A TEST OF THE DIFFERENTIATION OF SOIL SERIES WITHIN THE WILLAMETTE CATENA

by

JAMES ALBERT POMERENING

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1961

APPROVED:

Redacted for Privacy

Associate Professor of Soils

In Charge of Major

Redacted for Privacy

Head of Soils Department

Redacted for Privacy

Chairman of School Graduate Committee

Redacted for Privacy

Dean of Graduate School

Date thesis is presented June 10, 1960

Typed by Ina Glasgow

ACKNOWLEDGMENTS

I am especially grateful for the assistance given me by my Major Professor, Dr. Ellis G. Knox, in all stages of the research program for this thesis. I also appreciate the suggestions received from Dr. Moyle Harward during the time of writing the thesis.

A special note of appreciation is extended to Drs. W. H. Taubeneck and W. D. Wilkinson of the Geology Department, and Drs. G. R. Sitton and E. N. Castle of the Agricultural Economics Department for services rendered as members of my graduate committee, and to Dr. Lyle D. Calvin of the Statistics Department for advice concerning sampling procedure and statistical methods.

I am very grateful for the financial assistance provided me by the Oregon Agricultural Experiment Station Basic Research Committee for the thesis problem.

Many heartfelt thanks are due my wife, Doris, for the hours she spent at my side working on the thesis, and for the encouragement she gave whenever I most needed it.

TABLE OF CONTENTS

	Page
INTRODUCTION.	1
REVIEW OF LITERATURE.	4
DESCRIPTION OF THE SAMPLING AREA.	13
Geographic Location.	13
Physiography and General Geology	13
Climate.	18
SOIL SERIES DESCRIPTIONS.	19
Willamette Series.	19
Range of characteristics	21
Woodburn Series.	22
Range of characteristics	24
Amity Series	25
Range of characteristics	27
Concord Series	28
Range of characteristics	30
Dayton Series.	30
Range of characteristics	32
METHODS	33
Field Procedure.	33
Laboratory Procedures.	34
Chemical analysis.	34
Cation exchange capacity	34
Exchangeable calcium, magnesium, potassium and sodium	34
Soil reaction.	35
Organic carbon	35
Total nitrogen	35
Physical analysis.	35
Mechanical analysis.	35
Crushed dry color.	36
Classifying the Individuals into Series. . . .	38
Statistical Analysis	49
RESULTS AND DISCUSSION.	51
Depth to Evidence of Impeded Drainage.	51
Horizon Thickness.	56
Moist Color.	61
Hue.	61
Value.	64

Page

Chroma. 70
Dry Color 74
Hue 75
Value 78
Chroma. 84
Mean moist versus mean dry Munsell notations 88
Horizon Boundary Distinctness 90
Soil Texture. 94
Soil Structure. 100
Structural type 101
Structural size 103
Structural grade. 107
Soil Consistence. 110
Soil Reaction 115
Cation Exchange Capacity. 119
Base Saturation 123
Exchangeable Cations. 128
Calcium 128
Magnesium 131
Potassium 135
Sodium. 139
Organic Carbon. 142
Total Nitrogen. 145
Carbon-Nitrogen Ratios. 147
Discriminant Function Analysis. 151
For all series. 151
For Concord and Dayton series 162
Summary Analysis of Series Means. 168

CONCLUSIONS. 174

BIBLIOGRAPHY 181

LIST OF TABLES

		Page
1.	Drainage Sequences of All Individuals within Soil Series.	45
2.	A Comparison of the Tentative Field Classification and the Final Laboratory Classification.	49
3.	Frequency Distribution for Depth to Evidence of Impeded Drainage	52
4.	Sample Statistics for Depth to Evidence of Impeded Drainage	54
5.	Observed (f) and Hypothetic (h) Frequencies and Chi-square Values for the Individual Degree of Freedom Goodness of Fit Test for Several Intervals of the Depth to Evidence of Impeded Drainage Distribution for All Individuals Combined	55
6.	Frequency Distributions for Thickness of Horizons and Combinations of Horizons of the Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined.	58
7.	Sample Statistics for Horizon Thickness	59
8.	Frequency Distributions for Moist Munsell Hue Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined	63
9.	Sample Statistics for Moist Munsell <u>Hue</u> Notations	65
10.	Frequency Distributions for Moist Munsell <u>Value</u> Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined.	66
11.	Sample Statistics for Moist Munsell <u>Value</u> Notations	69

Page

12. Frequency Distributions for Moist Munsell _Chroma_ Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 71

13. Sample Statistics for Moist Munsell _Chroma_ Notations 73

14. Frequency Distributions for Dry Crushed Munsell _Hue_ Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 76

15. Sample Statistics for Dry Crushed Munsell _Hue_ Notations 77

16. Frequency Distributions for Dry Crushed Munsell _Value_ Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 79

17. Sample Statistics for Dry Crushed Munsell _Value_ Notations 83

18. Frequency Distributions for Dry Crushed Munsell _Chroma_ Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 85

19. Sample Statistics for Dry Crushed Munsell _Chroma_ Notations. 87

20. Comparison of Dry Crushed and Moist Munsell Notation Means. 89

21. Frequency Distributions for Horizon Boundary Thickness (distinctness) of the Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 91

22. Sample Statistics for Horizon Boundary Thickness 94

23. Frequency Distribution for Field-Determined Texture of Four Horizons of the Willamette, Woodburn, Amity, Concord, and Dayton Samples. . 95

Page

38. Sample Statistics for Percentage Base Saturation. 127

39. Frequency Distributions for Exchangeable Calcium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 129

40. Sample Statistics for Exchangeable Calcium Values. 130

41. Frequency Distributions for Exchangeable Magnesium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 132

42. Sample Statistics for Exchangeable Magnesium. . 133

43. Frequency Distributions for Exchangeable Potassium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined. 136

44. Sample Statistics for Exchangeable Potassium Values. 138

45. Frequency Distributions for Exchangeable Sodium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 140

46. Sample Statistics for Exchangeable Sodium . . . 141

47. Frequency Distributions for Percentage of Organic Carbon of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 143

48. Sample Statistics for Percentage of Carbon. . . 144

49. Frequency Distributions for Percentage of Nitrogen of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 146

50. Sample Statistics for Percentage of Nitrogen. . 147

Page

51. Frequency Distributions for Carbon-Nitrogen Ratios of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined 149

52. Sample Statistics for Carbon-Nitrogen Ratios. . 150

53. Sums of Squares and Products, within Soil Series, for Five Characteristics of Willamette, Woodburn, Amity, Concord, and Dayton Samples. . 155

54. Matrix of Multipliers Reciprocal to the Sums of Squares and Products, within Series. 156

55. Observed Means for Five Characteristics of the Willamette, Woodburn, Amity, Concord, and Dayton Samples and Their Greatest Differences 157

56. Sums of Squares and Products, within Series, for Six Characteristics of Concord and Dayton Samples. 163

57. Matrix of Multipliers Reciprocal to the Sums of Squares and Products, within Species 164

58. Observed Means for Six Characteristics of the Concord and Dayton Samples and Their Differences 165

59. Summary Analysis of Some of the Characteristics Expressed as the Ratio of the Mean Value of Each Series' Sample to the Mean Value of the Willamette Sample 170

LIST OF FIGURES

		Page
1.	Map of North Marion County, Oregon showing the sampling transect and the drainage pattern.	15
2.	Frequency histogram for the depth to evidence of impeded drainage of the observations of the five soil series of the Willamette catena. . .	53
3.	Frequency histograms for discriminant function values of the observations of the five soil series of the Willamette catena.	160
4.	Frequency histograms for discriminant function values of the Concord and Dayton observations.	167

A TEST OF THE DIFFERENTIATION OF SOIL SERIES WITHIN THE WILLAMETTE CATENA

INTRODUCTION

The earth's land surface is covered by a population of soils that is comprised of an almost infinite number of individuals. Each soil individual has vertical limits fixed by the thickness of the soil profile and horizontal limits fixed by the practical limits of space required for its observation (9, p. 88). A soil individual can be defined according to the values of its internal characteristics. It is impractical for man to deal with these individuals separately, because their numbers are so great that it is not feasible to remember the properties of each, and the area represented by each is too small to serve as a practical land unit for most operations. Therefore, man has found it convenient to systematically arrange soil individuals into classes. A soil class is a group of individuals, or of other classes, which are similar in selected properties, and which are distinguished from all other soil classes by differences in these properties (9, p. 81). The purpose of this study was to determine whether groups of soil individuals are naturally segregated according to specific values of selected properties, or whether the division between groups for taxonomic purposes must be made arbitrarily.

Natural soil groupings would be those groups of soil individuals that were segregated from other groups of individuals by minima in frequency distribution tabulations for one or more properties the individuals had in common. The allowable range of values for the common property or properties in a natural grouping would be fixed by the positions of the minima. Such groupings could be used for taxonomic classes, and could be precisely defined in terms of the mean values, standard deviations, and ranges of the segregating property or properties. Arbitrary soil groupings would be those for which man must set the limits to the ranges of values for selected properties, because of the absence of minima in frequency distribution tabulations for any of the properties, or sets of properties common to the soil population. The defined range of values for the segregating properties would depend upon man's choice, rather than upon the natural limits set by the minima in a frequency distribution tabulation.

The sample used in this study consisted of 114 individuals representing 5 soil classes at the series level of generalization. The series, all members of the Willamette catena, are Willamette, Woodburn, Amity, Concord, and Dayton.

The sample was obtained from a 20-mile transect north of Salem, along the Salem-Portland expressway from excavations dug for foundation footings of electrical line towers. One individual was described and sampled at each tower location.

The individuals were classified into series according to current concepts of the National Cooperative soil survey. Selected quantitative morphological, chemical, and physical characteristics of the individuals for each series, and for all the individuals combined, were summarized and statistically analyzed. Mean values, standard deviations, and ranges of the various characteristics were calculated. The significance of the difference between the means of adjacent classes (ranked according to degree of impeded drainage) was tested. The frequency distributions for the various characteristics were tabulated and examined for the presence of minima. Suggested minima were tested for significance by the Chi-square individual degree of freedom goodness of fit test. The frequency distribution pattern of the individuals for several characteristics considered together was studied by means of discriminant function analysis.

REVIEW OF LITERATURE

Pedologists have treated concepts concerning the manner in which soil individuals are grouped within classes much as the layman treats the weather. They have discussed the subject a great deal, but have not done much about it. Actually, it is unfair to say that they have not done much about it. Their concepts are based on a large number of field observations and subsequent armchair speculation. It is more correct to say that pedologists have made little effort to objectively test their concepts or hypotheses. A test to determine the kind of frequency distribution that soils have requires random sampling of a large number of individuals. Obtaining such a sample probably has been the biggest hindrance to an objective study of the problem.

Cline has presented the most comprehensive review of soil classification concepts (9, p. 81-91). He states, "A class of natural objects may be considered in terms of a frequency distribution according to value of a selected property. Commonly, within some small increment of value of that property, the frequency of occurrence of individuals is a maximum. This is the modal value of the property which defines the central nucleus of the class...the modal individual" (9, p. 82). The selected property is called the differentrating characteristic. Cline states that its "mean value within each class defines the modal individual of that group. Its standard deviation defines the variability of the group. Tests of statistical significance are measures as to whether the differences between classes are real or only apparent."

It appears that Cline is inferring that soil classes have natural limits set by minima in the frequency distribution of individuals at certain values of the differentiating characteristic. Yet, in the same paper, he writes, "Classes of natural objects are not separated by insurmountable barriers; they grade by small steps into other classes" (9, p. 81); and "When differentiation is based upon degree of expression of an attribute, the limiting value of that property between classes of a continuous series may be placed arbitrarily at any point in the series" (9, p. 86). Cline qualified his statement pertaining to the maximum occurrence of individuals at some modal value by the word, "commonly." Could he have meant that soil classes have natural boundaries only when the differentiating characteristic is one of kind rather than one of degree of expression? Hardly, since he refers to "increment of value" of the selected property which infers degree of expression rather than kind of characteristic. Certainly, classes differentiated according to kind of property would have to be discrete groups.

The mere fact that Cline says a class can be defined in terms of the mode and the standard deviation of the differentiating characteristic implies that maxima and minima exist in the frequency distribution of individuals for the differentiating characteristic. Then, does he assume that "commonly" soil classes have natural limits? Probably not, because he does not infer anywhere in his paper that the modal values of a characteristic would express themselves as maxima of a frequency distribution for a large sample including individuals from a variety of environments. Instead, he says that we determine the characteristics of the modal individual and the deviations from it for classes of the lower categories by drawing a sample from an area large enough to be feasible for treatment for most purposes (9, p. 88). Most of the characteristics of the population of soils probably have a bell-shaped frequency distribution curve. Likewise, samples drawn from centrally located segments of the population would probably yield bell-shaped frequency distributions for the various characteristics. The modal value of the distribution, however, would depend upon the segment of the population we sampled. The segment of the population sampled would not depend upon some existing modal value or minima values.

Other pedologists have expressed similar views concerning soil classes. Jenny, an advocate of the use of genetic factors rather than soil characteristics as the basis of soil classification, wrote, "Theoretically, one can pass from one soil type to any other by a series of infinitely small steps having equal classification significance" (25, p. 15). One could argue the point, "having equal classification significance," because of the dependency of a classification system to a specific objective, but the statement infers the absence of minima in the frequency distribution of individuals for specific properties.

Bushnell said, "characteristics and kinds of soils are conceived naturally to form a continuous spectrum and the operation of breaking this band up, by classification into distinct kinds of soils is a figment of the imagination rather than discovery of natural discrete segments" (7, p. 468).

Mill states, "It is a fundamental principle in logic that the power of framing classes is unlimited, as long as there is any (even the smallest) difference to found a distinction upon" (33, p. 91).

Whiteside said, "it seems more correct today to say that soil individuals should be defined in terms of the ranges of their differentiating properties rather than by a modal individual which would vary with the relative areas of the different portions of the range of soil properties" (47, p. 194). By "soil individuals," he was referring to the class, soil type, as defined in the Soil Survey Manual (43, p. 287-289).

Milne, describing topographical sequences of soils in East Africa, wrote, "in studying a sample area in detail it is possible to pick out three or four distinctive types of profiles and give series rank to each of them, making it clear in the descriptions of these series that they vary about their means so as to join up continuously" (34, p. 183).

Since there is almost universal agreement among the authorities about the continuous pattern of variation among soils, is there any need to objectively test for the possibility of natural limits between groups of soils that might be used for taxonomic purposes? This answer is yes, of course. Characteristics used to define soil classes are often selected because they reflect the genetic factors under which the soil was developed. It is possible that one or more of these factors could express itself in a discontinuous pattern. Finding this pattern of expression would be very beneficial for making class distinctions. An objective study of the population might be required to find this pattern.

Another reason for objectively studying a sample of the population is to permit precise definition of the classes regardless of whether they are natural or arbitrary units. Cline states, "The test of any grouping is the number, precision and importance of statements that can be made about each class for the objective" (9, p. 82). He also states that complete randomization is necessary for unbiased estimates of the variation within a class (8, p. 275).

Several studies concerning the amount and kinds of variations within taxonomic and cartographic soil units have been made, but "representative" samples were used in most of these.

Brown and Thorp investigated the morphology and chemical and physical composition of series of both the Miami catena and the Miami family (6, p. 1-53). They selected but one representative sample of each series. They found differences between the series but had no basis for testing significance.

Crawford studied the variation of pH, $CaCO_3$, and particle size distribution in the plow layer of two soil types (11, p. 156-162). He randomly selected 20 sites on each soil type from soil maps and took duplicate samples at each site, 20 yards apart. He found the variation between duplicates was much smaller than it was between sites. He also found significant differences between the means of the two types for complete coarse sand, complete fine sand, insoluble fine sand, and per cent $CaCO_3$ in the fine earth.

He also plotted the frequency distribution of the individuals for these characteristics and concluded that if a soil series is subdivided into two or more types, they must be defined in terms of a limiting per cent of one particle size fraction, or possibly a limiting ratio of fractions. In other words, he did not think it feasible to define thetypes on the basis of a modal individual and the deviations from it.

Davis studied the uniformity of soil types within 8 series in Alabama (15, 153 pp.). He sampled 22 sites for each series, but selected "representative" profiles of each. Despite the selection of representative profiles, he found the variation within a given type greater than the variation in properties between types, and concluded that the soil is a continuous body with ever-present variations and gradations and suggested latitudinal limits for series.

Harradine studied the variability of soil properties in relation to the stage of profile development (21, p. 302-310). He randomly sampled 16 profiles from each of 4 series selected to represent 4 stages of development in Colusa County, California. His primary objective was to obtain a thorough knowledge of the significant range of variability of soil properties within each series. He calculated means, standard deviations, standard errors, and coefficients of variations for several chemical and physical properties. He found significant differences in the mean values of some of the properties between series, and characteristic extreme-value ranges for the properties within series. However, all of the extreme-value ranges overlapped with those of adjacent series. Therefore, the characteristics he analyzed were not strictly differentiating in that they did not discriminate all individuals of one series from other series. He used statistical analysis for his data that assumes a normal population. Subsequently, had he analyzed a characteristic that differentiated all individuals of one series from all individuals in another series, one may have been able to conclude that soil series are natural classes. He summarized his results with the statements, "The continuous and heterogeneous nature of soil bodies is generally understood. It must follow that soil boundaries are median lines between two or more soil bodies that may be quite dissimilar in many properties, but may blend together with varying degrees of sharpness at their junctions"; and "It seems reasonable to assume that similar studies on a more comprehensive scale, will materially aid soil surveyors and research workers alike in defining and interpreting classification units" (21, p. 310).

Youden and Mehlich studied the variation of pH in the topsoil and subsoil for two soil types to determine the variability as a function of distance between sampling sites (50, p. 59-70). They took samples at intervals of 10 feet apart, 100 feet apart, 1000 feet apart, and 10,000 feet apart. They found that the variation among samples was greater as the distance between sites was increased. Their results do not tell anything about the presence or absence of natural boundaries between taxonomic units, but they do reveal heterogeneity within a cartographic unit.

Synecologists, working with plant communities, which are another system whose characteristics are dependent on the same genetic factors as soils, have studied the frequency distributions of plant species using random sampling techniques. Whittaker studied vegetation distributions in the Great Smoky Mountains in relation to elevation and topography (49, 80 pp.). He could find no point along a topographic gradient at which floristic composition or dominance changed abruptly, and concluded that plant associations are arbitrary groupings justified by their usefulness rather than by any correspondence to distinct clusters of species existing in the field. Curtis, working with vegetation communities in Wisconsin, was also led to conclude that plant communities are formed by the overlap of species distributions and are not organized into discrete units or associations (12, p. 476-496; 13, p. 558-566).

DESCRIPTION OF THE SAMPLING AREA

Geographic Location

The sampling transect paralleled the Salem-Portland expressway (Baldock highway) in northern Marion County, Oregon (Figure 1). It was approximately 20 miles long and extended in a northeasterly direction from the electrical transformer station, one mile north of Chemawa (SE. 1/4, Sec. 25, T. 6S., R. 3W.) to a point one-half mile northeast of Butteville Station (NE. 1/4, Sec. 34, T. 4S., R. 1W.). The southernmost site (number 1) was about 4 miles north of Salem and the northernmost site (number 120) was about one-half mile south of the Marion-Clackamas County line. The transect was east of the Willamette River at a distance varying between 2 and 12 miles.

Physiography and General Geology

The sampling transect crossed a portion of the Willamette Valley lowland of northwestern Oregon. The Willamette Valley is about 125 miles long and from 15 to 40 miles wide. It is bounded on the east by the Cascade Range and on the west by the Coast Range. It extends from Eugene, Oregon, to Portland, Oregon, where the Willamette River joins the Columbia River.

The Willamette Valley is cut into early tertiary sediments, but has been subsequently floored with a series of Pleistocene alluvial and lacustrine deposits, and Recent alluvial deposits (16, p. 5). The Recent alluvial deposits are valley flood plains of present stream channels that are incised in the Pleistocene deposits. The Pleistocene deposits form a broad, nearly level plain or terrace over the extent of the valley, except where they have been incised by post-glacial streams.

Some Pleistocene deposits along the borders of the valley are gravelly wherever tributaries flowing out of the surrounding uplands have built fans (4, p. 616). Most of the valley fill (at the surface, at least) is finer material, called the Willamette Silts (16, p. 65). The sampling transect was in this deposit.

The Willamette Silt deposit consists mainly of fine sediments (largely medium sand to silt) which are rudely stratified in beds that average about 1 foot in thickness (35, p. 31). Felts (17, p. 346) described a section of the deposit near St. Paul, Oregon, which consisted of alternating beds of fine sands and silts with very little clay. The qualitative mineral composition of these sediments was angular grains of quartz, mica, feldspar, magnetite, and other minerals; and sharp fragments of granite, basalt, and other rocks. Occasional quartzite, granite, and other rock-type erratics have been observed in the upper portion

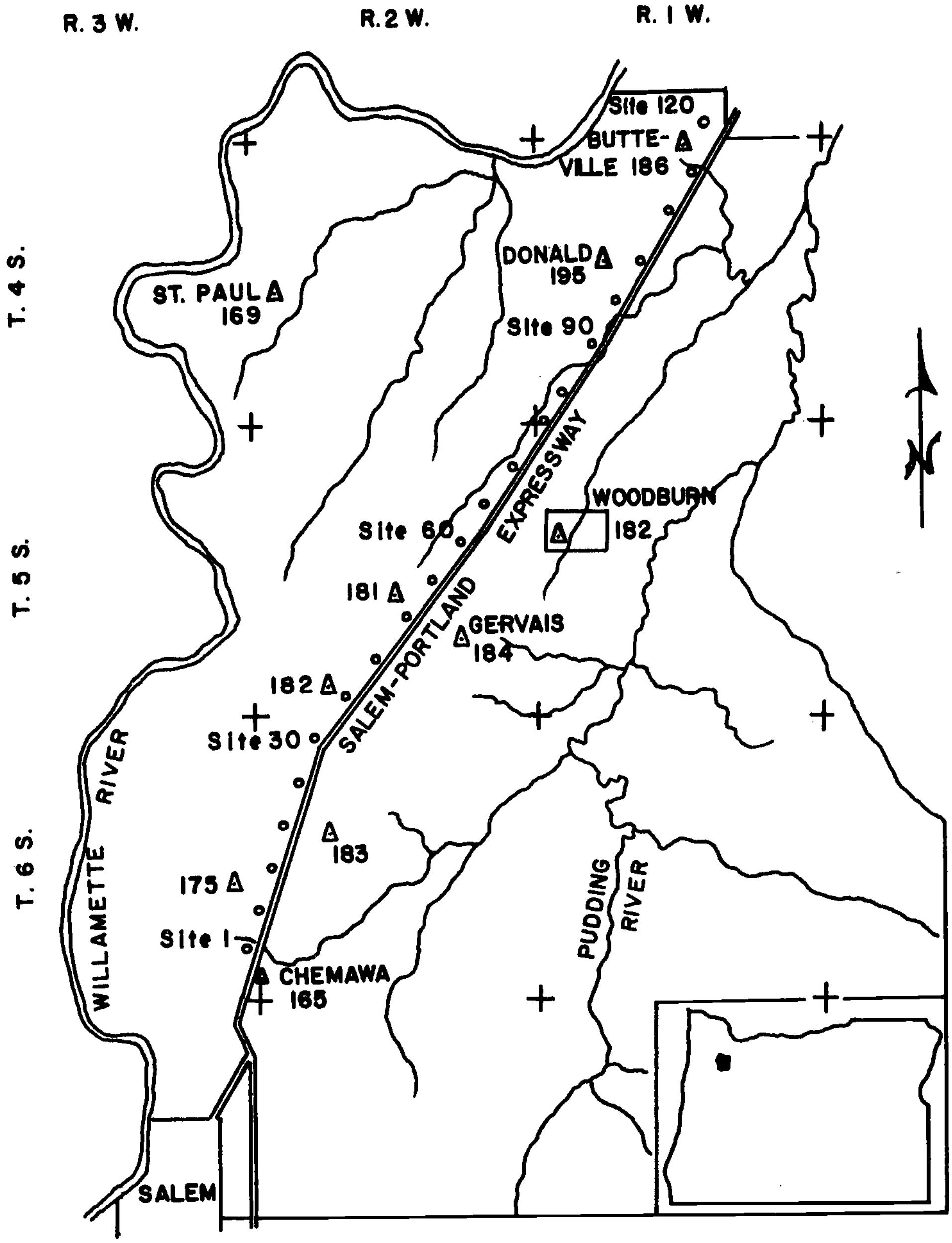

Figure 1. Map of North Marion County, Oregon showing the sampling transect and the drainage pattern. (Every sixth sampling site plotted.)
o Sampling site.
Δ Benchmark elevations.

0 4 8
Scale in miles.

of the silt deposit over the extent of the Willamette Valley (4, p. 615-632).

The valley fill material rests on a bedrock floor which is deepest near the center of the valley and more shallow near the borders. A well near Gervais was drilled to a depth of 252 feet without reaching the bedrock (35, p. 138). Gervais is near the center of the valley and also is within two miles of the sampling transect. Only the upper 68 feet consisted of the fine sediments as described above. From the base of the fine sands and silt deposit to the bottom of the well, the record showed 17 distinct zones of materials ranging in grain size from clay to gravel. A streak of peat was observed at 205 feet from the surface.

The Willamette Silt valley fill is said to have been deposited by glacial waters during a series of floods, repeated over an extended period of time (4, p. 625-626). The glacial water was periodically restrained from its normal course through the Columbia River Gorge by icejams in the vicinity of The Dalles, Oregon, and also west of the mouth of the Willamette River. These flood waters were dammed to depths of 1200 feet or more east of The Dalles, and occasionally poured out in sufficient volume to rush back into the Willamette Valley through the gaps at Oswego and Oregon City, carrying sand, silt, gravel, and icebergs along with them. The erratics scattered throughout the valley were ice-rafted by the icebergs. The icejams in the Columbia River Gorge west of the mouth of the Willamette River might have facilitated the reversal of the drainage into the Willamette Valley instead of out of the Valley. The locations of the erratics indicate that the backwaters in the Willamette Valley had to be at least 250 feet above the present level of the valley. The uniformity of the upper limit of the flood materials suggests a ponding of the flood for an extended period of time (a number of years). The bedding of the fine sands and silts might have been caused by seasonal changes in the sedimentation pattern; the sands being deposited in the summer, and the silts in the winter.

The relief of the valley floor in the immediate vicinity of the sampling transect was remarkably uniform. Elevations of the sites ranged from about 160 feet to 185 feet above mean sea level (Figure 1). There was virtually no relief between sites 18 and 66, each having an elevation of about 182 feet. This portion of the transect passed through a plain with no natural drainageways extending into it. North and south of this plain, the valley floor had been dissected by streams and the relief of the transect was slightly more variable.

