MORPHOLOGY AND GENESIS OF THE CONDON, MORROW, AND WALLA WALLA SERIES OF THE MID-COLUMBIA BASIN, OREGON

by

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MORPHOLOGY AND GENESIS OF THE CONDON, MORROW, AND WALLA WALLA SERIES OF THE MID-COLUMBIA BASIN, OREGON

INTRODUCTION

This investigation is concerned with the characterization of the Condon, Morrow, and Walla Walla soil series. These soils have presented problems in classification because their profiles developed with apparent uniformity of climate and other soil forming factors are similar. Wide ranges in easily recognized morphological features are not present as an aid to identification and classification. Differences in management and land capability for crop production are recognized nevertheless. This investigation was undertaken to determine factors that would help explain the characteristics and assist in the proper differentiation of these soils.

The soil series concerned in this study comprise the majority of the cultivated soils in the three counties included in the Mid-Columbia Basin area of Oregon. Approximate soil areas and location of experimental sites are indicated in figure 1. Previous studies have been conducted on the Walla Walla soils mainly in Washington but no previous work of this nature has been reported on the Morrow and Condon series. Detailed soil surveys have not been published of the area. Morphology descriptions are included for profiles representing typical and intergrade examples of the series, appendix A. Physical and chemical properties of the soils are noted by horizons. Conclusions are presented characterizing the soil series based on the interpretation of results from the profiles studied.

The purpose of this investigation was to:

1. Describe the field morphology of the Condon, Morrow, and Walla Walla soil series in the Mid-Columbia Basin area of north central Oregon.

2. Determine the physical and chemical characteristics of the soils.

3. Evaluate the source of parent materials.

4. Determine the relative influence of the soil forming factors.

5. Establish the genetic relationship among the series.

6. Obtain information concerning moisture relationships.

7. Correlate water permeability with observed soil characteristics.

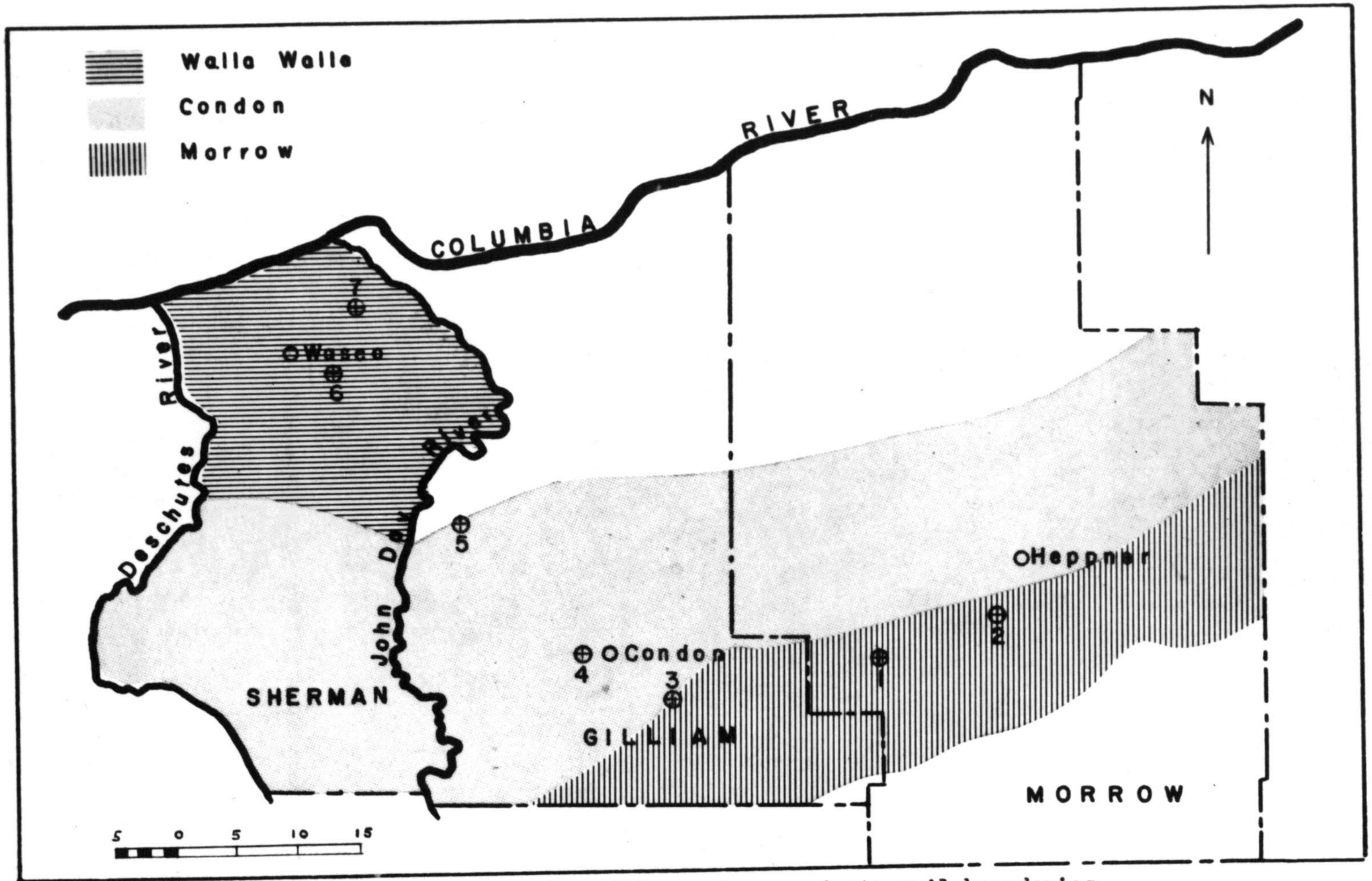

Fig. 1. Location of profiles and approximate soil boundaries

CHARACTERISTIC FEATURES OF THE AREA AND SOILS

Area

The Mid-Columbia Basin area is entirely within the Columbia Plateau physiographic province (3, p. 12). It is part of the Columbia Basin and has been described by Allison (1, pp. 3-6) as an irregular structural and topographic basin underlain by middle Tertiary basalt flows that have been depressed below sea level in the Pasco area and upwarped on the flanks of the surrounding mountains. The portion in north central Oregon includes a plateau incised by canyons, rolling upland, and a low plain of sand and gravel. Native vegetation over most of the area consists of bunchgrass and shrubs. The area is considered as semi-arid, with about 75 per cent of the land in crops. A typical farm on the rolling upland consists of tracts of crop land farmed to alternate wheat and fallow and separated from each other by canyons, steep slopes, or rocky outcrops, which are used mainly for pasture.

Soils

The Condon series was described by the Division of Soil Survey near Condon, Oregon in 1939 as comprising friable, shallow Chestnut soils developed from loess overlying basalt bedrock. The soils are in a semiarid microthermal climate with a mean annual precipitation of about 10 to 14 inches, a mean annual temperature of 47 to 52 degrees Fahrenheit, moderate snow, and fairly dry summers. The surface soils range in color from grayish brown to dark grayish brown and the subsoils from brown to light yellowish brown. They are shallower to lime and basalt bedrock than the Walla Walla soils and are distinguished from the Morrow soils by their more friable and coarser-textured subsoils.

Harper et al. (15, pp. 28-29) described the Morrow silt loam soils in Umatilla County, Oregon as shallow to the underlying basalt bedrock with good surface drainage. The surface layer is friable, grayish brown in color, and the subsoil to an average depth of 18 inches is grayish brown or brown. Below 18 inches the color is brown, the texture is heavier, and prismatic structure is distinct. The soil covers extensive areas of undulating to gently rolling uplands.

Harper et al. (15, pp. 112-114) also described the Walla Walla soils in Umatilla County, Oregon as occupying a great belt of semi-arid upland plains and being developed from loess under a cover largely of bunchgrass. The outstanding characteristics of this soil are remarkable uniformity of texture throughout, soft floury consistence, and lack of definite structure. The accumulation of organic matter in the two upper layers and the concentration of lime below 60 inches constitute the main evidence of soil development. Surface soils are grayish brown to dark brown and the subsoils are lighter in color. The surface has fine granular structure and the lower horizons indistinct coarse prismatic structure. The soil is slightly acid to about 16 inches and below that depth it is

alkaline. This series is commonly more than 6 feet deep to bed-
rock, with the greatest depths on north and east slopes.

FIELD PROCEDURES

A reconnaissance study of the soils in situ was conducted during the summer of 1954 over a five county area in order to determine the characteristics of the soils as mapped, to locate soil boundaries, and to evaluate broad differences due to relief. Experimental sites were selected in Morrow, Gilliam, and Sherman counties to represent typical and intergrade examples of the Morrow, Condon, and Walla Walla soil series, figure 1. All locations were in cultivated fields, on rolling upland except Walla Walla profile number 6 that was on a plateau with a uniform 6 per cent slope facing to the north. Pits were excavated at each site to expose the soil in cross section. Field morphology relationships are presented in the results section. A detailed description of each soil profile is given in appendix A. Samples for laboratory work were collected from each horizon.

Disturbed Samples

Soil samples were collected in the field from the middle portion of each horizon of the profile. The samples were air-dried in the laboratory, crushed, passed through a 2 mm. sieve, and stored. In most cases particles larger than 2 mm. were negligible, however when present, they were screened and weighed.

Undisturbed samples

Six replicate three inch cores of each horizon sampled for permeability were taken with the Uhland sampler. Six replicate two inch cores were also taken from each horizon in all profiles with a modified Pomona sampler for bulk density and moisture-tension measurements.

LABORATORY PROCEDURES

Physical Determinations

Mechanical analysis: The method described by Kilmer and Alexander (21, pp. 15-24) was used to obtain the particle size distribution of each horizon sample. Insulated jackets or a constant temperature room were employed to maintain constant temperature throughout the sedimentation cylinders used for the clay and silt analyses.

Bulk density: Natural core samples were dried to constant weight in a forced-air oven and weighed. Bulk density in grams per cubic centimeter was calculated on the basis of oven dry weights of known cylinder volumes.

Water permeability: The method described by Uhland (52, p. 362) was used.

Moisture-tension: The moisture-tension relationships for the undisturbed samples were obtained by determining the equilibrium moisture content at tensions of 1/10, 1/3, 1/2, and 1 atmosphere. The moisture-tension values for the disturbed samples were obtained at tensions of 2, 5, 10, and 15 atmospheres. The pressure plate apparatus was used for tensions of one atmosphere or less, and the pressure-membrane unit for tensions above one atmosphere. The procedure and equipment has been described by Richards (35, pp. 451-454, 36, pp. 105-110, 37, pp. 487-490, and 38, pp. 95-112), and later by Richards and Wadleigh (39, pp. 93-99).

Chemical Soil Analyses

Cation exchange capacity: The method of Schollenberger and Simon (42, pp. 14-17) was used but with the following modifications. Instead of sodium chloride, tenth normal hydrochloric acid was used to displace the ammonia and the distillate was caught in a saturated boric acid solution and titrated with standard sulfuric acid.

Exchangeable cations: Calcium, magnesium, potassium, and sodium were determined separately with a Beckman Model B flame photometer. In samples containing carbonates of calcium and magnesium, the exchangeable calcium and magnesium were obtained by the difference between the sum of the exchangeable sodium and potassium and the total cation exchange capacity, and are reported as exchangeable calcium plus magnesium, (53, p. 20).

Saturation extracts: These were prepared according to the method used in the U. S. Salinity Laboratory (53, pp. 84-88).

Soluble sodium: This was determined on an aliquot of the saturation extract using a Beckman Model B flame photometer.

Electrical conductivity: Measurements were made on an aliquot of the saturation extract using a Solu-Bridge-Soil tester, Model RD-26.

Organic matter: A modification of the Walkley-Black method (61, pp. 29-38 and 60, pp. 251-263) used in the Oregon State College soil testing laboratory was used. Sodium fluoride and ferrous ammonium sulfate were used in place of phosphoric acid and ferrous sulfate respectively.

Total nitrogen: The Kjeldahl method was used.

Alkaline-earth carbonates: The acid neutralization method described by the U. S. Salinity Laboratory was used (53, p. 105).

Exchangeable hydrogen: This was calculated as the difference between the sum of the exchangeable cations and the exchange capacity (32, p. 12).

Soil reaction: The soil reaction, expressed in pH units, was determined with a glass electrode on a saturated paste that has been allowed to set for an hour with occasional stirring (34, pp. 97-104).

The analytical experimental error of physical and chemical determinations were as follows. Mechanical analysis: results are the average of duplicate determinations that varied less than 2 per cent by weight of the total soil samples less than 2 mm. in diameter. Bulk density: results are the average of 6 replicate determinations that deviated less than 0.07 gm./cc. from the mean. Water permeability: results are the average of 6 replicate determinations. The highest and lowest rates deviated 0.51, 0.36, and 0.25 inches per hour from the mean in samples 12 to 14, 0.30, 0.22, 0.28, and 0.10 in samples 311 to 314, 0.12 in sample 318, 0.16, 0.45, and 0.26 in samples 421 to 423, and 0.18, 0.42, 0.06, and 0.11 in samples 637 to 640 respectively. Moisture content at various tensions: results are the average of duplicate determinations that varied less than 1.75 per cent moisture by volume. All results of chemical soil analyses are the average of duplicates that varied less than 0.4 me./100 gm. of soil for cation exchange capacity, 0.04, 0.03, and 0.50 for exchangeable potassium, sodium, calcium and magnesium respectively; 0.04% by wt. for organic matter; 0.001% by weight for total nitrogen; 0.1 pH unit for soil reaction.

RESULTS AND INTERPRETATION OF DATA

Field Morphology Relationships

The A_p horizons of the Morrow and Condon profiles in this study are friable, soft and slightly hard silt loams of granular structure. Thin, medium platy, plowpan layers are common at about 6 inches depth. The Walla Walla soil profiles studied are friable, soft to slightly hard loam or very fine sandy loam of crumb or granular structure. Colors in Morrow and Condon center around grayish brown (10YR 5/2) when dry; dark brown (10YR 3/3) in Walla Walla P_6 and dark grayish brown (10YR 4/2) in Walla Walla P_7. Moist colors are predominately very dark brown (10YR 2/2) in all soils. The lower boundaries range from abrupt and smooth in Morrow to gradual in the Walla Walla. A thin massive crust about 1/16 inch thick commonly covers the surface of the cultivated Morrow and Condon soils but is absent in the Walla Walla soils under similar land use.

Transitional A_3 horizons were described in profiles 3, 4, 6, and 7. The texture, consistence, and moist color of these horizons are like those of the corresponding A_p horizons. The structure is generally weak prismatic. The clay content is greater than in the A_p horizon in all cases and represents the maximum accumulation in profile 7.

More than one subdivision of the B horizon was observed in all profiles. Maximum clay accumulation and development of prismatic structure occurs in these horizons except in profile 7. Colors center around brown (10YR 5/3) when dry, or dark brown (10YR 4/3) when moist, but there is variation from these colors to those of chips adjacent on the Munsell chart. The texture is silt loam with the exception of the silty clay loam B_{21} horizon of Morrow profile 1, loam in Walla Walla profile 6, and very fine sandy loam in Walla Walla profile 7. Consistence is mostly friable when moist but ranges from soft to hard when dry. Thin clay flows and gray coatings appear on Morrow aggregates, but no distinct clay flows or gray coatings were noted in the Walla Walla profiles. Boundaries are abrupt or clear in profiles 1, 2, 3, and 4; gradual in profiles 5, 6, and 7. Continuous bands, approximately 1/2 inch thick, darker colored than the soil mass, are faintly visible running in a roughly horizontal direction in the upper part of the Morrow B horizon.

C horizons were noted in all soils except the Morrow. Free carbonates are present often in the form of lime threads. These horizons are all friable and mostly soft with massive structure. The texture is silt loam in profiles 3, 4, and 5, loam in profile 6, and very fine sandy loam in profile 7. The colors center around pale brown (10YR 6/3) when dry, or brown (10YR 5/3) when moist.

Basalt bedrock noted in profiles 1, 2, 3, and 4 is characteristically coated with lime. The coating is thicker on the undersides of the loose fragments.

Numerous fine basalt fragments, 1 to 2 millimeters in diameter, are mixed throughout all horizons of the Morrow and Condon soils, profiles 1 to 5. Medium size fragments 2 to 5 millimeters in diameter are also present but less numerous. The Walla Walla soils, profiles 6 and 7, do not contain preceptible amounts of basalt fragments.

Plowpans were observed in the lower 1/2 inch of the A_p horizon in profile 2, upper 1/2 inch of the A_3 horizon in profiles 3, 4, and 6, and in the upper 1/2 inch of the B_2 horizon in profile 5.

The depth of soil to bedrock is deeper on the northeast slopes at these profiles sites than soil immediately adjacent on the southwest slopes. This exposure effect is apparent at all profile sites even though the actual depth to bedrock was never ascertained in profiles 6 and 7. Depths to bedrock at 4 to 6 feet is common under soils on southwest slopes adjacent to profiles 6 and 7.

Extreme end locations of the experimental profile sites, figure 1, extend over an east-west direction of approximately 60 miles. Distance south from the Columbia River is 44, 45, 42, 33, 21, 11 and 6 miles for profile sites number 1 to 7 respectively.

The preceding section relating to field morphology relationships was summarized from data included in the profile descriptions, appendix A.

Morrow Silt Loam - Profile Number 1

Physical properties: Particle size distribution as obtained by mechanical analysis is summarized in table 1. A definite increase in the total clay fraction occurs in the B_{21} horizon as shown graphically in figure 2. The pronounced accumulation of clay to a maximum followed by an abrupt decrease is more evident in this profile than others of the sequence. This accumulation of clay together with the observation of clay flows, as noted in the field morphology description, appendix A, indicates clay migration and the formation of a textural B horizon. Silt is the predominant size fraction, comprising about 60 per cent of the total separates. A uniform relation between the coarse and fine silt, table 2, combined with a relatively slight variation in the percentage of very fine sand of the total sample within the profile indicates textural uniformity of the parent material. The bulk density of this profile increases slightly with depth with a corresponding decrease in total pore space.

Chemical properties: Results of chemical determinations on this profile are summarized in table 3. The total cation exchange capacity varies markedly in the profile but appears to vary as a function of the total clay content. The ratio of total cation exchange capacity to percent clay is uniformally 0.9 to 1.0 me./gm. of clay. The highest exchange capacity and total clay per cent of any solum horizon in this sequence are expressed in the B_{21} horizon

Table 1. Particle size distribution of the horizons of Morrow silt loam, P_1 (in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
26	A_p	0-8	0.3	0.5	0.9	8.6	11.5	27.0	33.3	17.8
27	B_{21}	8-13	0.2	0.5	0.5	5.1	9.5	23.5	28.2	32.4
28	B_{22}	13-21	0.6	0.9	0.5	3.3	10.8	25.1	36.7	22.0

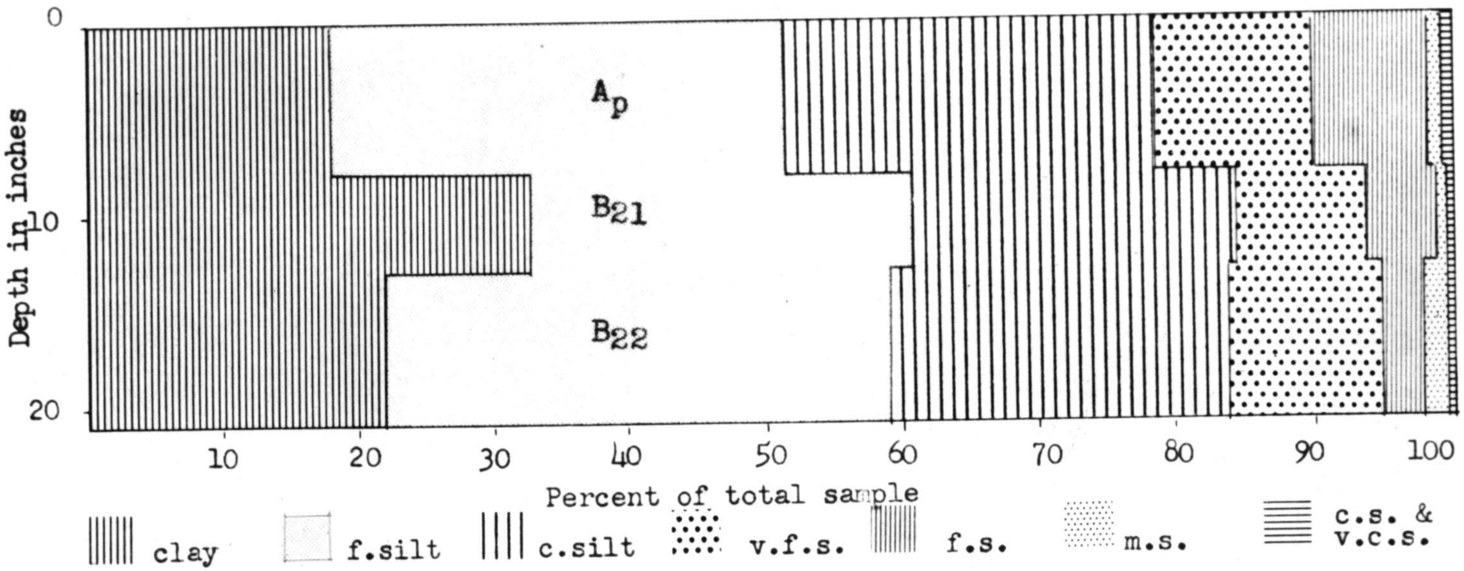

Fig. 2. Particle size distribution of Morrow silt loam -P 1

Table 2. Physical properties of the horizons of Morrow silt loam, P_1

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Moisture at saturation % by weight
26	A_p	0-8	53.6	1.23	2.3	2.9	0.8	0.17	33.0
27	B_{21}	8-13	51.3	1.29	2.5	3.0	0.8	0.12	39.9
28	B_{22}	13-21	49.8	1.33	2.3	3.4	0.7	0.14	41.1

Table 3. Chemical properties of the horizons of Morrow silt loam, P_1

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na	K	Ca Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
					me./100 g.							
26	A_p	0-8	6.1	15.4	0.04	0.76	14.6	0	100	0.2	4.9	0.05
27	B_{21}	8-13	7.3	28.6	0.45	0.93	27.2	0	100	1.6	3.2	0.13
28	B_{22}	13-21	7.5	22.9	0.52	0.64	21.7	0	100	2.3	2.8	0.14

Table 3 Con't. Chemical properties of the horizons of Morrow silt loam, P_1

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Electrical Conductivity mmhos/cm @ 25° C	Total Soluble Salts ppm
26	A_p	0-8	1.84	0.081	13.2	0.21	48
27	B_{21}	8-13	1.46	0.073	11.6	0.54	151
28	B_{22}	13-21	1.20	0.064	10.9	0.50	144

of this profile. Exchange positions are saturated with bases in all horizons with exchangeable calcium and magnesium comprising the bulk of the cations. The exchangeable potassium percentage decreases from 4.9 per cent in the surface to 2.8 per cent in the B_{22} horizon, with the largest decrease occurring in the upper part of the profile. Exchangeable sodium percentage increases with depth to a maximum of 2.3 per cent in the lowest horizon. The graph in figure 3 shows that the content of organic matter decreases gradually with depth and exhibits only a 0.6 per cent decrease from top to bottom of the profile. Total nitrogen, figure 3, shows a similar pattern of decrease with depth in the profile. The pH increases from pH 6.1 in the A_p to pH 7.5 in the B_{22} horizon that contains the equivalent of 1.8 per cent calcium carbonate.

