pm$ 1.24 feet. In this case about 77 per cent of the variation in site quality is associated with factors other than the three used in computing this index.

A knowledge of three soil values, colloidal content, amount of organic matter, and degree of acidity, furnishes only a fair measure of soil productivity. In order to obtain a really accurate measure of site quality, in which the standard error of estimate would be $\pm$ 0.5 and consequently 68 per cent of the predicted site values within 0.5 feet and practically all (95 per cent) within $\pm$ 1 foot of actual site values, it would be necessary to have some measure or measures giving a correlation index of approximately 0·95·

Note, however, that of the three soil measures used in the mUltiple correlation study, colloidal content is the most important. About 15 per cent of the variation in site quality is associated with colloidal content alone, while only 8 per cent is accounted for by both the amount of organic matter and the degree of acidity. This is shown by the figures in Table I, column 3;-100 minus 77, or 23 per cent of the variation in site quality, being associated with colloidal content, organic matter, and soil reaction combined, while 100 minus 85, or 15 per cent of this variation, is associated with colloidal content alone. It is true that there may be a definite working together or interrelation between these factors, not properly evaluated when the relative influence of each is estimated in this manner.

However, this bears out the evidence in the scatter diagrams for organic matter and soil reaction (presented respectively in Figures II and IV); namely, that both amount of organic matter and degree of soil acidity display only a slight degree of correlation with site index and consequently influence only slightly soil productivity in the forest areas covered in this study. Perhaps this is due in some measure to the fact that the soils studied are chiefly mediacid in character, the soil reaction ranging from about 4·5 to 5.5 pH, while organic matter varies only between 2 and 10 per cent. The differences in soil acidity and organic matter are probably too small to greatly influence relative productivity.

IMPORTANCE OF SOIL TYPE AND SOIL CLASS

As has been stated, the character of this investigation, while intended primarily as a study of the value of colloidal content in the estimation of site quality, also permits some comment on the relative worth of other soil factors in the same field. Two of these factors are soil type and soil class. Soil type is the more inclusive term and is in one sense equal to soil class plus soil series. A definition of these terms will clarify the situation.[24]

Soil class refers to the textural grade of the A layer or surface soil. The terms sand, sandy loam, silt loam, etc., are designations for soil classes, all being based on the various amounts of different sized particles making up the surface layer. Soil series designates a group of soils having the same character of profile, Le. the same general range in color, structure, consistence, and sequence of horizons, and in general the same conditions of relief, drainage, origin, and mode of formation. A soil type includes all soils which have relatively similar texture in the surface soil, Le. soils of the same soil class, and relatively similar profile characteristics, Le. members of the same soil series. This is indicated in the naming of various soil types.

24 *Report of the 8th Annual Meeting of the American Soil Survey Association,* Bulletin 9.

TABLE II

SITE INDEX ESTIMATED FROM SILT-PLUS-CLAY CONTENT OF A HORIZON

Soil pit no.	*Site index* *Actual* *feet*	*Site index* *Estimate* *feet*	*Errors of estimate* *feet*
1-1	11.8	12.5	+0.7
1-2	11.4	12.5	+1.1
1-3	12.5	12.0	−0.5
1-4	12.8	12.4	−0.4
1-5	11.2	12.4	+1.2
1-6	11.3	12.4	+1.1
1-7	12.3	12.2	−0.1
1-8	12.0	12.1	+0.1
1-9	11.3	11.7	+0.4
1-10	11.6	11.7	+0.1
1-11	11.7	11.5	−0.2
1-12	11.7	12.2	+0.5
1-13	11.8	12.2	+0.4
1-14	11.3	12.1	+0.8
1-15	10.7	12.1	+1.4
2-1	13.0	12.5	−0.5
2-2	12.4	12.5	−0.1
2-3	14.7	12.6	−2.1
2-4	13.7	12.6	−1.1
3-1	11.7	12.5	+0.8
3-2	11.2	12.5	+1.3
3-3	10.4	12.6	+2.2
3-4	12.1	12.1	0.0
4-1	11.5	12.1	+0.6
4-2	11.3	12.3	+1.0
4-3	12.3	12.5	+0.2
4-4	12.4	12.6	+0.2
4-5	13.2	12.5	−0.7
5-1	11.0	12.2	+1.2
5-2	11.0	12.4	+1.4
5-3	11.7	12.4	+0.7
5-4	10.2	12.4	+2.2
5-5	11.7	12.4	+0.7
6-1	12.0	12.4	+0.4
6-2	12.1	12.4	+0.3