Climate

The Willamette Valley has a humid temperate climate characterized by mild wet winters, cool dry summers, and a long growing season. At Salem, the mean annual temperature is 53° F, the mean January temperature is 38° F, and the mean July temperature is 68° F (44, p. 207-222). The mean annual precipitation is 40 inches at Salem, where the mean January precipitation is 5.7 inches and the mean July precipitation is only 0.3 inches. On the average, 44 per cent of the precipitation occurs in winter, 24 in spring, 5 in summer, and 27 in fall (46, p. 1086). Snow falls occasionally, but ordinarily this area is free from snow most of the winter. The average growing season is about 200 days. In summer there is abundant sunshine, but in winter there is much cloudiness. Westerly winds predominate, carrying the modifying effect of the Pacific ocean.

SOIL SERIES DESCRIPTIONS

Five series, all members of the Willamette catena, were represented in the sampling transect. They were Willamette, Woodburn, Amity, Concord, and Dayton.

Willamette Series

The Willamette soils are well-drained, medium-textured, Prairie-Gray Brown Podzolic intergrades, developed in fine-grained alluvial-lacustrine sediments of late Pleistocene age. They occur on a broad, nearly level to gently undulating terrace, in the narrow bands with good surface drainage along the escarpments made by post-glacial stream dissection. These soils have developed under a native vegetation cover of annual and perennial grasses, low-growing shrubs, and scattered oak and fir trees. They occur at elevations between 225 and 300 feet throughout the Willamette Valley.

Moderately well-drained Woodburn soils occupy similar sites but differ from Willamette soils by being mottled closer to the surface and by having a more pronounced fragipan below the B_2 horizon. Willamette soils may have mottling below 36 inches, but Woodburn soils are mottled between 24 and 36 inches from the surface.

Willamette soils are very dark brown in the surface horizon and dark brown in the B_2 horizon. The surface horizon soil material is friable, granular, and has a silt loam texture. The B_2 horizon material is firm, blocky, and has a silty clay loam texture. Thin clay skins coat the peds of the B_2 horizon.

A profile description of Willamette silt loam taken from site 3 of the sampling transect follows. This site was located in recently cleared Douglas-fir stumpland on a 3-per cent convex slope, 20 feet north of a moderately steep terrace escarpment.

A_1 0-8 inches, grayish-brown (10 YR 4.5/2.5, crushed dry) or very dark brown (10 YR 2/2, moist) silt loam with moderate medium and fine granular structure; friable, slightly sticky and slightly plastic; numerous roots; slightly acid (pH 6.1); wavy clear boundary. 7 to 9 inches thick.

A_3 8-15 inches, brown (10 YR 5+/3+, crushed dry) or dark brown (10 YR 3/3, moist) silt loam with weak thin platy structure; friable, slightly sticky and slightly plastic; numerous fine roots, medium acid (pH 5.6); smooth gradual boundary. 6 to 10 inches thick.

B_1 15-23 inches, brown (10 YR 5/3, crushed dry) or dark brown (10 YR 3/3, moist) heavy silt loam with moderate medium subangular blocky reducing to moderate fine and very fine subangular blocky structure; friable, slightly sticky and slightly plastic; few 1/4-to 1-inch tree roots, numerous smaller rootlets; few thin patchy clay flows; medium acid (pH 5.6), smooth gradual boundary. 6 to 10 inches thick.

B_2 23-40 inches, brown (10 YR 5.5/3, crushed dry) or dark brown (10 YR 3/3, moist) silty clay loam with strong medium angular blocky reducing to strong fine and very fine angular blocky structure; friable, sticky and plastic; few 1/4- to 1-inch tree roots, many finer roots; many fine pores inside peds; thin clay flows on ped surfaces and inside pores; thin black manganese oxide patchy streaks on ped surfaces; strongly acid (pH 5.2); smooth gradual boundary. 15 to 20 inches thick.

B_3 40-55 inches, pale brown (10 YR 6/3, crushed dry) or dark brown (10 YR 3/2.5, moist) silt loam with moderate coarse subangular blocky structure; firm, slightly sticky, slightly plastic; few large tree roots; very few fine pores in peds, few large (1/2 inch) vertical channels surrounded with 1/8-inch-wide dark grayish-brown (10 YR 4/2, moist) rings which in turn are surrounded by 1/8-inch-wide yellowish-brown (10 YR 5/8, moist) rings; thin clay flows and black manganese oxide stains on ped surfaces; strongly acid (pH 5.2); smooth gradual boundary. 12 to 18 inches thick.

C 55 inches+ , pale brown (10 YR 5.5/3, crushed dry) or dark grayish-brown (10 YR 3.5/2, moist) coarse silt loam; massive; friable, slightly sticky and slightly plastic; few vertical channels surrounded with dark grayish-brown and yellowish-brown rings as described in B_3 extend into upper part of C; strongly acid (pH 5.5).

Range of characteristics. The depth to evidence of restricted drainage, such as the mottled colors around the vertical cylinders, varies from 36 to greater than 60 inches. Soils with the shallower depths to mottling have weaker and coarser structure and firmer consistence in the B_3 horizon than the soils with the deeper depths to mottling. The texture of the B_2 varies from a loam to a silty clay loam or clay loam. Below 60 inches, the C horizon is commonly stratified with 4-12-inch-thick alternating beds of silt and fine sand. The hue of the horizons above the B_3 horizons is slightly more red than 10 YR for some of the soils. Values and chromas of the several horizons vary 0.5 Munsell units or more about the quantities listed in the above description. The depth to the B_2 horizon ranges from 17 to 30 inches; the thickness of the B_2 horizon ranges from 8 to 22 inches. The soils with the thinner B_2 horizons and the shallower depths to B_2 horizons also have shallower depths to mottling. The structure of the cultivated surface soils is usually moderate fine and medium subangular blocky. Cultivated soils that have not been limed commonly have strongly acid surface soils (pH 5.3-5.5).

Woodburn Series

The Woodburn soils are moderately well-drained, medium-textured, Prairie-Gray Brown Podzolic intergrades developed from the same parent material and under similar vegetation and climatic conditions as the Willamette soils. These soils occur on level to undulating portions of the terrace plain in association with Willamette and Amity soils. They have shallower depths to mottling than Willamette soils and deeper depths to mottling than Amity soils. The allowable range of depth to mottling for the Woodburn series is 24 to 36 inches. The surface drainage of the Woodburn soils is good, as it is for the Willamette series, but the internal drainage is impeded by a compact, rather impervious, fragipan below the B_2 horizon.

The following profile description is from sampling site 86 which was a cultivated field with less than 1 per cent slope, 500 feet east of the head of a shallow drainageway.

A_p 0-10 inches, brown (9 YR 4.5/3.0, crushed dry) or very dark grayish-brown (9 YR 3/2, moist) silt loam with moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; numerous roots; few concretions; medium acid (pH 5.8); smooth clear boundary. 9 to 11 inches thick.

A_3 10-20 inches, brown (9 YR 4.5/3.5, crushed dry) or dark yellowish-brown (9 YR 3/4, moist) silt loam with moderate very fine subangular blocky structure; very friable, slightly sticky and slightly plastic; numerous fine roots; many earthworm holes; few concretions; medium acid (pH 5.8); smooth gradual boundary. 9 to 12 inches thick.

B_1 20-28 inches, yellowish-brown (10 YR 5/4, crushed dry) or dark brown (10 YR 3/3, moist) silt loam with moderate very fine subangular structure; friable, slightly sticky and slightly plastic; many worm holes; few roots; few concretions; medium acid (pH 5.8); smooth gradual boundary. 7 to 10 inches thick.

B_2 28-38 inches, yellowish-brown (10 YR 5/4, crushed dry) or dark brown (10 YR 3/3, moist) silty clay loam with moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; many worm holes and fine pores within the peds; few concretions; thin dark brown (5 YR 3/3, moist) clay flows on ped surfaces and in pores; also thin dark grayish-brown (2.5 Y 4/2, moist) coatings on some of the peds; few black manganese stains on ped surfaces; medium acid (pH 5.6); smooth clear boundary. 9 to 11 inches thick.

B_{3m} 38-53 inches, brown (10 YR 5.5/3.5, crushed dry) or dark brown (10 YR 3/3, moist) coarse silt loam; massive; very firm in place, slightly brittle disturbed, slightly sticky, slightly plastic; few large (1/4 inch) vertical channels circumscribed with grayish-brown (2.5 Y 5/2, moist) and yellowish-brown (10 YR 5/8, moist) rings; clay flows in channels; few roots; slightly acid (pH 6.2); smooth gradual boundary. 13 to 17 inches thick.

C 53 inches +, brown (10 YR 5.5/3, crushed dry) or very dark grayish-brown (10 YR 3/2, moist) stratified very fine sandy loam and silt loam in alternating beds, 4 to 8 inches thick; massive; sand: very friable, non-sticky and non-plastic; silt: friable, slightly sticky and slightly plastic; few 1/4-inch vertical channels with grayish-brown and yellowish-brown rings as described in B_{3m}; dark brown (5 Y 3/4, moist) clay flows inside channels; neutral (pH 6.6).

Range of characteristics. The depth to evidence of impeded drainage ranges from 24 to 36 inches. Woodburn soils with the shallower depths to mottling have more pronounced grayish-brown (2.5 Y 5/2) coatings on the B_2 horizon ped surfaces than the soils with the deeper depths to mottling. The thickness of the B_2 horizon ranges from 6 to 20 inches and the depth to the fragipan (B_{3m}) ranges from 25 to 44 inches. The soils with the top of the fragipan between 25 and 30 inches from the surface have the thinner B_2 horizons, no B_1 horizons, and their B_2 horizon is commonly a friable silt loam with weak medium subangular blocky structure, which is, generally, not mottled. Their fragipan (B_{3m}) is, however, very firm and massive, and has a variegated color pattern of dark grayish-brown (2.5 Y 4/2, moist) and dark brown (10 YR 3/3, moist) in equal proportions. Most of the Woodburn soils have 10 YR hues in their surface horizons. Some show a greater influence of prairie vegetation than others by a very dark grayish-brown (10 YR 3/2, moist) A horizon extending to a depth of 18 inches or more. The soils with the shallower depths to the fragipan are commonly nearly neutral (pH 6.6-7.0) in the fragipan, while those with the deeper depths to the fragipan are medium acid (pH 5.6-6.0) in the fragipan.

Amity Series

Amity soils are imperfectly drained, medium-textured, Prairie-Gray Brown Podzolic intergrades occurring in association with other members of the Willamette catena in nearly level to slightly undulating positions of the terrace plain. Surface runoff is slower than for Willamette and Woodburn soils, and internal drainage is as slow or slower than for Woodburn soils because of a massive B_3 horizon or fragipan. Amity soils differ from Woodburn soils by a showing evidence of impeded drainage between 12 and 24 inches rather than between 24 to 36 inches. The Concord and Dayton soils show evidence of impeded drainage between 0 and 12 inches and have less permeable B_2 horizons than Amity soils.

The following description of Amity silt loam is from sampling site 75 which was grass wasteland on the top of a nearly level ridge, one and one-half miles wide, between two northeast trending creeks.

A_1 0-8 inches, dark grayish-brown (10 YR 4/2, crushed dry) or very dark brown (10 YR 2/2, moist) silt loam with strong medium and fine granular structure; very friable, slightly sticky and slightly plastic; many fine grass roots; many concretions; strongly acid (pH 5.1); wavy clear boundary. 7 to 9 inches thick.

A_3 8-19 inches, grayish-brown (10 YR 5/2.5, crushed dry) or very dark grayish-brown (10 YR 3/2, moist) silt loam with moderate fine subangular blocky structure; very friable, slightly sticky and slightly plastic; many grass roots; many earthworm holes; numerous concretions that leave rust stain on adjacent soil; strongly acid (pH 5.2). 10 to 12 inches thick.

B_1 19-28 inches, light grayish-brown (0.5 Y 6/2, crushed dry) or dark grayish-brown (10 YR 4/2, moist) silty clay loam with weak medium subangular blocky structure; very friable, slightly sticky and slightly plastic; very porous, many wormholes; numerous concretions that stain the adjacent soil; many roots; strongly acid (pH 5.3); smooth gradual boundary. 8 to 10 inches thick.

B_2 28-38 inches, light grayish-brown (0.5 Y 6/2.5, crushed dry) or dark brown (10 YR 3/3, moist) ped interiors and dark gray (2.5 Y 4/1, moist) thick ped coatings; silty clay loam; the brown interiors are 5 to 10 mm. in diameter, the gray coatings are 3 to 5 mm. thick; weak medium subangular blocky structure; friable, slightly sticky and slightly plastic; very porous, one continuous network of 2 mm. pores; few concretions; few roots; strongly acid (pH 5.5); smooth clear boundary. 9 to 12 inches thick.

B_{3m} 38-48 inches, brown (10 YR 5.5/3, crushed dry) or variegated dark brown (10 YR 3/3, moist) and dark grayish-brown (2.5 Y 4/2) silt loam; massive; firm, slightly sticky and slightly plastic; few large vertical channels with clay flows; few roots; slightly acid (pH 6.5); smooth gradual boundary. 8 to 10 inches thick.

C 48 inches + , brown (10 YR 5/3, crushed dry) or very dark brown (10 YR 3.5/2, moist) silt loam; massive; friable, slightly sticky and slightly plastic; mica conspicuous; water table at 55 inches; neutral (pH 6.7).

Range of characteristics. The depth to evidence of impeded drainage ranges from 12 to 24 inches. Depth to the fragipan (B_{3m}) ranges from 26 to 44 inches. There is no known algebraic relationship between the depth to evidence of impeded drainage and the depth to the fragipan. However, the soils with depths to fragipans of 36 inches or greater have B_2 horizons that express a greater degree of restricted drainage than the soils with shallower depths to fragipan. The B_2 horizon of the soils with the deeper fragipans are usually over 50 per cent dark grayish-brown (2.5 Y 4/2, moist), while the others are over 50 per cent dark brown (10 YR 3/3, moist). The range of thickness of the B_2 horizon is from 7 to 20 inches. Soils having the thicker B_2 horizons generally are deeper to the fragipan horizon. Amity soils, with the shallower depths to mottling, also have higher Munsell values (are lighter colored) in the A_3 horizon than the others.

Concord Series

The Concord series consists of poorly drained, medium-textured, Low Humic-Gley soils associated with the other members of the Willamette catena in nearly level to level positions of the terrace plain. Both surface runoff and internal drainage are very slow. The internal drainage is restricted by both a slowly permeable B_2 horizon and a massive B_3 horizon or fragipan. Concord soils differ from Amity soils by being mottled between 0 to 12 inches from the surface (as opposed to 12 to 24 inches for Amity soils) and by having heavier textured B_2 horizons and lighter colored A_3 and B_2 horizons. Concord soils differ from Dayton soils by not having distinct claypans and by being slightly browner in the A horizons.

The following description of Concord silt loam is from sampling site 33, which was a cultivated field on a level plain nearly one mile from the nearest natural drainageway.

A_p 0-10 inches, dark grayish-brown (10 YR 4.5/2.5, crushed dry) or very dark brown (10 YR 2/2, moist) silt loam with moderate fine and very fine granular structure; very friable, slightly sticky and slightly plastic; many grain roots; few concretions; few worm holes; strongly acid (pH 5.2); smooth abrupt boundary. 9 to 10 inches thick.

A_3 10-19 inches, pale brown (10 YR 5.5/3, crushed dry) or dark grayish-brown (10 YR 4/2, moist) silt loam with weak fine subangular blocky structure; very friable, slightly sticky and slightly plastic; numerous concretions that stain the adjacent soil material; very porous, many worm holes; many roots; strongly acid (pH 5.2); smooth clear boundary. 9 to 10 inches thick.

B_1 19-29 inches, light brownish-gray (1 Y 6.5/2, crushed dry) or dark brownish-gray (2.5 Y 4/2, moist) silty clay loam with common fine faint mottles of brown (2.5 Y 4/4); weak medium subangular blocky structure; friable, sticky, and plastic; very porous, many worm holes; many roots; few concretions; strongly acid (pH 5.5); smooth gradual boundary. 9 to 12 inches thick.

B_2 29-39 inches, pale brown (10 YR 6/3, crushed dry) or dark brown (10 YR 3/3, moist) ped interiors and dark grayish-brown (10 YR 4/2, moist) ped coatings; silty clay loam; weak medium subangular blocky structure; firm ped interiors, very friable ped coats, sticky, and plastic; common fine pores in peds; few roots; medium acid (pH 5.8); smooth abrupt boundary. 9 to 10 inches thick.

B_3 39-48 inches, pale brown (10 YR 6/3, crushed dry) or variegated very dark grayish-brown (10 YR 3/2, moist) and dark grayish-brown (10 YR 4/2, moist) silt loam with weak very coarse prismatic structure; very firm, slightly sticky, and slightly plastic; many worm holes with clay flows; few roots; neutral (pH 6.6); smooth clear boundary. 9 to 10 inches thick.

C_1 48 inches + , not described; ground water standing at 45 inches.

Range of characteristics. The depth to evidence of impeded drainage ranges from 0 to 12 inches. Depth to the fragipan ranges from 30 to 49 inches. Thickness of the B_2 horizon ranges from 8 to 21 inches. The soils with the thickest B_2 horizons are the ones with the deepest fragipans. The texture of the B_2 ranges from a heavy silt loam to a heavy silty clay loam. The color of the surface soil of the Concord soils ranges from very dark brown (10 YR 2/2, moist) to dark gray (10 YR 4/1, moist). The grayer soils are the ones showing evidence of impeded drainage at the shallower depths (0 to 6 inches). The proportion of the gray ped coating material in the B_2 horizon ranges from 50 to 90 per cent of the total material.

Dayton Series

Dayton soils are poorly drained, medium-textured, Planosols associated with the other members of the Willamette catena in level and slightly depressional portions of the terrace plain. Their surface runoff is slow or ponded and their subsoil permeability is very slow because of a dense claypan and a massive fragipan below the claypan. Dayton soils are distinguished from Concord soils by the presence of a heavy silty clay loam to clay-textured claypan (B_2 horizon) that has an abrupt upper horizon boundary with the overlying A_2 horizon. The B_2 horizons of the Dayton soils are also devoid of dark brown (10 YR 3/3, moist) ped interiors, but have, instead, 2 to 5 mm. horizontal bands of alternating dark yellowish-brown (10 YR 3/4, moist) and gray (2.5 Y 5/1, moist).

The following description of Dayton silt loam is from sampling site 37, which was a cultivated field with no slope more than one and one-half miles from the nearest natural drainageway.

A_p 0-8 inches, brown (10 YR 5/3, crushed dry) or very dark grayish-brown (10 YR 3/2, moist) silt loam with moderate medium granular structure; friable, slightly sticky, and slightly plastic; many grain roots; many concretions; very strongly acid (pH 4.8); smooth abrupt boundary. 7 to 8 inches thick.

A_{21} 8-14 inches, light brownish-gray (0.5 Y 6/2, crushed dry) or dark gray (10 YR 4/1, moist) silt loam with weak medium subangular blocky structure; very friable, slightly sticky, and slightly plastic; very porous, many worm holes; numerous concretions that stain the adjacent soil material; many roots; strongly acid (pH 5.2); smooth clear boundary. 6 to 7 inches thick.

A_{22} 14-19 inches, light grayish-brown (10 YR 6.5/2, crushed dry) or gray (2.5 Y 5/1, moist) silt loam with weak subangular blocky structure; friable, sticky, and plastic; many worm holes; many roots; few concretions; medium acid (pH 5.6); smooth abrupt boundary. 5 to 6 inches thick.

B_2 19-29 inches, pale brown (10 YR 6/3, crushed dry) or dark grayish-brown (2.5 Y 4/2, moist) and dark yellowish-brown (10 YR 4/4, moist) in alternating horizontal bands; clay; moderate medium prismatic breaking to moderate coarse angular blocky structure; firm, very sticky, and very plastic; common fine pores in peds; few roots; neutral (pH 6.6); smooth abrupt boundary. 9 to 11 inches thick.

B_{3m} 29-45 inches, brown (10 YR 5.5/3, crushed dry) or very dark grayish brown (10 YR 3/2, moist) silt loam with weak very coarse platy structure; very firm, slightly sticky, and slightly plastic; few large vertical channels, many smaller pores; channels and pores circumscribed with 1 mm. rings of dark grayish-brown (10 YR 4/2, moist) and dark yellowish-brown (10 YR 4/4, moist); neutral (pH 7.0); smooth gradual boundary. 15 to 18 inches thick.

C 45 inches + , not described; ground water standing at 42 inches.

Range of characteristics. The Dayton soils range from 0 to 12 inches to the depth of evidence of impeded drainage. They range from 12 to 31 inches to the depth of the claypan, and from 28 to 40 inches to the depth of the fragipan. The surface horizons of the Dayton soils with the deeper claypans are browner (10 YR 3/2, moist) than the surface horizons of those with the shallower claypans (10 YR 4/1 - 4/2, moist). The texture of the claypan ranges from heavy silty clay loam to clay. The clay content is not related to the depth of the claypan.

METHODS

Field Procedure

The field work consisted of describing and sampling one soil individual at each of 114 locations. The sampling excavations were dug for the construction of footings for power-line towers and were spaced approximately 880 feet or one-sixth mile apart. Sampling began at the southernmost site (Figure 1) and continued progressively northward. Concurrent construction of the towers and filling of the excavations in the same orderly manner as the sampling rendered a less systematic procedure impossible. Although the sampling was obviously systematic, data from this study were treated as if the sampling had been completely random. This is justifiable if we assume a random deposition of the Willamette silts and a nonsystematic soils pattern, because the excavations were made without regard to topography or soil series.

Each site had four footing excavations with approximate dimensions of 4 feet wide by 8 feet long by 5 feet deep. One excavation was randomly selected for sampling at each site by drawing from four cards respectively marked with the cardinal compass directions. A vertical section, 3 feet wide, was freshly exposed in the midsection of one side of the selected pit. The side chosen was generally opposite the spoil pile because it was the least disturbed at the surface.

The soil profile and its environment was described according to the standards and conventions of the Soil Survey Manual (43, p. 133-141). Two-quart, disturbed samples were taken from each horizon and contained in wax-lined, paper bags. The samples were air dried in the laboratory, crushed, passed through a 2 mm. sieve and stored.

Laboratory Procedures

Chemical analysis. Cation exchange capacity; exchangeable calcium, magnesium, potassium and sodium; and pH were determined in duplicate for all horizons. Organic carbon and total nitrogen were determined in duplicate for the upper two horizons of each profile.

Cation exchange capacity. Cation exchange capacity was determined by the ammonium acetate method of Schollenberger and Simon (39, p. 14-18; and 1, p. 3-4). The soils were not initially leached for removal of soluble salts, nor were corrections made for dissolved carbonates.

Exchangeable calcium, magnesium, potassium and sodium. Exchangeable calcium, magnesium, potassium and sodium were determined independently on the ammonium acetate filtrate of the exchange capacity determination with a Beckman model B flame photometer (1, p. 3).

Soil reaction. Soil reaction, expressed as pH units, was determined with a Beckman model N pH meter using a glass electrode on a 1:1 by weight soil-water paste (1, p. 1).

Organic carbon. Organic carbon was determined by the Walkley-Black potassium dichromate method (45, p. 36-37). Ferroin or O-Phenanthroline ferrous sulfate complex was used as the indicator instead of diphenylamine (1, p. 4-5). The method was assumed to recover 76 per cent of the organic carbon.

Total nitrogen. Total nitrogen was determined by the Kjeldahl method (1, p. 5-6).

Physical analysis. Particle size distribution of the B_2 horizon of each individual was determined. Dry crushed color was determined for all horizons.

Mechanical analysis. Particle size distribution was determined in duplicate by a modification of the Kilmer and Alexander method (28, p. 15-24). Soluble salts were not removed since preliminary trials gave comparable amounts of sand, silt, and clay whether salts were removed or not. Mechanical dispersion was accomplished by forcing air under 30 pounds of pressure through the suspension for five minutes. The material remaining on the 300-mesh sieve, after washing to remove the silt and clay, was not fractionated by dry sieving.

<u>Crushed dry color</u>. Hue, value, and chroma were determined by comparing dry crushed soil samples with Munsell soil color charts under artificial light. The light source was composed of two 18-inch, 15-watt, warm-white, deluxe fluorescent tubes in a floating fixture lamp. Readings were made with the tubes 5 inches above the sample. The sample was spread on a table and the color chart, with holes between adjoining color chips, was placed over the sample. Color chips appearing to most nearly match the soil were segregated for closer examination, and others were masked by a suitable card with four holes spaced and shaped like the chips on the charts.

Estimates of value and chroma not matching a particular chip were made by interpolation. Each unit interval of value and chroma was divided into four segments. Value and chroma were designated by the conventional whole numbers where matching was very close--that is, 4/3. If either value or chroma was estimated to be midway between chips, the rating was designated by the appropriate decimal figure--that is, 4.5/3. Whole numbers were suffixed with a plus (+) symbol or with a minus (-) symbol if the estimated rating was greater or less than the whole number by less than a half interval--that is, 4/3 + and 5-/3. The plus and negative signs were converted to the decimals 0.25 and 0.75, respectively, for the statistical analysis.

Interpolations of hue were made by dividing the interval between hue charts into three segments. For example, the interval between hues 10 YR and 2.5 Y was divided into three segments with centers of 10 YR, 1 Y, 2 Y, and 2.5 Y.

Dry colors were determined twice, with two independent, random sequences of examination. Complete agreement of the three characteristics (hue, value, and chroma) in combination was achieved 188 out of 585 times, or 32 per cent of the time. The percentages of precision for individual color characteristics were as follows: hue, 91 per cent; value, 54.9 per cent; chroma, 56.1 per cent. The degree of departure between duplicate readings for all nonagreeing hue measurements was 1.0 unit--that is, 10 YR and 1 Y. The mean of the duplicate hue examinations was used for the statistical analysis. Value and chroma duplicate readings disagreed by 0.25 units 96.2 and 95.3 per cent, and by 0.5 units 3.8 and 4.7 per cent of the times of disagreement, respectively.

These data indicate that value and chroma of dry crushed soil can be reliably estimated within limits of 0.25 units and hue within limits of 1.0 unit. The comparably high degree of precision (91.3 per cent) achieved for the hue determination was due to a relatively smaller variability of hue than of value and chroma. Hue differed from 10 YR only 104 out of 585 times. Of the 104 departures from the 10 YR hue, only 49 or 51 per cent were read the same for the duplicate determinations.

Classifying the Individuals into Series

The soil individuals were tentatively classified into five series at the time of sampling according to current concepts of the National Cooperative Soil Survey (48, p. 39-41, 53-58, 60-61, and 70-71). Individuals appearing to have characteristics intermediate of two series were indicated as "intergrades." Definite classification was required for statistical analysis of the analytical data. The differentiating characteristics used for the final classification were: (1) presence or absence of either a claypan or a fragipan, (2) depth to evidence of impeded drainage, (3) degree of expression of impeded drainage, and (4) depth to the pan, or to the C horizon if there was no pan. These characteristics were selected because they were assumed to show a relationship to the natural drainage conditions under which the soils had developed. These soils are, after all, from one catena and differ in morphology because of differences in ground-water conditions.