Morrow Silt Loam - Profile Number 2

Physical properties: Particle size distribution, table 4 and figure 4, shows a fairly marked increase in the clay content of the B horizon. The rate of increase to the maximum accumulation in the B_{22} horizon as well as the decrease following the maximum is pronounced. Silt is the predominant size fraction in the profile and includes approximately 60 per cent of the separates. The ratio of coarse silt to fine silt is uniform, table 5, and is consistently less than 1. This constant ratio together with the small variation among the horizons in the content of the per cent very fine sand fraction of the total sample indicates textural uniformity of the

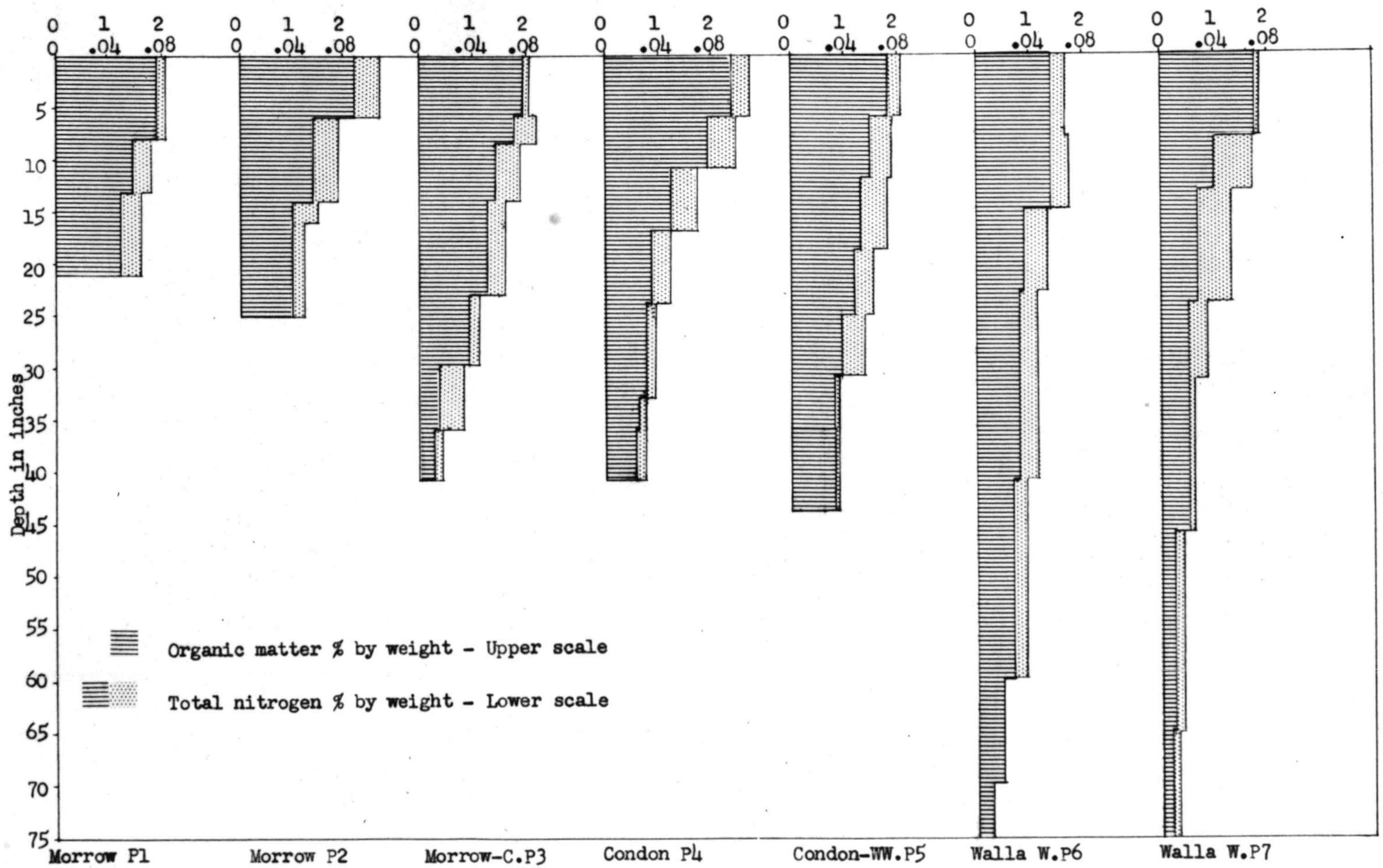

Fig. 3. Distribution of organic matter and total nitrogen with depth in profile

Table 4. Particle size distribution of the horizons of Morrow silt loam, P_2
(in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
11	A_p	0-6	0.6	0.4	0.5	5.1	8.5	30.0	37.0	17.8
12	B_{21}	6-14	0.3	0.6	0.6	4.3	8.8	27.9	34.8	22.7
13	B_{22}	14-16	0.7	0.8	0.6	3.3	9.2	28.0	34.1	23.3
14	B_{23}	16-25	1.4	2.0	1.0	3.5	11.2	24.6	34.1	22.2

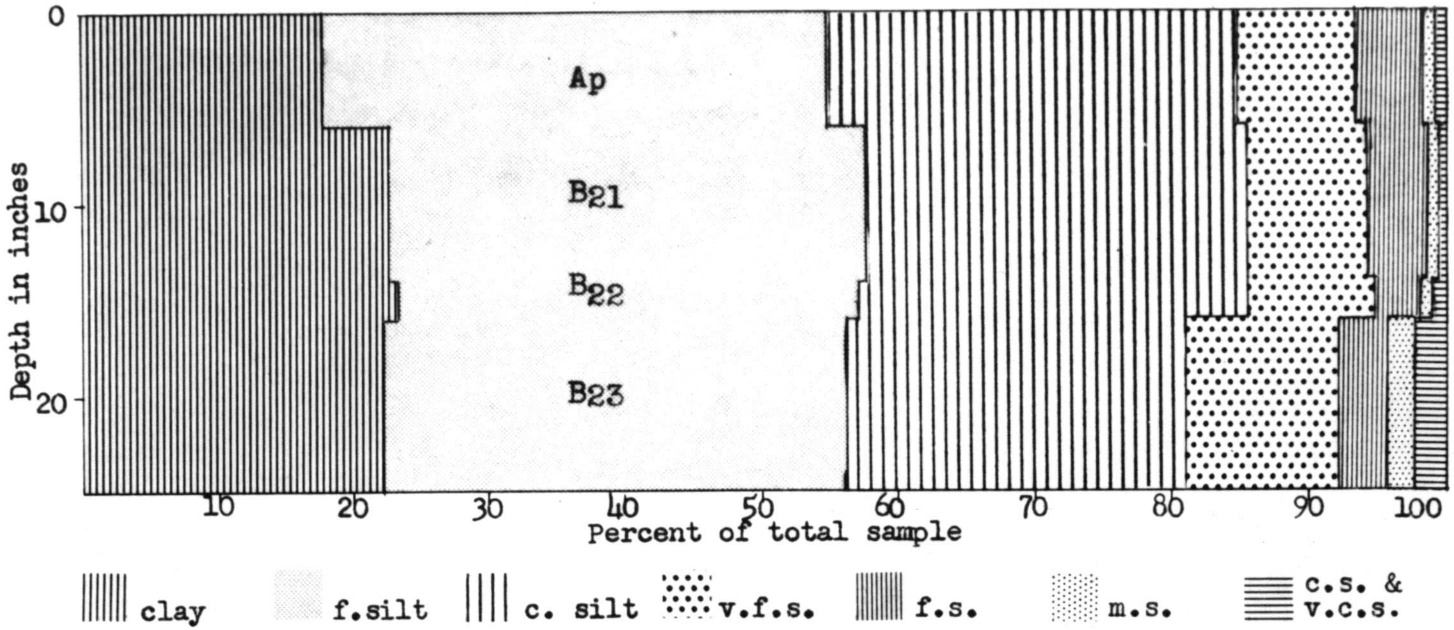

Fig.4. Particle size distribution of Morrow silt loam - P2

Table 5. Physical properties of the horizons of Morrow silt loam, P_2

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Water perme-ability inches/hour	Moisture at saturation % by weight
11	A_p	0–6	53.6	1.23	3.5	4.3	0.8	0.20	—	35.0
12	B_{21}	6–14	49.8	1.33	3.2	3.9	0.8	0.17	1.66	45.0
13	B_{22}	14–16	49.4	1.34	3.1	3.7	0.8	0.18	1.45	39.0
14	B_{23}	16–25	50.6	1.31	2.2	3.0	0.7	0.17	0.32	36.5

parent material. With the exception of the A_p horizon, that is disturbed annually by tillage implements, the bulk density is uniform throughout the profile.

Chemical properties, table 6: The total cation exchange capacity varies somewhat in the profile. It is a minimum in the surface and reaches a maximum in the B_{22} that is also the horizon of greatest clay accumulation. The ratio of exchange capacity to per cent clay is uniformally 0.9 to 1.0 me./gm. of clay throughout the profile. Exchangeable calcium and magnesium occupy the majority of the exchange positions that are completely saturated with bases in all horizons except the A_p. The exchangeable potassium percentage of the total cation exchange capacity shows only a slight decrease with depth. Exchangeable sodium percentage increases from none in the A_p to 3.4 per cent in the B_{23} horizon. Organic matter content, figure 3, is fairly high in the A_p horizon, and decreases with depth in the profile. Total nitrogen, figure 3, also decreases with depth and in about the same proportion as organic matter so that the carbon-nitrogen ratio is fairly uniform within the profile. The pH increases from pH 6.1 in the A_p to pH 7.8 in the B_{23} horizon that contains the equivalent of 1.8 per cent calcium carbonate.

Morrow Silt Loam Grading to Condon Silt Loam - Profile Number 3

Physical properties: Table 7 and figure 5 show the particle size distribution by horizons in this profile. With increasing

Table 6. Chemical properties of the horizons of Morrow silt loam, P_2

Sample number	Horizon	Depth inches	Reaction pH	Exchange capacity me./100 g.	Exchangeable Cations Na me./100 g.	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
11	A_p	0-6	6.1	17.2	0.01	0.80	8.08	7.97	0.3	98	0.0	4.6	0.04
12	B_{21}	6-14	6.9	20.4	0.16	0.92	19.3		0	100	0.8	4.5	0.11
13	B_{22}	14-16	7.5	23.3	0.58	1.01	21.7		0	100	2.5	4.3	0.15
14	B_{23}	16-25	7.8	22.5	0.77	0.92	20.8		0	100	3.4	4.1	0.15

Table 6 Con't. Chemical properties of the horizons of Morrow silt loam, P_2

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Calcium Magnesium Ratio	Electrical Conductivity mmhos/cm 25°C	Total Soluble Salts ppm
11	A_p	0-6	2.20	0.109	11.7	1.0	0.32	78
12	B_{21}	6-14	1.37	0.076	10.5	—	0.40	126
13	B_{22}	14-16	1.13	0.061	10.8	—	0.55	150
14	B_{23}	16-25	0.99	0.051	11.4	—	0.60	153

Table 7. Particle size distribution of the horizons of Morrow-Condon silt loam, P_3
(in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
419	A_p	0-6	0.2	0.5	0.9	4.9	14.5	23.1	36.0	19.9
427	Pan	6-6 1/2	0.1	0.3	0.6	4.1	12.2	24.5	34.3	23.8
420	A_3	6 1/2-8 1/2	0.1	0.4	0.8	4.3	12.4	22.9	35.0	24.1
421	B_2	8 1/2-14	0.1	0.4	0.6	4.1	12.0	21.8	35.4	25.5
422	B_{31}	14-23	0.2	0.4	0.6	3.9	11.2	23.0	34.1	26.6
423	C_1	23-30	0.4	0.5	0.6	3.4	10.1	28.0	36.9	20.1
424	C_{1ca}	30-36	0.6	1.1	1.4	7.1	12.3	28.0	36.4	13.1
425	B_{2b}	36-41	2.7	3.0	3.6	10.9	7.6	9.1	13.5	49.5

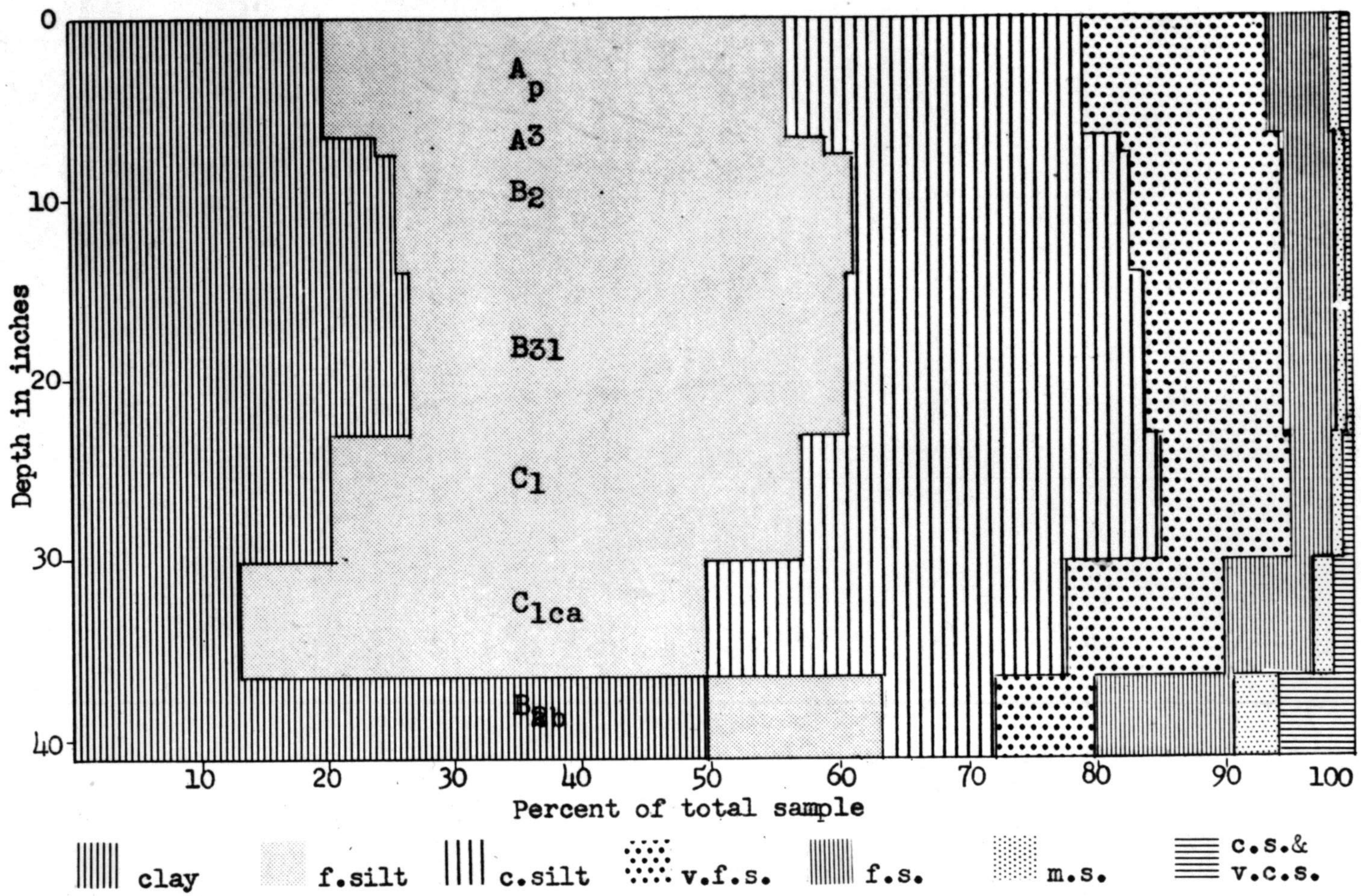

Fig.5. Particle size distribution of Morrow-Condon silt loam - P3

depth, the clay content increases gradually above and decreases sharply below the maximum in the B_{31}. This accumulation of clay to a maximum together with the observation of clay flows, as noted in the field morphology description, appendix A, indicates the formation of a textural B horizon. The C_{1ca} horizon contains 13.1 per cent clay and is followed by the B_{2b} horizon that contains 49.5 per cent clay. As noted in the field morphology description, appendix A, the B_{2b} horizon has originated from different materials than the horizons above. It is believed to be material weathered from basalt that was exposed before deposition of the aeolian material above. In all horizons above the B_{2b}, the silt fraction is dominant. It includes approximately 60 per cent of the total separates. The ratio of coarse silt to fine silt, table 8, varies between 0.6 to 0.8. The relatively constant ratio indicates vertical uniformity of the parent material. With the exception of the very fine sand in the residual B_{2b} horizon and the surface horizon which may have been influenced by erosion, the very fine sand percentage of the total sample also exhibits uniformity within the profile. Bulk density is somewhat variable in the profile. Due partly to compaction caused by tillage implements, the thin layer below the A_p horizon designed as a plowpan, shows a considerable increase in bulk density over the layer above and below it. The A_3 horizon may also be slightly influenced by mechanical compaction. Below the A_3 horizon, bulk density generally increases with depth. It attains a value of 1.34 gm./cc. in the C_{1ca} horizon. A large increase in bulk density separates the different soil material of the B_{2b} from the horizon above.

Chemical properties, table 9: With the exception of the C_{1ca} horizon, the total cation exchange capacity is fairly uniform and changes consistently with the clay content. The ratio of the exchange capacity to per cent clay ranges between 0.8 to 1.0 me./gm. of clay. An increase in exchange capacity associated with a decrease in clay content in the C_{1ca} horizon may indicate the presence of a different type of clay mineral. Calcium and magnesium comprise the majority of the exchangeable bases. The exchange complex is saturated with bases in all horizons. The exchangeable potassium percentage decreases from 4.3 per cent in the A_p to 1.0 per cent in the lowest horizon. Exchangeable sodium percentage of the exchange capacity is negligible through the B horizon but increases abruptly in the C horizon and reaches a maximum of 7.5 per cent in the lower part of the profile. Figure 3 shows that the organic matter content decreases gradually with depth. Total nitrogen, figure 3, shows a similar decrease with depth in the profile except that a slight increase occurs in the A_3 horizon. The pH is approximately uniform throughout the A horizon then increases gradually with depth. Appreciable amounts of sodium and the equivalent of 2.7 per cent calcium carbonate could easily account for the pH of 8.1 attained in the lower part of the profile. Total soluble salts increase with depth to a maximum of 337 parts per million in the lowest horizon.