SITE INDEX ESTIMATED FROM SILT-PLUS-CLAY CONTENT OF A HORIZON (cont.)

Soil pit no.	*Site index* *Actual* *feet*	*Site index* *Estimate* *feet*	*Errors of estimate* *feet*
6-3	12.7	12.4	—0.3
6-4	12.9	11.8	—1.1
6-5	13.0	12.2	—0.8
6-6	13.0	12.1	—0.9
7-1	13.0	12.4	—0.6
7-2	12.4	12.5	+0.1
7-3	13.0	12.5	—0.5
8-1	12.0	11.8	—0.2
8-2	12.2	12.5	+0.3
8-3	14.5	12.3	—2.2
9-1	12.0	12.4	+0.4
9-2	13.0	12.5	—0.5
10-1	8.8	10.3	+1.5
10-2	9.2	7.3	—1.9
11-1	12.8	10.5	—2.3
11-2	13.3	12.2	—1.1
12-1	12.9	11.8	—1.1
12-2	13.3	11.7	—1.6
12-3	12.3	12.4	+0.1
12-4	13.2	11.7	—1.5
12-5	11.2	10.9	—0.3
13-1	9.7	9.5	—0.2
13-2	11.0	11.5	+0.5
13-3	12.2	12.2	0.0
13-4	13.0	11.1	—1.9
14-1	11.3	12.6	+1.3
14-2	10.7	12.4	+1.7
14-3	9.9	12.4	+2.5
14-4	11.3	12.6	+1.3
15-1	10.2	11.7	+1.5
15-2	11.5	12.0	+0.5
15-3	11.6	11.8	+0.2
15-4	11.6	12.5	+0.9
16-1	11.0	12.4	+1.4
16-2	11.0	12.5	+1.5
16-3	11.3	12.4	+1.1
16-4	11.0	12.5	+1.5

SITE INDEX ESTIMATED FROM SILT-PLUS-CLAY CONTENT OF A HORIZON (cont.)

Soil pit no.	Site index Actual feet	Site index Estimate feet	Errors of estimate feet
16-5	12.9	10.5	-2.4
17-1	10.7	12.1	+1.4
17-2	9.7	12.6	+2.9
17-3	10.9	12.2	+1.3
17-4	10.4	11.4	+1.0
17-5	12.1	12.5	+0.4
18-1	14.0	12.6	-1.4
18-2	15.1	12.5	-2.6
18-3	14.6	12.6	-2.0
18-4	14.0	12.5	-1.5
18-5	14.2	12.6	-1.6
18-6	14.2	12.6	-1.6
18-7	14.0	12.6	-1.4
19-1	10.8	12.1	+1.3
20-1	14.5	11.8	-2.7
20-2	16.0	12.6	-3.4
21-1	12.3	12.1	-0.2
21-2	12.1	12.6	+0.5
22-1	6.8	8.9	+2.1
23-1	6.1	8.5	+2.4
24-1	6.5	8.2	+1.7
25-1	11.3	8.9	-2.4
26-1	9.5	9.5	0.0

For example, a specific soil type, Hollis loam, is so named because the profile characteristics of the soil show it to be a member of the Hollis series, while the textural grade of the surface soil designates its soil class as loam.