Classification of the individuals into the five series was accomplished by listing the individuals according to the selected characteristics as shown in Table 1. Kind of pan horizon was deemed to be of primary importance for differentiation; depth to evidence of impeded drainage of secondary importance; degree of expression of impeded drainage of tertiary importance; and depth to pan horizon of quartenary importance. Series distinctions were made by assigning definitive limits for the presence of a fragipan or claypan, the depth to evidence of impeded drainage, and the degree of expression of the evidence of impeded drainage.

The fragipan was a very compact, silty horizon underlying the B_2 horizon. It was either massive or had weakly developed, very coarse blocky or prismatic structure. The claypan was a compact clayey horizon separated abruptly from the overlying horizon. It had compound structure of moderately developed coarse prismatic aggregates which were divisible into moderately developed, coarse angular blocky aggregates. Soils with a claypan were placed in the Dayton series. Soils with a fragipan were placed in any of the other four series. Soils without a pan were placed in the Willamette series.

Evidence of impeded drainage was manifested by either a mottled color pattern or by a matrix color that was decidedly grayer than that of the better drained soils. Colors appearing in mottled zones consisted of characteristic amounts and patterns of grayish-brown and yellowish-brown soil material in a matrix of dark brown or brown. Horizons with the grayer matrix colors had a value of four or greater and a chroma of two or less. Scaler limits of the depth to evidence of impeded drainage for the series were: depths of 36 inches or more for Willamette; depths of 24 through 35 inches for Woodburn; depths of 12 through 23 inches for Amity; and depths of 0 through 11 inches for Concord and Dayton.

The degree of expression of impeded drainage was manifested by relative amounts of gray and yellowish-brown material and by the intensity of the gray colors. Scrutiny of the profile descriptions showed it was convenient to group color characteristics manifesting degree of impeded drainage into seven classes. A description of these classes follows. Munsell color notations are for moist soil.

Class 1. No evidence of restricted drainage. Only five of the Willamette profiles were in this class.

Class 2. Concentric mottling around cylindrical pores and channels. Vertical and horizontal channels from less than 1 mm. to greater than 3 cm. were surrounded by concentric rings of gray and yellowish-brown. The inner ring was gray (10 YR 4/2 to 2.5 Y 5/2) and the outer ring was yellowish-brown (10 YR 5/6 to 5/8). The bands of each were from 1 to 5 mm. thick. Distance between channels varied from less than 1 inch to greater than 1 foot. This kind of mottling was normally found in the B_3 and C horizons of Willamette and Woodburn profiles, but was observed in the B_2 horizon of Woodburn and in the B_3 of Amity in a few cases.

Class 3. Variegated browns and grays in about equal proportions. Nearly equal amounts of dark brown (10 YR 3/3) and dark grayish-brown to grayish-brown (2.5 Y 4/2 to 5/2) soil material were disseminated in a random manner. Mottles ranged from 5 to 15 mm., had no definite shape, and were often interconnected. This pattern was found in the B_3 horizon of Amity, Concord, and Dayton profiles. This class was not used to differentiate between soil series since color patterns of upper horizons were more diagnostic for differentiating purposes.

Class 4. Gray coatings on blocky ped surfaces. Dark grayish-brown to grayish-brown (10 YR 4/2 to 2.5 Y 5/2) silty material surrounded dark brown (10 YR 3/3) ped interiors. The coatings were from 1 mm. to 1 cm. thick and the gray material comprised from 10 per cent to 90 per cent of the total soil volume. This color pattern was observed in the B_2 horizons of Woodburn, Amity, and Concord profiles. Soils with greater than 50 per cent gray material normally had a uniformly gray A_2 or B_1 horizon and were classified in the Concord series.

Class 5. Gray matrix colors with a 10 YR hue. The soil material of these horizons was dark grayish-brown (4/2) to dark gray (4/1) with a 10 YR hue. A moderate number of medium-sized yellowish-brown mottles were commonly present. Horizons normally exhibiting this color pattern were: B_1 of Amity, A_3 of Concord, and A_1 of Dayton.

Class 6. Gray matrix colors with a 2.5 Y or yellower hue. This color pattern had value and chroma characteristics and mottles similar to class 5, but the hue was less brown. Horizons with this color pattern were: B_1 of Amity, A_2 and B_1 of Concord, and A_2 and B_2 of Dayton.

Class 7. Horizontally banded grays and browns. Alternating horizontal bands from 2 to 5 mm. thick of dark yellowish-brown (10 YR 4/4) and grayish-brown (2.5 Y 5/2) occurred within the blocky peds of the B_2 horizon of Dayton. The gray color predominated, comprising from 60 to 90 per cent of the volume.

Rust-colored stains on the soil material adjacent to spherical 1 to 5 mm. concretions were present in the A horizon of many of the individuals throughout the range of drainage as judged by the color characteristics above. Therefore, they were not considered diagnostic of the degree of restricted drainage.

Table 1 contains a listing of the individuals within each of the five soil series. Individuals are listed in the order of increasing degree of impeded drainage within each series. The Willamette, Woodburn, and Amity series were considered to correspond, respectively, to the good, moderately good, and imperfect natural drainage classes (43, p. 169-172). The series, Concord and Dayton, were considered to correspond to the poor natural drainage class.

Table 2 compares the placement of individuals in the five series according to the final classification and the tentative field classification.

The divergence between field and final classification of Willamette individuals is explained by a change in the definition of the depth to evidence of impeded drainage for the two classifications. For the field classification, soil individuals were classified Willamette only if they showed no evidence of restricted drainage above 42 inches, while for the final classification, the depth limit was 36 inches. This alteration was arbitrarily made because it made convenient the division of the depth to evidence of impeded drainage into uniform 12-inch intervals to a depth of 36 inches. Misclassification in the field for individuals within series, other than Willamette, was generally due to the weight given to the degree of evidence of impeded drainage in horizons below those showing first evidence of impeded drainage. In the field, if the lower horizon appeared to express a greater degree of impeded drainage than was assumed "normal" for the specific series, the individual was placed in the series corresponding to a wetter drainage class. If this horizon appeared to have drainage characteristics expressing a lesser degree of impeded drainage than was assumed "normal" for the specific series, the individual was placed in the series corresponding to a better drained class.

Table 1. Drainage Sequences of All Individuals within Soil Series

Rank	Sample site no.	Inches to evidence of impeded drainage	Degree of expression of impeded drainage[1]	Inches to pan or C horizon
I. Soils without a pan				
A. Willamette series				
1	116	?	0	70
2	4	?	0	67
3	115	?	0	55
4	13	?	0	54
5	14	?	0	53
II. Soils with a fragipan				
A. Willamette series				
6	88	50	C.M.[2]	35
7	93	47	"	47
8	96	43	"	43
9	12	41	"	41
10	3	40	"	40
11	1	39	"	47
12	97	39	"	39
13	11	39	"	39
14	91	38	"	38
15	10	38	"	38
16	95	37	"	37
17	5	37	"	37
18	110	36	"	36
19	9	36	"	36
B. Woodburn series				
20	107	35	"	35
21	84	34	"	34
22	90	32	"	32
23	92	31	"	31
24	94	30	"	30
25	65	30	"	30
26	15	29	"	45
27	69	29	"	38
28	60	29	"	29
29	86	28	"	38
30	64	28	"	28
31	20	28	P.C.[3]	36
32	63	28	"	28
33	87	27	C.M.	27

Table 1 cont.

Rank	Sample site no.	Inches to evidence of impeded drainage	Degree of expression of impeded drainage[1]	Inches to pan or C horizon
B.	Woodburn series cont.			
34	58	27	P.C.	27
35	59	26	P.C.	26
36	29	25	C.M.	25
37	103	25	P.C.	37
38	8	24	"	44
39	72	24	"	40
C.	Amity series			
40	66	23	P.C.	33
41	57	23	"	30
42	6	22	"	36
43	17	21	"	41
44	98	20	C.M.	35
45	109	20	"	31
46	117	20	P.C.	33
47	119	20	"	31
48	82	20	U.G.1[4]	42
49	112	20	"	38
50	7	19	P.C.	44
51	106	19	"	35
52	85	19	"	33
53	114	19	"	33
54	16	19	U.G.1	41
55	75	19	"	38
56	25	18	P.C.	37
57	81	18	"	30
58	111	18	U.G.1	40
59	76	18	"	38
60	101	17	P.C.	43
61	26	17	"	36
62	104	17	"	31
63	74	17	"	30
64	118	17	"	29
65	113	16	"	39
66	68	16	"	33
67	83	16	"	32
68	105	16	"	30
69	30	16	"	29
70	78	16	U.G.1	36

Table 1 cont.

Rank	Sample site no.	Inches to evidence of impeded drainage	Degree of expression of impeded drainage[1]	Inches to pan or C horizon
C.	Amity series cont.			
71	73	16	U.G.1	35
72	71	16	"	31
73	108	15	P.C.	28
74	61	15	"	26
75	100	14	"	36
76	102	13	"	31
77	70	13	"	28
D.	Concord series			
78	77	11	U.G.1	35
79	33	10	"	39
80	34	9	"	39
81	47	9	"	31
82	67	8	"	49
83	19	8	"	43
84	31	8	"	36
85	36	8	"	34
86	28	8	"	32
87	80	8	"	31
88	79	8	"	30
89	35	7	"	37
90	33	7	"	33
91	45	0	"	38
92	46	0	"	34
93	41	0	"	33
III.	Soils with a claypan A. Dayton series			
94	23	10	U.G.1	29
95	24	10	"	28
96	22	9	U.G.2[5]	25
97	21	8	U.G.1	26
98	37	8	"	20
99	55	8	"	17
100	53	8	"	12
101	48	8	U.G.2	12
102	18	7	U.G.1	31
103	56	7	"	20
104	52	7	"	12
105	51	6	"	16

Table 1 cont.

Rank	Sample site no.	Inches to evidence of impeded drainage	Degree of expression of impeded drainage[1]	Inches to pan or C horizon
A. Dayton series cont.				
106	43	0	U.G.1	19
107	38	0	"	18
108	39	0	"	18
109	40	0	"	18
110	42	0	"	17
111	44	0	"	17
112	99	0	"	16
113	49	0	"	14
114	120	0	"	13

[1]For uppermost zone showing evidence of impeded drainage.

[2]Mottling circumscribing cylindrical channels.

[3]Gray ped coatings.

[4]Uniform gray colors with 10 YR hue.

[5]Uniform gray colors with 2.5 Y hue.

Table 2. A Comparison of the Tentative Field Classification and the Final Laboratory Classification

Final classification		Tentative field classification							
Series	No.	Wi	Wo	Wo-Am[1]	Am	Am-Co[1]	Co	Co-Da[1]	Da
Wi	19	8	11						
Wo	20		15	3	2				
Am	38		1	1	33	2	1		
Co	16					2	11	3	
Da	21							5	16

[1]Intergrades

Statistical Analysis

The data were analyzed statistically to determine the presence or absence of natural groups in the population of soils and to determine the significance of mean value differences between predetermined soil series for the various characteristics.

Significance of the mean value differences between pairs of soil series was tested by the Student t-test (30, p. 87-99 and p. 127-128). The statistic t was calculated according to

$$t = \frac{(\bar{y}_1 - \bar{y}_2)}{\sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad \text{with } (n_1 + n_2 - 2) \text{ degrees of freedom}$$

where $\bar{y}_1$ and $\bar{y}_2$ = means of samples 1 and 2.

s_p^2 = pooled estimate of population variance,

and n_1 and n_2 = number of observations in samples 1 and 2.

Whenever minima in the frequency distribution of all individuals combined were suggested, they were tested by the individual degree of freedom test for goodness of fit (30, p. 435-436). The test was calculated according to

$$\chi^2 = \frac{(M_1f_1 + M_2f_2 + M_3f_3)^2}{n(M_1^2\pi_1 + M_2^2\pi_2 + M_3^2\pi_3)}$$

where

M = the multipliers - 1, + 2, and - 1, respectively,

f = the observed frequencies within categories,

n = the number of observations,

and π = the relative frequency within categories (0.33).

Selected characteristics that had significantly different mean values between series were analyzed collectively by means of discriminant functions. Discriminant functions provide a means of determining the joint differentiating abilities of several characteristics in combination. Computational procedures used for discriminant function analysis will be discussed in a later section along with the results of the analysis.

RESULTS AND DISCUSSION

Depth to Evidence of Impeded Drainage

Depth to evidence of impeded drainage was the depth of the uppermost point in the soil profile manifesting either a mottled color pattern or a matrix color that was decidedly grayer than that of the better drained soils. It was the differentiating characteristic used to classify the individuals into the Willamette, Woodburn, Amity, and Concord series after the Dayton individuals had been differentiated according to the presence of a claypan. The depth intervals arbitrarily assigned to the series were 0 to 12 inches for both the Concord and Dayton series, 12 to 24 inches for the Amity series, 24 to 36 inches for the Woodburn series, and 36 to 60 inches for the Willamette series. Five of the Willamette individuals did not show any sign of impeded drainage within the depth of the sampling excavation. These were assigned the value, 60 inches, for the sake of convenience in making calculations.

The frequency distributions of this characteristic for the five series and for the total depth interval of 60 inches are listed in Table 3 and plotted in Figure 2. The Concord and Dayton individuals listed in the 0 to 2 inch interval were mottled at the surface, or at zero depth.

Table 3. Frequency Distributions for Depth to Evidence of Impeded Drainage

Depth (inches)	Will.	Wood.	Amity	Concord	Dayton	Total
0-2				3	9	12
2-4				0	0	0
4-6				0	0	0
6-8				2	4	6
8-10				9	6	15
10-12				2	2	4
12-14			2			2
14-16			3			3
16-18			13			13
18-20			10			10
20-22			7			7
22-24			3			3
24-26		4				4
26-28		3				3
28-30		7				7
30-32		3				3
32-34		1				1
34-36		2				2
36-38	4					4
38-40	5					5
40-42	2					2
42-44	1					1
44-46	0					0
46-48	1					1
48-50	0					0
50-52	1					1
52+	5					5

The absence of individuals in the depth interval between 1 and 6 inches is the result of disturbance in this depth range by plowing. Plow layers were either mottled throughout or completely unmottled depending, presumably, on the depth to mottles in the virgin state and the tendency for regeneration of mottles after plowing.

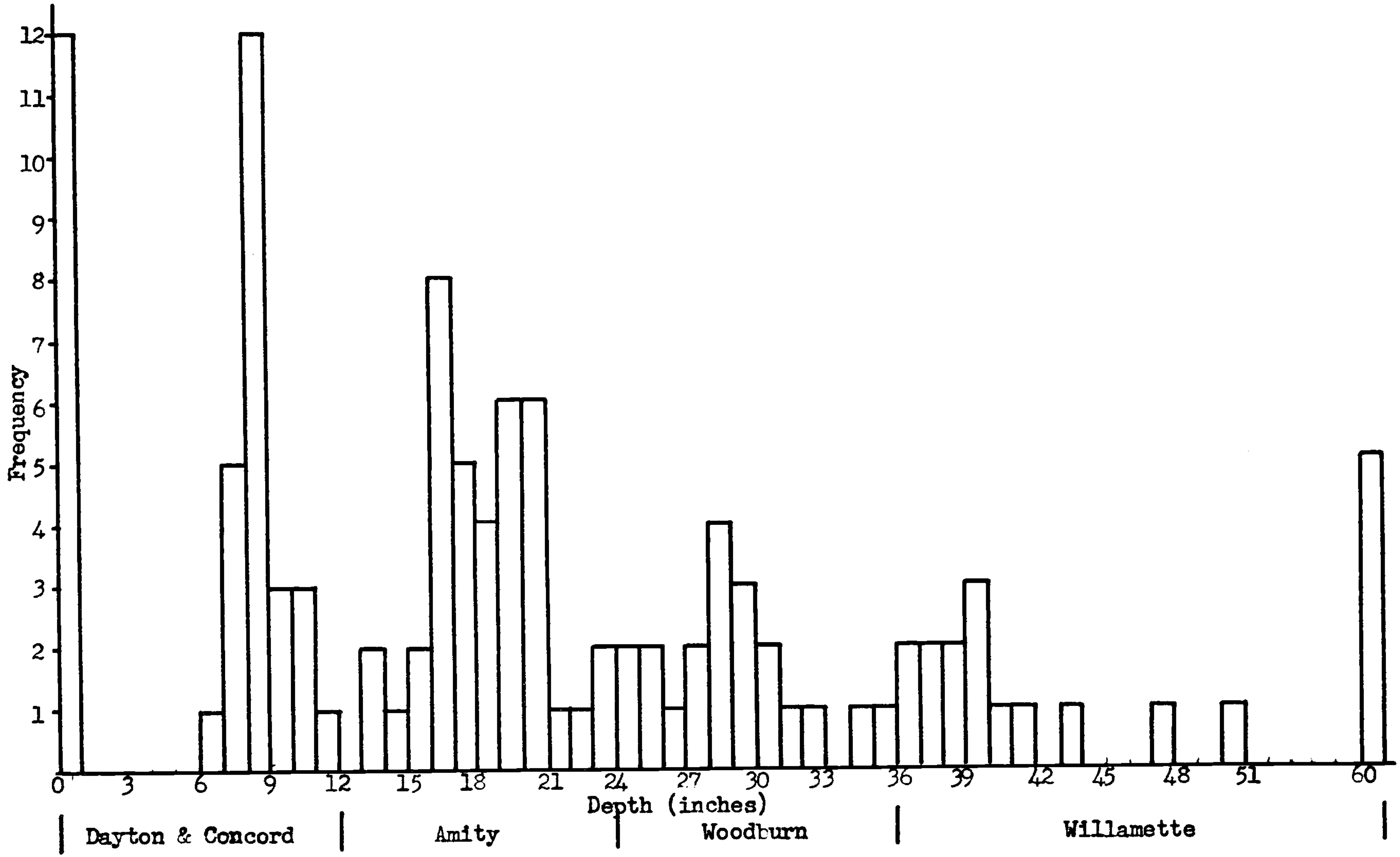

Figure 2. Frequency histogram for the depth to evidence of impeded drainage of the observations of the five soil series of the Willamette catena.

Table 4. Sample Statistics for Depth to Evidence of Impeded Drainage

Series	No. of obs.	Mean (inches)	Dif. bet. means	Standard deviation	Range
Wi	19	45.3[1]	16.9[2]	9.7	24.0
Wo	20	28.4	10.6[2]	3.0	12.0
Am	38	17.8	11.0[2]	2.6	12.0
Co	16	6.8	2.2	3.5	12.0
Da	21	4.6		4.2	12.0
All	114	20.3		14.6	60.0

[1]Depths to mottling beyond depth of sampling were designated 60 inches.

[2]Significant difference at 1-per cent level.

Natural groupings are suggested by apparent minima at 12, 22, and 33 inches in the frequency distribution histogram. These minima were tested for significance by the individual degree of freedom goodness of fit test. The results of the test are presented in Table 5. The hypothesis was that the theoretical frequency was the same in the minimal segments of the distribution as it was in the surrounding maximal segments. The 4-inch minimal segment between 10 and 14 inches was significant at the 1-per cent level, and the minimal segments between 21 and 25 and between 32 and 36 inches were significant at the 5-per cent level.

On the basis of this evidence, one might surmise that natural groupings do occur among the Willamette catena soils according to depth of evidence of impeded drainage. The minimum at 12 inches coincides exactly with the

Table 5. Observed (f) and Hypothetic (h) Frequencies and Chi-square Values for the Individual Degree of Freedom Goodness of Fit Test for Several Intervals of the Depth to Evidence of Impeded Drainage Distribution for All Individuals Combined

Interval (inches)	h	f	Explanation
6-10	16.7	21.0	Max. for Co & Da sample
10-14	16.7	6.0	Min. bet. Am & Co+ Da
16-20	16.7	23.0	Max. for Am sample
Sum	50.0	50.0	
Chi-square		10.24*	
16-20	13.3	23.0	Max. for Am sample
21-25	13.3	6.0	Min. bet. Am & Wo
27-31	13.3	11.0	Max. for Wo sample
Sum	40.0	40.0	
Chi-square		6.05**	
27-31	7.6	11.0	Max. for Wo sample
32-36	7.6	3.0	Min. bet. Wo & Wi
36-40	7.6	9.0	Max. for Wi sample
Sum	23.0	23.0	
Chi-square		4.25**	

* Significant minima at 1-per cent level.
**Significant minima at 5-per cent level.

arbitrary depth limit used to differentiate between the poor and imperfect natural drainage classes. The minima at 22 and 33 inches almost agree with the arbitrary depth limits of 24 and 36 inches used to differentiate between the imperfectly drained and the moderately well-drained soils, and between the moderately well-drained and the well-drained soils, respectively. Using the results of this study, it might be advisable to use the depth of 22 inches to evidence of impeded drainage for making the separation between imperfectly drained and moderately well-drained soils and the depth of 33 inches for making the separation between moderately well-drained and well-drained soils in this catena.

The means and other statistics for the depth to evidence of impeded drainage are tabulated in Table 4. The means were 45.3, 28.4, 17.8, 6.8, and 4.6 inches, respectively, for the Willamette, Woodburn, Amity, Concord, and Dayton samples. The difference between the means of the Concord and Dayton samples was not significant. Since all individuals of the other three series were restricted to non-overlapping depth intervals, the difference between their means were, naturally, highly significant. The comparatively large standard deviation of the Willamette sample is a natural result of the greater allowable range of 24 inches for that sample as opposed to a range of 12 inches for the other series samples.

Horizon Thickness

When the individuals were sampled and described, one of the first steps was to mark the limits of the different horizons and to measure them in inches. All of the individuals had four main horizons that were similar in position within the profile, and had somewhat similar characteristics, although they varied considerably in the degree of expression of these characteristics. These horizons were: (1) the A_1 or A_p horizon, (2) the A_2 or A_3 horizon, (3) the B_2 horizon, and (4) the B_3 horizon. The morphological, chemical, and physical characteristics of these horizons were compared among the five series. The thickness of the horizons will be discussed in this section, and the other characteristics will be discussed in subsequent sections.

Table 6 presents the frequency distributions for the thickness of several horizons, and combinations of horizons, for the samples of the Willamette, Woodburn, Amity, Concord, and Dayton series and for all of the individuals combined. The thickness of subdivisions of the A horizon was determined, for most individuals, by the depth of plowing, which did not vary in thickness between soil series. Accordingly, these frequency distributions are not listed. The frequency distributions for thickness of the B_3 horizon are not listed because the lower boundary of the horizon was below water for many of the individuals. The results of the statistical analysis for horizon thickness are listed in Table 7.

The total range of thickness for the total A horizon among all the individuals combined was between 12 and 25 inches, and each series sample had a similar range. The

Table 6. Frequency Distributions for Thickness of Horizons and Combinations of Horizons of the Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Thickness (inches)	Total A						B_2						B_1 & B_2						Total A, B_1 & B_2					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
6-7								2	2		1	5		2				2						
8-9							1	4	1	4	6	16		2			1	3						
10-11							0	3	12	7	1	23		2	4	2	1	9						
12-13	1	3	2	2	5	13	1	5	10	2	1	19		3	6	0	0	9						
14-15	5	1	3	0	2	11	3	3	9	1	1	17	1	3	9	2	3	18						
16-17	5	4	14	8	6	37	5	2	2	0	3	12	2	2	3	2	6	15						
18-19	4	3	10	4	5	26	4	0	1	0	3	8	3	2	6	3	4	18						
20-21	3	6	7	2	3	21	3	1	1	2	4	11	2	1	3	4	5	15						
22-23	1	1	2			4	2				1	3	3	1	5	1	1	11						
24-25		2				2							2	2	1	1		6		1				1
26-27													2		1	0		3		3	1			4
28-29													1			0		1		3	4		3	10
30-31													1			0		1		3	9	3	2	17
32-33													2			1		3		1	6	3	5	15
34-35																			2	2	3	3	5	15
36-37																			4	2	5	2	5	18
38-39																			5	2	4	3	0	14
40-41																			3	1	3	0	1	8
42-43																			1	0	2	1		4
44-45																			0	2	1	0		3
46-47																			2			0		2
48-49																			1			1		2
50-51																			1					1

Table 7. Sample Statistics for Horizon Thickness

Series	No. of obs.	Mean (inches)	Dif. bet. means (inches)	Standard deviation (inches)	Range (inches)
			Total A		
Wi	19	17.3		2.7	10
Wo	20	18.6	-1.3	3.4	13
Am	38	17.7	0.9	2.3	10
Co	16	17.4	0.3	2.2	8
Da	21	16.2	1.2	2.7	8
All	114	17.4		2.7	14
			B_2		
Wi	19	17.1		3.4	14
Wo	20	11.6	5.5*	3.6	14
Am	38	12.5	-0.9	2.7	13
Co	16	11.7		4.0	13
Da	21	14.5		5.2	15
All	114	13.6		4.3	16
			B_1 & B_2		
Wi	19	22.9		5.7	19
Wo	20	14.4	8.5*	5.7	18
Am	38	16.6	-2.2	4.2	16
Co	16	18.6	-2.0	5.2	22
Da	21	17.2	1.4	3.3	13
All	114	17.9		7.7	27
			Total A, B_1, & B_2		
Wi	19	40.3		4.6	15
Wo	20	33.0	7.3*	5.9	20
Am	38	34.3	-1.3	4.6	18
Co	16	36.0	-1.7	5.0	19
Da	21	33.4	2.4	3.2	12
All	114	35.3		5.3	25

*Significant difference at 1-per cent level.

mean thickness of the total A horizon was about 17 inches for each series and for the total population of the Willamette catena soils.

Horizon thickness values of the B_2 horizon ranged from 6 to 25 inches for all individuals combined, and each series' sample, again, had a similar range. However, Willamette's mean B_2 horizon thickness was significantly greater than Woodburn's mean B_2 horizon thickness. The mean thickness of the B_2 horizon of the Willamette sample was 17.1 inches, and the mean thicknesses of the B_2 horizons of the other samples were about 12 inches.

The statistical analysis of the thickness of the B_1 and B_2 horizons combined gave results similar to the analysis of the B_2 horizon. These results were to be expected. Not all individuals had B_1 horizons, but each series had some individuals with B_1 horizons, and the mean thickness of the B_1 horizon was about the same regardless of series. The total thickness of the B_1 and the B_2 horizons ranged from 6 inches to 33 inches in the frequency distribution of all individuals combined. Each of the series had some individuals with a thickness of the B_1 and B_2 horizons combined between 14 and 23 inches. The amount of overlap of the frequency distributions between series was so great that there were no minima in the frequency distribution tabulation of all individuals combined.

Soil profile thickness to the B_3 horizon ranged from 25 inches to 50 inches among all the observations. The mean profile thicknesses were 40.3, 33.0, 34.3, 36.0, and 33.4 inches for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. Willamette's mean was significantly greater than Woodburn's.

<u>Moist Color</u>

Soil color was measured by matching the soil with standard Munsell color charts, which allowed quantitative determination of the three variables--hue, value, and chroma. Each variable was statistically analyzed, independently. Moist colors were determined in the field at the time of sampling. Only one of the colors in multicolored horizons was statistically analyzed. The color of the ped interior is listed for horizons with ped interiors of a different color than the ped coatings. The B_2 horizons of the Amity and Concord observations commonly had this color pattern. Where the colors were arranged in a banded pattern, as in the B_2 horizon of the Dayton soils, the dominant color was used in the analysis.

