Late-Holocene soil toposequence in Stroud Basin, Central Wind River Mountains, western Wyoming

William C. Mahaney & K. Sanmugadas

Mahaney, William C. & Sanmugadas, K.: Late-Holocene soil toposequence in Stroud Basin, Central Wind River Mountains, western Wyoming. Geografisk Tidsskrift 89: 58-65. Copenhagen 1989.

Few differences are registered between the high and slope soil members of the toposequence, while several textural and chemical changes occur in the low soil member. High amounts of fine-grained material, higher organic matter, and nitrogen, are found here. Clay mineral data suggest that most vermiculite is pedogenic. The data for extractable iron show that Fed and Feo form most rapidly in the low soil member, and some organically-bound iron moves laterally through the toposequence into the low soil member. These data, plus that for an older toposequence of early-Holocene age (8000 yr BP), from the area show that considerable weathering and lateral translocation occur in soils of 3000 yr BP age in this middle latitude alpine environment.

Keywords:
Soils, toposequence, Wyoming.

William C. Mahaney, Assoc. Prof., Geomorphology and Pedology Laboratory, Geography Department, Atkinson College, York University, and K. Sanmugadas, Lab. Technician, Geography Department, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada.

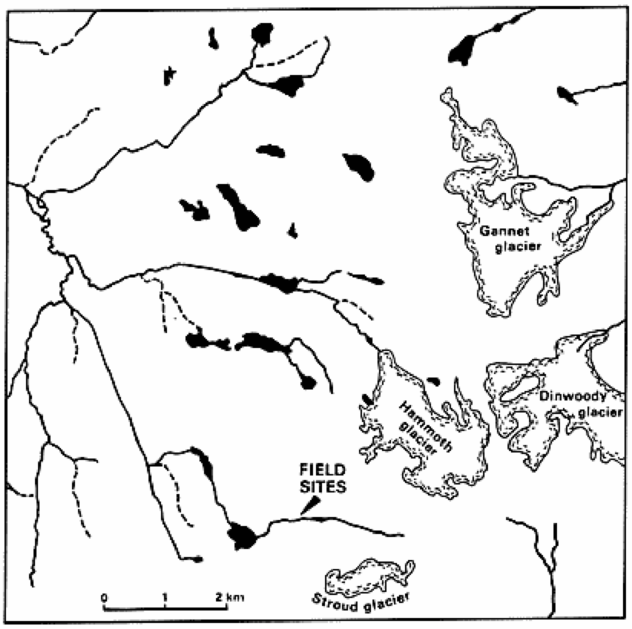

Fig. 1. Location of Stroud Basin in the Central Wind River Mountains, western Wyoming (altitudes in feet).

Soils of late-Holocene age in the alpine area of the Wind River Range in western Wyoming (fig. 1) form in glacial and periglacial deposits (see Mahaney, 1984a and b for a discussion of the Neoglacial) consisting mainly of granodiorite and granitic gneiss. Because of local shallow relief soil toposequences have formed over vertical differences of 6 to 15 m (fig. 2). High soil members in each toposequence provide a considerable variety of weathering products and organic constituents, some of which move through the slope soil member into the low soil member. In nearby Titcomb Basin, the low soil member of an early-Holocene soil toposequence is often influenced by a fluctuation of ground water perched on permafrost tables (Mahaney, 1978; Mahaney & Sanmugadas, 1983). Ground water fluctuations, which are most noticeable during the spring melt season, did not occur at the time of our field investigations in summer.

In this paper we examine the effects of topographic setting on three soil profiles that form a late-Holocene (early Neoglacial) toposequence (Birkeland, 1984) representative of a large area in the mid-latitude alpine zone. We examine the overall affects of topography on soil profile morphology, clay mineral genesis, and mobility of soil-chemical constituents. Evidence from field observations and laboratory analysis is used as a comparison against similar data for older, early-Holocene toposequences in similar environmental settings (Mahaney & Sanmugadas, 1983).