Soil type is the unit of soil maps as prepared by the United States Bureau of Soils. Thus a soil map would separate Hollis loams from Hollis silt loams, Gloucester fine sandy loams from either of the foregoing, and so on. It is obvious that if each of these soil types represented a different degree of fertility the soil map, within certain climatic and physiographic limitations, would be also a site map.

In Connecticut and similar regions one of the outstanding obstacles to the use of a soil map in this way is the complexity of soil conditions. There re approximately 150 soil types in Connecticut alone. Twenty-six types vere sampled in the limited region covered by this study and in one instance three distinct soil types occurred within the boundaries of a single acre sample plot. Obviously under such conditions soil types are too numerous to serve individually as site divisions, even if they were proved to represent different degrees of fertility.

In order to prevent the recognition of too many site divisions, it would be necessary in practical application to combine the soils of nearly similar grades of fertility into groups. The classification of these soil types into site divisions would require accurate knowledge of the average site index of each soil type and a measure of the dispersion of individual indices around this average (the greater the dispersion the more unreliable the average and the larger the errors in its application). To obtain this information for regions of complex soil conditions, such as Connecticut, is obviously a large and time-consuming task.

Yet soil type is easily and readily mapped by a trained soils investigator, many such maps are now available, and more will be available in the future, compiled in any event for various other purposes. Any indication of the value of soil type and hence soil map in estimating site quality is, therefore, of considerable interest. The incomplete and to some extent speculative comment on the value of soil type, based on the data collected, is included for this reason only. It should be understood that the basic data is too meager to permit definite conclusions, and that a great deal of further work is needed before the actual value of soil type can be determined.

To use soil type in estimating site quality it was first necessary to compute the average site index for each soil type. Only a few soil types occurred widely enough to permit an estimate of their average fertility. The average site indices for the commoner soil types are shown in Table III.

These average site index values were used in predicting site index values for each soil area in which their respective soil type occurred. This is predicated on the assumption that the average site index of the type was the best possible estimate of the site quality of land, wherever its respective soil type appeared. The estimates were compared with the actual site indices (in the same manner that site indices predicted with silt-plus-clay content were compared with actual in Table II) and the errors of estimate computed from this array. The standard error is listed in Table I.

From the data available, soil type appears to be a relatively accurate measure of site quality. Since each soil type was sampled in only a few

TABLE III

THE AVERAGE SITE INDICES OF THE COMMONER SOIL TYPES

Soil type	*Average site index* *Feet*	*Number of soil samples*	*Number of plantations in which soil type was sampled*
Gloucester fine sandy loam . .	12.0	16	4
Hollis fine sandy loam . . .	12.6	7	3
Hollis loam	12.5	6	4
Maltby very fine sandy loam . .	14.1	7	2
Merrimac coarse sand	8.0	5	1*
Peru fine sandy loam	11.4	5	1
Wethersfield loam	11.1	5	4

* One locality; five plantations.

plantations (never more than four), the deviation of individual site indices around the average soil index probably is considerably less than it would be with more adequate sampling. This tends to reduce the size of individual errors of estimate and hence, the size of the standard error. It is probable that the accuracy of soil type as a measure of site conditions is here somewhat exaggerated. The constants listed in Table I indicate that soil type (even if exaggerated) as a measure of site conditions is only slightly superior to that of soil class.

The basis on which to estimate the value of soil class is considerably stronger, for the soils of southern Connecticut are very similar in their general textural character. Some 65 to 70 per cent of the soils sampled are either loams or fine sandy loams and over 95 per cent fall into one of six such textural groups. It was possible to obtain fairly accurate measures of the average site indices of the more important groups for which the deviations around the average and hence the computed errors of estimate should be fairly reliable.