Table 8. Physical properties of the horizons of Morrow-Condon silt loam, P_3

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Water perme-ability inches/hour	Moisture at saturation % by weight
419	A_p	0-6	54.3	1.21	1.6	2.5	0.6	0.17	—	32.3
427	Pan	6-6 1/2	45.3	1.45	2.0	2.8	0.7	—	—	38.9
420	A_3	6 1/2-8 1/2	50.2	1.32	1.8	2.8	0.6	0.16	—	37.1
421	B_2	8 1/2-14	52.8	1.25	1.8	2.9	0.6	0.12	1.00	37.4
422	B_{31}	14-23	53.6	1.23	2.0	3.0	0.7	0.13	2.35	38.5
423	C_1	23-30	49.8	1.33	2.8	3.6	0.7	0.16	0.81	36.9
424	C_{1ca}	30-36	49.4	1.34	2.3	2.9	0.8	0.20	—	33.4
425	B_{2b}	36-41	37.0	1.67	1.2	1.8	0.7	0.29	—	49.1

Table 9. Chemical properties of the horizons of Morrow-Condon silt loam, P_3

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
					me./100 g.								
419	A_p	0-6	6.4	18.1	0.05	0.78	17.3		0	100	0.3	4.3	0.03
427	Pan	6-6 1/2	6.4	19.9	0.05	0.78	19.1		0	100	0.2	3.9	0.03
420	A_3	6 1/2-8 1/2	6.5	21.0	0.03	0.76	20.2		0	100	0.1	3.6	0.03
421	B_2	8 1/2-14	6.8	22.5	0.04	0.64	21.8		0	100	0.2	2.8	0.04
422	B_{31}	14-23	7.0	22.5	0.10	0.61	21.8		0	100	0.4	2.7	0.07
423	C_1	23-30	7.7	20.0	0.91	0.37	18.7		0	100	4.5	1.8	0.13
424	C_{1ca}	30-36	8.1	23.9	1.61	0.35	21.9		0	100	6.7	1.5	0.15
425	B_{2b}	36-41	7.9	46.4	3.47	0.48	42.5		0	100	7.5	1.0	0.38

Table 9 Con't. Chemical properties of the horizons of Morrow-Condon silt loam, P_3

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Electrical Conductivity Mmhos/cm @ 25°C	Total Soluble Salts ppm
419	A_p	0-6	1.91	0.082	13.5	0.35	79
427	Pan	6-6 1/2	1.91	0.087	12.7	0.23	63
420	A_3	6 1/2-8 1/2	1.72	0.088	11.9	0.32	83
421	B_2	8 1/2-14	1.37	0.076	10.5	0.39	102
422	B_{31}	14-23	1.24	0.064	11.2	0.38	102
423	C_1	23-30	0.90	0.044	11.8	0.39	101
424	C_{1ca}	30-36	0.29	0.033	5.1	0.52	122
425	B_{2b}	36-41	0.24	0.016	8.7	0.98	337

Condon Silt Loam - Profile Number 4

Physical properties: The per cent clay measured in the thin plowpan, A_3, and B_2 horizons was approximately the same, table 10. The difference in clay content of the surface layer and the B_2 is 3.9 per cent. This indicates only moderate clay accumulation. The silt fraction comprises approximately 60 per cent of the total separates in all horizons above the Cm. Figure 6 shows a slight break in the vertical distribution of the very fine sand fraction between the B_2 and B_3 horizons. The values for bulk density, table 11, are relatively uniform below the disturbed A horizon.

Chemical properties, table 12: The total cation exchange capacity reaches a maximum in the B_2 horizon that is also the horizon of greatest clay accumulation. Corresponding to the divided textural uniformity of the profile, the uniformity of the ratio of exchange capacity to per cent clay is also divided at the B_2 horizon. This ratio ranges from 0.9 to 1.1 me./gm. of clay from the A_p through the B_2 horizon but widens considerably below. Exchangeable calcium and magnesium occupy the bulk of the exchange positions. All horizons are completely saturated with bases. Exchangeable potassium percentage of the total exchange capacity decreases evenly from 5.9 per cent in the A_p to 1.5 per cent in the Cm horizon. Exchangeable sodium percentage is negligible in the A horizon but increases markedly in the B and C horizons. The portion of this profile below the B_2 horizon would be classified as nonsaline

Table 10. Particle size distribution of the horizons of Condon silt loam, P_4 (in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
310	A_p	0-6	0.1	0.5	1.0	6.3	14.0	27.4	34.2	16.4
318	Pan	6-6 1/2	0.2	0.5	1.1	6.2	13.8	24.8	32.9	20.5
311	A_3	6 1/2-11	0.2	0.5	1.3	6.4	14.7	22.1	34.9	19.9
312	B_2	11-17	0.3	0.5	1.1	5.8	13.6	25.8	32.6	20.3
313	B_3	17-24	0.2	0.6	1.0	5.4	18.5	26.4	33.3	14.5
314	C_{1ca}	24-33	0.2	0.9	1.5	6.4	17.3	28.8	33.8	11.1
315	C_{12}	33-36	0.5	1.4	2.4	9.3	19.1	25.1	31.3	10.7
316	C_m	36-41	3.0	8.0	8.0	20.3	18.7	16.1	20.3	5.3

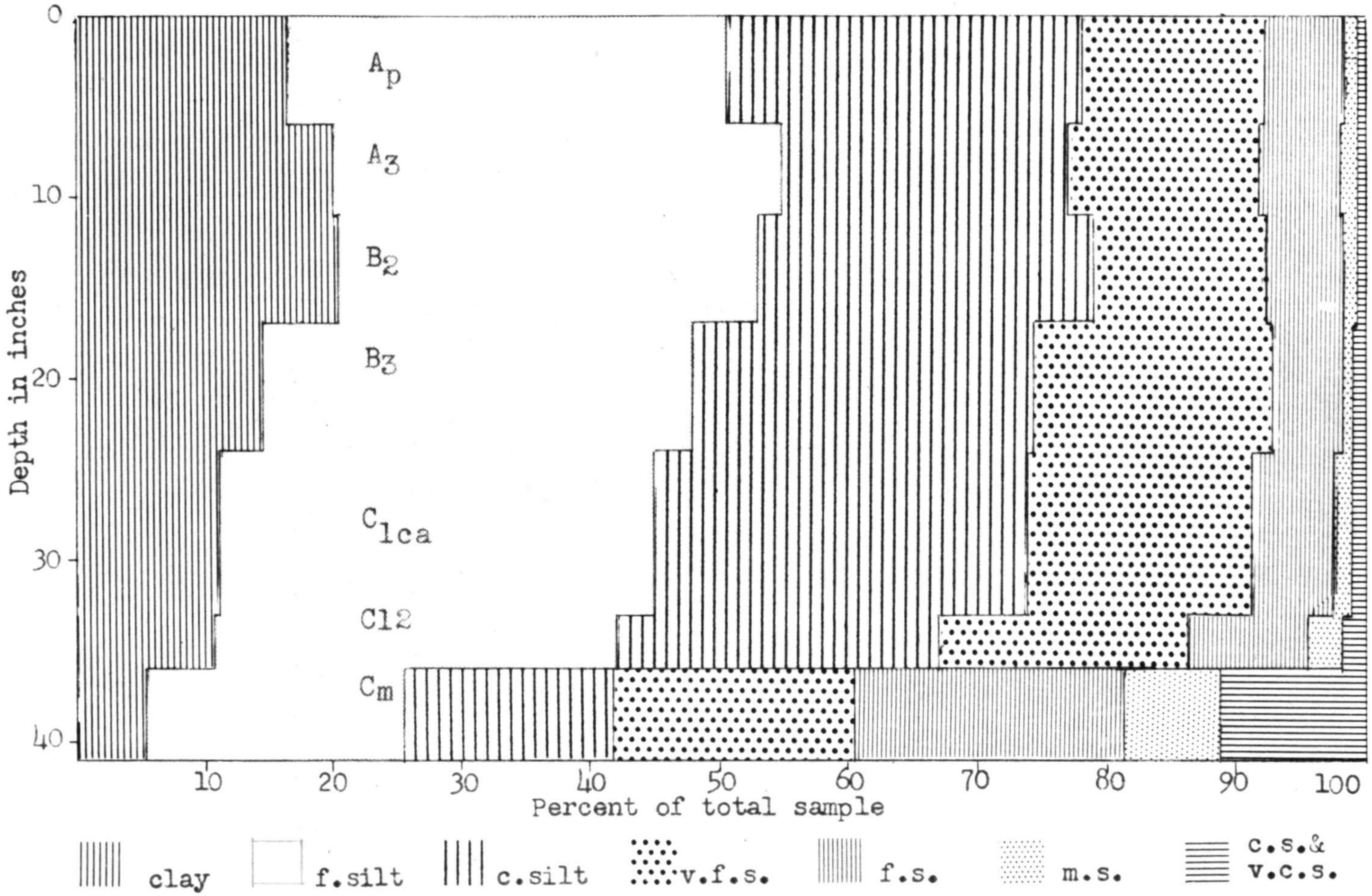

Fig.6. Particle size distribution of Condon silt loam - P4

Table 11. Physical properties of the horizons of Condon silt loam, P_4

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Water perme-ability inches/hour	Moisture at saturation % by weight
310	A_p	0-6	52.8	1.25	1.9	2.4	0.8	0.22	—	34.9
318	Pan	6-6 1/2	44.1	1.48	1.8	2.4	0.7	—	0.64	37.7
311	A_3	6 1/2 - 11	53.2	1.24	1.5	2.4	0.6	0.16	1.21	40.7
312	B_2	11-17	50.6	1.31	1.9	2.4	0.8	0.16	1.10	38.9
313	B_3	17-24	49.0	1.35	1.4	1.8	0.8	0.16	0.67	36.4
314	C_{1ca}	24-33	49.8	1.33	1.7	1.9	0.8	0.19	0.41	33.4
315	C_{12}	33-36	49.0	1.35	1.3	1.6	0.8	0.26	—	33.9
316	C_m	36-41	—	—	0.9	1.1	0.8	—	—	33.7

Table 12. Chemical properties of the horizons of Condon silt loam, P_4

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
					me./100 g.								
310	A_p	0-6	6.2	18.1	0.10	1.08	16.9	0		100	0.5	5.9	0.04
318	Pan	6-6 1/2	6.4	19.5	0.18	1.08	18.2	0		100	0.9	5.5	0.06
311	A_3	6 1/2-11	6.5	19.3	0.18	1.04	18.1	0		100	0.9	5.4	0.09
312	B_2	11-17	7.3	20.0	2.25	0.62	17.1	0		100	11.2	3.1	0.19
313	B_3	17-24	7.9	18.8	3.42	0.43	15.0	0		100	18.2	2.3	0.26
314	C_{1ca}	24-33	8.6	18.7	5.87	0.38	12.5	0		100	31.4	2.0	0.44
315	C_{12}	33-36	8.8	16.5	4.42	0.30	11.8	0		100	26.8	1.8	0.28
316	C_m	36-41	8.6	18.6	4.18	0.29	14.1	0		100	22.5	1.5	0.33

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Table 12 Con't. Chemical properties of the horizons of Condon silt loam, P_4

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Electrical Conductivity mmhos/cm	Total Soluble Salts ppm
310	A_p	0-6	2.34	0.110	12.4	0.35	85
318	Pan	6-6 1/2	2.20	0.103	12.4	0.30	79
311	A_3	6 1/2-11	1.93	0.100	11.2	0.30	85
312	B_2	11-17	1.22	0.070	10.1	0.50	136
313	B_3	17-24	0.82	0.049	9.8	0.71	181
314	C_{1ca}	24-33	0.74	0.039	11.0	1.30	304
315	C_{12}	33-36	0.64	0.031	11.9	0.90	214
316	C_m	36-41	0.57	0.020	16.5	1.00	236

alkali (53, p. 5). Figure 3 shows that organic matter and total nitrogen are comparatively high in the A horizon and decrease evenly with depth. This results in a fairly uniform carbon-nitrogen ratio in the profile. The pH is approximately the same throughout the A horizon but increases rapidly with depth in the B and C. A maximum pH of 8.8 in the C_{12} horizon is associated with an exchangeable sodium percentage of 26.8 and the equivalent of 9.0 per cent calcium carbonate. Total soluble salts generally increase with depth but nowhere attain a high value.

Condon Silt Loam Grading to Walla Walla Silt Loam - Profile 5

Physical properties: The distribution of clay is relatively uniform in the upper half of the profile, table 13 and figure 7. With increasing depth, the clay content increases gradually above and decreases abruptly below the maximum in the B_{32}. Silt is the predominant size fraction. It comprises approximately 57 per cent of the total separates in each horizon. The vertical uniformity of the per cent very fine sand fraction of the total sample, table 14, together with uniform ratios of coarse silt to fine silt and fine silt to very fine sand indicates textural uniformity of the profile. Below the disturbed A_p horizon, bulk density values increase slightly with depth.

Chemical properties, table 15: The total cation exchange capacity varies relatively uniform as a function of the clay content. The ratio ranges from 1.0 to 1.3 me./gm. of clay in the solum and

Table 13. Particle size distribution of the horizons of Condon-Walla Walla silt loam, P_5
(in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
528	A_p	0-6	0.3	0.8	1.5	5.9	18.2	28.0	29.4	15.9
529	B_2	6-12	0.3	0.9	1.4	5.6	18.2	27.6	30.4	15.6
530	B_{31}	12-19	0.3	0.8	1.4	5.8	18.9	27.5	29.3	16.0
531	B_{32}	19-25	0.4	1.0	1.2	5.1	16.7	29.1	29.9	16.5
532	B_{33}	25-30	0.4	1.0	1.1	4.5	14.2	34.1	31.9	12.9
533	C_{ca}	30-44	1.6	3.4	3.3	8.5	16.8	27.7	28.5	10.2

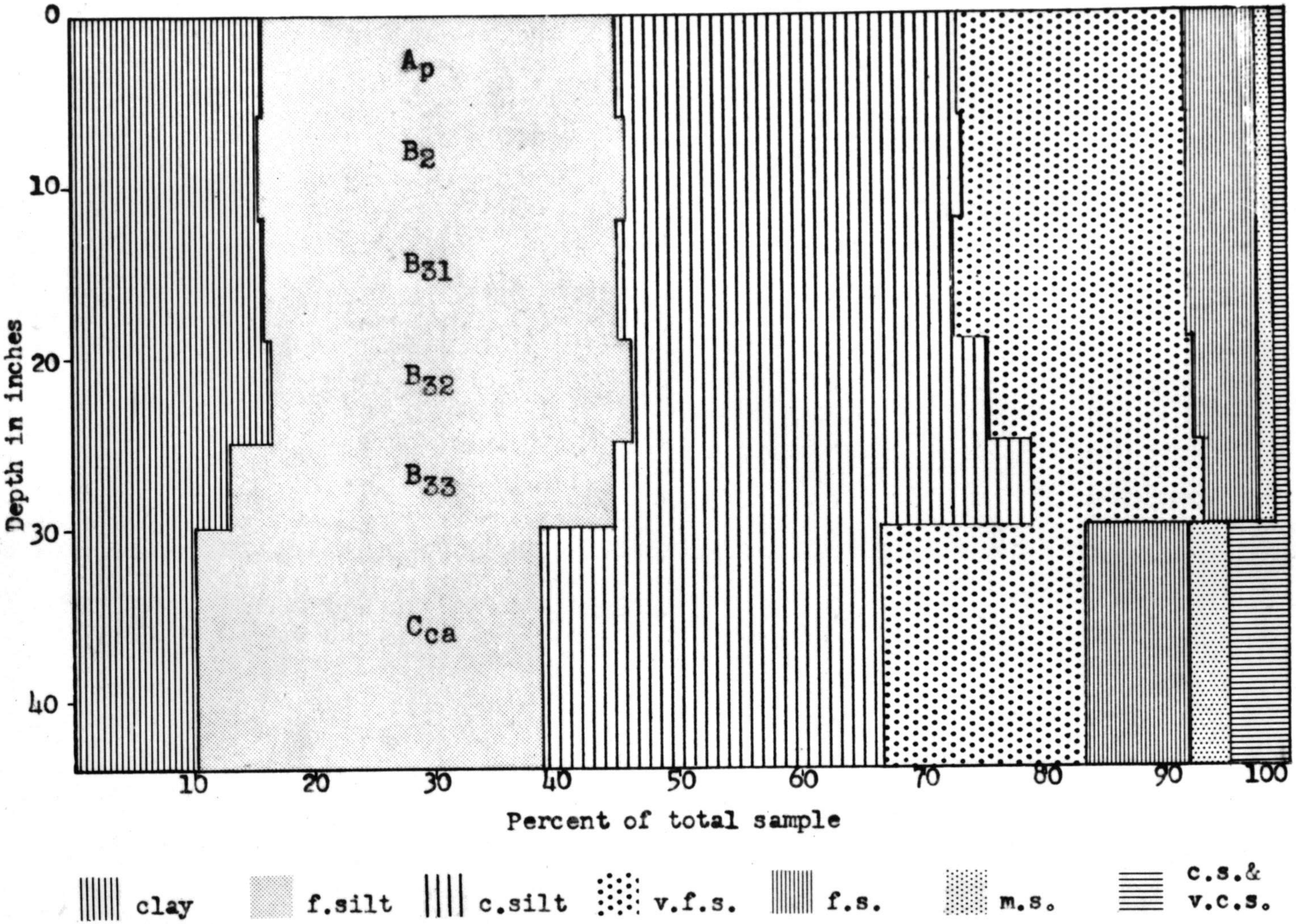

Fig.7. Particle size distribution of Condon-Walla Walla silt loam - P5

Table 14. Physical properties of the horizons of Condon-Walla Walla silt loam, P5

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Moisture at saturation % by weight
528	A_p	0-6	54.7	1.20	1.5	1.6	0.9	0.17	33.4
529	B_2	6-12	51.7	1.28	1.5	1.7	0.9	0.16	39.1
530	B_{31}	12-19	51.7	1.28	1.4	1.5	0.9	0.14	42.3
531	B_{32}	19-25	53.2	1.24	1.7	1.8	1.0	0.16	39.5
532	B_{33}	25-30	49.4	1.34	2.4	2.2	1.1	0.17	36.4
533	C_{ca}	30-44	47.5	1.39	1.6	1.7	1.0	0.23	33.8

Table 15. Chemical properties of the horizons of Condon-Walla Walla silt loam, P_5

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
					me./100 g.								
528	A_p	0-6	6.4	16.4	0.01	1.02	6.61	5.73	3.0	81.5	0.1	6.2	0.02
529	B_2	6-12	6.8	17.5	0.03	0.79	7.85	7.17	1.7	90.5	0.2	4.5	0.02
530	B_{31}	12-19	7.3	17.7	0.01	0.61	8.10	7.58	1.4	92.1	0	3.4	0.02
531	B_{32}	19-25	7.5	17.4	0.01	0.49	8.73	7.73	0.5	97.5	0	2.8	0.02
532	B_{33}	25-30	7.7	16.3	0.02	0.41	7.85	7.58	0.4	97.0	0.1	2.5	0.03
533	C_{ca}	30-44	8.1	13.5	0.21	0.33	13.0		0	100.0	1.5	2.4	0.11

Table 15 Con't. Chemical properties of the horizons of Condon-Walla Walla silt loam, P_5

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Calcium Magnesium Ratio	Electrical Conductivity mmhos/cm	Total Soluble Salts ppm
528	A_p	0-6	1.84	0.085	12.6	1.1	0.50	117
529	B_2	6-12	1.50	0.078	11.1	1.1	0.41	112
530	B_{31}	12-19	1.34	0.074	10.5	1.1	0.26	77
531	B_{32}	19-25	1.20	0.063	11.1	1.1	0.27	75
532	B_{33}	25-30	0.98	0.056	10.2	1.0	0.35	89
533	C_{ca}	30-44	0.82	0.036	13.3	-	0.54	128

indicates a slight tendency to widen with depth. Exchangeable hydrogen decreases from 3.0 me./100 gm. of soil in the A_p to 0.4 me. in the B_{33} horizon. The horizon below the solum is saturated with bases. Calcium and magnesium constitute the majority of the exchangeable cations and increase with depth in the solum at about the same rate. Exchangeable potassium is concentrated mostly in the surface and decreases to small amounts with depth. The exchangeable sodium percentage is negligible in the solum but increases in the C horizon to 1.5 per cent. Total soluble salts increase slightly in the C horizon but nowhere attain large amounts. Figure 3 shows that organic matter decreases more uniformally with depth than total nitrogen. The carbon-nitrogen ratio remains fairly constant throughout the solum. The pH increases with depth throughout the solum and attains a value of 8.1 in the parent material, that contains the equivalent of 8.5 per cent calcium carbonate.