FIELD AREA

Stroud Basin (fig. 1) is a typical, U-shaped glaciated valley with a well-preserved sequence of end moraines of Neoglacial age. The Basin, at an elevation of 3200 m a.s.l., is bounded on the east by the rugged buttress of Gannett Peak (4206 m). The existing glacier below Mount Arrowhead (3943 m) and Sulphur Peak (3908 m; fig. 1) extends down to 3400 m; below this elevation the valley floor is mantled with a remarkably complete sequence of Indian Basin moraines (Mahaney, 1984a; Mahaney et.al., 1984b). Near Peak Lake (fig. 1) a soil toposequence on a south-facing slope of the outer Indian Basin moraine (fig. 2) was investigated to determine soil profile expressions in late-Holocene deposits. Recovered organic-rich material from the Cu (parent material designation following Hodson, 1976; Birkeland, 1984) horizon of a soil in outwash associated with this moraine gave a radiocarbon age of 2760 ± 100 yr BP (GaK-9597) (see Mahaney et al., 1984b for details).

The soils described herein have formed in tills containing clasts of granodiorite and granitic gneiss derived from the underlying crystalline rocks. These tills were deposited during the Indian Basin advance of Neoglaciation (Mahaney et al., 1984a, 1984b) some time prior to 3000 radiocarbon years ago (Mahaney, 1981).

The soils in this toposequence retain many of the mineralogical characteristics of the glacial parent materials (which show some heterogeneity caused by variations in the amounts of granitic gneiss and granodiorite), and the high soil member appears to have been affected by airfall deposition of silt (loess), some of which was probably moved downslope by surface processes (Mahaney 1984a, 1984b).

CLIMATE

Mean annual temperature at Pinedale, Wyoming (2188 m) is +1.8°C, mean January temperature is -10.9°C, and the mean July temperature is +15.8°C. If a mean winter lapse rate of 4.1°C/km-1 and a mean summer lapse rate of 6.2°C/km-1 (Barry & Chorley, 1970, p. 42) are used, the calculated temperature distributions for Stroud Basin (3200 m) area are: mean annual -3.4°C, mean January -15.1°C, and mean July +9.6°C. These values resemble those computed for Grand Teton Glacier cirque (3200 m) in the Teton Range 125 km to the west (Mahaney, 1975). Precipitation is unknown, but it must be considerably higher than at Pinedale, Wyoming (231 mm) (Mahaney, 1978). Winds are strongest in winter, and the prevailing direction is from the northwest (Baker, 1944). Summer is short (mid-July to the end of August) and cool, with frequent thunderstorm activity which is often channelled through Mammoth Basin, thus avoiding Stroud Basin.

VEGETATION

Stroud Basin lies above timberline (3000 m) and supports alpine tundra consisting of perennial sedges, grasses and herbaceous plants. Stand-types range from Kobresia meadows, Dryas, and sedge-grass to willow sedge complexes. Lichens consist of Rhizocarpon, section Rhizocarpon, Lecanora thomsonii, Lecanora aspicilia, and Lecidea atrobrunnea which have been used for relative age assignment within the Neoglacial succession (Mahaney, 1986; Mahaney et al., 1984b).

METHODS

Some 60 soil profiles have been examined in detail in the Wind River alpine area and three of these are discussed below. Selection of sites was based on representative swell and swale topography on the moraine surface (fig. 2). Soil morphology follows the Soil Survey Staff (1951, 1975) and Birkeland (1984); color is based on the color charts of Oyama and Takehara (1970). Standard particle size analysis follows the Wentworth scale (Folk, 1968) and was made on samples treated with H_2O_2 to remove organic matter. Dispersion of colloids was achieved with sodium pyrophosphate and a Branson 350 cell disruptor. Determination of coarse grain sizes (64 mm-63 μm) was made by dry sieving and fine grain sizes (⟨63 μm) by sedimentation (Bouyoucos, 1962; Day, 1965). Oriented samples of the ⟨2 μm grain size materials were analyzed by XRD using a Toshiba ADG-301H X-ray diffractometer with Ni– filtered Cuk α-radiation. Semi-quantitative determinations of clay and primary mineral content follow procedures outlined by Whittig (1965) and Jackson (1956). For elemental analysis a mixture of soil (ground to pass 100 mesh), lithium carbonate, and boric acid were fused at 1000°C in a muffle furnace for 20 min., and the cooled melt was extracted with dilute HC1. The concentrations of elements in the extract were determined using a Perkin-Elmer 373 atomic absorption spectrophotometer. Cation exchange capacity and exchangeable cations were measured by the ammonium acetate extraction method of Peech et al. (1947) and Schollenberger & Simon (1945). Total nitrogen was analyzed using the Kjeldahl method of Bremner (1965).