Average site indices by soil classes are given in Table IV. These average site indices were used in turn to predict site index for the areas in which their respective soil classes occurred. As in similar cases the predicted values were compared with the actual and the errors of estimate computed. The standard error based on this grouping is listed in Table I. This standard error indicates that with a knowledge of soil class alone it is possible to predict site index within ± 1.16 feet of the actual site index in 68 per cent of the cases, and within ± 2.3 feet in practically all cases (95 per cent).

TABLE IV

THE AVERAGE SITE INDICES OF THE COMMONER SOIL CLASSES

Soil class	*Average site index Feet*	*Number of soil samples*	*Number of plantations in which soil class is sampled*
Coarse sand	8.2	6	2*
Sandy loam	12.0	6	5
Fine sandy loam	12.2	41	11
Very fine sandy loam	14.1	7	2
Loam	11.8	24	12
Silt loam	11.6	5	3

* Two localities; altogether a total of six plantations with five in one small area.

Soil class determined by field observation, or the textural quality of the A layer, is therefore a measure of site quality superior to colloidal content or to silt-plus-clay content, and only slightly inferior to soil type. The number of soil classes are few and it would be a relatively easy task to determine the average site index of each group. Soil class can be estimated readily in the field by any well-trained investigator with minimum effort. It seems to offer an excellent, quickly obtained measure of site quality of the soil.

SUMMARY

THIS study was based on a sample of ninety-five paired measures of soil value and site conditions, distributed throughout twenty-six forest plantations. Average height growth of red pine was used as a measure of site quality. The main purpose was to measure the value of colloidal content as an indicator of site quality, and to make such incidental observation of the value of other soil measures as the character of the data would permit. The conclusions are applicable only to the brown, weakly podsolized forest soils of southern Connecticut and adjacent territory, and particularly to such of these as occur commonly in the vicinity of New Haven. The conclusions are as follows:

(1) A-layer soil values appear superior to similar values of the Band C layers as measures of soil conditions. It is relatively easy to sample this surface layer.

(2) Colloidal content and a cl,osely allied measure, silt-pIus-clay content, are both definitely correlated with site quality. The correlation index of the better of these measures, silt-pIus-clay content, is 0.58 ± 0.07. Site index values predicted from silt-pIus-clay content will fall, in approximately 68 per cent of the cases, within ± 1.32 and, in practically all cases (95 per cent), within ± 2.6 feet or about one broad site class of the actual site index. Colloidal content and silt-plus-clay content are fair measures of site quality.

(3) Organic matter varies between 2 and 10 per cent and its influence on soil fertility is relatively negligible.

Soil reaction, measured in pH values, varies between 4.5 and 5.5 pH and its influence on soil fertility also is negligible.

The value of soil type as an indicator of site quality cannot be accurately estimated with the data available. The application of this method would require an immense amount of preliminary work to determine the average site quality of each soil type and, at best, soil type would be but slightly superior to soil class as a measure of fertility.'

(6) A knowledge of the soil class (the textural quality of the A horizon or surface soil) permits classification of soil quality within approximately one broad site class. Approximately 68 per cent of the site indices predicted from this measure will be within ± 1.2 feet, and practically all (95 per cent), within ±2.3 feet of the actual site index. Considering the relative ease with which this factor can be estimated by a trained investigator, it offers an excellent method for determining the site quality of forest soils.

APPENDIX

Probable Accuracy of Average Height Values

The average height values computed in this study are accurate in practically all cases to within one foot (±1.0). This statement is based on an analysis of height measurements taken on four permanent sample plots located in typical red pine plantations. The following table shows for each sample plot the standard deviation or dispersion of individual tree heights around the average height and the number of tree heights needed to compute for average height a figure with a standard error of ± 0.5 feet.

NECESSARY NUMBER OF HEIGHT MEASUREMENTS

Plot no.	*Period since planting* *Years*	*Standard deviation* *Feet*	*Standard error* *Feet*		*Number of tree heights required*
47	9	2.00	0.5		16
48	9	1.76	0.5		12
49	9	1.64	0.5		11
52	9	2.50	0.5		25
				Total	64
				Average	16

These standard deviations are taken from G. W. Dean's "Application of Statistical Methods to Forestry Use," a manuscript in Professor Hawley's files.