Walla Walla Loam - Profile Number 6

Physical properties, tables 16, 17, and figure 8: With increasing depth, the clay content increases gradually to the maximum in the B_2. It decreases slightly in the B_{31}, then more rapidly with depth in the profile. Although the percent clay increase is small in the B horizon it extends over a fairly deep area. Total sand and silt each comprise about 42 per cent of the separates of the total sample. Very fine sand constitutes about 80 per cent of the sand fractions and coarse and fine silt occur in approximately equal

Table 16. Particle size distribution of the horizons of Walla Walla loam, P_6 (in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
636	A_p	0-8	0	0.4	2.5	8.2	33.6	19.5	20.3	15.5
637	A_3	8-15	0	0.4	2.2	6.8	34.7	18.2	20.8	16.9
638	B_2	15-23	0	0.2	1.5	5.9	33.6	20.2	21.0	17.5
639	B_{31}	23-41	0	0.2	1.3	5.0	31.1	23.5	21.5	17.3
640	B_{32}	41-60	0	0.2	1.4	6.0	29.1	27.8	21.9	13.5
641	C_{1ca}	60-70	0	0.5	2.4	8.5	29.4	18.7	21.1	9.3
642	C_2	70-75	0.1	0.8	1.8	6.8	34.3	29.2	20.0	7.0

Table 17. Physical properties of the horizons of Walla Walla loam, P_6

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Water perme-ability inches/hour	Moisture at saturation % by weight
636	A_p	0-8	49.8	1.33	0.6	0.6	1.0	0.13	—	35.7
637	A_3	8-15	47.5	1.39	0.5	0.6	0.9	0.13	0.97	37.5
638	B_2	15-23	47.2	1.40	0.6	0.6	1.0	0.12	1.51	37.5
639	B_{31}	23-41	46.4	1.42	0.7	0.7	1.1	0.15	0.71	39.2
640	B_{32}	41-60	47.2	1.40	0.9	0.7	1.3	0.15	0.76	35.3
641	C_{1ca}	60-70	36.6	1.68	0.6	0.5	0.9	0.18	—	33.1
642	C_2	70-75	34.7	1.73	0.8	0.6	1.5	—	—	28.9

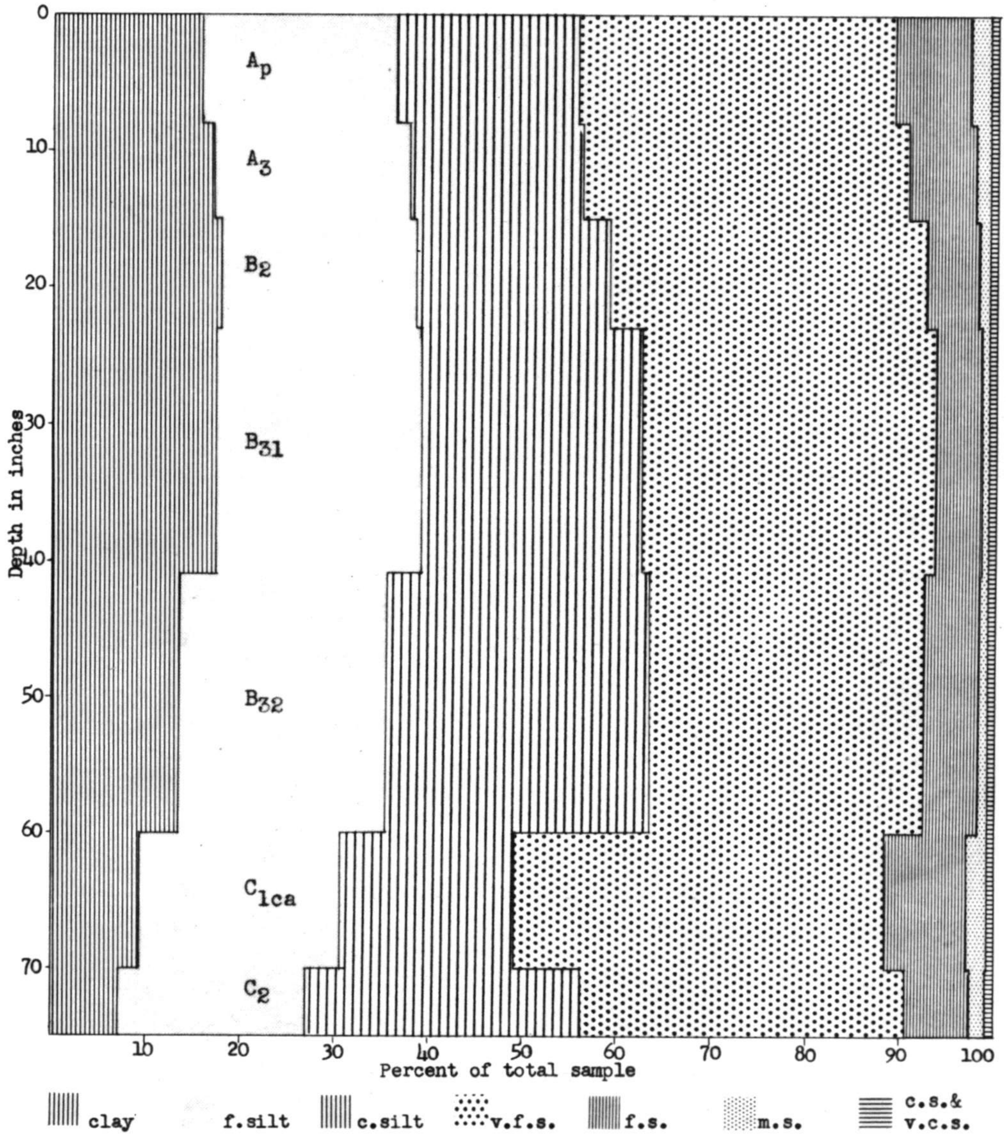

Fig.8. Particle size distribution of Walla Walla loam - P6

amounts in the silt fraction. The textural composition of the profile is considered uniform throughout even though a slight stratification effect may be indicated in the C_{1ca} horizon as evidenced by the increase in the per cent very fine sand fraction of the total sample. Bulk density increases from 1.33 in the surface to 1.73 gm./cc. in the lowest horizon sampled.

Chemical properties, table 18: The exchange capacity is very uniform throughout the profile. The ratio of total cation exchange capacity to per cent clay is uniformally 0.8 to 0.9 me./gm. of clay throughout the solum, however, the ratio widens in the parent material below. Exchangeable hydrogen decreases from 1.1 me./100 gm. of soil in the A_p to 0.6 me. in the B_{31} horizon. All horizons sampled below the B_{31} are saturated with bases. Exchangeable magnesium increases and exchangeable calcium tends to decrease with depth. Exchangeable potassium is fairly high in the A horizon and decreases with depth. It constitutes 8.5 per cent of the total cation exchange in the A_p and decreases to 2.1 per cent in the lowest part of the parent material sampled. Exchangeable sodium percentage is negligible throughout the solum but increases in the C horizon to 3.7 per cent. Total soluble salts nowhere attain large proportions in the profile but increase slightly in the parent material. The distribution of organic matter and total nitrogen is shown in figure 3. Organic matter decreases with depth, with the largest decrease between the A_3 and B_2 horizons, followed by a more gradual decrease through the remainder of the profile.

Table 18. Chemical properties of the horizons of Walla Walla loam, P_6

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na (me./100 g.)	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
636	A_p	0-8	6.2	13.7	0.02	1.17	6.59	4.79	1.1	92	0.1	8.5	0.01
637	A_3	8-15	6.3	13.9	0.02	0.90	7.08	5.00	0.9	93	0.1	6.5	0.01
638	B_2	15-23	6.6	13.8	0.02	0.66	6.19	6.13	0.8	94	0.1	4.8	0.01
639	B_{31}	23-41	6.8	13.8	0.02	0.53	5.88	6.74	0.6	95	0.1	3.8	0.01
640	B_{32}	41-60	7.2	12.3	0.02	0.43	11.9		0	100	0.2	3.5	0.02
641	C_{1ca}	60-70	7.9	14.4	0.21	0.30	13.9		0	100	1.4	2.1	0.08
642	C_2	70-75	8.0	13.8	0.51	0.29	13.0		0	100	3.7	2.1	0.12

Table 18 Con't. Chemical properties of the horizons of Walla Walla loam, P_6

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Calcium Magnesium Ratio	Electrical Conductivity mmhos/cm	Total Soluble Salts ppm
636	A_p	0-8	1.48	0.069	12.5	1.4	0.31	77
637	A_3	8-15	1.46	0.072	11.8	1.4	0.25	66
638	B_2	15-23	0.96	0.055	10.2	1.0	0.26	68
639	B_{31}	23-41	0.86	0.048	10.4	0.9	0.23	63
640	B_{32}	41-60	0.72	0.039	10.8	-	0.26	64
641	C_{1ca}	60-70	0.53	0.019	16.3	-	0.40	93
642	C_2	70-75	0.36	0.013	16.1	-	0.57	115

With the exception of a slight increase in the A_3 horizon, the total nitrogen decreases similarly with depth, resulting in a fairly uniform ratio between carbon and nitrogen within the solum. The pH increases with depth throughout the entire profile. A maximum pH value of 8.0 in the C_2 horizon is associated with the equivalent of 3.6 per cent calcium carbonate.

Walla Walla Very Fine Sandy Loam - Profile Number 7

Physical properties, table 19, 20, and figure 9: Small amounts of clay have accumulated in this profile at relatively shallow depths. The highest percentage of clay was measured in the A_3 horizon and the smallest in the parent material. The sand fractions, with very fine sand predominating, comprise the largest part of the separates in the total sample. This profile exhibits evidence of stratification of the parent material on the basis of the vertical differences in the clay, silt, and sand fractions. Differences of parent material uniformity is indicated in the B_2, C_{12}, and C_{1ca} horizons. The bulk density shows a general increase with depth but varies partly as a function of the stratified parent materials.

Chemical properties, table 21: The cation exchange capacity varies throughout the profile but is associated closely in the solum with clay content. The ratio of total cation exchange capacity to per cent clay is 0.7 to 1.0 me./gm. of clay through the B_{33}

Table 19. Particle size distribution of the horizons of Walla Walla very fine sandy loam, P_7 (in per cent) (particle size in mm.)

Sample number	Horizon	Depth inches	Very coarse sand 2-1	Coarse sand 1-0.5	Medium sand 0.5-0.25	Fine sand 0.25-0.10	Very fine sand 0.10-0.05	Coarse silt 0.05-0.02	Fine silt 0.02-0.002	Clay 0.002
743	A_p	0-8	0	0.5	3.0	8.6	45.5	15.8	13.3	13.2
744	A_3	8-13	0	0.3	2.1	7.2	42.1	20.3	11.7	16.1
745	B_2	13-24	0	0.2	1.9	5.8	40.9	19.5	17.0	14.7
746	B_{31}	24-31	0.1	0.3	0.9	4.4	48.5	15.2	18.6	12.0
747	B_{32}	31-46	0	0.1	0.8	4.3	48.9	20.6	15.7	9.5
748	B_{33}	46-65	0	0.4	1.8	9.7	53.2	15.6	9.7	9.7
749	C_{11}	65-78	0	0.4	2.2	9.7	54.5	13.2	10.2	9.7
750	C_{12}	78-84	0	0.6	1.8	7.2	57.5	16.2	10.7	6.0
751	C_{1ca}	84-88	2.7	4.4	2.6	7.9	39.7	16.2	14.7	11.6
752	C_{13}	88-93	0.8	1.3	1.5	6.4	51.8	18.2	13.5	6.4

Table 20. Physical properties of the horizons of Walla Walla very fine sandy loam, P_7

Sample number	Horizon	Depth inches	Total pore space %	Bulk density g./cc.	Ratio of coarse silt to very fine sand	Ratio of fine silt to very fine sand	Ratio of coarse silt to fine silt	Available moisture inches/inch soil	Moisture at saturation % by weight
743	A_p	0-8	49.4	1.34	0.3	0.3	1.2	0.13	35.5
744	A_3	8-13	46.8	1.41	0.5	0.3	1.7	0.15	37.4
745	B_2	13-24	44.1	1.48	0.5	0.4	1.1	0.17	33.2
746	B_{31}	24-31	44.1	1.48	0.3	0.4	0.8	0.12	32.6
747	B_{32}	31-46	48.3	1.37	0.4	0.3	1.3	0.09	34.0
748	B_{33}	46-65	38.9	1.62	0.3	0.2	1.6	0.13	34.3
749	C_{11}	65-78	42.3	1.53	0.2	0.2	1.3	0.14	34.7
750	C_{12}	78-84	37.0	1.67	0.3	0.2	1.5	0.15	34.0
751	C_{1ca}	84-88	51.7	1.28	0.4	0.4	1.1	—	46.3
752	C_{13}	88-93	38.5	1.63	0.3	0.3	1.3	—	35.0

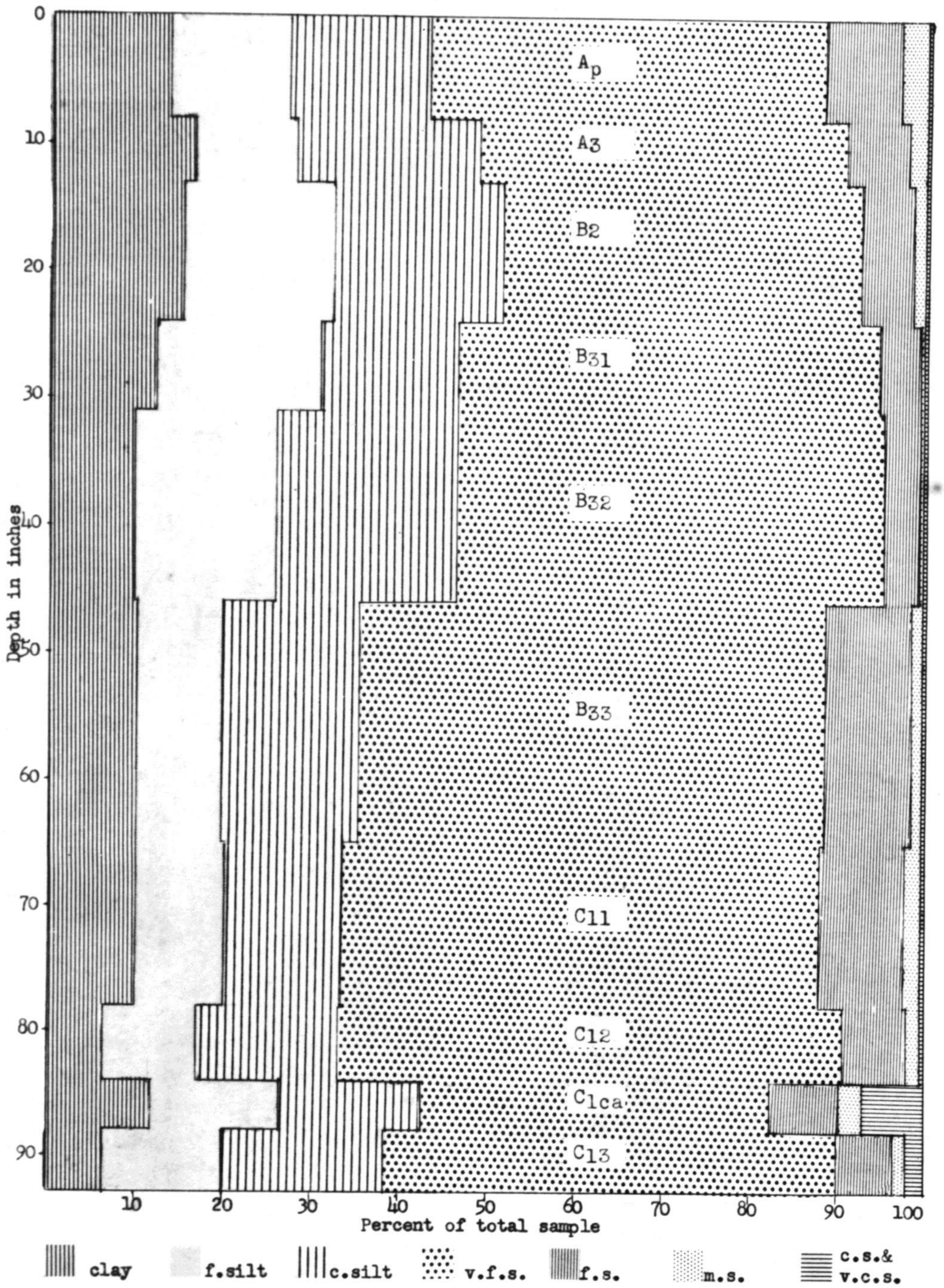

Fig.9. Particle size distribution of Walla Walla very fine sandy loam - P7

Table 21. Chemical properties of the horizons of Walla Walla very fine sandy loam, P_7

Sample number	Horizon	Depth inches	Reaction pH	Exchange Capacity me./100 g.	Exchangeable Cations Na	K	Ca	Mg	H	Base Saturation %	Exchangeable Sodium %	Exchangeable Potassium %	Water Soluble Sodium me./100 g.
					me./100 g.								
743	A_p	0-8	6.3	12.0	0.02	0.90	6.07	3.55	1.5	88	0.2	7.5	0.01
744	A_3	8-13	6.6	12.2	0.02	0.88	6.01	4.09	1.2	90	0.2	7.2	0.01
745	B_2	13-24	6.8	11.6	0.02	0.79	4.94	4.68	1.2	90	0.2	6.8	0.01
746	B_{31}	24-31	7.0	10.5	0.02	0.62	4.01	4.78	1.1	90	0.2	5.9	0.01
747	B_{32}	31-46	7.2	9.1	0.02	0.44	3.34	4.79	0.5	94	0.2	4.8	0.01
748	B_{33}	46-65	7.4	9.6	0.02	0.23	3.10	6.04	0.2	98	0.2	2.4	0.02
749	C_{11}	65-78	7.6	11.1	0.03	0.25	10.8		0	100	0.3	2.2	0.03
750	C_{12}	78-84	8.0	11.5	0.05	0.27	11.2		0	100	0.4	2.3	0.05
751	C_{1ca}	84-88	8.4	8.0	0.08	0.20	7.7		0	100	1.0	2.5	0.08
752	C_{13}	88-93	8.4	11.3	0.09	0.27	10.9		0	100	0.8	2.4	0.07

Table 21 Con't. Chemical properties of the horizons of Walla Walla very fine sandy loam, P_7

Sample number	Horizon	Depth inches	Organic Matter %	Total Nitrogen %	Carbon Nitrogen Ratio	Calcium Magnesium Ratio	Electrical Conductivity mmhos/cm	Total Soluble Salts ppm
743	A_p	0-8	1.74	0.077	13.1	1.7	0.25	62
744	A_3	8-13	1.07	0.075	8.3	1.5	0.25	65
745	B_2	13-24	0.74	0.054	8.0	1.0	0.26	60
746	B_{31}	24-31	0.53	0.037	8.4	0.8	0.26	59
747	B_{32}	31-46	0.53	0.026	11.9	0.7	0.20	48
748	B_{33}	46-65	0.29	0.019	8.9	0.5	0.20	48
749	C_{11}	65-78	0.26	0.014	10.7	-	0.22	53
750	C_{12}	78-84	0.26	0.014	10.7	-	0.35	83
751	C_{1ca}	84-88	0.67	0.021	18.6	-	0.42	136
752	C_{13}	88-93	0.29	0.011	15.4	-	0.43	105

horizon. Exchangeable hydrogen decreases from 1.5 me./100 gm. of soil in the A_p to 0.2 me. in the B_{33}. All horizons sampled below the B_{33} are saturated with bases. The ratio of exchangeable calcium to exchangeable magnesium decreases with depth from 1.7 in the A_p to 0.51 in the B_{33}. Exchangeable potassium constitutes 7.5 per cent of the total cation exchange capacity in the A_p and approximately 2.3 per cent in the parent material. Exchangeable sodium and soluble salts are present in small amounts. The distribution of organic matter and total nitrogen is shown to a depth of 75 inches in figure 3. Most of the organic matter and total nitrogen is concentrated in the upper 2 feet of soil. It levels off very gradually to small amounts in the horizons below. The pH increases with depth to a maximum of 8.4 in the lower horizons, that contain the equivalent of 7.0 per cent calcium carbonate.

Moisture Characteristics

Measurements of soil moisture relationships were included in this study in order to assess certain physical properties that would contribute to a better understanding of the characteristics of these soils. An evaluation of these relationships is important since they not only provide clues relating to soil development but have certain implications relating to the management and use of soils for crop production.

<u>Water permeability</u>: The three soil profiles considered typical examples of the series studied plus the Morrow-Condon intergrade were selected for water permeability measurements. The permeability rates measured for the samples from the typical profiles were considered to represent the characteristic water permeability rates for the respective series. The Morrow-Condon profile was selected in order to obtain comparative data between the typical and intergrade examples of the series.

Water permeability rates in inches per hour for the four profiles are included in table 22. Sample number 318 represents a thin plowpan layer collected in the middle of a three inch core. It is assumed that the permeability value obtained is determined by the pan layer. The permeability rates measured in the separate horizons of the profiles were higher for Morrow P_2, that typifies the fine textured end of the soils sequence studied, than for the coarser textured Walla Walla P_6.

Table 22. Relation of texture and structure to water permeability.

Profile	Sample number	Horizon	Depth inches	Structure	Texture	Water Permeability inches/hour	% pores drained at tension of 0.1 atmosphere
Morrow silt loam P_2	12	B_{21}	6-14	Mod. Med. and coarse prismatic	sil loam	1.66	12.2
	13	B_{22}	14-16	Mod. Med. and coarse prismatic	sil loam	1.45	9.5
	14	B_{23}	16-25	Weak med. and coarse prismatic	sil loam	0.32	8.2
Morrow-Condon silt loam P_3	421	B_2	8 1/2-14	Weak med. and coarse prismatic	sil loam	1.0	15.5
	422	B_{31}	14-23	Weak coarse prismatic	sil loam	2.35	17.0
	423	C_1	23-30	Very weak coarse prismatic	sil loam	0.81	7.7
Condon silt loam P_4	318	Pan	6-6 1/2	Massive or thin platy	sil loam	0.64	--
	311	A_3	6 1/2-11	Weak very fine granular	sil loam	1.21	13.1
	312	B_2	11-17	Weak med. and coarse prismatic	sil loam	1.10	9.1
	313	B_3	17-24	Very weak med. and coarse prismatic	sil loam	0.67	10.0
	314	C_{1ca}	24-33	Massive	sil loam	0.41	4.9

Table 22 Con't. Relation of texture and structure to water permeability.

Profile	Sample number	Horizon	Depth inches	Structure	Texture	Water permeability inches/hour	% pores drained at tension of 0.1 atmosphere
Walla Walla loam P6	637	A_3	8-15	Weak coarse prismatic	loam	0.97	8.9
	638	B_2	15-23	Weak very coarse prismatic	loam	1.51	8.9
	639	B_{31}	23-41	Very weak coarse prismatic	loam	0.71	6.1
	640	B_{32}	41-60	Very weak coarse prismatic	loam	0.76	8.3

<u>Moisture-tension relationships:</u> Soil moisture-tension values for a series of 8 different tensions are presented separately by profiles in table 23. Available moisture by volume was calculated as the difference between the moisture retained in the sample at 1/3 and 15 atmospheres of tension. The 15-atmosphere percentage is commonly accepted as the lower limit at which most plants show signs of permanent wilting, and the 1/3-atmosphere percentage correlates closely with the field capacity (40, pp. 215-235). Colman (9, pp. 278-282) studied soils covering a wide textural range and found the 1/3 atmosphere percentage to be consistent with field capacity determined under natural field conditions.