<u>Hue</u>. The frequency distributions for moist hue of four main horizons of each series are listed in Table 8.

The moist hue of the A_1 or A_p horizon was 10 YR for

107 of the 114 observations. A few of the Willamette and Woodburn individuals had moist hues of 7.5 YR, although the hues may not have been quite that red because hue was not interpolated between hue charts in the field determination of color.

More variation in hue, between and within series' samples, was found in the A_2 or A_3 horizon than in the A_1 or A_p horizon. Three of the Concord individuals and 12 of the Dayton individuals had hues of either 2.5 Y or 5.0 Y. A few of the Willamette, Woodburn, and Amity individuals had hues of 7.5 YR. Still, each of the series' samples had as many or more individuals with a hue of 10 YR as they had observations with other hues.

None of the Dayton individuals had a 10 YR hue in the B_2 horizon, and only two of the Concord individuals had hues in the same range as the Dayton individuals. Furthermore, a minima is suggested in the frequency distribution tabulation of all individuals combined at the hue value 2.5 Y. The hues listed for the B_2 horizon, however, represent but one of two colors for these two series, and the browner of the two colors is listed for the Concord individuals and the grayer of the two colors is listed for the Dayton individuals. Therefore, the minima is more apparent than real.

The B_3 horizon of all individuals had a hue of 10 YR

Table 8. Frequency Distributions for Moist Munsell Hue Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

	A_1 or A_p						A_2 or A_3						B_2 (ped interiors)						B_3					
Hue	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
5.0 YR													1					1						
7.5 YR	3	4				7	5	4	2			11	1	1	1			3						
10.0 YR	16	16	38	16	21	107	14	16	36	13	9	88	17	19	37	14		87	19	20	38	16	21	114
2.5 Y										2	9	11				1	8	9						
5.0 Y										1	3	4				1	13	14						

for the dominant color present. This characteristic is interesting in a curious way because it was the only one studied that had an invariant or discrete distribution for all individuals.

The results of the statistical analysis of moist hue are presented in Table 9. The difference between the means of the hue in the A_1 or A_p horizons of the Woodburn and Amity samples was significant, but the results of the t-test are not valid in this case. The t-test is based on the assumption that the variance of the two populations in question is the same (30, p. 128). Since the variance was 0 for the Amity sample and about 1 for the Woodburn, the results of the t-test are not valid. Obviously, the hue of the A_1 or A_p horizons could not be used to differentiate the soils of the Willamette catena.

The differences between the means of the Amity and Concord samples, and between the Concord and Dayton samples were significant for both the A_2 or A_3 and the B_2 horizons.

__Value__. The frequency distributions for moist value of the four main horizons of the five samples of the Willamette, Woodburn, Amity, Concord, and Dayton series, and for all individuals combined are tabulated in Table 10.

The frequency tabulations for all individuals combined have a polymodal appearance for the upper three horizons. The modes coincide with whole numbered integers of moist

Table 9. Sample Statistics for Moist Munsell Hue Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
		A_1 or A_p			
Wi	19	9.60 YR		0.93	2.5
Wo	20	9.50 YR	0.10	1.02	2.5
Am	38	10.00 YR	-0.50**	0.00	0.0
Co	16	10.00 YR	0.00	0.00	0.0
Da	21	10.00 YR	0.00	0.00	0.0
		A_2 or A_3			
Wi	19	9.34 YR		1.13	2.5
Wo	20	9.50 YR	-0.16	1.02	2.5
Am	38	9.87 YR	-0.37	0.57	2.5
Co	16	0.70 Y	-0.83**	1.45	5.0
Da	21	1.79 Y	-1.09**	1.79	5.0
		B_2 (ped interiors)			
Wi	19	9.60 YR		1.25	5.0
Wo	20	9.88 YR	-0.28	0.56	2.5
Am	38	9.93 YR	-0.05	0.41	2.5
Co	16	0.47 Y	-0.54*	1.36	5.0
Da	21	4.05 Y	-3.58**	1.24	2.5
		B_3			
Wi	19	10.00 YR		0.00	0.0
Wo	20	10.00 YR	0.0	0.00	0.0
Am	38	10.00 YR	0.0	0.00	0.0
Co	16	10.00 YR	0.0	0.00	0.0
Da	21	10.00 YR	0.0	0.00	0.0

* Significant difference at 5-per cent level.
**Significant difference at 1-per cent level.

Table 10. Frequency Distributions for Moist Munsell Value Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

	A_1 or A_p						A_2 or A_3						B_2 (ped interiors)						B_3					
Value	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
2.0	4	8	18	9	2	41		4	8			12												
2.5	1	1	2	1	0	5		1	2			3												
3.0	14	11	18	3	10	56	17	15	28	2		62	19	20	38	14		91	16	19	37	16	21	109
3.5				0	0	0	1			0		1				0		0	2	1	1			4
4.0				3	9	12	1			12	11	24				1	14	15	1					1
4.5										1	1	2				0	2	2						
5.0										1	9	10				1	5	6						

value and the minima coincide with one-half units of moist value. These distribution patterns are the result of an inadequate attempt at interpolation between color standard chips, which are available only for whole units of value and chroma.

Moist color value had a range of only 1 unit for the A horizons of the Willamette, Woodburn, and Amity samples. It ranged from 2.0 to 3.0 in the A_1 or A_p horizons for all three samples. In the A_2 or A_3 horizon, moist value ranged from 3 to 4 for the Willamette sample, and from 2 to 3 for the Woodburn and Amity samples. However, only two of the Willamette individuals had moist values of greater than 3.0 value units. On the other hand, 15 of the Woodburn and Amity individuals had moist values of less than 3.0 value units in the A_2 or A_3 horizon. At the time of sampling, it was noted that some of the Woodburn and Amity individuals had darker colors in the A_3 horizon than others, and it was thought that perhaps these individuals had developed under a more pronounced prairie vegetation type than the others.

All but two of the Concord individuals, and all of the Dayton individuals had moist values of 4.0 or more in the A_2 or A_3 horizon. On the other hand, all but two of the Willamette, Woodburn, and Amity individuals combined had moist values of 3.0 or less in this horizon. Moist value, therefore, almost completely differentiates the individuals into two main groups. However, it is doubtful whether there would be a natural boundary between the two groups, as indicated by a minima in a frequency distribution tabulation or plot, if moist value had been interpolated between chips more precisely than it was.

The frequency distributions of moist value for the B_2 horizon represent only the dominant color of the multi-colored observations. The Dayton individuals appear to be differentiated from most of the other individuals by this characteristic, but, again, there is no absolute minima between the Dayton individuals and the other individuals.

The moist value of the B_3 horizon was only slightly more variable among the individuals than the moist hue. One hundred nine of the 114 individuals had moist values of 3.0 units. Color of this horizon is obviously an inherited characteristic.

Mean moist values and other moist value statistics for the five series are listed in Table 11. The Dayton series had a significantly higher value than the Concord series in the A_1 or A_p horizon. All the differences between means of adjacent pairs of series were significant for the A_2 or A_3 horizon except the difference of 0.1 value units between the means of the Amity and Woodburn samples. Concord's mean was significantly higher than Amity's mean, and

Table 11. Sample Statistics for Moist Munsell Value Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.76		0.42	1.0
Wo	20	2.58	0.18	0.50	1.0
Am	38	2.50	0.08	0.50	1.0
Co	16	2.59	-0.09	0.80	2.0
Da	21	3.33	-0.74**	0.66	2.0
			A_2 or A_3		
Wi	19	3.13		0.24	1.0
Wo	20	2.78	0.35**	0.41	1.0
Am	38	2.79	-0.01	0.15	1.0
Co	16	3.97	-1.18**	0.45	2.0
Da	21	4.45	-0.48**	0.50	1.0
			B_2 (ped interiors)		
Wi	19	3.00		0.00	0.0
Wo	20	3.00	0.00	0.00	0.0
Am	38	3.00	0.00	0.00	0.0
Co	16	3.19	-0.19*	0.54	2.0
Da	21	4.29	-1.10**	0.43	1.0
			B_3		
Wi	19	3.10		0.27	1.0
Wo	20	3.02	0.08	0.11	0.5
Am	38	3.01	0.01	0.09	0.5
Co	16	3.00	0.01	0.00	0.0
Da	21	3.00	0.00	0.00	0.0

* Significant difference at 5-per cent level.
**Significant difference at 1-per cent level.

Dayton's mean was significantly higher than Concord's mean for the B_2 horizon.

The tendency of moist value to change as the degree of impeded drainage increased was in the direction of higher value units as the soil became more poorly drained.

Chroma. Moist chroma had a trend opposite that of moist value as can be seen in the frequency distribution tabulations in Table 12. As the degree of impeded drainage increased, going from Willamette to Dayton, the moist chroma tended to decrease in numerical magnitude. The trend is most noticeable in the tabulations for the B_2 horizon.

Moist chroma had comparatively less variation in the A_1 or A_p horizons for each series sample than it did in the A_2 or A_3 horizons. All the samples had pronounced modal values at 2.0 chroma units in their frequency distributions for the A_1 or A_p horizons. In the A_2 or A_3 horizons, on the other hand, the better drained soils (Willamette, Woodburn, and Amity) had greater numbers of individuals with chromas above 2.0 units than they did in the A_1 or A_p horizons, while the more poorly drained soils (Concord and Dayton) had more individuals with chromas less than 2.0 units than they did in the A_1 or A_p horizons.

The five frequency distributions of the series' samples for the B_2 horizon tend to cover slightly different

Table 12. Frequency Distributions for Moist Munsell Chroma Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

	A_1 or A_p						A_2 or A_3						B_2 (ped interiors)						B_3					
Chroma	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
1.0		1	4	3	3	11		1	5	5	5	16					10	10						
1.5		0	1	0	3	4		0	1	0	0	1					0	0						
2.0	17	18	31	13	15	94	4	7	23	11	16	61			2	2	11	15	4	2	2	2	3	13
2.5	1	0	0			1	1	4	0			5		3	10	1		14	8	6	18	9	4	45
3.0	1	1	2			4	8	6	8			22	8	12	22	12		54	1	10	14	5	14	44
3.5							1	0	0			1	4	2	4	0		10	6	2	3			11
4.0							5	2	1			8	7	3		1		11			1			1

ranges of values, but the amount of overlap between the ranges of adjacent pairs is too great to permit the presence of minima in the frequency distribution tabulation of all individuals combined.

The frequency distributions of the five series' samples for the B_3 horizon all included chroma notations of similar magnitude.

The tendency for chroma to decrease as the degree of impeded drainage increased is clearly shown by the sample means for this characteristic in Table 13. The differences between the means of adjacent series for the A_1 or A_p horizon are admittedly small and none were statistically significant. However, for the A_2 or A_3 and the B_2 horizons, the differences were larger and most were significant.

Within each series, the three moist color variables--hue, value, and chroma--showed variations with depth. The hue of all the horizons of the Willamette, Woodburn, and Amity samples was relatively constant. The A_2 or A_3 and the B_2 horizons of the Concord and Dayton samples were decidedly more yellow in hue than the A_1 or A_p and B_3 horizons of these samples.

Mean moist value increased progressively between the A_1 or A_p and the B_3 horizon for the Willamette, Woodburn, and Amity samples, but the total increase was generally less than 0.5 value units. The Concord and Dayton samples had

Table 13. Sample Statistics for Moist Munsell Chroma Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.08		0.25	1.0
Wo	20	2.00	0.08	0.32	2.0
Am	38	1.93	0.07	0.40	2.0
Co	16	1.81	0.12	0.40	1.0
Da	21	1.79	0.02	0.36	1.0
			A_2 or A_3		
Wi	19	3.05		0.72	2.0
Wo	20	2.55	0.50**	0.72	3.0
Am	38	2.12	0.43**	0.67	3.0
Co	16	1.69	0.43**	0.48	1.0
Da	21	1.76	-0.07	0.44	1.0
			B_2 (ped interiors)		
Wi	19	3.47		0.46	1.0
Wo	20	3.12	0.35**	0.45	1.5
Am	38	2.87	0.25**	0.36	1.5
Co	16	2.91	-0.04	0.45	2.0
Da	21	1.52	1.39*	0.51	1.0
			B_3		
Wi	19	2.89		0.81	1.5
Wo	20	2.80	0.09	0.41	1.5
Am	38	2.80	0.00	0.55	2.0
Co	16	2.59	0.21	0.33	1.0
Da	21	2.76	-0.17	0.37	1.0

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

relatively large mean increases in value (about 1.2 units) between the A_1 or A_p and the A_2 or A_3 horizon, and moderate decreases in value between the A_2 or A_3 and deeper horizons.

Mean moist chroma quantities of the Willamette, Woodburn, and Amity samples had a consistent increasing trend with depth to the B_2 horizon and then a decreasing trend to the B_3 horizon. The Concord sample had a slight decrease in mean chroma between the A_1 or A_p and the A_2 or A_3 horizon and then an increase between the A_2 or A_3 and the B_2 horizon. The mean chroma of the Dayton sample decreased markedly between the A_1 or A_p and the B_2 horizon and increased between the B_2 and the B_3 horizon.

Dry Color

The dry crushed color determinations were considered more reliable than the moist color determinations because (1) they were determined under constant light conditions, (2) they were determined at a constant moisture content (air dry), and (3) they were read more precisely between whole units of chroma and value. Furthermore, crushing and mixing the soil resulted in a uniform color for each horizon which was a blend of the several colors present in multicolored horizons.

Hue. The frequency distributions for dry crushed hue of the four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples and of all individuals combined are presented in Table 14. In each horizon the modal value for the distribution of all individuals combined is 10 YR. In the A_1 or A_p horizons, none of the observations had hue notations more than 0.5 units away from 10 YR.

The hue of the A_2 or A_3 and the B_2 horizons of the Willamette catena soils tends to get more yellow as the soil becomes more poorly drained. However, the range of hue values within each series overlaps with the ranges of hue values of other soil series too much to permit minima in the frequency distribution tabulation of all individuals combined. In the A_2 or A_3 and B_2 horizons, each series included some individuals that had a hue of 10 YR, although this quantity was at the higher end of the ranges of hue values for the Willamette and Woodburn samples and at the opposite end of the range for the Concord and Dayton samples. Therefore, dry crushed hue appears to be a characteristic that varies continuously among soils of the Willamette catena.

The means and other statistics of the dry crushed hue analysis are presented in Table 15. The mean dry hue of the A_1 or A_p horizons was near 10 YR for all five series'

Table 14. Frequency Distributions for Dry Crushed Munsell <u>Hue</u> Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

	A_1 or A_p						A_2 or A_3						B_2						B_3					
Hue	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
8.5 YR							1					1	1					1						
9.0 YR							0	4	1			5	2	1				3		1				1
9.5 YR	1	4	1			6	2	0	2			4	0	0	1			1	1	0				1
10.0 YR	18	16	37	16	18	105	16	16	34	12	5	83	16	19	36	7	5	83	18	19	38	14	17	106
0.5 Y					3	3			1	1	5	7			1	4	6	11				2	2	4
1.0 Y										1	3	4				4	6	10					1	1
1.5 Y										1	0	1				1	1	2					1	1
2.0 Y										0	3	3					0	0						
2.5 Y										1	5	6					3	3						

Table 15. Sample Statistics for Dry Crushed Munsell Hue Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	9.97 YR		0.11	0.5
Wo	20	9.90 YR	0.07	0.20	0.5
Am	38	9.99 YR	-0.09	0.08	0.5
Co	16	10.00 YR	-0.01	0.00	0.0
Da	21	0.07 Y	-0.07	0.18	0.5
All	114	9.99 YR		0.14	1.0
			A_2 or A_3		
Wi	19	9.87 YR		0.37	1.5
Wo	20	9.80 YR	0.07	0.42	1.0
Am	38	9.96 YR	-0.16	0.21	1.5
Co	16	0.34 Y	-0.38**	0.72	2.5
Da	21	1.14 Y	-0.80**	1.00	2.5
All	114	0.02 Y		0.80	4.0
			B_2		
Wi	19	9.82 YR		0.45	1.5
Wo	20	9.95 YR	-0.13	0.22	1.0
Am	38	10.00 YR	-0.05	0.13	1.0
Co	16	0.44 Y	-0.44*	0.51	1.5
Da	21	0.86 Y	-0.42	0.81	2.5
All	114	0.22 Y		0.63	4.0
			B_3		
Wi	19	9.97 YR		0.11	0.5
Wo	20	9.95 YR	0.02	0.22	1.0
Am	38	10.00 YR	-0.05	0.00	0.0
Co	16	0.06 Y	-0.06*	0.11	0.5
Da	21	0.17 Y	-0.11	0.40	1.5
All	114	0.03 Y		0.23	2.5

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

samples. The mean dry hues of the A_3 horizon of the Willamette, Woodburn, and Amity samples were also all about 10 YR. Concord's mean hue of the A_2 or A_3 horizon was significantly more yellow than Amity's mean hue, and Dayton's mean hue of A_2 or A_3 horizon was significantly more yellow than Concord's mean hue. The difference between the means of the Amity and the Concord samples was the only significant difference between adjacent series for the B_2 horizon. The dry hue means of the B_3 horizon of all five samples were near 10 YR.

All of the differences between sample means of adjacent pairs of series had a magnitude of less than 1.0, or less than the common unit of measurement of hue. The interval between hue charts of the standard color book for soils is 2.5 hue units. For practical reasons, the mean difference between the hue of two classes of soils would have to be at least 2.5 hue units before it could be considered as a differentiating characteristic.

Value. Dry crushed value frequency distributions of the four main horizons of each sample and of all individuals combined are presented in Table 16. The frequency distribution tabulation of all individuals combined for the A_1 or A_p horizons has a bimodal appearance with modal values of 4.0 and 5.0. The frequency distributions of the Willamette, Woodburn, and Amity samples have a similar

Table 16. Frequency Distributions for Dry Crushed Munsell Value Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Value	A_1 or A_p						A_2 or A_3						B_2 or B_{22}						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
3.50			1			1																		
3.75	1		2			3			1			1												
4.00	5	7	13	1	1	27	1	2	5			8												
4.25	1	4	4	2	0	11	0	2	3			5												
4.50	1	2	4	1	1	9	1	1	3			5		1	1			2						
4.75	2	3	5	2	1	13	1	4	1	1	1	8	1	0	0			1						
5.00	9	4	7	6	4	30	5	9	10	2	2	28	3	6	9			18						
5.25			1	1	2	4	7	2	7	2	1	19	7	4	4			15						
5.50			1	2	5	8	4		4	4	0	12	6	6	10	2	1	25	5	7	9	1	1	23
5.75				1	4	5			2	2	2	6	2	3	6	0	2	13	8	8	17	5	9	47
6.00					3	3			2	2	2	6			8	11	14	33	6	5	12	9	10	42
6.25										1	3	4				2	4	6				1	1	2
6.50										2	6	8				1		1						
6.75											0	0												
7.00											4	4												

appearance. The most likely explanation for this pattern of distribution is the impracticability of making the scrupulous interpolations that the procedure called for. Interpolations of value and chroma to 0.25 units were attempted in the dry color determination. The fact that the two modes of the frequency distribution of value for the A_1 or A_p horizons coincide with whole numbers indicates that it is not feasible to accurately read the dry value of soil material when it occurs between whole numbers. The mean values of the distributions under discussion were midway between whole numbers. Had the means been in the vicinity of a whole number, the insensitivity of the interpolation method would not have been apparent.

The trend among the frequency distributions of dry value is toward higher quantities as the soil is more poorly drained. The trend is not shown in the B_3 horizon and is not very pronounced in the A_1 or A_p horizons. But in the A_2 or A_3 horizons, four of the Dayton individuals had dry values that were 1.5 units higher than the highest value among the individuals of the Willamette sample. The Dayton individuals ranged in dry value from 4.5 to 7.0 units in the A_2 or A_3 horizon, while the Willamette individuals ranged from 4.0 to 5.5 units. Yet, this characteristic did not completely discriminate the observations of these two widely separated classes because four of the Dayton individuals had dry value notations within the range of notations of the Willamette sample. There could not be a minima in the frequency distribution of all individuals combined for this characteristic because there were three other soil series between the Willamette and Dayton series, each with a wide range of values that overlaps considerably with the ranges of adjacent series.

The frequency distributions of the B_2 horizon also indicate that dry value of this horizon does not differentiate the soils of the Willamette catena into natural groupings. The distributions of the Willamette, Woodburn, and Amity samples all had about the same range of dry value notations, and the Concord and Dayton samples had another common range of notations. The two combined distributions overlapped considerably with one another.

Dry crushed value means are presented in Table 17 along with the differences between means of adjacent pairs of series. The Concord sample had a significantly higher mean dry value than the Amity sample, and the Dayton sample had a significantly higher mean dry value than the Concord sample in the A_1 or A_p and the A_2 or A_3 horizons. Woodburn's mean dry value was significantly less than Willamette's in the A_2 or A_3 horizon. The only significant difference between the means for the B_2 horizon was the one between the Amity and Concord samples. All five of the means for dry value of the B_3 horizon were between 5.68 and 5.84 units, which is a small range when compared to the unit of measurement.

The mean dry values for the Woodburn and Amity samples were less than the mean dry values of the Willamette sample for both subdivisions of the A horizon. This is a reversal of the usual trend for value as related to the degree of impeded drainage. The reason for this anomaly is possibly related to differences in the native vegetation types between some of the Willamette and Woodburn or Amity individuals. Several of the Willamette individuals had comparatively light-colored A horizons that were suggestive of a native forest vegetation, while several of the Woodburn and Amity individuals had comparatively dark A horizons that were suggestive of a native prairie vegetation.

These data show that dry value does not segregate the soils of the Willamette catena into natural groupings. Although the means of dry value were significantly different between some of the adjacent pairs of series, the magnitude of the difference was always less than the total range of dry value units within each sample. Subsequently, the overlap of the ranges between series' samples was so great that minima did not appear in the frequency distribution of all individuals combined.

Table 17. Sample Statistics for Dry Crushed Munsell Value Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	4.54		0.48	1.38
Wo	20	4.36	0.18	0.41	1.12
Am	38	4.36	0.00	0.49	2.12
Co	16	4.93	-0.57*	0.49	1.75
Da	21	5.27	-0.34**	0.51	2.00
All	114	4.69		0.60	2.62
			A_2 or A_3		
Wi	19	5.04		0.37	1.50
Wo	20	4.74	0.30**	0.39	1.25
Am	38	4.86	-0.12	0.60	2.38
Co	16	5.61	-0.75*	0.49	1.88
Da	21	6.10	-0.51**	0.63	2.25
All	114	5.24		0.70	3.38
			B_2		
Wi	19	5.25		0.27	1.00
Wo	20	5.25	0.00	0.31	1.25
Am	38	5.42	-0.17	0.38	1.50
Co	16	5.93	-0.51*	0.21	0.88
Da	21	5.94	-0.01	0.17	0.75
All	114	5.55		0.42	1.88
			B_3		
Wi	19	5.71		0.20	0.62
Wo	20	5.68	0.03	0.20	0.62
Am	38	5.69	-0.01	0.16	0.62
Co	16	5.84	-0.15*	0.16	0.62
Da	21	5.80	0.04	0.15	0.62
All	114	5.74		0.20	0.76

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Chroma. The frequency distributions for dry crushed chroma are presented in Table 18. Dry chroma had a pronounced downward numerical trend as the degree of impeded drainage increased for these soils. The trend is most noticeable in the A_2 or A_3 and B_2 horizons.

The frequency distributions of all individuals combined have two or three apparent maxima in the A_1 or A_p and the A_2 or A_3 horizons. These maxima coincide with whole numbered units of chroma and are probably the result of inaccurate interpolation as was discussed under dry value.

The individuals of each of the five samples had a similar range of chroma units in the A_1 or A_p horizons; so dry chroma of this horizon is obviously not a differentiating characteristic. The same phenomenon was observed in the B_3 horizon.

In the A_2 or A_3 horizon, however, the two ranges of chroma units of the Willamette and Dayton samples had only one chroma quantity in common. All of the Willamette individuals had chroma units of 3.00 or more, and all of the Dayton individuals had chroma units of 3.00 or less. Yet, about one-fifth of the individuals of both samples had dry chroma quantities of 3.0, and so the two groups were not segregated by a minima in the frequency distribution of the two samples combined. The ranges of chroma units for

Table 18. Frequency Distributions for Dry Crushed Munsell Chroma Notations of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

	A_1 or A_p						A_2 or A_3						B_2						B_3					
Chroma	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
1.75											1	1												
2.00	1	1	8	5	6	21			2	2	12	16				1	3	4						
2.25	0	1	5	2	1	9			2	6	0	8				1	3	4						
2.50	2	2	4	4	4	16		1	5	1	1	8			1	1	2	4						
2.75	2	4	9	2	5	22		3	6	2	3	14			1	2	2	5						
3.00	11	9	6	3	5	34	5	3	10	4	4	26	1	3	14	8	8	34	8	7	10	11	15	51
3.25	2	2	5			9	6	4	2	1		13	3	3	7	3	3	19	8	6	22	5	5	46
3.50	1	0	1			2	2	2	1			4	5	6	5			16	3	5	6			14
3.75		1				1	4	3	5			12	5	3	10			18		2				2
4.00							2	5	5			12	5	3				8						
4.25														2				2						

the three samples of Woodburn, Amity, and Concord overlapped considerably with the ranges of each other and with the ranges of Willamette and Woodburn.

The frequency distributions for dry chroma of the B_2 horizon of the five samples resembled those of the A_2 or A_3 horizons. No natural groupings were indicated by minima in the frequency distribution of all individuals combined.

Sample statistics of the dry crushed chroma determinations are presented in Table 19. The difference of 0.26 chroma units between the means of the Woodburn and Amity samples for the A_1 or A_p horizon was significant. The differences between the means of Woodburn and Amity, and between the means of Amity and Concord were significant for the A_2 or A_3 horizon. These same differences were also significant in the B_2 horizon. The mean dry chroma of the B_3 horizon was slightly over 3.0 units for each sample.

Dry crushed chroma appears to be a normally distributed characteristic in each horizon of the Willamette catena soils. It also appears to be related to the degree of impeded drainage of the soils. However, it does not naturally segregate groups of the soils from other groups of the total population, but varies continuously from one extreme to the other.

Table 19. Sample Statistics for Dry Crushed Munsell Chroma Notations

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.85		0.31	1.38
Wo	20	2.82	0.03	0.38	1.62
Am	38	2.56	0.26**	0.44	1.38
Co	16	2.39	0.17	0.37	1.00
Da	21	2.47	-0.08	0.37	1.00
All	114	2.62		0.45	1.62
			A_2 or A_3		
Wi	19	3.34		0.37	1.12
Wo	20	3.26	0.08	0.54	1.50
Am	38	2.99	0.27**	0.57	2.00
Co	16	2.48	0.51*	0.43	1.12
Da	21	2.29	0.19	0.43	1.38
All	114	2.90		0.60	2.38
			B_2		
Wi	19	3.55		0.32	1.00
Wo	20	3.51	0.04	0.39	1.25
Am	38	3.22	0.29*	0.32	1.25
Co	16	2.82	0.40*	0.34	1.12
Da	21	2.65	0.17	0.43	1.12
All	114	3.15		0.52	2.25
			B_3		
Wi	19	3.15		0.16	0.50
Wo	20	3.22	-0.07	0.22	0.62
Am	38	3.15	0.07	0.13	0.38
Co	16	3.05	0.10**	0.08	0.25
Da	21	3.01	0.04	0.08	0.38
All	114	3.12		0.17	0.88

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

<u>Mean moist versus mean dry Munsell notations</u>. Table 20 compares mean moist and mean dry Munsell color notations for four main horizons of each series studied. The table shows the difference between the means of the two determinations, thus indicating the effect moisture conditions have on hue, value, and chroma quantities.