The necessary number of measurements was computed as follows:

$$\text{Necessary number of measurements} = \left(\frac{\text{Standard deviation}}{\text{Standard error}}\right)^2.$$

The average height values given in the Record of Basic Data, being based on sixteen measurements and taken in plantations with standard deviations essentially similar to those of the permanent sample plots listed above, should fall (in about 95 per cent of the cases) within ± 1.0 foot (twice the standard error) of the actual average height, which would be obtained through the measurement of every tree.

APPENDIX

Record of Basic Data

Number of soil pit	Soil type	Colloidal content of horizon A (Per cent)	Colloidal content of horizon B (Per cent)	Colloidal content of horizon C (Per cent)	Horizon A values: Silt-plus-clay content (Per cent)	Horizon A values: Organic matter (Per cent)	Horizon A values: Soil acidity (pH values)	Site measures: Average height (Feet)	Site measures: Site index (Feet)	Period since planting (Years)
1-1	Gloucester f.s.l.	11	12	10	37	5.5	4.9	21.1	11.8	
1-2	Gloucester f.s.l.	11	13	6	37	5.9	4.9	20.7	11.4	
1-3	Gloucester f.s.l.	10	11	10	30	6.0	5.0	22.6	12.5	
1-4	Hinsdale f.s.l.	17	19	17	34	4.6	5.2	23.1	12.8	
1-5	Gloucester f.s.l.	14	14	10	35	4.9	4.9	20.1	11.2	
1-6	Gloucester f.s.l.	15	14	4	34	4.2	5.0	20.5	11.3	
1-7	Gloucester f.s.l.	13	13	7	32	5.0	5.0	22.3	12.3	
1-8	Gloucester f.s.l.	11	12	5	31	4.3	5.0	21.8	12.0	14
1-9	Gloucester f.s.l.	11	8	5	28	6.2	4.9	20.4	11.3	
1-10	Gloucester f.s.l.	13	11	8	28	3.7	4.9	20.8	11.6	
1-11	Woodbridge f.s.l.	10	10	10	27	4.4	4.6	21.0	11.7	
1-12	Gloucester f.s.l.	9	11	11	32	4.3	4.8	20.9	11.7	
1-13	Gloucester f.s.l.	10	13	14	32	6.3	4.9	21.1	11.8	
1-14	Hinsdale f.s.l.	13	16	14	31	5.2	5.0	20.6	11.3	
1-15	Gloucester f.s.l.	14	12	12	31	5.3	4.7	19.1	10.7	
2-1	Gloucester f.s.l.	14	16	12	37	6.2	5.0	18.3	13.0	
2-2	Hinsdale f.s.l.	14	17	12	37	5.5	5.3	17.4	12.4	
2-3	Brookfield f.s.l.	12	24	10	40	5.1	5.0	20.7	14.7	12
2-4	Woodbridge f.s.l.	14	22	26	39	7.4	5.0	19.1	13.7	
3-1	Hartford gr. loam	18	20	4	46	5.1	5.2	18.5	11.7	
3-2	Wethersfield loam	23	19	rock	47	5.2	5.6	17.8	11.2	
3-3	Hartford gr. loam	19	10	5	39	5.9	6.1	16.6	10.4	13
3-4	Hartford gr. loam	20	25	2	55	6.0	4.8	19.4	12.1	

Record of Basic Data (cont.)