The total moisture available to plants as totaled for the soil profiles was 3.1, 4.4, 7.1, 6.7, 6.1, 10.3, and 11.1 inches for profiles 1 to 7 respectively. In general, the finer textured soils held more available water per inch of soil than the coarser textured soils.

Moisture characteristic curves for the A_p and B_2 horizons of the Morrow P_2 and Walla Walla P_6 profiles are shown in figures 10 and 11. These curves show that 75 per cent of the available water is removed from these horizons when a tension of approximately 4 atmospheres is attained. Curves for profiles 1 and 3 are similar to those of profile 2, and profiles 5 and 7 to profile 6. Curves for profile 4 are intermediate between profiles 3 and 5.

Data in table 24, derived from the curves in figures 12 and 13, shows the amounts of available moisture present at various tension

Table 23. Moisture percentages by volume at successive soil moisture tensions.

Profile number	Sample number	Horizon	Depth inches	1/10	1/3	1/2	1.0	2.0	5.0	10	15
				Equilibrium Tension—Atmospheres							
Morrow silt loam P_1	26	A_p	0-8	36.04	29.31	27.17	24.21	18.94	14.81	11.94	12.05
	27	B_{21}	8-13	36.92	34.87	30.62	28.63	31.10	25.09	23.09	22.41
	28	B_{22}	13-21	34.76	30.17	28.53	25.87	24.67	19.10	17.12	16.29
Morrow silt loam P_2	11	A_p	0-6	40.06	32.67	29.79	26.19	19.45	15.50	12.79	12.58
	12	B_{21}	6-14	37.70	34.53	33.35	31.90	25.08	20.63	17.61	17.24
	13	B_{22}	14-16	39.93	34.65	32.32	28.22	24.63	20.00	17.04	16.59
	14	B_{23}	16-25	42.40	32.12	28.30	24.21	21.64	18.08	15.78	15.39
Morrow-Condon silt loam P_3	419	A_p	0-6	37.69	28.76	26.35	24.16	18.65	14.53	12.55	11.39
	420	A_3	6-8 1/2	38.61	30.58	28.99	26.65	23.31	18.66	16.45	14.37
	421	B_2	8 1/2-14	37.30	28.09	26.00	22.37	24.90	19.76	17.95	15.62
	422	B_{31}	14-23	36.59	27.32	24.80	21.79	22.11	17.71	15.98	14.25
	423	C_1	23-30	42.08	30.20	27.03	23.01	22.41	17.10	15.39	13.55
	424	C_{1ca}	30-36	44.57	34.44	30.91	25.46	22.58	17.77	15.81	14.06
	425	B_{2b}	36-41	-	72.07	-	-	63.56	52.24	47.13	42.98
Condon silt loam P_4	310	A_p	0-6	41.73	34.01	30.55	27.51	19.10	14.67	12.65	11.72
	311	A_3	6-11	40.13	28.65	25.29	21.32	18.69	15.25	13.63	12.87
	312	B_2	11-17	41.49	29.55	25.75	21.47	19.87	15.92	14.37	13.51
	313	B_3	17-24	39.04	29.21	26.44	21.58	18.52	14.98	13.59	12.74
	314	C_{1ca}	24-33	44.90	30.27	27.67	24.45	18.29	14.23	12.46	11.17
	315	C_{12}	33-36	45.32	38.20	33.94	29.00	20.34	16.21	13.53	11.96

Table 23 Con't. Moisture percentages by volume at successive soil moisture tensions.

Profile number	Sample number	Horizon	Depth inches	Equilibrium Tension--Atmospheres 1/10	1/3	1/2	1.0	2.0	5.0	10	15
Condon-	528	A_p	0-6	37.25	26.66	23.33	20.26	15.38	12.26	10.69	9.72
Walla	529	B_2	6-12	42.20	26.82	22.96	19.53	15.46	12.84	11.42	10.38
Walla	530	B_{31}	12-19	36.75	24.23	21.15	18.24	15.23	12.76	11.28	10.37
silt loam	531	B_{32}	19-25	39.84	25.85	21.72	18.25	13.99	11.49	10.42	9.42
P_5	532	B_{33}	25-30	40.98	26.43	22.51	18.01	14.08	11.47	10.28	9.26
	533	C_{ca}	30-44	42.80	33.96	30.46	25.31	16.90	13.43	11.73	10.52
Walla	636	A_p	0-8	33.03	22.08	20.45	17.76	13.67	11.24	9.89	9.32
Walla	637	A_3	8-15	38.65	23.20	19.72	17.50	13.86	11.74	10.62	10.15
loam	638	B_2	15-23	38.35	22.63	19.19	16.89	14.27	11.91	10.85	10.40
P_6	639	B_{31}	23-41	40.29	25.08	20.88	16.86	14.13	11.71	10.63	10.10
	640	B_{32}	41-60	38.86	24.24	19.60	16.86	16.66	13.47	12.38	9.28
	641	C_{1ca}	60-70	-	30.66	-	21.28	17.29	14.09	12.97	12.67
Walla	743	A_p	0-8	36.26	20.00	17.45	16.69	10.71	9.04	8.12	7.32
Walla	744	A_3	8-13	37.02	23.16	19.06	14.24	11.77	10.35	9.33	8.60
very fine	745	B_2	13-24	39.31	25.99	19.69	15.97	12.99	10.74	9.56	9.00
sandy	746	B_{31}	24-31	39.34	20.53	16.73	13.62	11.99	9.68	8.52	8.36
loam	747	B_{32}	31-46	35.82	16.37	13.33	10.87	9.70	7.99	7.00	6.85
P_7	748	B_{33}	46-65	39.04	21.61	19.30	15.41	11.61	9.77	8.70	8.68
	749	C_{11}	65-78	40.88	23.72	19.29	15.80	11.78	10.11	9.27	9.32
	750	C_{12}	78-84	41.28	25.11	21.16	17.67	13.58	11.59	10.25	10.15
	751	C_{1ca}	84-88	-	-	-	-	25.71	22.48	18.66	17.19
	752	C_{13}	88-93	-	-	-	-	16.38	14.07	12.39	12.04

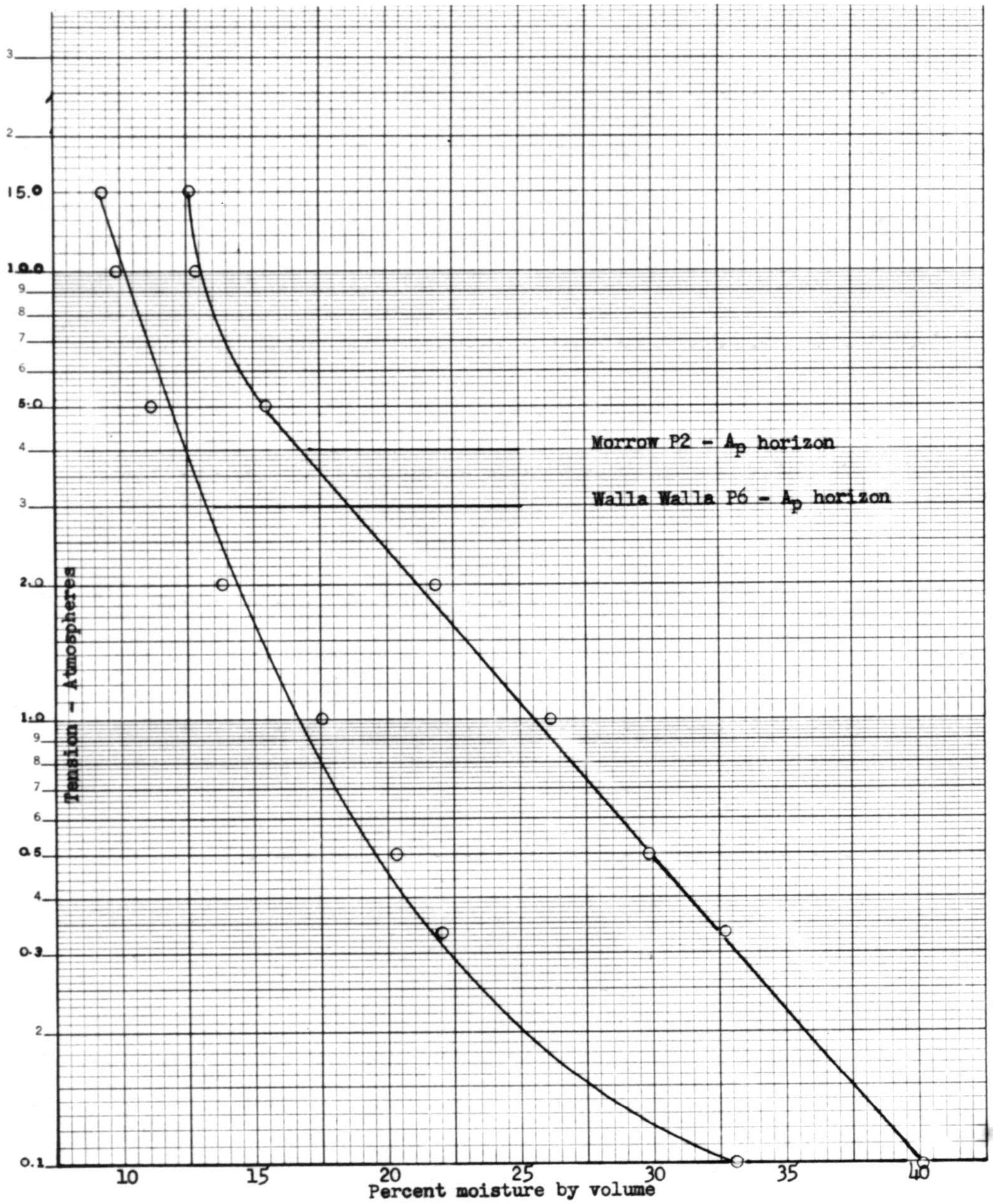

Fig.10. Moisture characteristic curves for Morrow P2 and Walla Walla P6 - A horizon

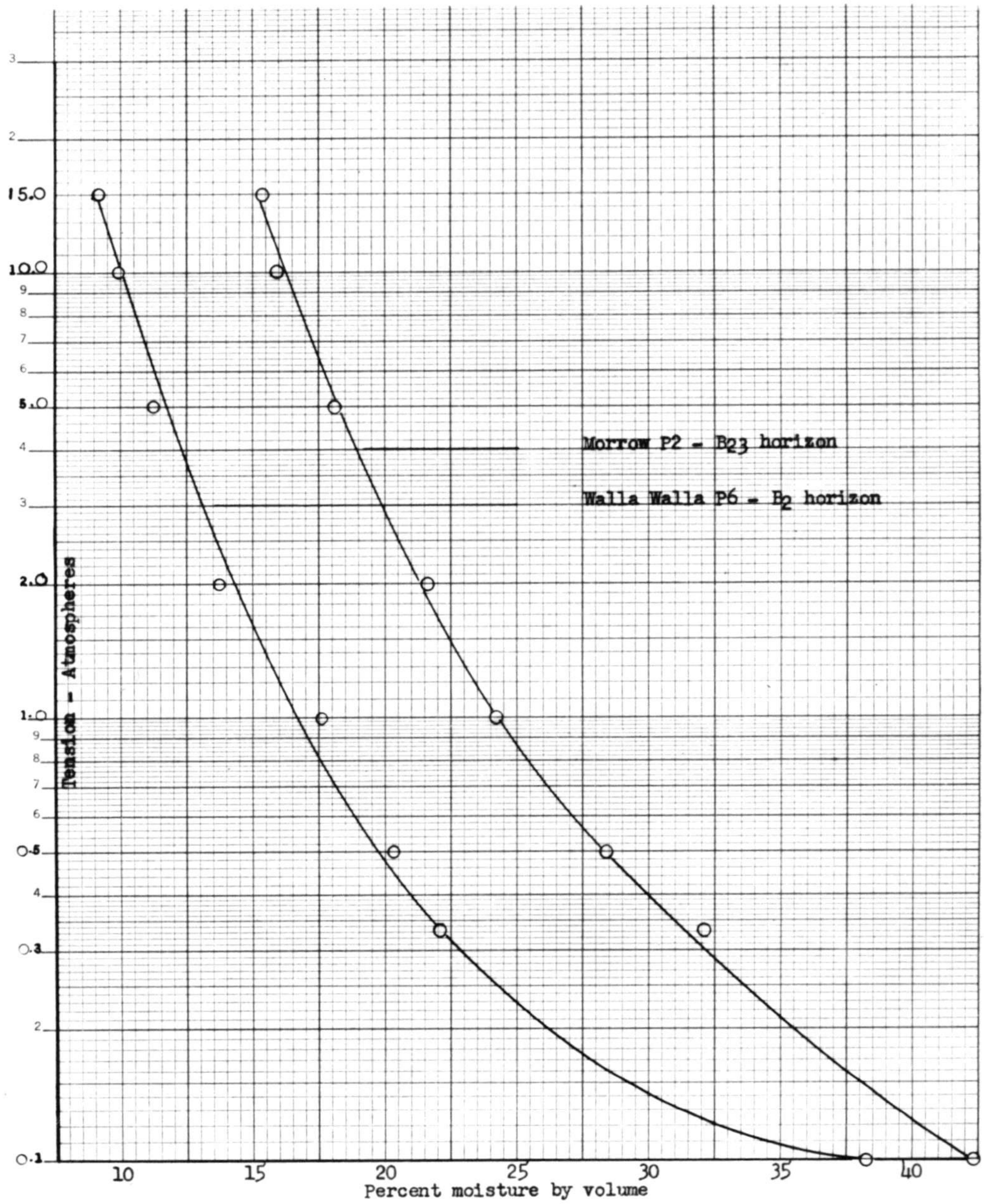

Fig.11. Moisture characteristic curves for Morrow P2 and Walla Walla P6 - B horizon

values.

Table 24. Relation of available moisture to tension

Profile	Available range % moisture by volume	Horizon	Tension in atmospheres at various increments of available moisture present 2/3	1/2	1/3	1/4
Morrow P_2	32.67 to 12.58	A_p	1.0	1.6	2.7	3.5
	32.12 to 15.39	B_{23}	0.7	1.1	2.2	3.3
Walla Walla P_6	22.08 to 9.32	A_p	0.8	1.4	2.7	4.1
	22.63 to 10.40	B_2	0.8	1.4	2.8	4.1
Average			0.8	1.4	2.6	3.7

DISCUSSION

Moisture Relationships

Weather observations at Heppner, Condon, and Wasco, Oregon, reported in appendix A, are assumed to represent climatic conditions of the Morrow, Condon, and Walla Walla soils respectively. If precipitation during the summer period of high evaporation in July, August, and September, is ignored, the total moisture that may be considered the most effective for crop use is about 11 inches for the Morrow and 10 inches each for Condon and Walla Walla. Jacquot (18, pp. 12-15) found in eastern Washington that the efficiency of moisture utilitization varies from 2.5 to 4.5 bushels of wheat per acre for each inch of available soil water. From the data in the results section it is obvious that the shallower soils of the Morrow and Condon series can not store enough moisture to produce high yields of grain. Moisture received during the growing periods of early summer must be considered essential for yields of 20 to 30 bushels of wheat on these soils. Evidence pointed out in the discussion of certain morphological features indicate an excess of moisture may be present during the winter months in the Morrow and Condon soils. The possibility results that some of this moisture is retained in these soils above field capacity and is later used by crops during the summer months.

The capacity to retain available moisture per unit of soil depth in the solum increases from Walla Walla, P_7, to Morrow, P_2. However, because of the great depth of the Walla Walla soils, available moisture in the profile is limited only by the amount of natural precipitation in years of normal rainfall.

Water permeability: The permeability rates, table 22, which were determined from laboratory measurements of the movement of water through natural core samples may not represent actual permeability rates under field conditions. Laboratory measurements can not exactly simulate field conditions due mainly to the difficulty of maintaining the original soil structure and in duplicating the natural air relationships. Christiansen (8, pp. 363-364) found that entrapped air caused a large reduction in permeability compared with completely saturated soil. Smith and Browning (15, p. 21) believed that the effect of trapped air must be eliminated and they attempted to accomplish this by evaculation of the sample prior to wetting in the laboratory. Smith et al. (46, pp. 203-211) made permeability studies in the laboratory with no attempt to remove air because they thought the results would be more applicable to field conditions. Trapped air due to a sealed condition on the surface of the soil may influence infiltration rates (10, pp. 61-63) and may further influence permeability rates in the lower horizons. Free and Palmer (14, pp. 395-397) studied trapped air in sand columns and pointed out that many of the field conditions commonly considered responsible for excessive runoff are associated with those conditions making the release and escape of air difficult. In this study, extreme care was exercised in sampling and transportation of cores to eliminate structure differences, and the samples were wetted in the laboratory with upward flow by capillarity in an attempt to obtain uniform air relationships. The reported rates are believed to show relationships among actual field permeability conditions whether or not they are numerically equal to field rates.

Soil structure as displayed in the natural profile indicates a relationship to permeability in this group of soils, however, textural class when considered alone is not a reliable indice. Bulk density apparently influences permeability as a result of its effect on the noncapillary porosity.

In general, the horizons of the Morrow profiles have more pronounced structure and higher permeability rates than those of the Walla Walla profile. The horizons with massive or platy structure are accompanied by little or no vertical orientation of separate structure units that may permit the more rapid downward movement of water as compared to horizons with prismatic structure.

In contrast to the usual assumption that coarse textured soils have high permeability rates, the finer textured soils in this study generally display higher rates than the coarser textured soils. Since rate variation occurred within the same textural class neither a positive nor negative correlation could be established between textural class and water permeability. Table 22 shows the relationship of texture and structure to water permeability.

High soil density restricts water movement as well as root penetration. Veihmeyer and Hendrickson (58, pp. 487-493 and 57, pp. 454-456) found that the bulk density of soil is sometimes high enough under field conditions to preclude root penetration. They observed that densities greater than 1.75 grams per cubic centimeter for sands and 1.46 to 1.65 grams per cubic centimeter for clays prevented the intrusion of sun flower roots, and that when the bulk density of medium to fine-textured subsoils exceeds approximately 1.7 grams per cubic centimeter, drainage difficulties can be anticipated. The plowpan layer and the coarser textured soils with relatively higher bulk densities in the present study were generally associated with lower permeability rates.

The relationship between the volume of pores drained at a tension of 0.1 atmosphere and the water permeability rates as measured in four profiles is presented graphically in figure 12. A correlation coefficient of 0.709 shows a highly significant positive relationship between pores drained and permeability. For 12 degrees of freedom the r value was 0.532 at the 5% level and 0.661 at the 1% level. The volume of pores drained was based upon the amount of water withdrawn from natural core samples with an increase in tension from zero to 0.1 atmosphere.

These data support the contention that soil permeability, among other factors, is dependent in these soils upon the noncapillary porosity, when using a reference tension of 0.1 atmosphere. Bradfield and Jamison (5, p. 72) stated that noncapillary pores are responsible for drainage, percolation and aeration. They described

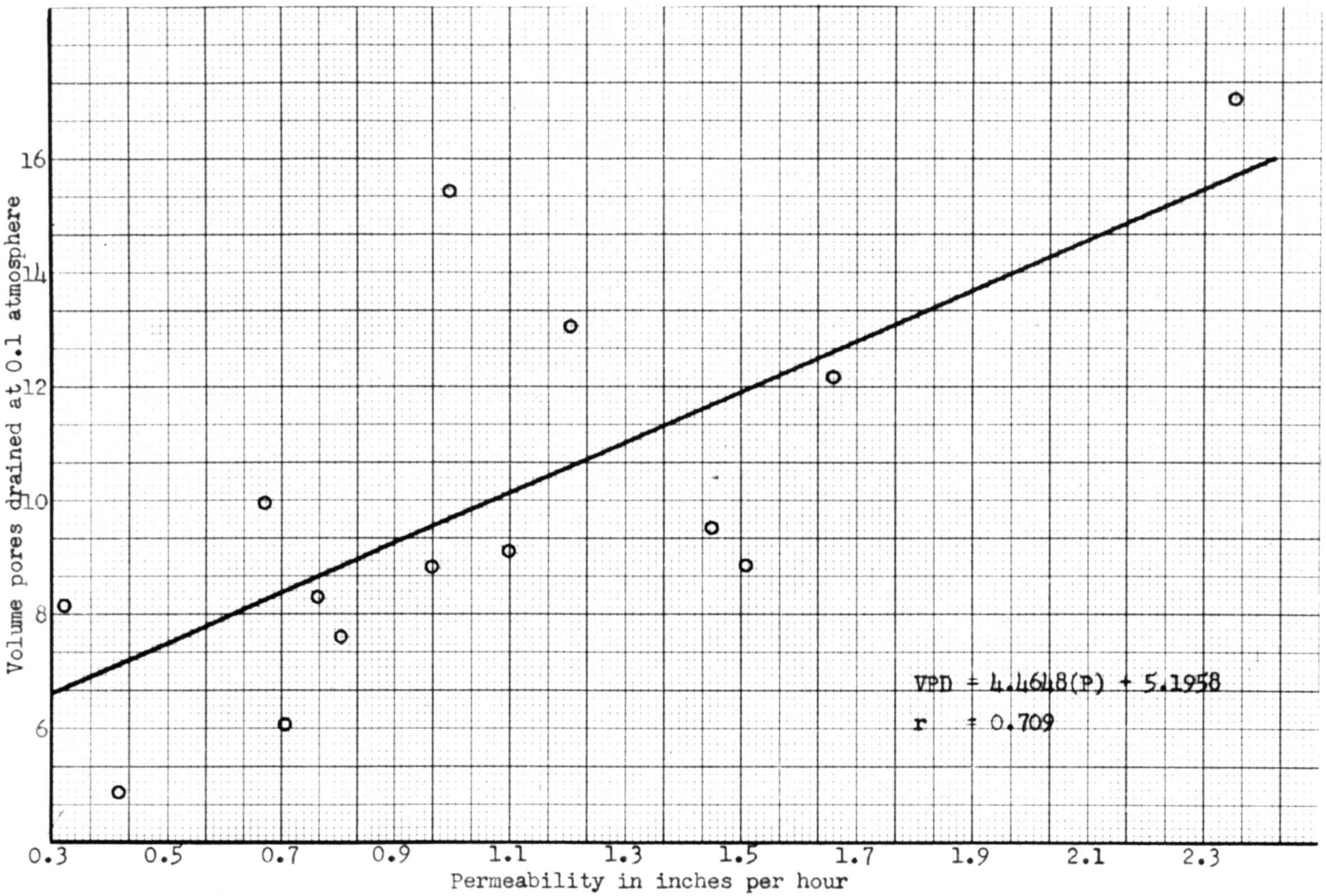

Fig.12. Relationship between volume of pores drained and permeability

noncapillary pores as those between the aggregates, and capillary pores as those existing between the unit particles within the aggregate. Wilson et al. (64, pp. 110-118) also showed that the percentage of noncapillary pores is closely related to permeability. In studying the movement of water in soils Baver (4, pp. 237-243) concluded that permeability of the soil for water is unquestionably a function of the amount of larger pores, however, the tension at which the porosity is chosen is important. Nelson and Baver, (29, pp. 70-75) found the use of the volume of pores at a tension equivalent to 40 centimeters of water is appropriate for many purposes as a single index of soil permeability. Other investigators (22, pp. 353-359, 23, pp. 1004-1007, 28, pp. 411-422, and 26, pp. 29-30) have used 100 centimeters of water (approximately 0.1 atmosphere) as a tension sufficient to drain all pores making important contributions of water permeability.