Hue apparently does not change appreciably when the soil dries. The relatively large difference between the moist and dry hue determination for the B_2 horizon of the Dayton sample resulted from using only the dominant color of a multicolored material in the moist determination. Other discrepancies resulted from the lack of interpolation between hue charts for the moist determination.

Value increases markedly when the soil dries. The two A horizons averaged about 1.9 value units higher for the dry rating than for the moist rating. The B horizons showed even greater mean differences between the two moisture conditions. The mean difference was greater in the B_2 and B_3 horizons because the dominant moist color selected for reading was normally the one having the lower value. An exceptional case was the B_2 horizon of Dayton, where the dominant color had the higher value. That is the reason the mean difference between dry and moist value for the B_2 horizon of Dayton is only 1.65 units, while it is over 2.2 for all the other soils.

Table 20. Comparison of Dry Crushed and Moist Munsell Notation Means

Series	Hue mean dif. (dry - moist)	Value mean dif. (dry - moist)	Chroma mean dif. (dry - moist)
		A_1 or A_p	
Wi	0.37	1.78	0.77
Wo	0.40	1.78	0.82
Am	-0.01	1.86	0.63
Co	0.00	2.34	0.58
Da	0.07	1.94	0.68
Mean	0.14	1.91	0.69
		A_2 or A_3	
Wi	0.53	1.91	0.29
Wo	0.30	1.96	0.71
Am	0.09	2.07	0.87
Co	-0.36	1.64	0.79
Da	-0.65	1.65	0.53
Mean	0.01	1.89	0.67
		B_2	
Wi	0.22	2.25	0.08
Wo	0.07	2.25	0.39
Am	0.07	2.42	0.35
Co	-0.03	2.74	-0.09
Da	-3.19	1.65	1.13
Mean	-0.46	2.26	0.39
		B_3	
Wi	-0.03	2.61	0.26
Wo	-0.05	2.66	0.42
Am	0.00	2.68	0.35
Co	0.06	2.84	0.46
Da	0.17	2.80	0.25
Mean	0.03	2.71	0.34

Chroma also appeared to increase upon drying of the soil, but to a lesser extent than value. It averaged about 0.7 units higher for the dry analysis than for the moist analysis in the A horizons, and about 0.35 units higher in the B horizons. The lesser increase noted in the B horizons is a reflection of the reading of the higher chroma moist color in multicolored horizons. The Dayton B_2 horizon is an exceptional case again where the lower chroma color was read for the moist determination.

Horizon Boundary Distinctness

The distinctness and topography of horizon boundaries were described at the time of sampling. Horizon boundary distinctness was identified by the four conventional classes--abrupt, clear, gradual, and diffuse (43, p. 139). The numerical limits of these classes were 0.0 to 1.0, 1.0 to 2.5, 2.5 to 5.0, and 5.0 + inches, respectively. For the statistical analysis, the distinctness classes identified in the field were assigned the values, 0.5, 1.5, 3.5, and 7.5 inches, respectively.

The frequency distributions for the horizon boundary distinctness values of several horizon boundaries of the Willamette, Woodburn, Amity, Concord, and Dayton samples, and of all individuals combined are presented in Table 21.

The boundary between the A and the B horizons was the

Table 21. Frequency Distributions for Horizon Boundary Thickness (distinctness) of the Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Thickness		A to B (B_1 or B_2)						B_2 to above (A_2, A_3 or B_1)						B_2 to B_3					
inches	class	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
0.5	abrupt					12	12					19	19		4	3	9	17	33
1.5	clear	7	3	16	10	4	40	3	7	10	12	2	34	4	12	26	7	4	53
3.5	gradual	12	17	22	6	5	62	16	13	28	4		61	14	4	9			27
6.5	diffuse													1					1

boundary between either the A_3 or A_2 horizon and the B_1 or B_2 horizon. The A to B horizon boundary of all the Willamette, Woodburn, Amity, and Concord individuals was in the two distinctness classes—clear and gradual. Nine of the Dayton individuals also had A to B horizon boundaries in these two classes, but 12 of the Dayton individuals had A to B horizon boundaries in the abrupt distinctness class. The boundary between the A and B horizons became somewhat more distinct as the degree of impeded drainage increased.

The boundary between the B_2 horizon and the horizon above the B_2 horizon was between the B_2 horizon and an A_2, A_3, or B_1 horizon. This characteristic almost differentiated all of the Dayton individuals from the rest of the individuals. All but two of Dayton's individuals had abrupt boundaries between the B_2 horizon and the horizon above the B_2, while none of the other series' individuals had abrupt boundaries between these two horizons. If boundary distinctness would have been measured in fractions of an inch, it undoubtedly would have varied in a continuous manner from one end of the range to the other end, and would not have naturally segregated groups of soils by the presence of a minima within the frequency distribution tabulation of all individuals combined.

The frequency distributions of the B_2 to B_3 horizon boundary distinctness classes indicate that this horizon boundary tended to become more distinct as the soil became more poorly drained.

The results of the statistical analysis for horizon boundary distinctness are presented in Table 22. Boundary thickness means of the A to B horizon boundary were 2.8, 3.2, 2.7, 2.3, and 1.4 inches for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. The differences between the Woodburn and the Amity samples and between the Concord and Dayton samples were significant.

The mean thickness of the boundary between the B_2 and the overlying horizon was about 3.0 inches for the Willamette, Woodburn, and Amity samples. Concord's sample had a mean of 2.0 inches, and Dayton's sample had a mean of 0.6 inches for this characteristic.

Mean thickness of the B_2 to B_3 boundary was 3.2, 1.7, 1.9, 0.9, and 0.7 inches for the Willamette, Woodburn, Amity, Concord, and Dayton samples in that order. The differences between the means of the Willamette and Woodburn samples, and the Amity and Concord samples, were significant.

Table 22. Sample Statistics for Horizon Boundary Thickness

Series	No. of obs.	Mean (inches)	Dif. bet. means (inches)	Standard deviation (inches)	Range (inches)
			A to B (B_1 or B_2)		
Wi	19	2.8		1.0	2.0
Wo	20	3.2	-0.4	0.8	2.0
Am	38	2.7	0.5**	1.0	2.0
Co	16	2.3	0.4	1.0	2.0
Da	21	1.4	0.9**	1.3	3.0
			B_2 to above (A_2, A_3 or B_1)		
Wi	19	3.2		0.8	2.0
Wo	20	2.8	0.4	1.0	2.0
Am	38	3.0	-0.2	0.9	2.0
Co	16	2.0	1.0*	0.9	2.0
Da	21	0.6	1.4*	0.3	1.0
			B_2 to B_3		
Wi	19	3.2		1.2	5.0
Wo	20	1.7	1.5*	1.0	3.0
Am	38	1.9	-0.2	0.9	3.0
Co	16	0.9	1.0*	0.5	1.0
Da	21	0.7	0.2	0.4	1.0

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Soil Texture

The texture of each horizon was determined at the time of sampling. The frequency distributions for the field-determined textures of four main horizons of each series are listed in Table 23. The texture of the B_2 horizon varied

Table 23. Frequency Distribution for Field-Determined Texture of Four Horizons of the Willamette, Woodburn, Amity, Concord, and Dayton Samples

Text. class	A_1 or A_p					A_2 or A_3					B_2					B_3				
	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da
sl																1	1	1		
sil	19	20	38	16	21	18	20	38	11	17	7	13	23	1		17	19	37	15	19
sicl						1			5	4	12	7	15	14	5	1			1	2
sic														1	9					
c															7					

more between series' samples than the texture of the other horizons. The B_2 horizon of each individual was therefore analyzed for particle size distribution. The frequency distributions for the sand, silt, and clay fractions of the B_2 horizons of each series' sample are listed in Table 24.

The percentage of clay in the B_2 horizon differentiated the Dayton individuals from the Concord individuals. None of the Dayton individuals had less than 34 per cent clay, and none of the Concord individuals had more than 33 per cent clay. However, there was no significant minimum between the two groups according to the individual degree of freedom goodness of fit test. The number of Concord individuals in the 32 to 33 per cent clay interval was fully as great as it was in any other 2-per cent interval.

The variation in the percentage of sand within each of the series' samples was very large. Willamette's individuals ranged from 17 to 45 per cent sand, and Woodburn's individuals ranged from 20 to 48 per cent sand. The other samples had less variation in percentage of sand than the Willamette and Woodburn samples, but they still had ranges of 15 per cent or more. The percentage of sand of the B_2 horizon tended to decrease as the soil became more poorly drained.

The percentage of sand occurring in the B_2 horizons of

Table 24. Frequency Distributions for Percentage Sand, Silt, and Clay of B_2 Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples and of All Individuals Combined

Per cent	Sand						Silt						Clay					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
12-13					4	4												
14-15					2	2								1				1
16-17					4	5								1				1
18-19	0			1	3	4							1	2	1			4
20-21	0	1		2	4	7							6	6	7			19
22-23	1	2	1	4	1	9							2	4	11			17
24-25	5	2	7	1	1	16							1	3	12	2		18
26-27	5	4	8	3	1	21							4	3	7	4		18
28-29	0	0	5	3	1	9							2			3		5
30-31	0	3	5	1		9					1	1	1			3		4
32-33	1	0	3	1		5					0	0	1			4		5
34-35	0	2	4			6	1	2	1		1	5	1				1	2
36-37	0	1	1			2	2	0	1		2	5					6	6
38-39	0	2	3			5	3	2	0	2	2	9					4	4
40-41	3	1	1			5	1	1	2	2	4	10					1	1
42-43	2	1				3	0	2	2	0	4	8					5	5
44-45	1	0				1	1	1	7	3	3	15					2	2
46-47		0				0	3	2	9	2	2	18					2	2
48-49		1				1	4	1	6	4	1	16						
50-51							3	2	7	3	1	16						
52-53							0	3	2			5						
54-55							1	1	1			3						
56-57								2				2						
63								1				1						

the soils was somewhat related to the geographic position of the sampling site. Of the 37 individuals with 30 per cent or more sand, 34 were sampled from the 40 excavations between sites 65 and 105 (see Figure 1). The C horizon of 20 of these 34 individuals had either uniform very-fine sandy loam textures or alternating strata of very-fine sandy loam and silt loam textures. The C horizons of the other 14 individuals were below the depth of sampling. The individuals that had slightly redder hues than the majority were also located within this segment of the transect. They occurred between sites 85 and 105. The sampling transect paralleled a meandering stream that had cut into the Willamette silts to a depth of about 50 feet, between sites 65 and 105. These three phenomena may be related, but an explanation of the relationship awaits a more comprehensive understanding of the origin and composition of the Willamette silt deposit.

The silt content of the B_2 horizons did not vary much between series' samples but varied considerably within the samples. The range in percentage of silt for all individuals combined was from 33 to 63 per cent. Woodburn's individuals ranged from 35 to 63 per cent silt. The individuals of Willamette and Amity varied between 35 and 55 per cent silt. Concord's individuals ranged from 38 to 51 per cent silt, and Dayton's individuals ranged from 30 to 51 per cent silt.

The results of the mean statistical analysis for the mechanical analysis of the B_2 horizon are presented in Table 25. The mean sand percentages were 30.4, 31.2, 29.9, 25.2, and 18.2 for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. The differences between the means of Amity and Concord, and between Concord and Dayton were significant. The silt percentages were between 41 and 47 per cent for all five series.

The mean percentages of clay in the B_2 horizon were 24.8, 21.4, 23.5, 29.0, and 40.3 for the Willamette, Woodburn, Amity, Concord, and Dayton samples. All the differences between means of adjacent pairs of samples were significant.

Table 25. Sample Statistics for Mechanical Analysis of B_2 Horizon

Series	No. of obs.	Mean (%)	Dif. bet. means (%)	Standard deviation (%)	Range (%)
			<u>Sand</u>		
Wi	19	30.4		8.6	28
Wo	20	31.2	1.2	7.4	27
Am	38	29.9	1.3	4.7	18
Co	16	25.2	4.7**	4.2	15
Da	21	18.2	7.0**	4.6	15
All	114	26.9		7.9	36
			<u>Silt</u>		
Wi	19	44.7		5.8	20
Wo	20	47.3	-3.4	7.7	28
Am	38	46.6	0.7	4.2	20
Co	16	45.7	0.9	4.3	13
Da	21	41.5	4.2*	4.9	21
All	114	45.1		5.9	33
			<u>Clay</u>		
Wi	19	24.8		4.6	16
Wo	20	21.4	3.4*	3.2	12
Am	38	23.5	-2.1**	2.2	11
Co	16	29.0	-5.5**	2.9	8
Da	21	40.3	-11.3**	3.8	12
All	114	27.9		7.8	33

* Significant difference at 5-per cent level.
**Significant difference at 1-per cent level.

<u>Soil Structure</u>

Soil structure was described for type, size, and grade of aggregates in each horizon (43, p. 225-230). Structural type refers to the shape and arrangement of aggregates. Size of aggregate is self-explanatory. Structural grade refers to the degree of distinctness of aggregates in situ and in disturbed soil. Horizons having no observable aggregates were described as massive.

Structural type. Table 26 presents the frequency distributions of structural type for four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples. Only the smaller type is listed for those horizons having compound structure. The type of structure did not vary between series in the A_1 or A_p and A_2 or A_3 horizons. The individuals of each series' sample had either granular or subangular blocky structure in these horizons.

The two poorly drained series, Concord and Dayton, and the well-drained series, Willamette, had more individuals with angular blocky structure than subangular blocky structure in the B_2 horizon. The other series, Woodburn and Amity, had more individuals with subangular blocky than with angular blocky structure in the B_2 horizon.

In the B_3 horizon, each series' sample had some individuals with massive structure, but each sample also had some individuals with either blocky or prismatic structure.

Obviously, structural type was not a differentiating characteristic among these soils. The same types of aggregates were found in comparable horizons of all five series.

Table 26. Frequency Distributions for Structural Type of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples

	A_1 or A_p					A_2 or A_3					B_2 or B_{22}					B_3				
Type	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da
gr	8	4	14	9	9		1	1	1	1										
sbk	11	16	24	7	12	19	19	37	15	20	6	16	29	5	0	8	6	11	1	5
abk											13	4	9	11	21	4	0	0	0	0
pr																3	1	5	2	0
mass																4	13	22	13	16

Structural size. Structural size was noted by the five conventional classes--very fine, fine, medium, coarse, and very coarse--using the size limits defined in the Soil Survey Manual (43, p. 238). The numerical limits of a size class depend upon the structural type. For example, the numerical limits of the fine granular and the fine blocky types are 1 to 2 mm. and 5 to 10 mm., respectively. Therefore, two different size classes of different structural types can have the same numerical limits. For example, medium granular and very fine blocky aggregates both have numerical size limits of 2 to 5 mm. For the statistical analysis, all size classes of equal numerical limits were considered as one class. The midpoints of the size classes identified in the field were used to quantify structural size. The resulting seven discrete quantities representing structural size were 0.5, 1.5, 3.5, 7.5, 15.0, 35.0 and 75.0 mm.

The frequency distributions for structural size of four main horizons of the five series' samples are presented in Table 27. The distributions prominantly show that structural size increased with increasing depth of horizon regardless of soil series. Structural size did not vary appreciably between soil series in the A_1 or A_p, A_2 or A_3 and the B_3 horizons. The size did increase with the degree of impeded drainage in the B_2 horizon. The range of size

Table 27. Frequency Distributions for Structural Size of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples

Size (mm)	A_1 or A_p					A_2 or A_3					B_2					B_3				
	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da
0.5	3	2	1	1	2															
1.5	4	2	15	8	7	1	1	1	1	1										
3.5	12	16	22	6	12	12	13	30	12	17		3								
7.5				1		6	6	7	3	3	10	7	25	3						
15.0											6	7	7	5	6	1				
35.0											3	3	6	8	15	5	2	3		3
75.0																9	5	13	3	2
massive																4	13	22	13	16

values for any one series overlapped considerably with the range of values of other series, however, and structural size did not completely differentiate one series from other series.

Table 28 shows that the mean structural sizes of the A_1 or A_p, A_2 or A_3, and B_3 horizons were about the same for all five series' samples. The mean structural size was about 2.6 mm. for the A_1 or A_p horizon, 4.3 mm. for the A_2 or A_3 horizon, and 60 mm. for the B_3 horizon for all five series.

The mean sizes of aggregates in the B_2 horizon were 14.2, 12.1, 13.2, 23.6, and 29.3 mm. for the Willamette, Woodburn, Amity, Concord, and Dayton samples. The difference between the means of the Amity and the Concord samples was significant.

Table 28. Sample Statistics for Structural Size

Series	No. of obs.	Mean (mm)	Dif. bet. means (mm)	Standard deviation (mm)	Range (mm)
			A_1 or A_p		
Wi	19	2.6		1.2	3.0
Wo	20	3.0	-0.4	1.0	3.0
Am	38	2.6	0.4	1.1	3.0
Co	16	2.6	0.0	1.7	7.0
Da	21	2.6	0.0	1.2	3.0
			A_2 or A_3		
Wi	19	4.7		2.0	6.0
Wo	20	4.6	0.1	2.0	6.0
Am	38	4.2	0.4	1.6	6.0
Co	16	4.1	0.1	1.7	6.0
Da	21	4.0	0.1	1.6	6.0
			B_2 or B_{22}		
Wi	19	14.2		9.8	27.5
Wo	20	12.1	2.1	9.0	31.5
Am	38	13.2	-1.1	10.0	27.5
Co	16	23.6	-10.4*	12.0	27.5
Da	21	29.3	-5.7	9.2	7.5
			B_3		
Wi	15 1/	57.7		2/	2/
Wo	7	63.6	-5.9		
Am	16	67.5	-3.9		
Co	3	75.0	-7.5		
Da	5	51.0	24.0		

* Significant difference at 5-per cent level.

1/ Massive observations were disregarded when calculating the mean size of peds for the B_3 horizons.

2/ Could not be calculated because the observations with massive structure had infinite size.

__Structural grade__. Structural grade was described by the four classes--structureless, weak, moderate, and strong--at the time of sampling (43, p. 229). The classes were quantified for the statistical analysis by assigning the numerals 0, 1, 2, and 3 to the classes in the order given. The frequency distributions for structural grade of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Table 29.

Each series' sample had a preponderance of individuals with moderate structural grade in the A_1 or A_p and the A_2 or A_3 horizons. The Willamette, Concord, and Dayton samples each had more individuals with strong grades of structure than of other grades in the B_2 horizons. The Woodburn and Amity samples had a total of 13 individuals with a weak grade of structure in the B_2 horizon. All the samples had some individuals with a moderate grade of structure in the B_2 horizon.

The degree of aggregate distinctions was less in the B_3 horizon than it was in the B_2 horizon for all five series. The well-drained Willamette series, however, had a relatively smaller proportion of individuals with massive structure than did the other series.

Structural grade did not vary enough between series' samples to completely segregate one sample from other samples. Table 30 shows that the series' means for

Table 29. Frequency Distributions of Structural Grade for Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples

Grade	A_1 or A_p					A_2 or A_3					B_2 or B_{22}					B_3				
	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da
mass (0)																4	13	22	13	16
weak (1)	3	1	10	4	1	4	4	8	6	11	1	5	8			6	6	13	3	5
mod (2)	14	18	25	12	19	12	14	26	9	9	8	12	27	6	5	9	1	3		
str (3)	2	1	3		1	3	2	4	1	1	11	3	3	10	16					

Table 30. Sample Statistics for Structural Grade

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.0		0.5	2.0
Wo	20	2.0	0.0	0.3	2.0
Am	38	1.8	0.2	0.6	2.0
Co	16	1.8	0.0	0.4	1.0
Da	21	2.0	-0.2	0.3	2.0
			A_2 or A_3		
Wi	19	2.0		0.4	2.0
Wo	20	1.9	0.1	0.6	2.0
Am	38	1.9	0.0	0.6	2.0
Co	16	1.7	0.2	0.6	2.0
Da	21	1.7	0.0	0.6	2.0
			B_2		
Wi	19	2.5		0.6	2.0
Wo	20	1.9	0.6*	0.5	2.0
Am	38	1.9	0.0	0.5	2.0
Co	16	2.6	-0.7*	0.5	1.0
Da	21	2.8	-0.2	0.4	1.0
			B_3		
Wi	19	1.3		0.8	2.0
Wo	20	0.4	0.9*	0.6	2.0
Am	38	0.5	-0.1	0.7	2.0
Co	16	0.2	0.3	0.4	1.0
Da	21	0.2	0.0	0.4	1.0

* Significant difference at 1-per cent level.

structural grade were not significantly different between any of the series for the A_1 or A_p and the A_2 or A_3 horizons. The more poorly drained soils appeared to have a slightly weaker mean structural grade in the A_2 or A_3 horizon than the better drained soils. On the other hand, the poorly drained Concord and Dayton series had significantly stronger structural grades than the Woodburn and Amity series in the B_2 horizon. The Willamette sample's structural grade was significantly stronger than that of the Woodburn and Amity series in both the B_2 and the B_3 horizons.

Soil Consistence

Both moist and wet consistence were described according to the definitions presented in the Soil Survey Manual (43, p. 232-233). Four terms were used to express soil consistence in each moisture condition. Moist consistence was described by the terms: very friable, friable, firm, and very firm. These terms express the degree of resistance the soil aggregates manifest in attempts to deform or rupture. They were quantified for the statistical analysis by substituting the numerals 1, 2, 3, and 4 for the terms very friable, friable, firm, and very firm, respectively. Wet consistence was described by terms that express the degree of adhesion and cohesion of the soil material. The terms were nonsticky, slightly sticky, sticky, and very sticky, and were quantified with the respective numerals 1, 2, 3, and 4 for the statistical analysis.

Frequency distributions for moist and wet consistence are presented in Table 31. Moist consistence tended to become more firm with depth for each of the five series. All of the individuals were either friable or very friable in the A_1 or A_p horizon, and all but four were friable or very friable in the A_2 or A_3 horizon. In the B_2 horizon, each series' sample had some individuals with firm consistence, and in the B_3 horizon, each sample had some individuals with very-firm consistence. Therefore, moist consistence did not differentiate all the individuals of one series from the individuals of the other series.

Almost all of the individuals had slightly sticky consistence in the A_1 or A_p, A_2 or A_3, and the B_3 horizons. All but two of the Willamette, Woodburn, and Amity individuals taken together also had slightly sticky consistence in the B_2 horizon, while only two of the Concord individuals and none of the Dayton individuals had slightly sticky consistence in this horizon. Therefore, wet consistence almost completely differentiated the observations into two groups. However, there was no minimum in the frequency distribution of all individuals combined between the two groups, so the groups were not naturally segregated.

Table 31. Frequency Distributions for Field-Determined Moist and Wet Consistence of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples

Consistence	A_1 or A_p					A_2 or A_3					B_2 or B_{22}					B_3				
	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da	Wi	Wo	Am	Co	Da
Moist consistence																				
vfr (1)	10	15	33	10	10	5	13	28	11	16	1	4	6							
fr (2)	9	5	5	6	11	11	6	10	5	5	12	13	20	9	7	4	1	4		
fi (3)						3	1				6	3	12	7	14	7	6	14	9	12
vfi (4)																8	13	20	7	9
Wet consistence																				
so (1)		2		3	3		1													
ss (2)	19	18	38	13	18	19	19	38	16	21	18	19	38	2		19	20	38	16	20
s (3)											1	1		12	8					1
vs (4)														2	13					

Table 32 presents the means and other statistical data for moist consistence of four horizons and for wet consistence of the B_2 horizon. The mean moist consistence of the Amity sample was significantly more friable than the Concord, Dayton, and Willamette sample means for the A_1 or A_p horizon. Willamette's mean moist consistence of 1.9 for the A_2 or A_3 horizon was significantly less friable than the mean moist consistence of the other series' sample. None of the moist consistence sample means were significantly different between pairs of adjacent soils in either the B_2 or the B_3 horizons.

The B_2 horizon wet consistence means were 2.1, 2.0, 2.0, 3.0, and 3.6 for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. Concord's mean wet consistence was significantly more sticky than Amity's mean, and Dayton's mean was significantly more sticky than Concord's mean.

Table 32. Sample Statistics for Consistence

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
Moist consistence					
			A_1 or A_p		
Wi	19	1.5		0.5	1.0
Wo	20	1.3	0.2	0.4	1.0
Am	38	1.1	0.2	0.3	1.0
Co	16	1.4	-0.3**	0.5	1.0
Da	21	1.5	-0.1	0.5	1.0
			A_2 or A_3		
Wi	19	1.9		0.6	2.0
Wo	20	1.4	0.5**	0.6	2.0
Am	38	1.3	0.1	0.4	1.0
Co	16	1.3	0.0	0.5	1.0
Da	21	1.2	0.1	0.4	1.0
			B_2		
Wi	19	2.3		0.6	2.0
Wo	20	2.0	0.3	0.6	2.0
Am	38	2.2	-0.2	0.7	2.0
Co	16	2.4	-0.2	0.5	1.0
Da	21	2.7	-0.3	0.5	1.0
			B_3		
Wi	19	3.2		0.8	2.0
Wo	20	3.6	-0.4	0.6	2.0
Am	38	3.4	0.2	0.7	2.0
Co	16	3.4	0.0	0.5	1.0
Da	21	3.4	0.0	0.5	1.0
Wet consistence					
			B_2		
Wi	19	2.1		0.2	1.0
Wo	20	2.0	0.1	0.2	1.0
Am	38	2.0	0.0	0.0	0.0
Co	16	3.0	-1.0*	0.5	2.0
Da	21	3.6	-0.6*	0.5	1.0

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Soil Reaction

Soil reaction, expressed in pH units, was determined colorimetrically in the field and electrometrically in the laboratory. The laboratory determinations were statistically analyzed because they were made with greater precision.