Number of soil pit	Soil type	Colloidal content of horizon A	B	C	Horizon A values: Silt-plus-clay content	Organic matter	Soil acidity	Site measures: Average height	Site index	Period since planting
		Per cent	Per cent	Per cent	Per cent	Per cent	pH values	Feet	Feet	Years
4-1	Hollis f.s.l.	16	17	9	31	3.3	4.9	16.1	11.5	12
4-2	Hollis f.s.l.	16	16	rock	33	3.4	4.5	15.9	11.3	
4-3	Hollis f.s.l.	17	18	rock	36	4.0	4.6	17.2	12.3	
4-4	Hollis loam	19	23	11	40	4.5	4.8	17.5	12.4	
4-5	Hollis f.s.l.	18	21	10	36	3.6	4.7	18.6	13.2	
5-1	Wethersfield loam	13	11	10	32	3.3	5.5	17.4	11.0	13
5-2	Wethersfield loam	16	18	7	34	4.4	5.3	17.5	11.0	
5-3	Holyoke loam	18	20	18	34	4.6	5.5	18.7	11.7	
5-4	Holyoke loam	16	18	25	35	5.7	5.4	16.2	10.2	
5-5	Holyoke loam	14	21	12	34	5.7	5.1	18.7	11.7	
6-1	Hollis silt loam	25	21	17	51	5.3	4.9	21.7	12.0	14
6-2	Hollis loam	27	26	15	51	8.8	5.1	21.8	12.1	
6-3	Hollis f.s.l.	17	20	16	51	8.7	4.9	22.9	12.7	
6-4	Hollis f.s.l.	23	23	21	57	8.6	5.4	23.1	12.9	
6-5	Hollis loam	26	22	13	54	6.5	5.0	23.2	13.0	
6-6	Maltby v.f.s.l.	22	26	3	55	5.9	5.3	23.2	13.0	
7-1	Hollis silt loam	26	29	24	49	5.8	5.3	23.5	13.0	14
7-2	Hollis loam	21	26	19	47	4.8	4.6	22.4	12.4	
7-3	Hollis loam	26	27	20	48	4.6	4.7	23.3	13.0	
8-1	Gloucester f.s.l.	15	14	8	29	4.5	4.8	19.2	12.0	13
8-2	Wethersfield loam	21	31	30	47	4.3	5.1	19.7	12.2	
8-3	Gloucester f.s.l.	14	16	9	33	5.5	4.9	23.2	14.5	
9-1	Hollis loam	19	26	27	51	7.7	4.8	21.6	12.0	14
9-2	Bernardston loam	24	23	14	47	5.5	5.0	23.3	13.0	

Record of Basic Data (cont.)

Number of soil pit	*Soil type*	*Colloidal content of horizon A*	*B*	*C*	*Horizon A values: Silt-plus-clay content*	*Organic matter*	*Soil acidity*	*Site measures: Average height*	*Site index*	*Period since planting*
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*pH values*	*Feet*	*Feet*	*Years*
10-1	Hinckley gr. coarse sand	11	7	2	21	4.7	4.6	14.1	8.8	
10-2	Hinckley coarse sand	9	7	2	12	3.5	4.9	14.8	9.2	
11-1	——— f.s.l.	12	15	19	22	5.3	5.3	20.4	12.8	
11-2	Gloucester f.s.l.	15	17	4	32	4.9	5.4	21.2	13.3	
12-1	Manchester f.s.l.	13	15	9	29	4.0	4.9	20.8	12.9	
12-2	Manchester sandy loam	14	8	2	28	2.1	5.0	21.4	13.3	
12-3	Manchester f.s.l.	17	15	3	35	3.9	5.0	19.9	12.3	13
12-4	Wethersfield f.s.l.	14	15	12	28	3.1	5.1	21.2	13.2	
12-5	Manchester sandy loam	11	12	3	24	3.2	5.3	18.0	11.2	
13-1	Merrimac loamy sand	9	7	1	18	2.7	4.9	15.7	9.7	
13-2	Merrimac loamy fine sand	12	8	2	27	3.5	5.1	17.8	11.0	
13-3	Wethersfield f.s.l.	16	19	rock	32	3.7	4.9	19.8	12.2	
13-4	Manchester f.s.l.	13	11	2	25	3.2	4.9	20.9	13.0	
14-1	Whitfield loam	14	10	16	40	4.0	5.3	8.9	11.3	
14-2	Whitfield loam	16	18	20	35	3.1	5.2	8.4	10.7	
14-3	Wethersfield loam	19	20	..	34	3.1	5.2	7.8	9.9	9
14-4	——— f.s.l.	19	20	..	43	4.3	5.4	8.9	11.3	
15-1	Whitman silt loam	26	28	10	59	4.7	5.2	16.3	10.2	
15-2	Whitman silt loam	26	20	13	56	5.2	5.1	18.3	11.5	
15-3	Whitman silt loam	30	14	9	58	4.3	5.0	18.4	11.6	
15-4	Whitman loam	20	17	18	47	4.0	5.3	18.5	11.6	13
16-1	Peru f.s.l.	14	9	6	34	9.7	5.1	17.8	11.0	
16-2	Peru f.s.l.	16	18	6	37	8.9	4.9	17.8	11.0	
16-3	Peru f.s.l.	12	15	5	35	9.6	4.9	18.2	11.3	