On the basis of this water permeability data, and neglecting the influence of surface crusts and plowpan layers, the rate of water movement in these soils may be listed in the decreasing order of Morrow, Condon, and Walla Walla. In the event that crusts and pan layers are not eliminated by soil management practices then water permeability for the entire profile under field conditions may be different. Since these restricting layers are not common in Walla Walla soils, as noted in the field morphology descriptions, appendix A, field permeability rates of these profiles may be higher than field rates of Condon and Morrow profiles.

Genesis of Certain Morphological Features

The presence of gray patches on the peds of the B horizons and increasing amounts of exchangeable sodium and soluble salts in the lower horizons in the Morrow and Condon soils, lead to the hypothesis that these profiles have not had free internal drainage and leaching, but rather have been subjected to conditions of saturation or near saturation with water during the wet winter and spring months each year. These soils occur in topographic positions commonly associated with good drainage, nevertheless the shallow basalt bedrock, commonly capped with a thin, presumably impervious layer of calcareous material high in clay, may prevent drainage of water from the profiles to an extent sufficient to make the hypothesis plausible. The high base saturation of the exchange complex of these profiles relative to the Walla Walla profiles is additional supporting evidence. It is possible that the darker colored bands in the B horizon of the Morrow soils may also have some connection with a temporary perched water table accompanied by alternate oxidizing and reducing conditions, however, this study did not attempt to confirm this reasoning. The crop yield to available moisture relationships presented in the preceeding section also support this hypothesis. No observations of a water table in these soils is known to the writer, but field operations are very commonly 3 to 5 weeks later in the spring on these soils than on Walla Walla because farmers have learned that Condon and Morrow are too wet for good trafficability early in the spring. According to the above hypothesis, during the wet season of approximately November to May, an excess of moisture saturates the lower part of the profile, causing a temporary anaerobic condition. Through the years, localized gleying made possible by the anaerobic conditions, has bleached the ped surfaces to form the gray patches which were observed. At the same time, the restriction of drainage out of the soil has prevented intense leaching and made possible the accumulation of exchangeable bases and soluble salts relative to Walla Walla.

Nikiforoff (30, pp. 781-796) noted a similar formation of gray patches in his study of the solonetz-like soils in California. Sigmond (43, pp. 46-49) stated that percolation is influenced by the parent rock as well as the upper soil horizons. In some early investigations he showed that the salt content of alkali land did not correspond as much with the topography of the surface as with the undulation of an impervious clay layer found in the subsoil.

The formation of gray patches along root channels in the middle horizons of the Walla Walla soils was assigned to deposition of lime, soluble salts, or some other material rather than to gleying.

Laboratory treatment of soil samples with hydrochloric acid incidental to several of the analyses reported in the results section revealed a material with limey appearance that is not soluble in acid. This white, apparently amorphous or finely crystalline material in masses of irregular shape up to 1 mm. in diameter was found in the B_{2b} horizon of profile 3, the C_{1ca} horizon of profile 3, the C_{ca} horizon of profile 5 and, in lesser amounts in other horizons of profiles 3 and 5 either on rock fragments or disseminated through the soil material. This material was found to be more nearly white, harder, and of course, much less soluble in acid than the calcium and magnesium carbonates in the same horizons. The material is insoluble in water, dilute and concentrated hydrochloric, sulfuric, nitric acid, and aqua regia. It is soluble in hydrofluoric acid. The gas from the hydrofluoric acid solution, when absorbed in a drop of water and treated with ammonium molybdate in acid solution, gives a yellow color. This latter test is diagnostic for silica. Microscopic examination by H. A. Boyd, Oregon State College, Department of Geology, showed optical properties characteristic of either opal (hydrated silica) or metacristobalite. The presence of this material as an apparently secondary deposit tends to support identification of this material with opal.

Among the many properties of parent material affecting solum thickness, the porosity of the material has been considered the most important (19, pp. 52-87). Porosity of the coarse parent material associated with the deep profiles in this sequence was undoubtedly high through the long periods of loess deposition. The relationship of solum thickness to particle size of the parent material is shown graphically in figure 13. The first two Morrow profiles, P_1 and P_2, are not included in the graph because the profiles rest directly on bedrock, so that solum thickness has been limited by the depth of

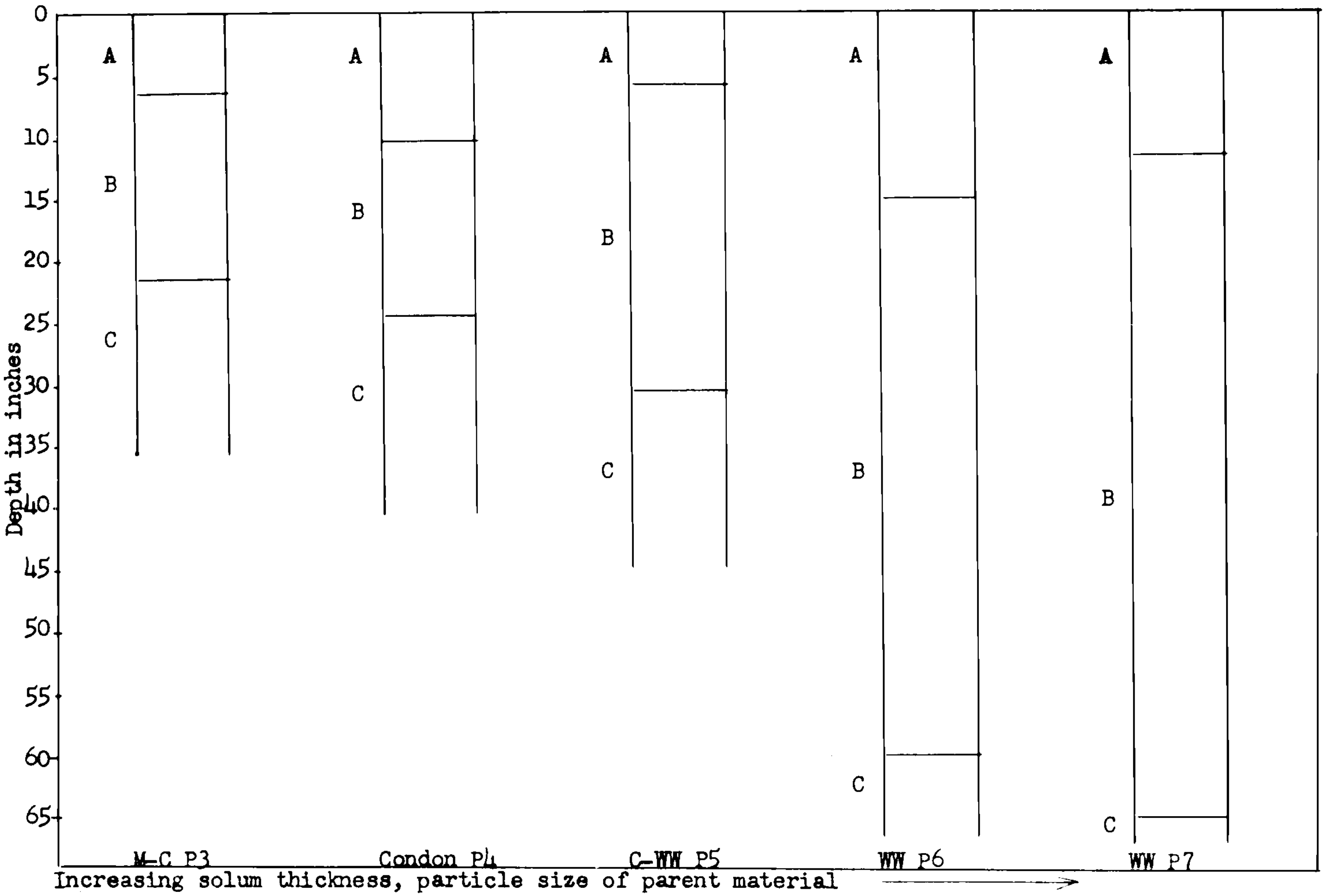

Fig.13. Relation of particle size to solum thickness

bedrock rather than by the properties of the parent material.

Background for the presentation of figure 16 is based on the work of Smith et al. (45, pp. 178-182).

The presence of fine basalt fragments in the Condon and Morrow soils may have originated by a combination of the drifting action of southwesterly winds across areas containing weathered basalt, and by the mechanical mixing of fragments by animal life. The Walla Walla soils in this study that are more distant from a source of surface basalt do not have fragments mixed in the profile. They are also deep over bedrock so the activity of animal life such as gophers would be reduced in the transportation of material from deeper to shallower horizons.

Relationship Among the Series

All profiles studied in this sequence are representative of soils belonging to the Chestnut great soil group. Subdivisions of Prairie soils proposed by Thorp and Smith (50, pp. 117-126), based on the relative degree of horizon differentiation as revealed mainly by texture of the B horizon may also be applied to the Chestnut group. Members of this sequence may be placed in each of the three groups proposed. The Morrow profile number 1 represents a weak maximal; Morrow P_2, Morrow-Condon P_{31} and Condon P_4 are more typical of medial; Condon-Walla Walla P_5, Walla Walla P_6, and Walla Walla P_7 represent minimal members of the Chestnut soil group.

The limited number of soil profiles examined in this investigation do not permit a critical review of the range of characteristics of the Walla Walla, Morrow, and Condon soil series. On the basis of the data obtained, however, the Walla Walla soils may be clearly differentiated from the Condon or Morrow soils in structure, color, and texture as well as in physical and chemical relationships determined in the laboratory. Walla Walla soils have weaker structure, coarser texture, and differ in color, appendix A, from Condon and Morrow. These relationships confirm the present status of the Walla Walla soils as a separate series.

On the other hand, the Morrow and Condon soils do not exhibit great differences from each other in morphological, chemical, or physical properties. Color can not be used for differentiating between the series, however, significant differences in the texture and structure of the B horizon may be used as field criteria. A higher clay content in the Morrow is related to a correspondingly higher exchange capacity. This study indicates a higher content of exchangeable sodium in the typical Condon profile but this may not be a true condition for the whole series. The Morrow soils extend to higher elevations and are usually shallower to bedrock than Condon. These variations may partly account for the need of different soil management practices now in use on the two soils. Even with less average depth of soil, crop yields on Morrow tend to be equal or greater than yields on Condon soils according to field trials conducted by Oregon State College. These trials have also shown greater crop response to nitrogen fertilizer on Condon than Morrow soils.

On the basis of these considerations, it is felt that Morrow and Condon should be retained as the separate series now recognized, and differentiated in the field mainly on the basis of texture and structure.

Source of Parent Material

The soils described in this study have been developed in large part from materials accumulated by aeolian processes. Harper et al. (15, pp. 112-114) described the Walla Walla soils in Umatilla County, Oregon as having developed from loess and the Morrow soils partly from loess. The Condon soils were described in Gilliam County, Oregon in 1939 by the Division of Soil Survey as developed from loess with the lower subsoil influenced by basalt residuum. Thorp (49, pp. 263-270) pointed out that soils developed from loess is generally very silty, and the mechanical composition of loess is homogeneous. Ratios of size fractions in the soils of this study were essentially uniform in textural composition. Cumulative curves representing the two end members of the sequence, Morrow and Walla Walla, are shown in figures 14 and 15. These curves illustrate the textural uniformity that is typical of all the profiles.

The clear differentiation in physical and chemical properties of material believed to be basalt residuum, which was found in a thin layer immediately overlying the bedrock in profile 3, from the loessial material in other horizons, is evidence that basalt has contributed little or nothing to the parent material of these profiles.

Deposition materials associated with the glacial period of Pleistocene time (2, pp. 172-176) are a likely source of the loess. Glacial material deposited on the flood plains of the Columbia River

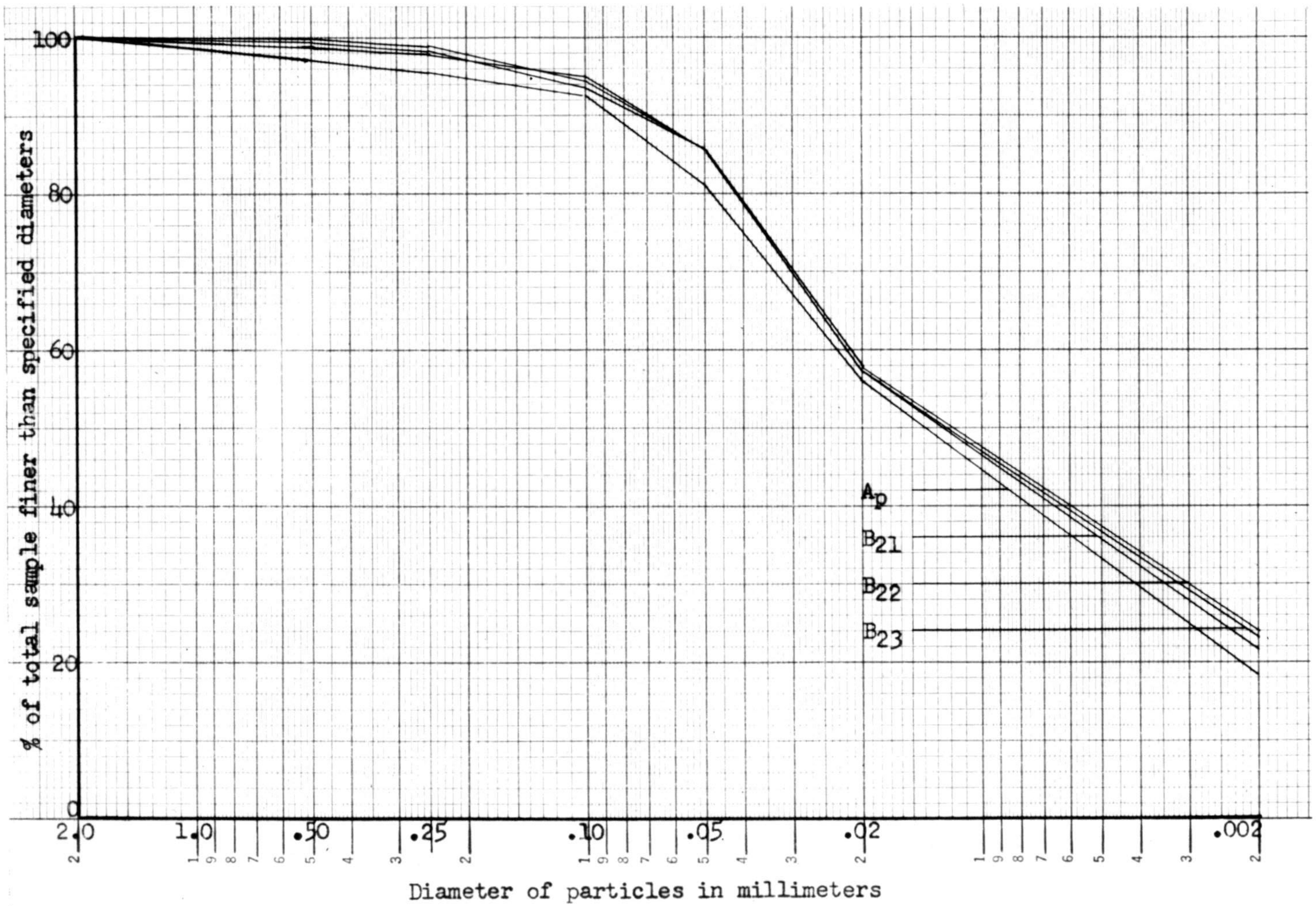

Fig.14. Cumulative particle size distribution curve of Morrow silt loam - P2

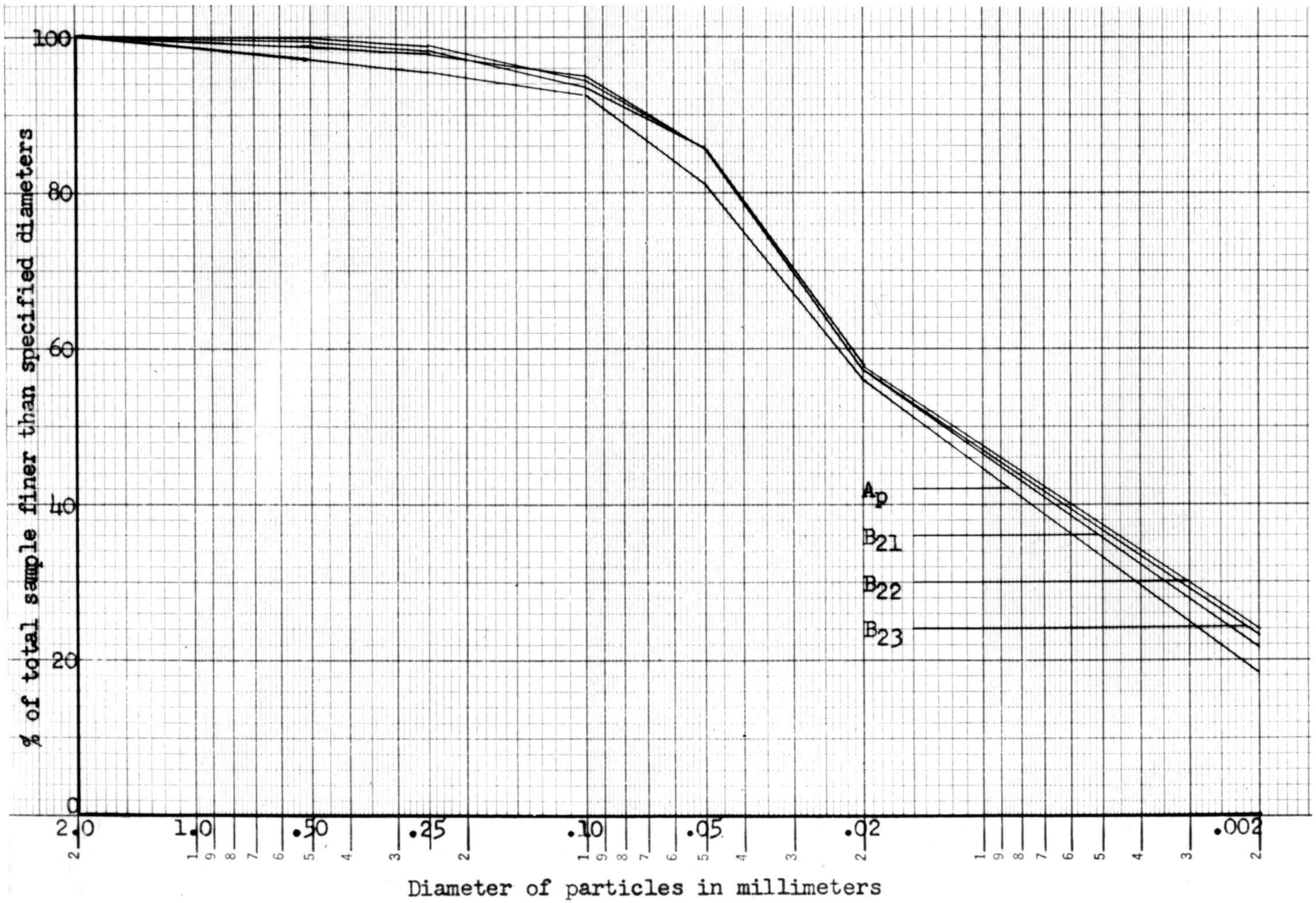

Fig.14. Cumulative particle size distribution curve of Morrow silt loam - P2

so as to be available for subsequent wind erosion and redeposition would constitute a source similar to the sources of loess accumulations that have been described in other areas (59, pp. 472-479, 48, pp. 19-29, and 12, pp. 203-231) and especially in areas where the loess formations have valley relationships (24, pp. 599-622).