The frequency distributions for pH of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Table 33. The trends of pH in relation to degree of impeded drainage and to depth are readily apparent from the frequency distribution tabulations. Soil acidity increased slightly in the A_1 or A_p horizon, and decreased decidedly in the B_2 and B_3 horizons with increasingly poor drainage. The frequency distribution tabulations of all individuals combined in each horizon indicate that pH has a normal distribution among the soils of the Willamette catena. Each frequency distribution tabulation has a pronounced maximum near the center of the range of pH values. The frequency distribution of the Dayton sample for the A_1 or A_p horizon has one individual that had a pH value of 6.4, which is 1.0 pH unit higher than any of the other Dayton observations. It obviously was sampled from a site that had been recently limed. The ranges of pH values within each series' sample overlapped with the ranges of the other samples to the degree that

Table 33. Frequency Distributions for pH Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

pH	A_1 or A_p						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
4.5-4.6									1			1												
4.7-4.8				2	4	6			0			0	1					1						
4.9-5.0			2	3	7	12	2		0	3	5	10	0					0						
5.1-5.2		1	10	8	6	25	0	2	7	7	8	24	4	1	1	3	1	10	1					1
5.3-5.4	3	7	10	1	3	24	5	5	11	4	5	30	7	2	2	1	2	14	6	1				7
5.5-5.6	8	5	13	1	0	27	6	7	11	2	1	27	4	5	8	4	1	22	6	1	1			8
5.7-5.8	6	3	3	1	0	13	5	3	6		1	16	2	4	16	3	6	31	2	6	3	2		13
5.9-6.0	1	3			0	4	0	2	1		1	4	1	5	6	0	3	15	4	3	15	1		23
6.1-6.2	1	0			0	1	1	1	0			2		2	4	3	2	11		3	11	2	1	17
6.3-6.4		1			1	2			0			0		1		0	3	4		5	3	4	3	15
6.5-6.6									1			1				1	1	2		0	1	2	8	11
6.7-6.8																1	1	2		0	3	1	4	8
6.9-7.0																	1	1		1	0	4	3	8
7.1-7.2																					1		0	1
7.3-7.4																							1	1
7.5-7.6																							0	0
7.7-7.8																							1	1

but one maximum occurred in the frequency distribution tabulation of all individuals combined. Consequently, there was no natural segregation of groups of soils in the Willamette catena.

Table 34 shows the mean values and other statistics for pH of the Willamette, Woodburn, Amity, Concord, and Dayton samples and of all individuals combined. Amity's mean pH was significantly lower than Woodburn's mean pH, and Concord's mean pH was in turn significantly lower than Amity's mean pH in the A_1 or A_p horizon. The difference of 0.3 units between the Amity and Concord means was significant in the A_2 or A_3 horizon. Willamette's mean pH was significantly more acid than Woodburn's mean in the B_2 horizon. All the differences between means of adjacent pairs were significant in the B_3 horizon, except the one of 0.2 pH units between the Woodburn and Amity sample means.

Table 34. Sample Statistics for Soil Reaction (pH)

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	5.6		0.2	1.0
Wo	20	5.6	0.0	0.3	1.3
Am	38	5.4	0.2*	0.2	0.9
Co	16	5.1	0.3*	0.2	1.0
Da	21	5.0	0.1	0.2	0.8
All	114	5.3		0.2	1.7
			A_2 or A_3		
Wi	19	5.5		0.2	1.3
Wo	20	5.6	-0.1	0.2	1.1
Am	38	5.5	0.1	0.3	2.1
Co	16	5.2	0.3*	0.2	0.7
Da	21	5.2	0.0	0.2	0.9
All	114	5.3		0.2	2.1
			B_2		
Wi	19	5.4		0.3	1.3
Wo	20	5.7	-0.3*	0.3	1.2
Am	38	5.8	-0.1	0.3	1.1
Co	16	5.8	0.0	0.5	1.6
Da	21	6.0	-0.2	0.6	1.9
All	114	5.8		0.4	2.4
			B_3		
Wi	19	5.6		0.3	0.9
Wo	20	6.0	-0.4*	0.4	1.8
Am	38	6.2	-0.2	0.3	1.6
Co	16	6.4	-0.2**	0.4	1.4
Da	21	6.7	-0.3**	0.4	1.7
All	114	6.2		0.4	2.7

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Cation Exchange Capacity

Cation exchange capacity is an accessory characteristic of the kinds and amounts of inorganic and organic collodial material in the soil. It cannot be observed in the field and so its usefulness for differentiating soil classes is limited. However, since it is accessory to texture, which was used to differentiate the Dayton observations, it is important to know its magnitude. Cline (9, p. 82) states that a good differentiating characteristic should be associated with a number of covarying properties or accessory characteristics about which a precise statement can be made.

The frequency distributions for cation exchange capacity values of four horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Table 35.

The frequency distributions indicate a comparable range of cation exchange capacity values for each series in the A_1 or A_p, A_2 or A_3, and B_3 horizons. However, the distributions for the Concord and Dayton observations in the B_2 horizon include a range of values that has little overlap with the ranges of the other series. The minimum within the frequency distribution tabulation of all individuals combined at 24 to 25 m.e./100 g. is significant at the

Table 35. Frequency Distributions for Cation Exchange Capacity Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

C.E.C. me/ 100 g	A_1 or A_2						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
10-11			1		1	2					1	1												
12-13	1	1	1	3	7	13	5	5	3	2	5	20												
14-15	2	4	8	2	7	23	10	6	16	4	6	32	1	2				3						
16-17	8	5	9	5	3	30	2	7	9	7	4	29	2	4	8			14						
18-19	3	7	10	6	1	27	2	2	5	2	3	14	3	8	7			18	4	4	1			9
20-21	3	1	6		2	12			5	0	1	6	9	5	11			25	7	13	24	3	6	53
22-23	2	0	3			5				1	1	2	3	1	11	3		18	6	3	13	9	5	36
24-25		1				1							1		1	3	1	6	2			1	5	8
26-27		1				1										9	3	12				3	3	6
28-29																1	4	5					2	2
30-31																	5	5						
32-33																	3	3						
34-35																	3	3						
36-37																	2	2						

5-per cent level when compared with the frequencies at 22 to 23, and 26 to 27 m.e./100 g. Thus the soils of the Willamette catena appear to be separated into two natural groupings according to the cation exchange capacity of the B_2 horizon.

Cation exchange capacity series means and other statistics are presented in Table 36. There was little difference between mean cation exchange capacities of the five series for either the A_1 or A_p or the A_2 or A_3 horizon. That was to be expected in view of the fact that most of the individuals had silt loam textures for these two horizons. Nevertheless, the mean cation exchange capacity of the Dayton sample was significantly less than the mean of the Concord sample in the A_1 or A_p horizon. The mean cation exchange capacities of all the series were between 15 and 16 m.e./100 g. for the A_2 or A_3 horizon. All the differences between the means of adjacent pairs of series were significant for the B_2 horizon, which was to be expected since these differences were all significant for the clay percentage of the B_2 horizon. For both of these characteristics, Willamette's mean was greater than Woodburn's mean, and the means of the other series increased progressively as the degree of impeded drainage increased. Amity's mean cation exchange capacity was significantly greater than Woodburn's for the B_3 horizon, and Concord's

Table 36. Sample Statistics for Cation Exchange Capacity Values

Series	No. of obs.	Mean (m.e./ 100 g)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	17.6		2.5	9
Wo	20	17.7	-0.1	3.4	14
Am	38	17.5	0.2	2.7	12
Co	16	16.2	1.3	2.4	7
Da	21	15.0	1.2	2.7	10
All	114	16.7		3.0	15
			A_2 or A_3		
Wi	19	14.8		1.8	7
Wo	20	15.3	-0.5	2.0	7
Am	38	16.2	-0.9	2.2	7
Co	16	16.2	0.0	2.4	9
Da	21	15.5	0.7	3.1	11
All	114	15.6		2.3	11
			B_2		
Wi	19	20.0		2.3	10
Wo	20	18.5	1.5**	2.2	7
Am	38	19.9	-1.4**	2.4	8
Co	16	25.9	-6.0*	1.8	7
Da	21	30.7	-4.8*	3.2	11
All	114	23.0		4.5	21
			B_3		
Wi	19	21.1		1.7	6
Wo	20	20.3	0.8	1.2	5
Am	38	21.2	-0.9*	1.1	5
Co	16	23.2	-2.0*	1.8	5
Da	21	23.4	-0.2	2.5	8
All	114	21.8		2.1	10

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

mean was significantly greater than Amity's.

Base Saturation[1]

The ratio of the sum of the exchangeable bases, calcium, magnesium, potassium, and sodium, to the cation exchange capacity times 100, here called percentage base saturation, is of interest to the field of soil genesis because its magnitude is related to the degree of leaching; and it is of interest to the field of soil fertility because it is related to plant nutrient availability. Since man is primarily interested in the soil from the standpoints of its genesis and of its use, base saturation data are very useful. The frequency distributions for percentage base saturation of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Table 37.

Five of the individuals had base saturation values greater than 90 per cent in the A_1 or A_p horizon. These values were 10 to 15 per cent greater than all the other

---

[1]The term "base saturation" is used in this thesis for the sake of brevity and convenience in lieu of the more correct, but more cumbrous, "ratio of the sum of the exchangeable calcium, magnesium, potassium, and sodium to the cation exchange capacity times 100."

Table 37. Frequency Distributions for Percentage Base Saturation of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Base sat. (%)	A_1 or A_p						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
30-34			2	1	2	5																		
35-39			0	2	2	4			1	1		2												
40-44		2	1	4	3	10	2		0	0	1	3												
45-49		0	10	4	7	21	0		2	4	0	6												
50-54	2	3	5	3	2	15	2	1	4	3	2	12												
55-59	5	3	7	1	3	19	3	3	10	3	1	20												
60-64	4	6	4	1	1	16	5	6	3	1	4	19				1		1						
65-69	3	2	6		0	11	3	7	4	3	4	21	2	1	1	0		4						
70-74	2	2	2		0	6	0	2	8	0	4	14	7	3	2	0		12	1	2	1			4
75-79	1	1	0		0	2	4	1	4	0	1	10	3	3	6	0		12	2	0	0			2
80-84	0	0	0		0	0			2	1	2	5	3	6	8	0	3	20	5	3	1			9
85-89	0	0	0		0	0					2	2	2	4	13	4	0	23	5	5	6		1	17
90-94	1	1	0		1	3							0	2	6	7	8	23	2	6	17	3	3	31
95-99	1		0			1							1	1	1	1	6	10	4	2	12	6	5	29
100-104			1			1							1		1	3	4	9		1	0	3	4	8
105-109																				1	0	4	6	11
110-114																					1		2	3

individuals and apparently were from sites that had been limed recently.

The frequency distributions of the A_1 or A_p horizon indicate that the percentage base saturation of this horizon decreased as the degree of impeded drainage increased. The opposite trend was found in the B_2 and B_3 horizons. Soil reaction showed the same trends as percentage base saturation in relation to depth of horizon.

Several of the individuals had base saturation values greater than 100 per cent in the B_2 and B_3 horizons because the soluble salts and carbonates were not removed for the exchangeable cation determinations.

The large amounts of overlap between the wide ranges of base saturation values for each series clearly indicated that percentage base saturation did not naturally segregate groups that correspond to the present series. However, the minimum at the interval of 100 to 104 per cent in the frequency distribution of all individuals combined for the B_3 horizon was significant at the 5-per cent level when compared with the frequency in the intervals of 95 to 99 per cent, and 105 to 109 per cent. This minimum may not be a real natural limit between groups of these soils, however, since the number of individuals in the minimal segment is only three less than the number of individuals in one of the maximal segments. The validity of the minimum should be tested with a larger sample.

The series' mean percentages of base saturation are presented in Table 38 for four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples. The Concord sample mean percentage base saturation was significantly different from the Amity mean for all four horizons. Concord's mean was significantly higher than Amity's mean for the A_1 or A_p and the A_2 or A_3 horizons, and significantly lower for the B_2 and B_3 horizons. The Dayton mean percentage base saturation was significantly greater than Concord's mean for the A_2 or A_3 horizon. The Willamette, Woodburn, and Amity series were not significantly different from one another according to percentage base saturation.

Table 38. Sample Statistics for Percentage Base Saturation

Series	No. of obs.	Mean (%)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	65.3		12.4	48
Wo	20	61.4	3.9	11.8	51
Am	38	56.1	5.3	13.0	68
Co	16	45.3	10.8*	8.6	31
Da	21	48.6	-3.3	13.4	64
All	114	55.6		14.0	70
			A_2 or A_3		
Wi	19	62.1		10.3	36
Wo	20	64.6	-2.5	5.5	23
Am	38	63.6	1.0	10.5	46
Co	16	56.2	7.4**	11.8	48
Da	21	67.9	-11.7*	10.9	43
All	114	63.2		8.0	51
			B_2		
Wi	19	78.3		9.6	36
Wo	20	81.3	-3.0	8.1	33
Am	38	84.3	-3.0	6.9	33
Co	16	90.6	-6.3*	9.6	41
Da	21	93.9	-3.3	9.5	22
All	114	85.6		10.0	42
			B_3		
Wi	19	86.6		7.0	25
Wo	20	89.7	-3.1	8.2	33
Am	38	92.6	-2.9	6.2	40
Co	16	100.0	-7.4*	4.9	18
Da	21	101.4	-1.4	6.4	21
All	114	94.0		7.5	40

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Exchangeable Cations

Calcium. Calcium was the dominant exchangeable cation in all of the horizons of each series. Frequency distributions for exchangeable calcium values of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Table 39.

Exchangeable calcium tended to decrease in relation to the degree of impeded drainage in the A_1 or A_p horizon, and it had the opposite tendency in the B_2 and B_3 horizons. It had an over-all tendency to increase in relation to depth of horizon for each series. The unusually high values of some of the individuals in the A_1 or A_p horizon were probably from sites that had been recently limed.

The mean values of exchangeable calcium are listed in Table 40. Concord's means were significantly different from Amity's means for all four horizons. They were significantly lower for the A_1 or A_p and A_2 or A_3 horizons, and significantly higher for the B_2 or B_3 horizons. Amity's mean exchangeable calcium was significantly greater than Woodburn's mean for the B_2 or B_3 horizon. Dayton's mean was significantly higher than Concord's mean for the B_2 horizon.

Although the amounts of exchangeable calcium in the B_2 and B_3 horizons vary according to soil series, the percentage of calcium saturation appears to be relatively constant

Table 39. Frequency Distributions for Exchangeable Calcium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Ca me/ 100 g	A_1 or A_p						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
2-3				1	4	5	1			1		2												
4-5	1		7	9	13	30	4	3	6	5	7	25												
6-7	6	11	17	5	3	42	11	10	17	7	10	55		3	1			4						
8-9	8	6	11	1	0	26	2	6	11	3	2	24	4	4	4			12		1				1
10-11	2	1	2		1	6	1	1	4		2	8	8	6	11	1		26	4	6	1			11
12-13	0	0	1			1							5	4	14	2		25	8	4	18	2	5	37
14-15	0	2				2							2	3	7	6	3	21	6	9	16	9	12	52
16-17	2					2									1	7	11	19	1		3	5	4	13
18-19																	6	6						
20-21																	1	1						

Table 40. Sample Statistics for Exchangeable Calcium Values

Series	No. of obs.	Mean (m.e./ 100 g)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	8.6		3.1	11.2
Wo	20	8.1	0.5	2.5	8.9
Am	38	7.3	0.8	1.8	9.6
Co	16	5.2	2.1*	1.3	5.0
Da	21	4.9	0.3	1.8	8.0
All	114	6.9		2.5	13.8
			A_2 or A_3		
Wi	19	6.3		1.6	6.6
Wo	20	7.1	-0.8	1.6	6.4
Am	38	7.3	-0.2	1.7	7.1
Co	16	6.1	1.2**	1.6	5.9
Da	21	6.6	-0.5	1.9	7.4
All	114	6.7		1.8	8.0
			B_2		
Wi	19	11.0		2.1	7.4
Wo	20	10.5	0.5	2.4	8.2
Am	38	11.8	-1.3*	1.9	8.4
Co	16	15.0	-3.2*	1.6	6.5
Da	21	17.0	-2.0*	1.6	6.6
All	114	12.8		3.1	14.0
			B_3		
Wi	19	12.9		1.6	5.5
Wo	20	12.7	0.2	1.8	5.6
Am	38	13.6	-0.9**	1.1	5.6
Co	16	14.9	-1.3*	1.2	4.0
Da	21	14.4	0.5	1.2	4.6
All	114	13.7		1.5	7.9

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

among these soils. The mean percentage calcium saturation for all five series was about 55 per cent for the B_2 horizon and about 62 per cent for the B_3 horizon.

Magnesium. Magnesium was the second most dominant exchangeable base in all horizons of all individuals. The frequency distributions for exchangeable magnesium are listed in Table 41.

Exchangeable magnesium, like exchangeable calcium, tended to increase in relation to depth of horizon. The rate of increase was much greater for the poorly drained Concord and Dayton individuals than it was for the other individuals. Subsequently, the poorly drained soils are naturally segregated from the better drained soils by a minimum in the frequency distribution tabulation for this characteristic in the B_3 horizon. The minimum at 6 m.e. mg./100 g. of soil was significant at the 5-per cent level.

The exchangeable magnesium mean values are listed in Table 42. Dayton's sample mean for the B_2 horizon was five times greater than it was for the A_1 or A_p horizon, while Willamette's sample mean was only two times larger in the B_2 horizon than it was in the A_1 or A_p horizon.

All of the series had mean exchangeable magnesium values of around 2.0 m.e./100 g. and mean magnesium saturation values of about 12 per cent in the A_1 or A_p horizon.

Table 41. Frequency Distributions for Exchangeable Magnesium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Mg me/ 100 g	A_1 or A_p						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
1	4	7	11	5	6	33	3	2	1	2		8												
2	12	9	24	11	12	68	12	14	25	5	2	58			1			1	1					1
3	3	4	3		3	13	3	4	10	7	8	32	8	7	5			20	1	3	5			9
4							1		1	0	7	9	7	8	9	1		25	11	13	19			33
5									1	1	2	4	3	5	17	0		25	5	3	11			19
6										1	1	2	1		5	1		7	1	1	3	2		7
7											1	1			1	5	1	7				8	4	12
8																5	1	6				4	10	14
9																2	3	5				0	3	3
10																1	3	4				1	1	2
11																1	4	5				1	2	3
12																	6	6					0	0
13																	2	2					1	1
14																	0	0						
15																	1	1						

Table 42. Sample Statistics for Exchangeable Magnesium

Series	No. of obs.	Mean (m.e./ 100 g)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.0		0.5	1.9
Wo	20	1.9	0.1	0.7	2.6
Am	38	1.9	0.0	0.5	2.3
Co	16	1.8	0.1	0.3	1.0
Da	21	1.9	-0.1	0.6	2.5
All	114	1.9		0.5	2.7
			A_2 or A_3		
Wi	19	2.2		0.6	2.4
Wo	20	2.1	0.1	0.5	1.9
Am	38	2.5	-0.4	0.7	3.4
Co	16	2.8	-0.3	1.2	4.6
Da	21	3.7	-0.9**	1.4	4.9
All	114	2.6		1.0	6.1
			B_2 or B_{22}		
Wi	19	3.9		0.8	3.5
Wo	20	3.9	0.0	0.8	2.8
Am	38	4.6	-0.7*	1.0	4.8
Co	16	7.8	-3.2*	1.6	7.0
Da	21	11.0	-3.2*	2.0	8.8
All	114	6.0		3.0	13.0
			B_3		
Wi	19	4.4		0.8	3.3
Wo	20	5.0	-0.6**	0.6	3.0
Am	38	5.4	-0.4**	0.8	3.3
Co	16	7.6	-2.2*	1.1	4.9
Da	21	8.6	-1.0**	1.6	6.7
All	114	6.0		1.8	11.0

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Mean exchangeable magnesium values of the A_2 or A_3 horizon were 2.2, 2.1, 2.5, 2.8, and 3.7 m.e./100 g. for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. The difference between the means of the Concord and Dayton samples was significant. Since the mean cation exchange capacities of each of the samples was about the same for the A_2 or A_3 horizon, the mean percentage magnesium saturation varied between samples. The mean magnesium saturation values were about 15, 14, 15, 17, and 24 per cent for the five samples in the usual order of listing.

Mean exchangeable magnesium values of the B_2 horizon were 3.9, 3.9, 4.6, 7.8, and 11.0 m.e./100 g. for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. Mean magnesium saturation values were about 19, 21, 23, 30, and 36 per cent in the same order. Magnesium saturation varies between soils, whereas calcium saturation does not.

The exchangeable magnesium data showed the same trends in the B_3 horizon as they did in the B_2 horizon. Both the m.e./100 g. values and the percentage magnesium saturation values increased as the soil was more poorly drained. The mean exchangeable magnesium values were 4.4, 5.0, 5.4, 7.6, and 8.6 m.e./100 g. for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. All differences between means of adjacent pairs of samples were significant. The mean percentage magnesium saturations, in the same order, were approximately 21.0, 25.0, 25.0, 33.0, and 37.0.

Potassium. Potassium was the third most abundant exchangeable metallic cation in nearly all horizons of all five series' samples. The B_2 horizon of the Dayton sample had slightly more exchangeable sodium than potassium. The frequency distributions for exchangeable potassium values are tabulated in Table 43.

A very noticeable feature of the frequency distributions is the wide range of values they have for the Willamette, Woodburn, and Amity samples in the upper two horizons. Also, Willamette's frequency distribution for the B_2 horizon is noticeably wider than those of the other soils. The wide spread of these distributions was probably caused by sampling sites which had been recently fertilized with potassium. The continuation of the wide spread into deeper horizons reflects the high degree of mobility of potassium. The highly mobile nature of the exchangeable potassium was very noticeable in the potassium data for one of the individuals that was sample in an old barn site. The barn had been moved to permit construction of an electrical line tower at the proper interval. The exchangeable potassium values for this individual were 3.8, 2.9, 2.4, and 1.8 m.e. /100 g. for the A_1, A_3, B_2, and B_3 horizons, respectively.

Table 43. Frequency Distributions for Exchangeable Potassium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

K me/100 g	A_1 or A_p						A_2 or A_3						B_2						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
0.1			1	1	11	13		2	2	5	10	11											1	1
0.2		3	6	14	7	30		3	16	9	11	39		6	6			12			4	3	8	15
0.3	1	5	12	0	2	20	2	3	12	2		19	2	4	22	14	14	56	5	13	26	13	12	69
0.4	1	1	6	1	1	10	2	3	2			7	5	4	8	2	6	25	6	6	7			19
0.5	1	0	3			4	4	3	2			9	3	3	1		1	8	3		0			3
0.6	4	3	3			10	3	4	2			9	3	1	1			5	2		0			2
0.7	2	1	3			6	3	0	0			3	0	0				0	3		1			4
0.8	1	2	1			4	0	0	1			1	3	1				4						
0.9	2	2	0			4	3	0	0			3	1					1						
1.0	1	1	2			4	0	1	1			2	0					0						
1.1	4	0	0			4	1					1	0					0						
1.2	0	0	0			0	0					0	1					1						
1.3	0	1	1			2	0					0	1					1						
1.4	0					0	1					1												
1.5	0					0																		
1.6	1					1																		
2.0	1					1																		

None of the other individuals had potassium values higher than 0.7 m.e./100 g. in the B_3 horizon. The potassium data for this individual were not used in the statistical analysis.

The sample means for exchangeable potassium are listed in Table 44. The Willamette series had significantly more exchangeable potassium than the Woodburn series for all four horizons. The only other significant difference between means of adjacent pairs was the one between the Amity and Concord series in the A_1 or A_p horizon. Amity's mean was significantly greater than Concord's mean. The exchangeable potassium values had been confounded by dissimilar fertilizer practices among the series. The better drained series had more fertilized individuals than the poorly drained series.

The mean exchangeable potassium values were slightly lower in the A_2 or A_3 horizon than they were in the A_1 or A_p horizon for each series. The mean values were also lower in the B_2 horizon than they were in the A_2 or A_3 horizon for the Willamette and Woodburn series, but they were higher in the B_2 horizon than they were in the A_2 or A_3 horizon for the Concord and Dayton series. The poorly drained soils had about the same amounts of exchangeable potassium in the B_3 horizon as the moderately well and imperfectly drained soils. This phenomenon is a departure

Table 44. Sample Statistics for Exchangeable Potassium Values

Series	No. of obs.	Mean (m.e./ 100 g)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	0.87		0.41	1.65
Wo	19	0.56	0.31**	0.31	1.04
Am	38	0.44	0.12	0.26	1.12
Co	16	0.21	0.23*	0.08	0.36
Da	21	0.17	0.04	0.09	0.31
All	113	0.40		0.42	1.88
			A_2 or A_3		
Wi	19	0.66		0.28	1.14
Wo	19	0.42	0.24*	0.23	0.92
Am	38	0.32	0.10	0.18	0.89
Co	16	0.18	0.14	0.06	0.22
Da	21	0.14	0.04	0.06	0.14
All	113	0.34		0.23	1.33
			B_2 or B_{22}		
Wi	19	0.62		0.29	1.00
Wo	19	0.38	0.24*	0.16	0.61
Am	38	0.33	0.05	0.18	0.35
Co	16	0.32	0.01	0.04	0.16
Da	21	0.34	-0.02	0.05	0.23
All	113	0.39		0.21	1.13
			B_3		
Wi	19	0.47		0.14	0.44
Wo	19	0.33	0.14*	0.04	0.16
Am	38	0.32	0.01	0.08	0.50
Co	16	0.30	0.02	0.04	0.12
Da	21	0.27	0.03	0.02	0.21
All	113	0.32		0.10	0.59

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

from the trends observed for calcium and magnesium, where it was noted that the amounts of exchangeable calcium and magnesium increased in the B_3 horizon as the degree of impeded drainage increased.

Sodium. Sodium was the least dominant of the exchangeable bases for these soils. The frequency distributions for exchangeable sodium are tabulated in Table 45.

The frequency distributions tend toward higher values in relation to depth for each of the series. They tend toward higher values in the B_2 horizon as the degree of impeded drainage increases.

The sample means for exchangeable sodium are presented in Table 46. The means for each sample had about the same magnitude in the A_1 or A_p and the A_2 or A_3 horizons. They were 0.15, 0.13, 0.16, 0.11, and 0.11 m.e./100 g. for the A_1 or A_p horizon; and 0.16, 0.14, 0.17, 0.12, and 0.13 m.e. /100 g. for the A_2 or A_3 horizon in the usual order of listing.

The exchangeable sodium means of the B_2 horizon were 0.23, 0.20, 0.24, 0.27, and 0.41 m.e./100 g. for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively.