RECORD OF BASIC DATA (cont.)

Number of soil pit	Soil type	Colloidal content of horizon A	B	C	Horizon A values: Silt-plus-clay content	Organic matter	Soil acidity	Site measures: Average height	Site index	Period since planting
		Per cent	Per cent	Per cent	Per cent	Per cent	pH values	Feet	Feet	Years
16-4	Peru f.s.l.	12	8	10	36	9.6	5.0	17.8	11.0	13
16-5	Peru f.s.l.	14	9	4	22	5.2	5.1	20.8	12.9	
17-1	Fairlea loam	24	16	4	55	6.3	5.5	17.0	10.7	
17-2	Hartford sandy loam	18	14	. .	40	4.7	5.3	15.4	9.7	
17-3	Hartford loam	23	28	4	53	5.8	5.8	17.3	10.9	
17-4	Ellington loam	26	27	16	61	2.2	5.8	16.8	10.4	
17-5	——— loam	15	14	. .	48	6.4	5.7	19.5	12.1	
18-1	Maltby v.f.s.l.	19	22	10	40	7.1	5.4	19.9	14.0	12
18-2	Maltby v.f.s.l.	18	25	4	48	5.7	5.5	21.2	15.1	
18-3	Maltby v.f.s.l.	19	17	12	45	4.3	5.0	20.4	14.6	
18-4	Maltby v.f.s.l.	16	15	3	38	5.2	5.0	19.9	14.0	
18-5	Hollis f.s.l.	16	18	12	44	5.3	5.0	20.1	14.2	
18-6	Maltby v.f.s.l.	15	21	11	45	6.0	5.0	20.2	14.2	
18-7	Maltby v.f.s.l.	17	19	9	44	5.4	5.1	19.8	14.0	
19-1	Hartford sandy loam	15	17	14	31	4.0	5.0	27.1	10.8	18
20-1	Hartford sandy loam	15	7	2	29	3.9	5.4	11.5	14.5	9
20-2	Hartford loam	22	15	6	41	3.7	5.2	12.5	16.0	
21-1	Hartford sandy loam	14	14	12	31	3.9	5.1	9.8	12.3	9
21-2	Hartford loam	20	21	9	40	5.8	5.2	9.6	12.1	
22-1	Merrimac coarse sand	10	8	2	16	2.7	4.6	25.2	6.8	26
23-1	Merrimac coarse sand	8	9	2	15	2.1	4.5	22.7	6.1	26
24-1	Merrimac coarse sand	8	7	4	14	2.2	4.8	7.8	6.5	11
25-1	Merrimac coarse sand	10	9	4	16	2.2	4.6	13.7	11.3	11
26-1	Merrimac coarse sand	12	11	2	18	2.3	4.9	7.5	9.5	9

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