The loess deposit becomes thinner and finer textured with increasing distance south from the river. These relationships were observed in the field and are illustrated by the 7 profiles studied in detail. It is logical that the thickest and coarsest part of the loess must be nearest the source if the original strong winds from off the glaciers carried the loess toward the south and sorted it according to the surface-mass ratio of the particles. Flint (11, p. 179) suggests that wind blowing from the region of high pressure over the ice sheet to the north could aid in distributing loess. Smith (44, pp. 139-184) found that the character of the loess deposits in Illinois changed regularly as related to the distance from the source. He showed that the texture and rate of thinning of the loess was a linear function of the logarithm of the distance from the source. Brown (7, pp. 5-41) noted that loess derived soils also occur in belts in Iowa and divided soils partly on the thickness of the loess deposit. Similar observations have been made in other parts of central United States (56, pp. 7-29).

The present day soils of the area are deepest on the northeast slopes.

A similar condition which has been described in the Palouse area of Washington (25, pp. 467-480 and 41, pp. 301-317) was attributed to deposition by south winds on lee north slopes of a blanket of loess plus volcanic dust younger than the underlying Palouse loess. Free (13, pp. 41-45) thought the accumulation of aeolian materials was mainly dependent upon the force of retention and that whatever decreases wind velocity will favor this. Vegetation can cause a decrease in velocity and thereby favor wind deposition and prevent wind erosion. More recent studies (16, pp. 381-385, and 51, pp. 647-653) have shown that loess accumulates in vegetation and sheltered areas. At the present time vegetative cover is greatest on north and east slopes in the study area. It is believed that the greater thickness of loess on northeast slopes in the study area may be attributed to a combination of (1) preferential accumulation on north slopes because of differences in vegetative cover, (2) erosion on windward slopes and deposition on lee slopes by southwest winds after the original accumulation, and (3) preferential wind and water erosion on south slopes because of differences in vegetative cover.

Relative Influence of the Soil Forming Factors

Horizon characteristics observed in the sequence of soil profiles in this study have developed as a result of the soil-forming factors. However, certain factors have exerted greater influence than others.

Influence of climate: The rate of soil development as influenced by the leaching action of water would be considered highly effective over the entire sequence because the rainfall period corresponds to months of low temperatures and reduced activity of vegetation (20, pp. 335-349 and 33, pp. 9-19). Although a difference of approximately one inch of total rainfall per year occurs across the area, figure 1, this small amount could not be considered critical in causing great changes in the soils (27, pp. 1-12). Morrow soils are known to extend to higher elevations than Condon and Walla Walla, however, in this investigation profile examples of Morrow and Condon were both at approximately 3000 feet elevation and Walla Walla at 1220 feet. This difference in elevation may cause a more effective use of moisture by Morrow and Condon soils, however, no direct influence on the progression of soil development has been ascertained.

Influence of vegetation: The analyses of carbon and nitrogen gives no indication that measurable differences have occurred that would reflect differences in soil development due to kind and density of vegetation. The total organic matter and nitrogen contents of the profiles per unit surface area are presented in table 25. These values are all for cultivated soils but the same relationships may be expected for virgin conditions. These data show no trend that would permit a development sequence to be established on the basis of vegetation.

Table 25. Quantitative evaluation of organic matter

Profile	Profile depth is in inches to bedrock P_1 to P_5; into C horizon P_6 and P_7	Total organic matter in the profile in gm./sq. cm.*	Total nitrogen in the profile in gm./sq. cm.*
Walla Walla, P_6	75	2.38	0.120
Condon, P_4	41	1.55	0.081
Morrow-Condon, P_3	41	1.40	0.073
Morrow, P_2	25	1.16	0.059
Walla Walla, P_7	93	1.12	0.109
Morrow, P_1	21	1.02	0.049
Condon-Walla Walla, P_5	44	0.97	0.089

* Calculated as follows: organic matter or nitrogen content in per cent by weight, times bulk density, times depth in centimeters for each horizon. Values represent summation of all horizons in the profile.

Influence of topography: All experimental profile sites were selected in areas that would represent constant topographic relationships in order that this influence would not constitute a variable factor in soil formation. These sites were located approximately one-fourth to one-third of the distance down hill from the top of gentle slopes in areas of rolling upland. Slopes were all about 5 per cent and faced to the north or northeast. Conditions of surface drainage and erosion were similar.

Influence of parent material and time: The source of the parent material for all the soils is the same except for the possible inclusion of small amounts of basalt bedrock material in Morrow and Condon. If sample number 425 is regarded as typical of residual material from basalt, the chemical and physical homogeneity of other profile horizon samples indicates that they have originated mainly from loess parent material. Thickness and texture relationships of the loess deposits indicate effective age differences in the parent material of the soil. Parent material for the thinner Morrow and Condon soils that are more distant from the loess source was accumulated over the same geologic age as the parent material of the deeper Walla Walla soils. It is older material because it took longer to accumulate per unit of depth. Effective age is greater in the thin soils due to a combination of older geologic material and the greater intensity of the soil forming processes acting on finer textured parent material. The effect of thin parent material together with fine texture has resulted in a faster rate of soil development. Studies on Prairie soils developed from loess, have invariably related increased soil development to effective weathering that in turn is related to thickness of the loess parent material (17, pp. 424-431, 6, pp. 1-14, and 62, pp. 389-399).

As a result of time acting on different depths and particle size of parent material, the thinner Morrow and Condon soils are more mature than Walla Walla. Soil development is more advanced as evidenced by clay migration, structure, and horizon differentiation. Data summarized in table 26 indicate the textural and horizon changes that have taken place in the soils developed from thin loess, profile 1, as compared to thicker loess, profile 7. The magnitude of the clay maximum in the B horizon has increased in order from the Walla Walla to the Morrow soils and has been accompanied by a corresponding change in structure and horizon distinctness.

Time, acting on similar parent material has been the most important of the soil forming factors in differentiation of these soils.

Table 26. Variation of texture and horizon changes with soil development

Profile	Ratio of coarse silt to fine silt in B_2 horizon	Percent difference in clay content between A and B horizon	Relative degree of horizon differentiation as determined by field morphology
Morrow, P_1	0.7	14.6	Stronger
Morrow, P_2	0.7	5.5	
Morrow-Condon, P_3	0.6	6.7	
Condon, P_4	0.8	3.9	
Condon-Walla Walla P_5	0.9	0.6	
Walla Walla, P_6	1.0	2.0	
Walla Walla, P_7	1.1	1.5	Weaker

CONCLUSIONS

Investigations showed that characteristic changes occur across a sequence of Morrow, Condon, and Walla Walla soils in the Mid-Columbia Basin of Oregon. The depth of soil profiles to bedrock is consistently deeper on north and east slopes than on south and west slopes. Texture, structure, horizon distinctness, and depth of solum change preceptibly as a function of the degree of soil development and character of the parent material. Colors were similar in Morrow and Condon and generally darker than in Walla Walla.

Morrow and Condon retain approximately 2 inches, and Walla Walla 1.5 inches, of available moisture per foot of soil depth. This difference may be accounted for in part by texture and structure. However, total moisture available to crops is higher in the Walla Walla soil due to greater depth of the solum.

The water permeability rates of all the profiles in the sequence is moderate. Differences in the permeability rates are more closely related to soil structure and per cent of non-capillary porosity than texture. Stronger developed structure and greater noncapillary porosity resulted in greater permeability rates. A correlation coefficient of 0.709 shows a highly significant positive relationship between the volume of pores drained at 0.1 atmosphere of tension and the water permeability rate.

Slight variation from the zonal type of soil development is indicated in the Morrow and Condon soils, probably as a result of interrupted leaching caused by temporary restricted drainage conditions. The maintenance or accumulation of sodium, soluble salts, and bases are at a higher level than in the Walla Walla soils. Fine basalt fragments occur throughout the solums of Morrow and Condon but not the Walla Walla profiles. Perceptible quantities of white material mixed in those horizons close to basalt bedrock in the Morrow and Condon profiles was tentatively identified as opal. This material may be readily distinguished from lime by acid treatment.

The Morrow soils exhibit texture profiles, moderately to strongly developed structure units, and distinct horizons. On the other end of the sequence, the Walla Walla soils have little or no texture profile, weak to very weak structure units, and the horizon boundaries are difficult to distinguish. Condon soils are intermediate but more like Morrow than Walla Walla. They have less clay accumulation and weaker structure development than Morrow. This study indicates that the Morrow, Condon, and Walla Walla soils should be retained as the three series now recognized. Several morphological characteristics distinguish the Walla Walla from the other two series, however, texture, accompanied by its influence on structure must remain the chief field criterion in the differentiation of the Morrow and Condon series. The range of characteristics exemplified in this study indicates that soils representative of profiles number 1, 2, and 3 may be classified in the Morrow series, profile 4 the Condon, and profiles 6 and 7 in the Walla Walla series. Profile number 5 is more nearly a true intergrade, however, the majority of evidence indicates that soils representative of this profile should be classified as moderately deep Walla Walla.

A relationship exists between the particle size of the parent material and the depth of solum. The relatively thicker solum of the Walla Walla soils is associated with the coarser materials from which they have developed. Condon and Morrow have less depth of solum and finer textured parent material than Walla Walla.

This study indicates that the soils have developed from loess derived in large part from glacial deposits on the flood plains of the Columbia River. It is postulated that north winds fractionated the loess, depositing coarser material near the source close to the river, and finer material at greater distances south of the river. Preferential erosion and southwesterly winds have since caused accumulations on northeast slopes.

Variations in effective time and texture of the parent material, both of which are related to soil development, are considered the most important factors in differentiation of the soils. Soil development is more advanced in the thinner soils of the Morrow series than the deeper Walla Walla soils. The degree of soil development increases in the order: Walla Walla-Condon-Morrow. All three of the soil series studied in this sequence would be classified in the Chestnut great soil group with the Morrow and Condon more typical of medial and the Walla Walla of minimal subgroups.

BIBLIOGRAPHY

1. Allison, Ira S. Landforms. In Atlas of Pacific Northwest Resources and development. Corvallis, Oregon state college, 1953, pp. 3-6.

2. Antevs, Ernst. Climatic variations during the last glaciation in North America. American meteorological society bulletin 19: 172-176. 1938.

3. Atwood, Wallace W. The physiographic provinces of North America. Boston, Ginn, 1940. 535 p.

4. Baver, L. D. Soil physics. 2d ed. New York, John Wiley, 1948. 398 p.

5. Bradfield, R. and V. C. Jamison. Soil structure—attempts at its quantitative characterization. Soil science society of America proceedings 3:70-76. 1938.

6. Bray, R. H. Chemical and physical changes in soil colloids with advancing development in Illinois soils. Soil science 43:1-14. 1937.

7. Brown, P. E. Soils of Iowa. Ames, Iowa state college, 1936. 261 p. (Iowa. Agricultural experiment station. Special report no. 3)

8. Christiansen, J. E. Effect of entrapped air upon the permeability of soils. Soil science 58:355-365. 1944.

9. Colman, E. A. A laboratory procedure for determining the field capacity of soils. Soil science 63:277-283. 1947.

10. Duley, F. L. Surface factors affecting the rate of intake of water by soils. Soil science society of America proceedings 4:60-64. 1939.

11. Flint, Richard Foster. Glacial geology of the Pleistocene epoch. New York, John Wiley, 1947. 589 p.

12. Flint, Richard Foster. Pleistocene drift border in eastern Washington. Geological society of America bulletin 48:203-231. 1937.

13. Free, E. E. The movement of soil material by the wind. Washington, Government printing office, 1911. 272 p.

14. Free, G. R. and V. J. Palmer. Interrelationship of infiltration, air movement and pore size in graded silica sand. Soil science society of America proceedings 5:390-398. 1940.

15. Harper, W. G., F. O. Youngs and T. W. Glassey. Soil survey of the Umatilla area, Oregon. Washington, Government printing office, 1948. 125 p.

16. Hobbs, William H. Loess, pebble bands, and boulders from glacial outwash of the Greenland continental glacier. Journal of geology 39:381-385. 1931.

17. Hutton, Curtis E. Studies of loess-derived soils in southwestern Iowa. Soil science society of America proceedings 12:424-431. 1947.

18. Jacquot, Harley D. Annual cropping with nitrogen in the intermediate rainfall areas of eastern Washington. Pullman, Washington state college, 1953. 21 p. (Washington. Agricultural experiment station. Station circular no. 214)

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

20. Kardos, L. T. and O. C. Bowlsby. Chemical properties of some representative samples of certain great soil groups and their relation to genetic soil classification. Soil science 52: 335-349. 1941.

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

22. Leamer, Ross W. and J. F. Lutz. Determination of pore-size distribution in soils. Soil science 49:347-360. 1940.

23. Leamer, Ross W. and Byron Shaw. A simple apparatus for measuring noncapillary porosity on an extensive scale. Journal of the American society of agronomy 33:1003-1008. 1941.

24. Leighton, Morris M. and H. B. Willman. Loess formations of the Mississippi Valley. Journal of geology 58:599-623. 1950.

25. Lutspeich, F. B. and H. W. Smith. Soils of the Palouse loess: I. The Palouse catena. Soil science 76:467-480. 1953.

26. Lutz, J. F. and Ross W. Leamer. Pore size distribution as related to the permeability of soils. Soil science society of America proceedings 4:28-31. 1939.

27. Marbut, C. F. Soil genesis and classification. Lectures to the graduate school of the United States department of agriculture. Lecture no. 4, 1928. 12 p. (Mimeographed)

28. Moore, Ross E. Water conduction from shallow water tables. Hilgardia 12:383-426. 1939.

29. Nelson, W. R. and L. D. Baver. Movement of water through soils in relation to the nature of the pores. Soil science society of America proceedings 5:69-76. 1940.

30. Nikiforoff, C. C. The solonetz-like soils in southern California. Journal of the American society of agronomy 29: 781-796. 1937.

31. O'Neal, Alfred M. A key for evaluating soil permeability by means of certain field clues. Soil science society of America proceedings 16:312-315. 1952.

32. Peech, M. et al. Methods of soil analysis for soil fertility investigations. Washington, U. S. Government printing office, 1947. 25 p. (U. S. Dept. of agriculture. Circular no. 757)

33. Prescott, J. A. A climatic index for the leaching factor in soil formation. Journal soil science 1:9-19. 1949.

34. Reed, J. Fielding and R. W. Cummings. Soil reaction-glass electrode and colorimetric methods for determining pH values of soils. Soil science 59:97-104. 1945.

35. Richards, L. A. Pressure-membrane apparatus construction and use. Agricultural engineering 28:451-454. 1947.

36. Richards, L. A. Porous plate apparatus for measuring moisture retention and transmission by soil. Soil science 66:105-110. 1948.

37. Richards, L. A. Methods for mounting porous plates used in soil moisture measurements. Agronomy journal 41:487-490. 1949.

38. Richards, L. A. Methods of measuring soil moisture tension. Soil science 68:95-112. 1949.

39. Richards, L. A. and C. H. Wadleigh. Soil water and plant growth. In Byron T. Shaw's (ed.) Soil physical conditions and plant growth. New York, Academic press, 1952. pp. 73-251.

40. Richards, L. A. and L. R. Weaver. Moisture retention by some irrigated soils as related to soil-moisture tension. Journal of agricultural research 69:215-235. 1944.

41. Rieger, Samual and H. W. Smith. Soils of the Palouse loess: II. Development of the A_2 horizon. Soil science 79:301-319. 1955.

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

43. Sigmond, A. A. J. de. The principles of soil science. London, Thomas Murby, 1938. 362 p.

44. Smith, G. D. Illinois loess, variations in its properties and distribution. Urbana, University of Illinois, 1942. 45 p. (Illinois. Agricultural experiment station. Bulletin no. 490)

45. Smith, G. D., W. H. Allaway and F. F. Riecken. Prairie soils of the upper Mississippi Valley. Advances in agronomy 2: 157-203. 1950.

46. Smith, R. M., D. R. Browning and G. G. Pohlman. Laboratory percolation through undisturbed soil samples in relation to pore-size distribution. Soil science 57:197-213. 1944.

47. Smith, R. M. and D. R. Browning. Some suggested laboratory standards of subsoil permeability. Soil science society of America proceedings 11:21-26. 1946.

48. Tedrow, J. C. F. and Paul MacClintock. Loess in New Jersey soil materials. Soil science 75:19-29. 1953.

49. Thorp, James. Significance of loess in classification of soils. American journal of science 243:263-270. 1945.

50. Thorp, James and G. D. Smith. Higher categories of soil classification: Order, suborder, and great soil groups. Soil science 67:117-126. 1949.

51. Tuck, Ralph. The loess of the Matanuska Valley, Alaska. Journal of geology 46:647-653. 1938.

52. Uhland, R. E. Physical properties of soils as modified by crops and management. Soil science society of America proceedings 14:361-366. 1949.

53. U. S. Department of agriculture. Diagnosis and improvement of saline and alkali soils. Washington, Government printing office, 1954. 160 p. (Its Handbook no. 60)

54. U. S. Department of agriculture. Soil survey manual. Washington, Government printing office, 1951. 503 p. (Its Handbook no. 18)

55. U. S. Department of commerce. Weather bureau. Climatological data Oregon. vo. 60, no. 13. Washington, Government printing office, 1955. pp. 200-209. (Annual summary 1954.)

56. Vanderford, Harvey B. and W. A. Aldricht. The development of loessial soils in Central United States as it reflects differences in climate. Columbia, University of Missouri, 1942. 31 p. (Missouri. Agricultural experiment station. Research bulletin no. 345)

57. Veihmeyer, F. J. and A. H. Hendrickson. Soil density as a factor in determining the permanent wilting percentage. Soil science 62:451-456. 1946.

58. Veihmeyer, F. J. and A. H. Hendrickson. Soil density and root penetration. Soil science 65:487-493. 1948.

59. Visher, S. S. The time of glacial loess accumulation in its relation to the climatic implications of the great loess deposits. Journal of geology 30:472-479. 1922.

60. Walkley, Allan. A critical examination of a rapid method for determining organic carbon in soils-effect of variations in digestion conditions and of inorganic soil constituents. Soil science 63:251-264. 1947.

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

62. Wascher, H. D., R. P. Humbert and J. G. Cady. Loess in the southern Mississippi Valley: Identification and distribution of the loess sheets. Soil science society of America proceedings 12:389-399. 1947.

63. Wells, Edward L. Climate of Oregon. In U. S. Department of agriculture. Climate and man: the yearbook of agriculture, 1941. Washington, Government printing office, 1941. pp. 1075-1086.

64. Wilson, H. A., F. F. Riecken and G. M. Browning. Soil profile characteristics in relation to drainage and level terraces. Soil science society of America proceedings 11:110-118. 1947.

APPENDIX

APPENDIX A: LOCATION AND DESCRIPTION OF SOIL PROFILES

1. Nomemclature used in the description of soil profiles is adapted from the Soil Survey Manual. (54, pp. 173-234).
2. The color range from dry to moist soil was determined by means of Munsell color charts. Dry colors are designated first.
3. The pH values were obtained in the laboratory using a glass electrode on a saturated soil paste. The laboratory pH values were lower by an average of 0.8 pH units than values obtained in the field by the use of indicators.
4. Textural classes noted in parentheses were obtained in the laboratory. They are listed only when different from texture values obtained in the field.
5. Permeability and infiltration data are from laboratory determinations.
6. Approximate stability of the aggregates was determined by testing aggregates with water dropped from a height of 2 inches (31, p. 313). Three classes are recognized:

   Unstable — Less than 10 drops required for slaking.

   Moderately stable — 10 to 25 drops required for slaking.

   Stable — More than 25 drops required for slaking.
7. Very fine holes are less than 1 millimeter in diameter.
8. Fine basalt fragments are 1 to 2 millimeters in diameter. Medium basalt fragments are 2 to 5 millimeters in diameter.

Morrow silt loam - Profile No. 1

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 27, 1954, in Morrow County, Oregon, NW 1/4 of SE 1/4 Section 12, T 4 S, R 24 E., approximately 15 1/4 miles southwest of Heppner, Oregon, via state highway 206, and 1 3/4 miles south on the old Hardman road, approximately 2 miles east and 1 1/2 miles south of Eight mile, approximately 300 feet north and 150 feet east of the west corner of an east-west fence adjacent to an unimproved road on the Rill farm.

The location was on a 5% slope facing northeast, on rolling upland, at 3000 feet. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained, with medium runoff, moderate infiltration and moderate to moderately slow permeability. The parent material is probably loess and residuum from basalt. This profile was considered to be finer textures than the other Morrow profile.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Heppner, Oregon, which is 15 1/4 miles northeast of the sample site and at an elevation of 1950 feet; for 53 years of record the January average temperature is 32.5° F; July average temperature is 68.8° F; with a growing season of 168 days. The average annual precipitation based on 57 years of record 13.27 inches, and is distributed as follows: January 1.40, February 1.26, March 1.25, April 1.33, May 1.30, June 1.17, July 0.44, August 0.37, September 0.89, October 1.12, November 1.37, December 1.37.

Description of Profile No. 1

Sample 26

A_p 0-8" Light brownish gray (10YR 6/2) to very dark grayish brown (10YR 3/2) silt loam with very weak very fine granular structure. Soft, friable, slightly sticky and slightly plastic. Roots plentiful; numerous very fine holes; pH 6.1. Aggregates moderately stable; fine basalt fragments numerous; little worm activity. The upper surface is a thin massive crust about 1/16 inch thick over weak vesicular material 5 inches thick. Lower boundary abrupt and smooth.