Table 45. Frequency Distributions for Exchangeable Sodium Values of Four Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

K me/ 100 g	A_1 or A_p						A_2 or A_3						B_2 or B_{22}						B_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
.05	3	3	5	3	1	15	2	1	3		2	8	1					1						
.10	2	5	9	9	14	39	3	6	5	8	8	30	1	2	3			6	1					1
.15	5	5	5	1	4	20	5	7	10	5	7	34	4	7	5	4	2	22	3	4	5	1	1	14
.20	7	5	12	2	1	27	4	4	12	1	1	22	3	5	9	4	0	21	3	7	5	4	2	21
.25	2	2	5	1	0	10	4	2	3	1	1	11	6	3	7	2	2	20	2	0	7	4	3	16
.30			2		0	2	1		5	1	1	8	2	2	9	1	3	17	4	5	6	1	6	22
.35					1	1					1	1	0	1	5	1	6	13	1	3	14	2	3	23
.40													0			1	1	2	1	0	1	2	2	6
.45													0			1	2	3	1	1		0	3	5
.80													1			2	2	5	2			0	0	2
.55													1				2	3	0			2	1	3
.60																			1					1
1.45																	1	1						

Table 46. Sample Statistics for Exchangeable Sodium

Series	No. of obs.	Mean (m.e./ 100 g)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	0.15		0.07	0.19
Wo	20	0.13	0.02	0.06	0.22
Am	38	0.16	-0.03	0.07	0.25
Co	16	0.11	0.05*	0.05	0.20
Da	21	0.11	0.00	0.06	0.27
All	114	0.13		0.06	0.31
			A_2 or A_3		
Wi	19	0.16		0.07	0.22
Wo	20	0.14	0.02	0.05	0.19
Am	38	0.17	-0.03	0.07	0.25
Co	16	0.12	0.05*	0.06	0.20
Da	21	0.13	-0.01	0.07	0.29
All	114	0.14		0.06	0.29
			B_2		
Wi	19	0.23		0.12	0.48
Wo	20	0.20	0.03	0.07	0.26
Am	38	0.24	-0.04	0.07	0.25
Co	16	0.27	0.03	0.13	0.35
Da	21	0.41	-0.14**	0.26	1.29
All	114	0.27		0.15	1.39
			B_3		
Wi	19	0.32		0.20	0.88
Wo	20	0.25	0.07	0.09	0.32
Am	38	0.28	-0.03	0.08	0.27
Co	16	0.29	-0.01	0.13	0.40
Da	21	0.32	-0.03	0.11	0.41
All	114	0.29		0.08	0.88

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

Organic Carbon

The percentage of carbon is an estimate of the amount of organic matter in the soil. The product of the percentage of carbon and the factor 1.72 is expressed as the percentage of organic matter. This relationship is based on the assumption that the average soil organic matter is 58.0 per cent carbon. The results were expressed as percentage of carbon because they were also used to determine carbon-nitrogen ratios. The percentage of carbon was determined for the upper two horizons of each profile. The results of the determinations are summarized in Tables 47 and 48.

Table 47 shows the frequency distributions for the percentage of carbon of the Willamette, Woodburn, Amity, Concord, and Dayton samples. The distributions of the Willamette, Woodburn, Amity, and Dayton samples had wide ranges of values in the A_1 or A_p horizon. Each of these distributions had concentrations of individuals toward the lower end of their ranges of values, but each also had one or more individuals with disproportionally high values. Organic carbon values above 3.4 per cent invariably were from individuals that had never been cultivated. Furthermore, values over 4.1 per cent were from sites that had been recently burned. Charcoal and ash were observed in

Table 47. Frequency Distributions for Percentage of Organic Carbon of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Per cent carbon	A_1 or A_p						A_2 or A_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
0.2-0.3								1	3	2	10	16
0.4-0.5							6	3	11	4	3	27
0.6-0.7							2	4	6	4	5	21
0.8-0.9					1	1	5	5	2	4	1	17
1.0-1.1			1	2	6	9	1	3	6	2	1	13
1.2-1.3		1	2	1	4	8	2	0	4		1	7
1.4-1.5	1	2	3	2	3	11	3	3	1			7
1.6-1.7	1	3	3	0	2	9		0	3			3
1.8-1.9	4	2	4	3	1	14		0	2			2
2.0-2.1	3	4	6	3	1	17		1				1
2.2-2.3	1	0	4	2	0	7						
2.4-2.5	1	3	6	2	1	13						
2.6-2.7	2	1	3	1	1	8						
2.8-2.9	0	2	1		0	3						
3.0-3.1	1	0	2		0	3						
3.2-3.3	2	0	1		0	3						
3.4-3.5	1	1	1		0	3						
3.6-3.7	1	0	0		0	1						
3.8-3.9	0	0	0		0	0						
4.0-4.1	0	0	0		1	1						
4.2-4.3	1	0	1			2						
6.0-6.1		1				1						

Table 48. Sample Statistics for Percentage of Carbon

Series	No. of obs.	Mean (%)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	2.4		0.8	2.7
Wo	20	2.3	0.1	1.1	4.7
Am	38	2.2	0.1	0.6	3.1
Co	16	1.9	0.3	0.5	1.7
Da	21	1.6	0.3	0.7	3.2
All	114	2.1		0.8	5.1
			A_2 or A_3		
Wi	19	0.8		0.4	1.1
Wo	20	0.9	-0.1	0.4	1.8
Am	38	0.9	0.0	0.5	1.6
Co	16	0.7	0.2	0.3	0.8
Da	21	0.5	0.2*	0.3	1.0
All	114	0.8		0.4	1.9

* Significant difference at 5-per cent level.

these individuals. Most of the individuals with values less than 3.4 per cent carbon were from cultivated sites.

The individuals for each sample were spread over a lesser range of values in the A_2 or A_3 horizon than in the A_1 or A_p horizon. The trend of the frequency distributions within a horizon was toward lower values as the soil became more poorly drained, indicating that the percentage of organic matter in these soils decreased as they became more poorly drained.

The means and other statistics for the percentage of carbon are presented in Table 48. Sample mean carbon percentages for the A_1 or A_p horizon were 2.4, 2.3, 2.2, 1.9, and 1.6 for the Willamette, Woodburn, Amity, Concord, and Dayton samples. None of the differences between means of adjacent pairs was significant, although Dayton's mean was significantly lower than the means of the Willamette, Woodburn, and Amity samples.

Mean carbon percentages for the A_2 or A_3 horizon were 0.8, 0.9, 0.9, 0.7, and 0.5 for the five series' samples in the same order of listing as above. Dayton's sample mean was significantly lower than the means of the other soils.

Total Nitrogen

Total nitrogen percentage of the upper two horizons was determined so that the carbon-nitrogen ratios could be calculated. The frequency distributions and the sample means for the nitrogen percentages of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are presented in Tables 49 and 50.

The mean percentages of total nitrogen did not vary significantly between series' samples in either of the A horizons. The total nitrogen mean value for all individuals combined was 0.15 per cent in the A_1 or A_p horizon and 0.07 per cent in the A_2 or A_3 horizon.

Table 49. Frequency Distributions for Percentage of Nitrogen of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

Per cent nitrogen	A_1 or A_p						A_2 or A_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
.02-.03										1		1
.04-.05							9	5	11	3	12	40
.06-.07							4	4	10	2	5	25
.08-.09		3	1	1	1	6	4	6	5	9	2	26
.10-.11	3	2	5	1	6	17	2	2	4	1	2	11
.12-.13	7	2	5	3	5	22		2	3			5
.14-.15	2	4	4	1	4	15		0	5			5
.16-.17	6	1	8	4	2	21		0				0
.18-.19	1	2	9	4	1	17		1				1
.20-.21		4	3	1	0	8						
.22-.23		1	2	1	1	5						
.24-.25		0	1		0	1						
.26-.27		1			0	1						
.28-.29					0	0						
.30-.31					1	1						

Table 50. Sample Statistics for Percentage of Nitrogen

Series	No. of obs.	Mean (%)	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	0.14		0.02	0.09
Wo	20	0.16	-0.02	0.05	0.18
Am	38	0.16	0.00	0.04	0.16
Co	16	0.16	0.00	0.04	0.13
Da	21	0.14	0.02	0.05	0.22
All	114	0.15			
			A_2 or A_3		
Wi	19	0.06		0.02	0.06
Wo	20	0.08	-0.02	0.03	0.14
Am	38	0.08	0.00	0.03	0.11
Co	16	0.07	0.01	0.02	0.08
Da	21	0.06	0.01	0.02	0.07
All	114	0.07		0.02	0.15

The frequency distributions of the Willamette sample had the narrowest range of values of all the samples for total nitrogen percentage, while they had among the widest ranges of values for percentage of carbon.

Carbon-Nitrogen Ratios

Carbon-nitrogen ratios are among the values used to describe the nature of the organic matter. Generally, the organic matter in soils developed under native prairie vegetation has a narrower carbon-nitrogen ratio than the organic matter in soils developed under native forest vegetation. The carbon-nitrogen ratio has been found to be among the more constant parameters for characterizing soil organic matter of a particular climatic or vegetative zone.

The frequency distributions for the carbon-nitrogen ratios of four main horizons of the Willamette, Woodburn, Amity, Concord, and Dayton samples are tabulated in Table 51. Five of the individuals had carbon-nitrogen ratio values greater than 21 in the A_1 or A_p horizons. These individuals were all sampled from sites had had never been cultivated, and three of them were from sites that had been recently cleared and subsequently burned. Even if these five individuals are disregarded, the frequency distribution tabulations indicate that the carbon-nitrogen ratio tended to become narrower as the degree of impeded drainage increased.

The sample means for the carbon-nitrogen ratios are listed in Table 52. The carbon-nitrogen means in the A_1 or A_p horizon were 17.2, 14.5, 13.8, 12.1, and 11.1 for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. Woodburn's sample mean was significantly narrower than Willamette's sample mean, Concord's sample mean was significantly narrower than Amity's sample mean, and Dayton's sample mean was significantly narrower than Concord's sample mean.

The carbon-nitrogen ratio means were three to four

Table 51. Frequency Distributions for Carbon-Nitrogen Ratios of Two Horizons of Willamette, Woodburn, Amity, Concord, and Dayton Samples, and of All Individuals Combined

C-N ratio	A_1 or A_p						A_2 or A_3					
	Wi	Wo	Am	Co	Da	All	Wi	Wo	Am	Co	Da	All
4-5										1	6	7
6-7								1	4	3	6	14
8-9					1	1	2	4	15	6	5	32
10-11			2	5	14	21	5	8	11	5	4	33
12-13	1	12	22	9	6	50	1	5	8	1		15
14-15	4	5	10	1		20	8	2				10
16-17	7	1	2	1		11	3					3
18-19	4	0	0			4						
20-21	1	1	0			2						
22-23	1	0	0			1						
24-25	0	0	1			1						
26-27	0	1	1			2						
28-29	1					1						

Table 52. Sample Statistics for Carbon-Nitrogen Ratios

Series	No. of obs.	Mean	Dif. bet. means	Standard deviation	Range
			A_1 or A_p		
Wi	19	17.2		3.7	16
Wo	20	14.5	2.7**	3.5	14
Am	38	13.8	0.7	2.9	15
Co	16	12.1	1.7**	1.5	6
Da	21	11.1	1.0**	1.1	4
All	114	13.7		3.5	19
			A_2 or A_3		
Wi	19	13.0		2.4	8
Wo	20	10.7	2.3*	2.1	9
Am	38	9.8	0.9	1.9	7
Co	16	8.8	1.0	1.6	7
Da	21	7.2	1.6**	2.2	7
All	114	9.9		2.8	13

* Significant difference at 1-per cent level.
**Significant difference at 5-per cent level.

units smaller for each sample in the A_2 or A_3 horizon than they had been in the A_1 or A_p horizon. The means were 13.0, 10.7, 9.8, 8.8, and 7.2 for the five series' samples in the same order of listing as above. The differences between the means of the Willamette and Woodburn samples and between the Concord and Dayton samples were significant.

The values of the carbon-nitrogen ratios did not naturally differentiate the soils of the Willamette catena. The ratios tended to become narrower as the degree of impeded drainage increased, but they did so in a continuous manner so that there were no minima within the frequency distribution tabulation of all observations combined.

Discriminant Function Analysis

For all series. Significant differences between the mean values of the predetermined soil series were found for some of the morphological, chemical, and physical characteristics. One of these characteristics had been used to classify the 114 individuals into four natural drainage classes--that is, depth to evidence of impeded drainage. Others were directly related to the characteristics used as differentia, such as the percentage of clay in the B_2 horizon which was related to the texture, and Munsell color notations which were related to the degree of impeded drainage.

Certain of the characteristics associated with the degree of impeded drainage were statistically analyzed jointly to test their combined abilities for discriminating the individuals. Five characteristics that showed large differences between the means of the Willamette and Dayton samples, and consistent trends in relation to degree of impeded drainage were selected for the multiple characteristic analysis. They were (x_1) inches to evidence of impeded drainage (mottling), (x_2) dry hue of the A_2 or A_3 horizon, (x_3) dry chroma of the A_2 or A_3 horizon, (x_4) dry hue of the

B_2 horizon, and (x_5) dry chroma of the B_2 horizon.

The multiple characteristic analysis was performed by the discriminant function analysis method of Fisher (18, p. 179-188; 19, p. 376-386; and 20, p. 422-429). Fisher has shown that the discriminant function is that linear function which best discriminates predetermined populations when several characteristics are analyzed jointly (18, p. 179). The analysis is based on the assumptions that the characteristics follow a multivariate normal distribution, and that their variances are equal in all populations under consideration.

Any individual characterized by n measurements can be represented by a point in an n-dimensional space. The problem of classifying an observed collection of individuals from a mixed population of p groups is the same as the division of the n-dimensional space into p mutually exclusive regions. Discriminant function analysis simplifies the problem by reducing the n measurements to a single variate by using a linear compound of the several variables where the compounding coefficients are chosen to maximize the value of a statistic suitable for a single variate. The compounding coefficients are chosen to maximize the ratio of the mean square between the populations (mean square for regression) to the mean square within populations (mean square for error). This is equivalent to maximizing the ratio of the maximum difference of the compound variate (D) between p sample means to the estimated standard deviation within populations.

The discriminant function (X) is expressed as

$$X = b_1x_1 + b_2x_2 + \cdots\cdots b_nx_n,$$

where b_i = specific characteristic coefficient,

and x_i = value of specific characteristic.

The square of the maximum difference (D^2) in mean values of this compound for p samples is

$$(1) \qquad (b_1d_1 + b_2d_2 + \cdots\cdots b_nd_n)^2,$$

where d_i = maximum mean difference for a specific characteristic.

The variance (s^2) of the compound function is

$$(2) \qquad \sum_{i=1}^{m}\sum_{j=1}^{m} SS_{ij}b_ib_j,$$

where SS_{ij} = sums of squares or products within populations.

The coefficients are determined by maximizing the ratio of equation (1) to equation (2), which is equivalent to maximizing the ratio of the maximum difference between p sample means to the estimated standard deviation within populations.

According to Fisher (18, p. 181), the coefficients are proportional to solutions of the equations

$$SS_{11}b_1 + SS_{12}b_2 + \cdots\cdots SS_{15}b_5 = d_1$$

$$SS_{12}b_1 + SS_{22}b_2 + \cdots\cdots SS_{25}b_5 = d_2$$

$$SS_{13}b_1 + SS_{23}b_2 + \cdots\cdots SS_{35}b_5 = d_3$$

$$SS_{14}b_1 + SS_{24}b_2 + \cdots\cdots SS_{45}b_5 = d_4$$

$$SS_{15}b_1 + SS_{25}b_2 + \cdots\cdots SS_{55}b_5 = d_5 .$$

The sums of squares and products of the five characteristics related to degree of impeded drainage are listed in Table 53.

The above equations were solved simultaneously by inverting the matrix of the sums of squares and products. The resultant solutions of the equations gave the matrix of multipliers reciprocal to the matrix of the sums of squares and products. The matrix of multipliers is presented in Table 54.

The coefficients (b_i) were obtained by multiplying each column of the matrix of multipliers by the observed maximum differences between means. The means for each series and the maximum difference of the means between series are presented in Table 55. Some of the means for hue have negative numbers because the 10 YR hue was assigned the value 0.0, and any hues redder than that were assigned corresponding negative values. For example, 9.87 YR was

Table 53. Sums of Squares and Products, within Soil Series, for Five Characteristics of Willamette, Woodburn, Amity, Concord, and Dayton Samples

	Depth to mottling	Dry hue, A_2 or A_3	Dry chroma, A_2 or A_3	Dry hue, B_2	Dry chroma, B_2
Depth to mottling	2635.00	-62.46	36.39	-23.15	19.22
Dry hue, A_2 or A_3	-62.46	35.24	-12.05	8.48	-1.46
Dry chroma, A_2 or A_3	36.39	-12.05	27.63	-6.26	9.97
Dry hue, B_2	-23.15	8.48	-6.26	22.31	-9.65
Dry chroma, B_2	19.22	-1.46	9.97	-9.65	14.36

Table 54. Matrix of Multipliers Reciprocal to the Sums of Squares and Products, within Series

	Depth to mottling	Dry hue, A_2 or A_3	Dry chroma, A_2 or A_3	Dry hue, B_2	Dry chroma, B_2
Depth to mottling	0.0003994	0.0006751	-0.0000834	-0.0000593	-0.0004478
Dry hue, A_2 or A_3	0.0006751	0.0404671	0.0212263	-0.0193291	-0.0245157
Dry chroma, A_2 or A_3	-0.0000834	0.0212263	0.0599464	-0.0117786	-0.0472656
Dry hue, B_2	-0.0000593	-0.0193291	-0.0117786	0.0726389	0.0551056
Dry chroma, B_2	-0.0004478	-0.0245157	-0.0472656	0.0551056	0.1375921

Table 55. Observed Means for Five Characteristics of the Willamette, Woodburn, Amity, Concord, and Dayton Samples and Their Greatest Differences

	Wi	Wo	Am	Co	Da	Difference(d) (Wi-Da)
Depth to mottling	45.3	28.4	17.8	6.8	4.6	40.7
Dry hue A_2 or A_3	-0.13	-0.10	-0.04	0.34	1.14	-1.27
Dry chroma, A_2 or A_3	3.34	3.26	2.98	2.51	2.29	1.05
Dry hue, B_2	-0.18	-0.05	0.01	0.44	0.86	-1.04
Dry chroma, B_2	3.55	3.51	3.21	2.85	2.65	0.90

equivalent to −0.13.

The resultant coefficients were $b_1 = 0.0150$, $b_2 = -0.0036$, $b_3 = 0.0030$, $b_4 = -0.0162$, and $b_5 = 0.0298$. The coefficient for dry chroma of the A_2 or A_3 horizon (b_3) was assigned unity and the resultant discriminant function was

$$X = 5.03x_1 - 1.20x_2 + x_3 - 5.43x_4 + 10.00x_5.$$

The discriminant function index value (X) was determined for each of the 114 individuals. The results of the analysis are presented as frequency histograms in Figure 3.

This compound function consisting of five measurements related to the degree of impeded drainage apparently discriminated the observations according to natural drainage class. The index values ranged from 5 to 345. The most poorly drained individuals had the highest values. The poorly drained Concord and Dayton individuals had index values between 5 and 84. The imperfectly drained Amity individuals had index values between 96 and 150. The moderately well-drained Woodburn individuals had index values between 153 and 216, and the well-drained Willamette individuals had index values between 215 and 345. One Willamette individual had an index value that barely overlapped with Woodburn's range of values.

The soils are segregated according to drainage class, to be sure, but of even more importance for the objective of this study is the tendency for the frequency to be at a minimum at or near the limiting values of the ranges of index values for each of the drainage classes. The soils of the Willamette catena appear to be segregated into four natural groups that are separated from the neighboring groups by minima within the frequency distribution histogram for this compound linear function.

The minimum at 215 index units does not exactly correspond with the class boundary between the moderately well and the well-drained soils as they were defined for this study. Two of the 20 Woodburn individuals are within the natural group comprised of the Willamette individuals. Perhaps it would be advisable to redefine these classes so that all well-drained soils from this catena would have index values greater than 210, and moderately well-drained soils would have index values less than 210.

The minima in the discriminant function histograms reflect the minima in the depth to evidence of impeded drainage histogram. The differences between the relative distributions for depth to evidence of impeded drainage and for discriminant function indices can be seen by comparing Figures 2 and 3. Both plots have the same gross appearance. Differences between the distributions within drainage classes are apparent, however. For example, the 12

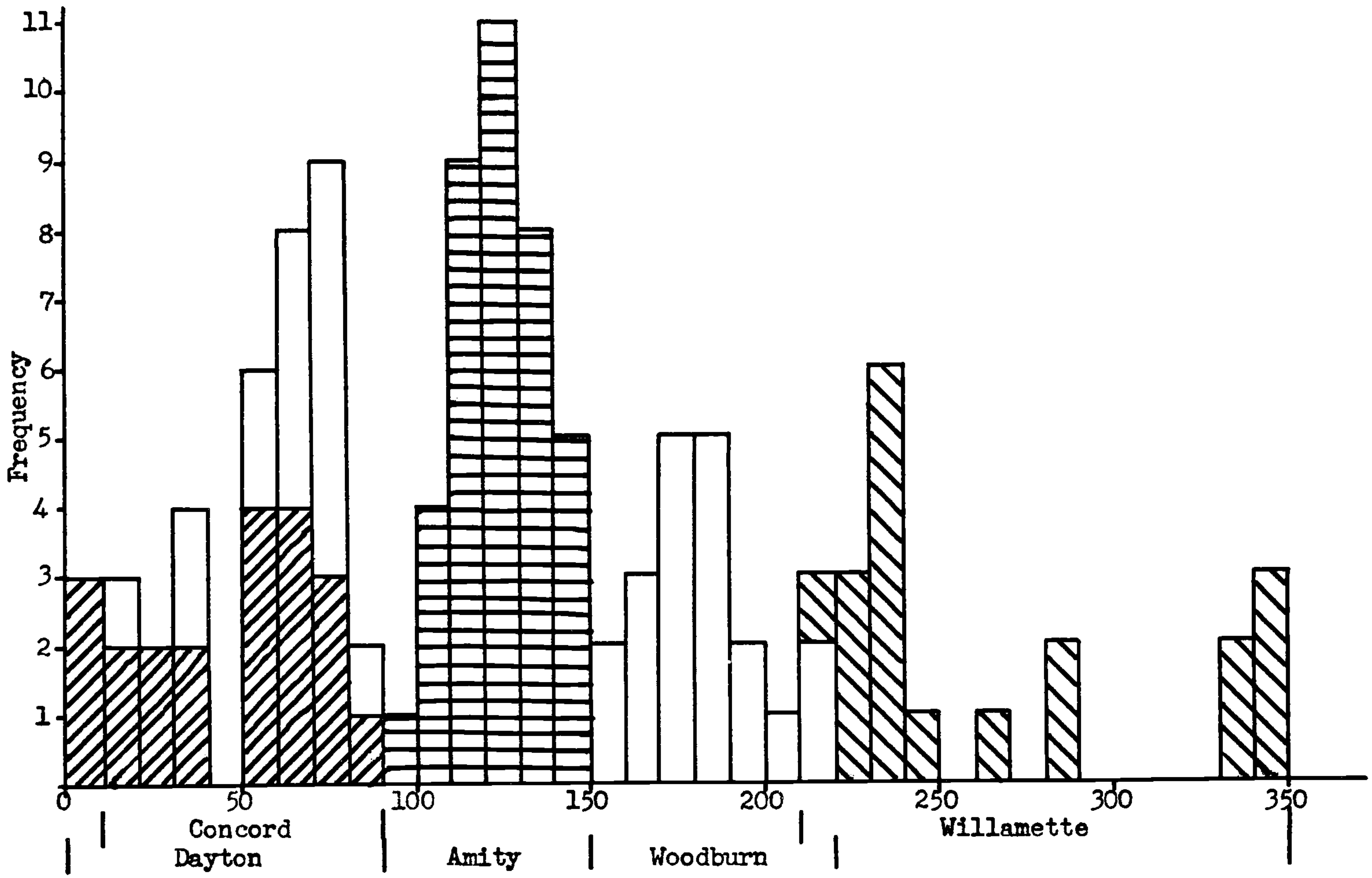

Figure 3. Frequency histograms for discriminant function values of the observations of the five soil series of the Willamette catena.

individuals with zero depth to evidence of impeded drainage were spread over 40 discriminant function indices, because of variations in hue and chroma. The five Willamette individuals assigned the value of 60 inches to depth of evidence of impeded drainage were spread over 20 discriminant function index values for the same reason. The maxima of the Amity and Woodburn samples are better defined in the discriminant function histogram than they are in the depth to evidence of impeded drainage histogram.

Depth to evidence of impeded drainage obviously influenced the value of the discriminant function indices more than the four color characteristics. It had a range of values of 60 inches, whereas hue and chroma had ranges of 3 to 4 units for any one horizon. The maximum difference between the means was 40.7 inches for depth to evidence of impeded drainage, while it was only 1.05 units for chroma of the A_2 or A_3 horizon (Table 55). The one difference is 40 times that of the other. Depth to evidence of impeded drainage also had a much greater variance than the other characteristics, however. Subsequently, its coefficient for the compound function was only five times greater than the coefficient for dry chroma of the A_2 or A_3 horizon.

Depth to evidence of impeded drainage was originally used as the differentiating characteristic for classifying these soils into four natural drainage classes. What then was the advantage of using a compound function for discriminatory purposes that included a variable that was differentiating by itself? The compound function permitted an evaluation of the kind of frequency distribution these soils have when several characteristics are considered collectively. The results of the determination indicated that the Willamette catena soils are naturally grouped into four bell-shaped or Gaussian distributions. They also indicated that the arbitrary limit imposed between the moderately good and good drainage classes did not correspond with the natural limit.

For Concord and Dayton series. A second discriminant function was used to discriminate the Concord and Dayton individuals. Six characteristics were selected that had significant mean differences between the two series. They were (x_1) percentage of clay of the B_2 horizon, (x_2) percentage of silt of the B_2 horizon, (x_3) dry value of the A_1 or A_p horizon, (x_4) dry value of the A_2 or A_3 horizon, (x_5) distinctness of the B_2 to the above horizon boundary, and (x_6) pH of the B_3 horizon.

The means and the differences between the means of each series are presented in Table 58. The matrices of the sums of squares and products and of the multipliers reciprocal to the sums of squares or products are presented in Tables 56 and 57, respectively. The discriminant

Table 56. Sums of Squares and Products, within Series, for Six Characteristics of Concord and Dayton Samples

	Per cent clay B_2	Per cent silt B_2	Dry value, A_1 or A_p	Dry value, A_2 or A_3	B_2 to above hor. bound. thickness	pH, B_3
Per cent clay, B_2	416.94	-244.83	24.20	13.57	6.93	10.58
Per cent silt, B_2	-244.83	760.67	-14.04	-20.87	-22.55	-24.17
Dry value, A_1 or A_p	24.20	-14.04	8.79	7.26	-2.96	2.91
Dry value, A_2 or A_3	13.57	-20.87	7.26	11.43	-2.14	3.03
B_2 to above horizon boundary thickness	6.93	-22.55	-2.96	-2.14	13.81	1.02
pH, B_3	10.58	-24.17	2.91	3.03	1.02	5.29

Table 57. Matrix of Multipliers Reciprocal to the Sums of Squares and Products, within Species

	Per cent clay B_2	Per cent silt B_2	Dry value, A_1 or A_p	Dry value, A_2 or A_3	B_2 to above hor. bound. thickness	pH, B_3
Per cent clay, B_2	0.0036996	0.0010925	-0.0153338	0.0060271	-0.0026532	0.0030871
Per cent silt, B_2	0.0010925	0.0019502	-0.0046594	0.0037366	0.0017130	0.0068180
Dry value, A_1 or A_p	-0.0153338	-0.0046594	0.3363081	-0.1708679	0.0521780	-0.0878145
Dry value, A_2 or A_3	0.0060271	0.0037366	-0.1708679	0.1993341	-0.0015599	-0.0148611
B_2 to above horizon boundary thickness	-0.0026532	0.0017130	0.0521780	-0.0015599	0.0898453	-0.0320002
pH, B_3	0.0030871	0.0068180	-0.0878145	-0.0148611	-0.0320002	0.2770021

Table 58. Observed Means for Six Characteristics of the Concord and Dayton Samples and Their Differences

	Per cent clay B_2	Per cent silt B_2	Dry value, A_1 or A_p	Dry value, A_2 or A_3	B_2 to above hor. bound. thickness	pH, B_3
Concord	29.1	45.7	4.93	5.61	2.00	6.41
Dayton	40.3	41.5	5.27	6.10	0.59	6.70
Difference (Concord - Dayton)	-11.2	4.2	-0.34	-0.49	1.41	-0.29

function coefficients were $b_1 = -0.0394$, $b_2 = -0.0039$, $b_3 = 0.2211$, $b_4 = -0.0896$, $b_5 = 0.1559$, and $b_6 = -0.0945$. After assigning unity to the coefficient for the percentage of silt of the B_2 horizon (b_2), the discriminant function (X) was

$$X = 9.98x_1 + x_2 - 56.07x_3 + 22.70x_4 - 39.52x_5 + 23.97x_6.$$

The results of the discriminant function analysis for the Concord and Dayton samples are presented in Figure 4.