Sample 27

B_{21} 8-13" Brown (10YR 5/3) to very dark grayish brown (10YR 3/2) silty clay loam or silty clay (silty clay loam) with strong medium and coarse prismatic structure which breaks apart to strong fine blocks. Hard, firm, very sticky and very plastic. Roots plentiful but fewer than in horizon above; numerous very fine holes; pH 7.3. Aggregates stable; fine basalt fragments numerous; little worm activity; thin clay flows on some surfaces. Lower boundary clear and smooth.

Sample 28

B_{22} 13-21" Pale brown (10YR 6/3) to dark brown (10YR 4/3) silty clay loam (silt loam) with moderate medium and coarse prismatic structure which breaks apart to strong fine blocks. Slightly hard, firm, sticky and plastic. Roots few; numerous very fine holes; pH 7.5. Aggregates stable; basalt fragments more numerous and larger; no worm activity. Lower boundary clear and wavy.

Sample 29

Dr 25" + Basalt; undersides of fragments are lime coated in the upper part. The basalt is only a part of the parent material but it is considered as a Dr rather than a D.

Morrow silt loam - Profile No. 2

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 27, 1954, in Morrow County, Oregon, NW 1/4 of SE 1/4, Section 21, T 3 S, R 26 E., approximately 6 1/4 miles southwest of Heppner, Oregon, via state highway 206, approximately 285 feet east of a blazed fence post 1/4 mile south of the O. C. Haguewood farm home.

The location was on a 5% slope facing northeast, on rolling upland, at 2800 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained, with medium runoff, moderate infiltration, and moderate to moderately slow permeability. The parent material is probably loess and residuum from basalt. This profile was considered as being typical of the Morrow series.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Heppner, Oregon, which is 6 1/4 miles northeast of the sample site and at an elevation of 1950 feet; for 53 years of record the January average temperature is 32.5° F; July average temperature is 68.8° F; with a growing season of 168 days. The average annual precipitation based on 57 years of record is 13.27 inches, and is distributed as follows: January 1.40, February 1.26, March 1.25, April 1.33, May 1.30, June 1.17, July 0.44, August 0.37, September 0.89, October 1.12, November 1.37, December 1.37.

Description of profile No. 2

Sample 11

A_p 0-6"

Grayish brown (10YR 5/2) to very dark grayish brown (10YR 3/2) silt loam with weak very fine granular structure. Soft, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.1. Aggregates moderately stable; fine basalt fragments numerous; worm activity moderate. The upper surface is a thin massive crust about 1/16 inch thick over weak vesicular material 2 inches thick. A medium platy layer forms a plowpan at 5-6 inches. Lower boundary abrupt and smooth.

Sample 12

B_{21} 6-14"

Grayish brown (10YR 5/2) to very dark grayish brown (10YR 3/2) silt loam with moderate medium and coarse prismatic structure which breaks apart to strong fine blocks. Slightly hard, firm, sticky and plastic. Roots abundant; numerous very fine holes; pH 6.9. Aggregates stable, gray-coated; fine basalt fragments numerous; worm activity moderate; no clay flows apparent. Continuous bands, approximately 1/2 inch thick, darker colored than the soil mass, are faintly visible running in a wavy roughly horizontal direction. Lower boundary abrupt and smooth.

Sample 13

B_{22} 14-16" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam with moderate medium and coarse prismatic structure which breakd apart to strong fine blocks. Slightly hard, firm, sticky and plastic. Roots plentiful; numerous very fine holes; pH 7.5. Aggregates stable; fine basalt fragments numerous; worm activity moderate; no clay flows apparent. Lower boundary clear and smooth.

Sample 14

B_{23} 16-25" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam with weak medium and coarse prismatic structure which breaks apart to moderate fine and medium blocks. Slightly hard, friable, sticky, and plastic. Roots plentiful; numerous very fine holes; pH 7.8. Aggregates moderately stable; basalt fragments more numerous and larger; worm activity slight. Lime threads following old root channels present on one side of sample site but absent to very few on the other side.

Sample 15

Dr 25" + Basalt, undersides of fragments are lime-coated in the upper part. The basalt is only a part of the parent material but it is considered as a Dr rather than a D.

Morrow Silt Loam Grading to Condon Silt Loam -
Profile No. 3

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 29, 1954, in Gilliam County, Oregon NE 1/4 of NE 1/4, Section 28, T 4 S, R 22 E., approximately 7 miles southeast of Condon, Oregon via the Condon-Lonerock road, approximately 800 yards southeast of a windmill on the Bob Worley farm then 100 feet south of a bare spot in the fence row adjacent to the Condon-Lonerock road.

The location was on a 5% slope facing northwest, on rolling upland, at 3000 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained, with medium runoff, moderate infiltration and permeability. The parent material is probably loess and residuum from basalt. This profile was considered to represent the Morrow series integrading toward the Condon series. A profile typical of the Condon series was examined 800 yards west of this site and at a slightly lower elevation, and a profile typical of the Morrow series was observed 800 yards east and at a slightly higher elevation.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Condon, Oregon which is approximately 7 miles northwest of the sample site and at an elevation of 2844 feet; for 45 years of record the January average temperature is 28.7; July average temperature is 67.1; with a growing season of 120 days. The average annual precipitation based on 46 years of record is 12.16 inches, and is distributed as follows: January 1.40, February 1.01, March 0.94, April 1.05, May 1.18, June 1.07, July 0.39, August 0.35, September 0.87, October 0.99, November 1.58, December 1.32.

Description of Profile No. 3

Sample 419

A_p 0-6" Grayish brown (10YR 5/2) to very dark brown (10YR 2/2) silt loam with weak very fine granular structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.4. Aggregates moderately stable; fine basalt fragments numerous; worm activity moderate. The upper surface is a thin massive crust about 1/16 inch thick over weak vesicular material 3 inches thick.

Sample 420

A_3 6-8 1/2" Dark grayish brown (10YR 4/2) to very dark grayish brown (10YR 3/2) silt loam with weak very fine prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.5. Aggregates moderately stable with indistinct gray coatings; fine and medium basalt fragments numerous; worm activity moderate. A thin and medium platy layer forms a plowpan in the upper 1/2 inch.

Sample 421

B_2 8 1/2-14" Dark grayish brown (10YR 4/2) to very dark grayish brown (10YR 3/2) silty clay loam (silt loam) with weak medium and coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.8. Aggregates moderately stable, gray-coated in upper 3 inches mostly over tops of prisms, possibly due to clean sand grains; fine and medium basalt fragments numerous; worm activity moderate; clay flows below upper 3 inches. Continuous bands, approximately 1/2 inch thick, darker colored than the soil mass, are faintly visible running in a wavy horizontal direction.

Sample 422

B_{31} 14-23" Brown (10YR 5/3) to dark brown (10YR 3/3) silt loam with weak coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 7.0. Aggregates stable; fine and medium basalt fragments abundant; worm activity moderate.

Sample 423

C_1 23-30" Pale brown (10YR 6/3) to dark brown (10YR 4/3) silt loam with very weak coarse prismatic structure. Soft, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 7.7. Aggregates moderately stable; fine and medium basalt fragments abundant; worm activity slight.

Sample 424

C_{1ca} 30-36" Pale brown (10YR 6/3) to brown (10YR 5/3) silt loam with massive structure. Soft, friable, slightly sticky and slightly plastic. Roots few, numerous very fine holes; pH 8.1. Aggregates moderately stable; fine and medium basalt fragments abundant; no worm activity. Lime specks faintly visible around old root channels.

Sample 425

B_{2b} 36-41" Dark brown (10YR 4/3) to dark brown (10YR 3/3) clay with massive structure. Brittle, hard, friable, sticky and very plastic. Roots few; numerous very fine holes; pH 7.9. Fine and medium basalt fragments numerous; no worm activity; clay flows in the form of bridges between sand grains. Lime coating on rock fragments and weathered material.

Sample 426

Dr 41" + Basalt; fragments coated with lime on all surfaces in the upper part. This horizon is the parent material of the horizon above but the material above 36 inches is a mixture of loess and basalt with the loess dominating.

Remarks: Most of the horizon boundaries are wavy and clear eventhough there has been some mixing of the layers by rodents.

Condon Silt Loam - Profile No. 4

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 28, 1954, in Gilliam County, Oregon, SE 1/4 of NW 1/4, Section 8, T 4 S, R 21 E., approximately 2 miles west of Condon, Oregon, via state highway 206, approximately 100 feet north of a blazed post in a fence line adjacent to highway 206 1/2 mile south of the Carl Meyer farm home.

The location was on a 5% slope facing northeast, on rolling upland, at 3000 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained, with medium runoff, moderate infiltration, and moderate to moderately slow permeability. The parent material is probably loess and residuum from basalt. This profile was considered as being typical of the Condon series.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Condon, Oregon, which is 2 miles east of the sample site and at an elevation of 2844 feet; for 45 years of record the January average temperature is 28.7; July average temperature is 67.1; with a growing season of 120 days. The average annual precipitation based on 46 years of record is 12.16 inches, and is distributed as follows: January 1.40, February 1.01, March 0.94, April 1.05, May 1.18, June 1.07, July 0.39, August 0.35, September 0.87, October 0.99, November 1.58, December 1.32.

Description of Profile No. 4

Sample 310

A_p 0-6" Grayish brown (10YR 5/2) to very dark brown (10YR 2/2) silt loam with weak very fine granular structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.2. Aggregates moderately stable; fine basalt fragments numerous; worm activity moderate. The upper surface is a thin massive crust about 1/16 inch thick over weak vesicular material 2 inches thick.

Sample 311

A_3 6-11" Dark brown (10YR 3/3) to very dark brown (10YR 2/2) silt loam with weak very fine granular structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.5. Aggregates stable; fine basalt fragments numerous; worm activity moderate. A thin platy to massive layer forms a brittle plowpan in the upper 1/2 inch.

Sample 312

B_2 11-17" Dark brown (10YR 4/3) to very dark grayish brown (10YR 3/2) silt loam with weak medium and coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; very fine holes numerous; pH 7.3. Aggregates stable; indistinct gray coatings; fine basalt fragments numerous; worm activity plentiful; no clay flows apparent.

Sample 313

B_3 17-24" Yellowish brown (10YR 5/4) to dark brown (10YR 4/3) silt loam with very weak medium and coarse prismatic structure. Soft, friable, slightly sticky and slightly plastic. Roots plentiful; numerous very fine holes; pH 7.9. Aggregates stable; fine basalt fragments numerous; worm activity moderate.

Sample 314

C_{1ca} 24-33" Yellowish brown (10YR 5/4) to dark brown (10YR 4/3) silt loam with massive structure. Soft, friable, slightly sticky and slightly plastic. Roots plentiful; numerous very fine holes; pH 8.6. Aggregates stable; fine basalt fragments numerous; worm activity slight. Lime threads follow old root channels.

Sample 315

C_{12} 33-36" Brown (10YR 5/3) to dark brown (10YR 3/3) silt loam with massive structure. Softer than layer above, friable, slightly sticky and slightly plastic. Roots few; numerous very fine holes;

pH 8.8. Aggregates stable; basalt fragments more numerous and larger; no worm activity.

Sample 316

C_m 36–41" Very pale brown (10YR 7/3) to brown (7.5 YR 5/4) very fine sandy loam (not textured in field) with weak very thin platy structure. Brittle, slightly hard, very friable, non-sticky and non-plastic. No roots; very fine holes more numerous and slightly larger; pH 8.6. Upper surface of plates are gray-coated; basalt fragments more numerous and larger; no worm activity. Boundary clear and wavy.

Sample 317

Dr 41" – Basalt; fragments are lime coated in the upper part, coating is thicker on the underside. The basalt is only a part of the parent material but it is considered as a Dr rather than a D.

Condon Silt Loam Grading to Walla Walla Silt Loam - Profile No. 5

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 29, 1954, in Gilliam County, Oregon, NW 1/4 of NW 1/4, Section 15, T 2 S, R 19 E., approximately 19 miles northwest of Condon, Oregon via state highway 206, approximately 3 miles northwest of Ajax corner, 200 feet east and 85 feet north of a fence corner adjacent to highway 206 on the Schaffer farm.

The location was on a 4% slope facing north, on rolling upland, at 2000 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained, with medium runoff. The parent material is loess and possibly some residuum from basalt. This profile was considered to represent the Condon series intergrading toward the Walla Walla series.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Condon, Oregon, which is 19 miles southeast of the sample site and at an elevation of 2844 feet; for 45 years of record the January average temperature is 28.7; July average temperature is 67.1; with a growing season of 120 days. The average annual precipitation based on 46 years of record is 12.16 inches, and is distributed as follows: January 1.40, February 1.01, March 0.94, April 1.05, May 1.18, June 1.07, July 0.39, August 0.35, September 0.87, October 0.99, November

1.58, December 1.32.

Description of Profile No. 5

Sample 528

A_p 0-6" Grayish brown (10YR 5/2) to very dark brown (10YR 2/2) silt loam with weak fine granular structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.4. Aggregates moderately stable; fine basalt fragments numerous, worm activity moderate. The upper surface is a thin massive crust about 1/16 inch thick over weak vesicular material 1 inch thick.

Sample 529

B_2 6-13" Dark brown (10YR 4/3) to very dark grayish brown (10YR 3/2) silt loam with moderate coarse prismatic structure, which breaks apart to weak medium subangular blocks. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 6.8. Aggregates stable; fine basalt fragments numerous. No clay flows. A weak medium platy layer forms an indistinct plowpan at 6-7 inches.

Sample 530

B_{31} 13-19" Brown (10YR 5/3) to dark brown (10YR 3/3) silt loam with weak coarse prismatic structure which breaks apart to weak medium subangular blocks. Slightly hard, but less hard than layer above, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 7.4. Aggregates stable; fine basalt fragments numerous.

Sample 531

B_{32} 19-25" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam with very weak coarse prismatic structure which break apart to weak medium subangular blocks. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 7.5. Aggregates stable; fine basalt fragments numerous.

Sample 532

B_{33} 25-30" Pale brown (10YR 6/3) to brown (10YR 5/3) silt loam with very weak coarse prismatic structure which break apart to weak medium subangular blocks. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; numerous very fine holes; pH 7.7. Aggregates stable; fine basalt fragments numerous.

Sample 533

C_{ca} 30-44" Pale brown (10YR 6/3) to dark brown (10YR 4/3) silt loam with massive structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots few, numerous very fine holes; pH 8.1. Aggregates stable: fine and medium basalt fragments numerous; no worm activity. Lime in streaks in upper part, coated on rock fragments in lower part.

Sample 534

D_r 44" + Basalt; fragments coated with lime on all surfaces in the upper part. The basalt is only a part of the parent material but it is considered as a Dr rather than a D.

All horizon boundaries are gradual.

Walla Walla Loam - Profile No. 6

This profile was sampled by Ray Roberts, Ellis Knox, Rudy Mayko, and John Douglass, September 29, 1954, in Sherman County, Oregon, NE 1/4 of SW 1/4, Section 12, T 1 N, R 17 E., approximately 3 1/4 miles southeast of Wasco, Oregon, on the Fred Hennigan farm approximately 1 mile west and 1 1/8 miles south of the Klondike elevator.

The location was on a 6% slope facing north, on a plateau, at 1240 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained with medium runoff. The parent material is loess. This profile was considered as being typical of the Walla Walla series.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Wasco, Oregon, which is 3 1/4 miles northwest of the sample site and at an elevation of 1222 feet: For 37 years of record the January average temperature is 30.4° F; July average temperature is 70.4° F; with a growing season of 173 days. The average annual precipitation based on 47 years of record is 11.80, and is distributed as follows: January 1.86, February 1.33, March 0.95, April 0.71, May 0.74, June 0.59, July 0.17, August 0.21, September 0.60, October 0.95, November 1.83, December 1.86.

Description of Profile No. 6

Sample 636

A_p 0-8" Dark brown (10YR 3/3) to very dark brown (10YR 2/2) silt loam (loam) with weak very fine crumb structure. Upper three fourths soft, lower fourth slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 6.2. Aggregates moderately stable; very few to no fine basalt fragments throughout profile; worm activity moderate.

Sample 637

A_3 8-15" Dark brown (10YR 3/3) to very dark brown (10YR 2/2) silt loam (loam) with weak coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant, pH 6.3. Aggregates moderately stable; worm activity moderate. Upper 1/2 inch slightly denser forming an indistinct plowpan.

Sample 638

B_2 15-23" Dark brown (10YR 4/3) to very dark grayish brown (10YR 3/2) silt loam (loam) with weak very coarse prismatic structure units which are about 4 inches by 8 inches and readily break into weak medium subangular blocks. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant. pH 6.3. Aggregates moderately stable; worm activity moderate. No clay flows apparent.

Sample 639

B_{31} 24-41" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam (loam) with very weak coarse prismatic structure. Soft, friable, slightly sticky and slightly plastic. Roots abundant. pH 6.8. Aggregates moderately stable; worm activity moderate. Gray streaks along root channels.

Sample 640

B_{32} 41-60" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam (loam) with very weak coarse prismatic structure. Soft, friable, slightly sticky and slightly plastic. Roots abundant. pH 7.2. Aggregates moderately stable; worm activity moderate. Gray streaks along root channels absent.

Sample 641

C_{1ca} 60-70" Brown (10YR 5/3) to dark brown (10YR 4/3) silt loam (loam) with massive structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 7.9, no worm activity. Lime streaks following root channels. Sampled by auger.

Sample 642

C_2 70-75" Dark brown (10YR 4/3 dry or moist) silt loam (loam) with massive structure. Hard, friable, slightly sticky and slightly plastic. Roots few; pH 8.0; no worm activity. Lime streaks common. Sampled by auger.

All horizon boundaries are gradual.

Walla Walla Very Fine Sandy Loam - Profile No. 7

This profile was sampled by Ray Roberts, Ellis Knox, and John Douglass, September 30, 1954, in Sherman County, Oregon NE 1/4 of NW 1/4, Section 19, T 2 N, R 18 E., approximately 5 1/2 miles northeast of Wasco, Oregon, on the Watkins farm, approximately 4 miles north of the Klondike elevator.

The location was on a 5% slope facing northeast, on rolling upland, at 1250 feet elevation. The immediate area was in a wheat-fallow rotation and was in fallow at time of sampling. The profile is well drained with medium runoff. The parent material is loess. This profile was considered to be coarser textured than the other Walla Walla.

The following climatological data (63, pp. 1076-1078 and 55, pp. 201-208) is for the weather station at Wasco, Oregon, which is 5 1/2 miles southwest of the sample site and at an elevation of 1222 feet: For 37 years of record the January average temperature is 30.4° F; July average temperature is 70.4° F; with a growing season of 173 days. The average annual precipitation based on 47 years of record is 11.80, and is distributed as follows: January 1.86, February 1.33, March 0.95, April 0.71, May 0.74, June 0.59, July 0.17, August 0.21, September 0.60, October 0.95, November 1.83, December 1.86.

Description of Profile No. 7

Sample 743

A_p 0-8" Dark grayish brown (10YR 4/2) to very dark brown (10YR 2/2) very fine sandy loam with weak medium granular structure. Upper half soft, lower half slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 6.3; worm activity moderate. Aggregates moderately stable; very few to no fine basalt fragments throughout profile.

Sample 744

A_3 8-13" Dark brown (10YR 4/3) to very dark grayish brown (10YR 3/2) loam with very weak coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 6.6. Aggregates moderately stable; worm activity moderate.

Sample 745

B_2 13-24" Brown (10YR 5/3) to dark brown (10YR 3/3) silt loam (loam) with moderate coarse prismatic structure breaking into weak medium and fine subangular blocky. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 6.8. Aggregates stable; worm activity moderate; no clay flows apparent but some of the peds appear to have colloidal coats and individual sand grains are thinly coated.

Sample 746

B_{31} 24-31" Brown (10YR 5/3) to dark brown (10YR 4/3) very fine sandy loam with weak very coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 7.0. Aggregates stable; worm activity moderate; scattered gray patches along root channels; sand grains not coated as much as in layer above.

Sample 747

B_{32} 31-46" Pale brown (10YR 6/3) to dark brown (10YR 4/3) very fine sandy loam with very weak very coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots abundant; pH 7.2. Aggregates moderately stable; worm activity moderate; scattered gray patches along root channels; sand particles free from any coatings.

Sample 748

B_{33} 46-65" Pale brown (10YR 6/3) to dark brown (10YR 4/3) very fine sandy loam with very weak very coarse prismatic structure. Slightly hard, friable, slightly sticky and slightly plastic. Roots plentiful; pH 7.4. Aggregates moderately stable. Little worm activity. No gray patches along root channels or on sides of peds.

Sample 749

C_{11} 65–78" Pale brown (10YR 6/3) to yellowish brown (10YR 5/4) very fine sandy loam with massive structure. Soft, friable, slightly sticky and slightly plastic. Roots few; pH 7.6. No worm activity. Sampled by auger.

Sample 750

C_{12} 78–84" Pale brown (10YR 6/3) to yellowish brown (10YR 5/4) very fine sandy loam with massive structure. Soft, friable, slightly sticky, and slightly plastic. No roots; pH 8.0. Scattered streaks of lime. Sampled by auger.

Sample 751

C_{1ca} 84–88" Light gray (10YR 7/2) to light brownish gray (10YR 6/2) very fine sandy loam with massive structure. Calcareous material; light color dominant; pH 8.4. Sampled by auger.

Sample 752

C_{13} 88–93" Pale brown (10YR 6/3) to yellowish brown (10YR 5/3) massive very fine sandy loam. pH 8.4. Calcareous material, part loose, and part brittle and lighter colored. Sampled by auger.

All horizon boundaries are gradual.