The Concord and Dayton individuals are indeed discriminated by these six characteristics when considered collectively. All the Concord individuals had index values below 330, and all the Dayton individuals had index values above 350.

Furthermore, the two groups appear to be separated by a minimum at the index value of 340. Thus it might be concluded that the Concord and Dayton series are natural groupings.

None of the six characteristics used in this compound function had significant minima between the Concord and Dayton samples when analyzed separately. Five of them had ranges of values that overlapped between the two samples. Values of percentage of clay of the B_2 horizon did not overlap between the series, but they were not discontinuous between the series, either.

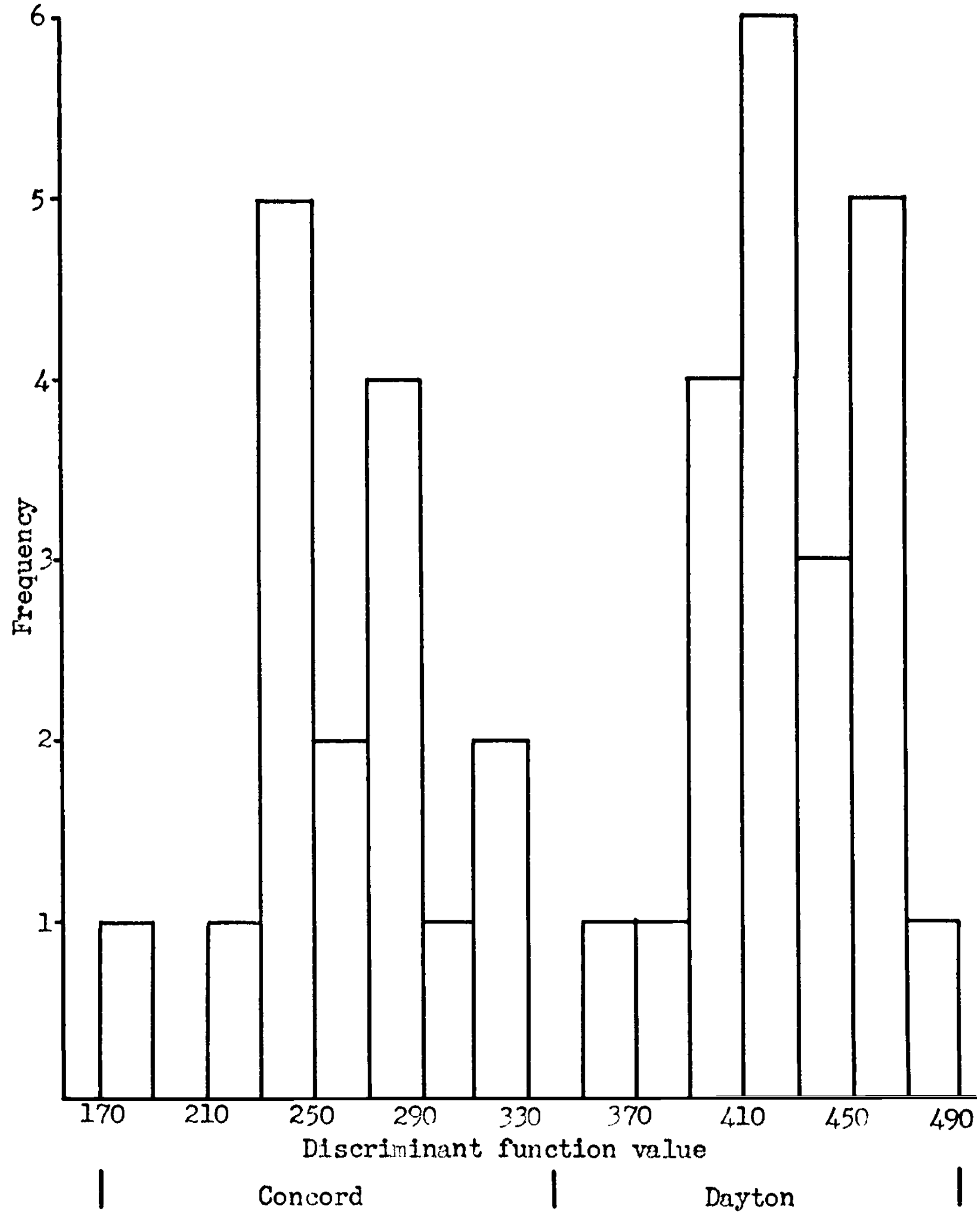

Figure 4. Frequency histograms for discriminant function values of the Concord and Dayton observations.

Granted, this evidence for natural groupings is based on a relatively small number of individuals. There were only 16 Concord individuals and 21 Dayton individuals. The histograms for each series show frequencies within one interval of discriminant function values that is less than the frequencies in surrounding intervals. In other words, neither histogram has a well-pronounced maximum. A larger sample is needed to more precisely determine the exact pattern of frequency distribution these soils have according to values of the discriminant function described previously.

Summary Analysis of Series Means

During the statistical analysis of the means for the various morphological, chemical, and physical characteristics, it was noted that the differences between means of adjacent series of the catena (that were ranked according to the degree of impeded drainage) showed trends in relation to the degree of impeded drainage for many of the characteristics. Some characteristics had average values that became greater as the soil became more poorly drained, and others showed the opposite trend. The means of the characteristics that had definite trends, and which were significantly different between at least one adjacent pair of series, were studied to see the relative difference of each with respect to the mean of the Willamette series.

The Willamette sample mean was selected as a basis of comparison, simply because it was an end member of the drainage sequence. The relative degree of difference of each series' mean with respect to Willamette's mean was expressed as the ratio of a specific series' mean to the mean of Willamette's sample. The ratios are summarized in Table 59.

The ratios indicate the proportionate difference of each series' mean for a specific characteristic from the mean of the Willamette series. For example, the average depth to mottling for the Dayton sample was only one-tenth that of the Willamette sample, and Concord's individuals had a mean exchangeable magnesium content in the B_2 horizon that was twice that of the Willamette sample mean.

The ratios were also examined in composite to see relative differences between series when the means were considered collectively. Two kinds of summations were made of the ratios. First, the ratios within each series were merely added. The sums are shown in Table 59. As would be expected, little difference was observed between series because of the conflicting upward and downward trends that were present among the means.

For the second summation, 1.0 was subtracted from each ratio. The differences were positive if the ratio had been

Table 59. Summary Analysis of Some of the Characteristics Expressed as the Ratio of the Mean Value of Each Series' Sample to the Mean Value of the Willamette Sample

Characteristic	Ratio of dissimilarity from the Willamette sample				
	Wi	Wo	Am	Co	Da
Depth to mottling	1.00	0.63	0.39	0.15	0.10
Per cent clay, B_2	"	0.86	0.95	1.17	1.62
Per cent silt, B_2	"	1.06	1.04	1.02	0.93
Per cent sand, B_2	"	1.03	0.98	0.83	0.60
Dry value, A_1 or A_p	"	0.98	0.98	1.07	1.18
Dry value, A_2 or A_3	"	0.94	0.98	1.12	1.22
Dry value, B_2	"	1.00	1.04	1.14	1.14
Dry value, B_3	"	1.00	1.00	1.12	1.12
Dry chroma, A_1 or A_p	"	1.00	0.93	0.86	0.89
Dry chroma, A_2 or A_3	"	1.00	0.91	0.76	0.70
Dry chroma, B_2	"	0.97	0.89	0.78	0.73
Dry chroma, B_3	"	1.00	1.00	0.94	0.94
Dry hue, A_1 or A_p	"	0.96	1.00	1.00	1.60
Dry hue, A_2 or A_3	"	0.96	1.04	1.17	1.46
Dry hue, B_2	"	1.04	1.08	1.26	1.49
Dry hue, B_3	"	0.96	1.00	1.04	1.08
Hor. thickness, B_2	"	0.68	0.73	0.68	0.85
Hor. thickness, B_1 B_2	"	0.63	0.72	0.81	0.75
Solum thickness, to B_3	"	0.82	0.85	0.89	0.83
Bound. thickness					
B_2 to above hor.	"	0.88	0.94	0.62	0.19
B_2 to B_3	"	0.53	0.59	0.28	0.22
A to B (B_1 or B_2)	"	1.15	0.96	0.81	0.51
M. consistence, A_1 or A_p	"	0.80	0.73	0.93	1.00
M. consistence, A_2 or A_3	"	0.74	0.68	0.68	0.63
W. consistence, B_2	"	1.00	1.00	1.50	1.80
Struc. size, B_2	"	0.85	0.93	1.66	2.06
Struc. grade, A_2 to A_3	"	0.95	0.95	0.85	0.75
Struc. grade, B_2	"	0.76	0.76	1.04	1.12
pH, A_1 or A_2	"	1.00	0.96	0.91	0.89
pH, A_2 or A_3	"	1.04	1.02	0.96	0.96
pH, B_2	"	1.07	1.07	1.07	1.11
pH, B_3	"	1.07	1.11	1.14	1.20
C. E. Cap., A_1 or A_p	"	1.01	0.99	0.93	0.83
C. E. Cap., B_2	"	0.93	1.00	1.30	1.54

Table 59 cont.

Characteristic	Ratio of dissimilarity from the Willamette sample				
	Wi	Wo	Am	Co	Da
C. E. Cap., B_3	1.00	0.97	1.01	1.10	1.11
Per cent base sat, A_1 or A_p	"	0.94	0.86	0.69	0.74
Per cent base sat, A_1 or A_3	"	1.04	1.02	0.90	1.09
Per cent base sat, B_2	"	1.04	1.08	1.16	1.20
Per cent base sat, B_3	"	1.04	1.07	1.16	1.17
Exch. Ca., A_1 or A_p	"	0.94	0.85	0.60	0.57
Exch. Ca., A_2 or A_3	"	1.12	1.16	0.97	1.05
Exch. Ca., B_2	"	0.96	1.07	1.36	1.54
Exch. Ca., B_3	"	0.98	1.05	1.16	1.12
Exch. Mg., A_2 or A_3	"	0.95	1.14	1.27	1.68
Exch. Mg., B_2	"	1.00	1.18	2.00	2.82
Exch. Mg., B_3	"	1.14	1.23	1.73	1.96
Exch. K, A_1 or A_p	"	0.64	0.51	0.24	0.19
Exch. K, A_2 or A_3	"	0.64	0.48	0.27	0.21
Exch. K, B_2	"	0.62	0.53	0.52	0.55
Exch. K, B_3	"	0.70	0.68	0.64	0.57
Exch, Na, A_2 or A_3	"	0.88	1.06	0.75	0.81
Per cent C, A_1 or A_p	"	0.96	0.92	0.79	0.67
Per cent C, A_2 or A_3	"	1.12	1.12	0.88	0.62
C-N ratio, A_1	"	0.84	0.80	0.70	0.64
Sum	55.00	50.64	50.77	52.06	54.90
Adjusted sums*					
a) positive no.	0.00	0.97	1.59	5.76	10.48
b) negative no.	0.00	-5.33	-5.81	-8.70	-10.58
Total difference (a-b)	0.00	6.30	7.40	14.46	21.06
Difference between pairs		-6.30	-1.10	-7.06	-6.60

*The sum of the indices after subtracting 1.0 from each.

greater than 1.0, and negative if it had been less than 1.0. Then the positive and negative numbers were added separately. These sums are also shown in Table 59. Willamette's net value was zero in both instances, naturally. Positive trending characteristics increased proportionately more between the Amity and Dayton series than they did between the Willamette and Amity series. Negative trending characteristics increased proportionately more between the Willamette and Woodburn series than they did between other series.

The negative sums were next subtracted from the positive sums to obtain the over-all difference between the means of each series from that of Willamette's mean and to see the relative differences between series. These final differences for each series might be considered as the total index of dissimilarity from the Willamette series. The values are 0.00, 6.30, 7.40, 14.46, and 21.06 for the Willamette, Woodburn, Amity, Concord, and Dayton samples, respectively. The degree of dissimilarity increased progressively as the degree of impeded drainage increased. However, the increase was not evenly distributed between the series. Amity's index of 7.40 was only 1.10 units greater than Woodburn's index. The increases between the total indices of the other series were all greater than 6.00 units. It is apparent that the difference in total character was less between the Woodburn and the Amity series than it was between the other series.

CONCLUSIONS

The results of this investigation provide evidence that the soil individuals of the Willamette catena population are naturally separated into five groups according to minima within frequency distribution tabulations for certain characteristics or combinations of characteristics.

Significant minima were found in the frequency distribution tabulations for the four characteristics: (1) depth to evidence of impeded drainage, (2) cation exchange capacity of the B_2 horizon, (3) base saturation of the B_3 horizon, and (4) exchangeable magnesium of the B_3 horizon.

The frequency distribution tabulation for the depth to evidence of impeded drainage had three significant minima that separated the total sample into four natural groups. The minima very nearly coincided with the arbitrary depth limits used to classify the soils into four natural drainage classes. If the observed minima are not refuted by further investigation, it would seem advisable to use the values at which the minima occurred to define the limits of the depth to evidence of impeded drainage for the natural drainage classes in this catena.

The frequency distribution tabulations for the cation exchange capacity of the B_2 horizon, and for the exchangeable magnesium of the B_3 horizon each had one minimum which separated the total sample into two natural groups. In both instances, the minima very nearly segregated all of the poorly drained Concord and Dayton observations from the better drained, Willamette, Woodburn, and Amity individuals.

Natural groupings among these soils were also indicated by the results of the discriminant functions analysis.

The total sample was segregated into four groups by three minima within the frequency distribution tabulation for the compound linear function comprised of the five variables: (1) depth to evidence of impeded drainage, (2) dry hue of the A_2 or A_3 horizon, (3) dry chroma of the A_2 or A_3 horizon, (4) dry hue of the B_2 horizon, and (5) dry chroma of the B_2 horizon. The three minima segregated all but two of the individuals according to drainage class. Two of the 20 moderately well-drained Woodburn individuals occurred in the natural group containing the well-drained Willamette individuals.

The poorly drained Concord and Dayton individuals were segregated into two natural groups by a discriminant function comprised of the six variables: (1) percentage clay of the B_2 horizon, (2) percentage silt of the B_2 horizon, (3) dry value of the A_1 or A_p horizon, (4) dry value of the A_2 or A_3 horizon, (5) thickness of the boundary between the B_2 horizon and the overlying horizon, and (6) pH of the B_3 horizon.

The evidence presented here for natural groupings of soils suggests that a large proportion of the recognized soil series are in reality natural grouping. The soil series may not appear to be naturally separated from neighboring soil series according to any one characteristic. However, if the distribution of the individuals from a mixed population of several series could be visualized in n-dimensional space (where n is the number of definitive characteristics), it is probable that the dispersion of points throughout the space would not be uniform. Certain planes within the space would probably have smaller numbers of points than other planes. These planes would mark the boundaries between natural groupings of soils. The existence of just such groupings among the individuals of one mixed population was suggested in this study by discriminant functions, which in effect reduced the n-dimensional space to one dimension by replacing the several measurements by a suitably chosen linear compound.

One of the several characteristics used in each of the discriminant functions had non-overlapping ranges of values between the series. It is only natural that the compound function should segregate the series according to non-overlapping ranges of discriminant function index values. A discriminant function containing only variables with overlapping ranges between populations would probably not completely discriminate between populations. Discriminant functions are best for classifying individuals when they contain the variables that differ the most in mean values between populations. Discriminant functions were not used in this study for specifically assigning individuals to one or two or more groups. They were used, instead, to show the frequency distribution pattern for combinations of characteristics.

The discriminant function has a refined mathematical basis, and is the best linear compound function for classification when the selected variables are multivariate normal and the variance is the same within populations. However, it has limitations as far as practical application is concerned. The means and variances in the probability distributions used to determine the coefficients are usually not known. The only solution is to obtain their best estimates from a sample and substitute them for the unknown values in setting up the discriminant function. The reliability of the estimates depends upon the sample's representation of the population and the accuracy of the measurements made on each of the sample units.

It seems plausible to assume that most of the variability found in the Willamette catena population was represented by the sample used in this study. The sample was obtained from a transect covering one-sixth of the linear extent of the population. All of the dominant series mapped throughout the Willamette Valley on the Willamette Silt deposit were represented by the sample. The tendency for the frequency to be at a minimum at both extremes of the frequency distribution tabulations for each of the characteristics suggests that at least a large central segment of the population was represented by the sample, if not the whole population. The proportionate amounts of each series are not known for the population, but the proportions of the series in the sample are roughly commensurate with the proportions mapped in Marion County. The relative amounts of the series represented by the sample were 17, 19, 32, 14, and 18 per cent for the Willamette, Woodburn, Amity, Concord, and Dayton series, respectively. The relative proportions of the series mapped in Marion County are approximately 43 per cent for the Willamette and Woodburn series combined; and 42, 7, and 8 per cent for the Amity, Concord, and Dayton series (42, p. 12).

The accuracy of the measurements made on some of the morphological characteristics may be questioned because of its dependence upon the perceptiveness and judgement of the observer. One observer made all of the morphological measurements to the best of his ability according to the standards and definitions of the Soil Survey Manual (43, 503 pp.). Any errors made in the measurements requiring personal judgement presumably should have had magnitudes of comparable size for all of the individuals. Therefore, the errors could have either cancelled themselves or they could have been consistently additive among the sample units. In either case the errors should not have greatly influenced the shapes of the frequency distribution patterns for the various characteristics, and thus not influenced the conclusions concerning natural groupings.

To be sure, a larger sample, randomly selected from throughout the Willamette Valley, would have made estimates of the means and variances more reliable and permitted a better evaluation of the frequency distribution patterns. Additional studies should be conducted to test the validity of the possible minima found in the frequency distributions for some of the characteristics by this study. If these minima can be verified, it is also suggested that future investigations be conducted to explain the reasons why the minima occur where they occur.

Recognition of the presence of natural groupings within the population of soils can make soil classification a more exacting science. Groups of soil individuals can truly be considered natural entities. If the natural groupings are homogeneous enough for practical use objectives, care must be exercised in defining classes to avoid making class separations at points not representing natural limits. Arbitrary separation of classes at values other than natural limits would result in the separation of like things and possibly the grouping of unlike things. Some natural groupings may be too heterogeneous for certain practical use objectives. It may be necessary to separate these into arbitrary classes that are homogeneous enough for the objectives.

The problems facing the pedologists concerning soil classification are not reduced by recognition of the presence of natural groupings within the soil population. The classes must be defined according to such parameters as mean values and ranges of values of the distinguishing characteristics whether they are natural or arbitrary. Actually, recognition of natural soil groupings challenges the pedologist with the additional tasks of determining whether existing series are naturally segregated from neighboring series, of redefining them if they are not, and of locating the natural limiting values between soil groupings in areas where the soils have not been classified. To meet these challenges, pedologists should make greater use of the statistical methods at their disposal which combine the information of several characteristics for classification purposes, and make possible the evaluation of the relative amount of information provided by each of the several characteristics for differentiation.

BIBLIOGRAPHY

1. Alban, L. A. and Mildred Kellogg. Methods of soil analysis as used in the OSC soil testing laboratory Corvallis, Oregon State College, 1959. 9 p. (Oregon. Agricultural Experiment Station. Miscellaneous paper 65)

2. Ableiter, J. K. Soil classification in the United States. Soil Science 67:183-191. 1949.

3. Ableiter, J. K. Trends in soil classification and correlation at the series level. Soil Science Society of America Proceedings 14:320-322. 1950.

4. Allison, I. S. Glacial erratics in the Willamette Valley. Geological Society of America Bulletin 48:615-632. 1935.

5. Baldwin, Mark. et al. Soil classification. In: U. S. Department of Agriculture. Soils and men; the Yearbook of Agriculture, 1938. p. 979-1001.

6. Brown, I. C. and J. Thorp. Morphology and composition of some soils of the Miami family and the Miami catena. Washington, 1942. 53 p. (U. S. Dept. of Agriculture. Technical Bulletin 834)

7. Bushnell, T. M. Some aspects of the catena concept. Soil Science Society of America Proceedings 7:466-476. 1942.

8. Cline, M. G. Principles of soil sampling. Soil Science 58:275-288. 1944.

9. Cline, M. G. Basic principles of soil classification. Soil Science 67:81-91. 1949.

10. Cramer, Harold. The elements of probability theory. New York, John Wiley, 1955. 281 p.

11. Crawford, D. V. Some observations on the classification of soil types. Journal of Soil Science 1:156-162. 1950.

12. Curtis, J. T. and R. P. McIntosh. An upland forest continum in the prairie forest border region of Wisconsin. Ecology 32:476-496. 1949.

13. Curtis, J. T. A prairie continuum in Wisconsin. Ecology 36:558-566. 1955.

14. Davidson, D. T. and R. L. Handy. Property variations in the Peorian loess of southwestern Iowa. Iowa Academy of Science Proceedings 59:248-265. 1952.

15. Davis, F. L. A study of the uniformity of soil types and the fundamental differences between the different soil series. Auburn, Alabama polytechnic institute, 1936. 153 p. (Alabama. Agricultural experiment station. Bulletin 244)

16. Felts, W. M. Geology of the Lebanon quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1936. 83 numb. leaves.

17. Felts, W. M. Analysis of Willamette Valley fill (abstract). In: Geological Society of America Proceedings 1935. New York, Geological Society of America, 1936. p. 346.

18. Fisher, R. A. The use of multiple measurements in taxonomic problems. Annals of Eugenics 7:179-188. 1938.

19. Fisher, R. A. The statistical utilization of multiple measurements. Annals of Eugenics 8:376-386. 1938.

20. Fisher, R. A. The precision of discriminant functions. Annals of Eugenics 10:422-429. 1940.

21. Harradine, F. F. The variability of soil properties in relation to stage of profile development. Soil Science Society of America Proceedings 14:302-310. 1949.

22. Hutton, C. E. Studies of the chemical and physical characteristics of a chrono-litho-sequence of loess-derived prairie soils of southwestern Iowa. Soil Science Society of America Proceedings 15:318-324. 1950.

23. Jenny, Hans. Factors of soil formation. New York, McGraw Hill, 1941. 281 p.

24. Jenny, Hans. Arrangement of soil series and types according to functions of soil forming factors. Soil Science 61:375-391. 1946.

25. Jenny, Hans. Role of the plant factor in the pedogenic functions. Ecology 39:5-16. 1958.

26. Jeyaseelan, K. N. and B. C. Matthews. Chemical properties of southern Ontario soils. Canadian Journal of Agricultural Science 36:394-400. 1956.

27. Kellogg, C. E. Soil classification. Introduction. Soil Science 67:77-80. 1949.

28. Kilmer, Victor J. and Lyle T. Alexander. Methods of making mechanical analyses of soils. Soil Science 68:15-24. 1949.

29. Lapham, Macy H. Variations permissible with the soil series. In: Report of the eighth annual meeting of the American soil survey association. Ames, Iowa, American soil survey association, 1928. p. 59-64 (Bulletin 9)

30. Li, Jerome C. R. Introduction to statistical inference. Ann Arbor, Edwards Brothers, 1957. 553 p.

31. MacLean, A. J. and R. A. Summerly. A study of the variability of certain chemical properties of soils. Canadian Journal of Agricultural Science 25:221-230. 1945.

32. Marbut, C. F. Soil classification. In: Report of the second annual meeting of the American association of soil survey workers. Madison, Wisc. American Association of Soil Survey Workers, 1922. p. 24-32. (Bulletin 3)

33. Mill, John Stuart. Philosophy of scientific method. New York, Hofner, 1950. 461 p.

34. Milne, G. Some suggested units of classification and mapping, particularly for East African soils. Soil Research 6:183-198. 1935.

35. Piper, Arthur M. Ground-water resources of the Willamette valley, Oregon. Washington, 1942. 194 p. (U. S. Dept. of the Interior. Water-supply paper 890)

36. Riecken, F. F. and G. D. Smith. Lower categories of soil classification: family, series, type, and phase. Soil Science 67:107-115. 1949.

37. Robinson, G. W. Some considerations on soil classification. Journal of Soil Science 1:150-155. 1950.

38. Russell, J. S. and H. F. Rhoades. Water table as a factor in soil formation. Soil Science 82:319-328. 1956.

39. Schollenberger, C. J. and R. H. Simon. Determination of exchange capacity and exchangeable bases in soils. Soil Science 59:13-24. 1945.

40. Simonson, Roy W. Lessons from the first half century of soil survey. 1. Classification of soils. Soil Science 74:249-257. 1952.

41. Tedrow, J. C. F. Influence of topography and position on classification of soils having impeded drainage. Soil Science 71:429-437. 1951.

42. Torgerson, E. F. and T. W. Glassey. Soil Survey of Marion County, Oregon. Washington, 1927. 46 p. (U. S. Department of Agriculture. Bureau of Chemistry and Soils. Soil survey no. 32)

43. U. S. Department of Agriculture. Soil survey manual. Washington, 1951. 503 p. (Its Handbook no. 18)

44. U. S. Department of Commerce. Weather bureau. Climatological data. Oregon 62(13):207-222. 1957.

45. Walkley, Allan and I. A. Black. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29-38. 1934.

46. Wells, Edward L. Climate of Oregon. In: U. S. Department of Agriculture. Climate and man; the Yearbook of Agriculture, 1941. p. 1075-1086.

47. Whiteside, E. P. Changes in the criteria used in soil classification since Marbut. Soil Science Society of America Proceedings 18:193-195. 1954.

48. Williams, Lynn. Soil survey descriptive legend for Marion county, Oregon. Stayton, Soil Conservation Service, 1955. 138 p. (Mimeographed).

49. Whittaker, R. H. Vegetation of the Great Smoky mountains. Ecological Monographs 26:1-80. 1956.

50. Youden, W. J. and A. Mehlich. Selection of efficient methods for soil sampling. Boyce Thompson Institute for Plant Research Contributions 9:59-70. 1937.