Organic carbon determinations follow the Walkley & Black (1934) procedures. Soil pH was measured with an electrode in a 1:1 paste. Total soluble salts (1:1 paste) were measured by electrical conductivity (Bower & Wilcox, 1965). Dithionite extractable iron (Fed) determinations were made following the method of Coffin (1963); oxalate extractable iron (Feo), and pyrophosphate extractable iron (Fep) follow procedures established by KcKeague and Day (1966).

Soil profiles

Soil profile samples were collected from the moraine crest, along the mid-section of slope, and in a swale on the proximal side of the outer moraine (fig. 2) of Indian Basin age (Mahaney, 1984a). The high soil member (fig. 3a) intercepts wind moving along the basin floor, mainly downslope winds in summer (personal observations, July 14-15, 1980) with a drying effect. The slope soil member (fig. 3) is in an ~18° slope approximately 3 m vertically below the crest; the low soil member (fig. 3c), is located in a depression 6 m vertically below the crest of the moraine. Because the lithology, climate, biota (all three sites are covered with sedge grass), and age are largely unvarying at the three sites, any differences in the three profiles that form in the toposequence must be due mainly to the overall effect of topography, which induces changes in soil drainage. The low soil member is situated in a till substrate presently free of sporadic permafrost to a depth of ~1.0 m. The degree to which Neoglacial permafrost may have affected the sites is unknown. Thus, changes in orga-

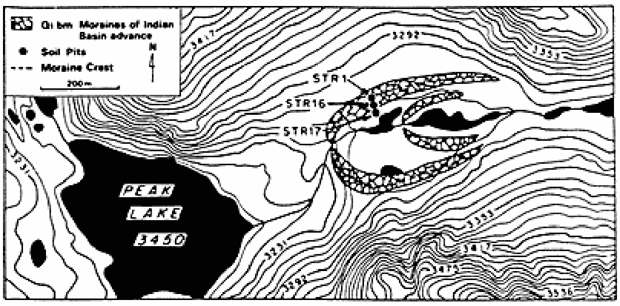

Fig. 2. Location of sites STR1, STR16 and STR17 in the late-Holocene soil catena in Stroud Basin, Central Wind River Mountains, western Wyoming.

nic, chemical, and mineralogical components in the low soil member are attributed to movement along the surface and through the toposequence to a depth of ~1.0 m, rather than to fluctuations of ground water plus toposequence movement as observed in nearby Titcomb Basin (Mahaney & Sanmugadas, 1983). The parent materials, while somewhat nonuniform in particle size and mineralogical composition, have similar organic and chemical components at the three sites. The soils are all Cryochrepts (Soil Survey Staff, 1975). The low soil member is compound paleosol consisting of superposed Cryochrepts.

DISCUSSION

Profiles in the high and slope positions of the toposequence (figs. 3a, 3b) are similar and have high percentages of cobbles and pebbles, firm to friable moist consistence, low root frequency, and very weak grades of blocky and granular structure in the soil sola. The soil solum (A + B horizons) thickens to 26 cm in the mid-slope position, apparently as a result of input of material from upslope. The situation changes in the low soil member where fewer cobbles and pebbles are present. Mottling (fig. 3) is common in the lower solum and subsoil (C horizons) and input of organic-rich material from upslope (table 4) produces a darker surface color.

Stone inclinations shown on figs. 3a-c serve to illustrate the combined effects of till deposition, frost heave, and gravity in producing a stone fabric. In profile STR1 clasts below the solum show an east-west orientation parallel, or nearly parallel, to the longitudinal valley axis (fig. 1); however, in the solum about 50 % of stones observed were oriented with their long axes nearly normal to the soil surface, suggesting that frost heave processes may intervene to give stones a vertical attitude. In the slope soil member (STR16; fig. 3b) most stones are located in the subsoil (Cox horizon) and parent material (Cu), and a large number appear parallel to the slope rather than normal to it, suggesting that soil creep may play a more pronounced role in producing stone orientation than frost heave processes. There is no evidence of solifluction activity on this moraine system. In the low soil member (STR17), stone frequency declines considerably, and most stones are oriented parallel with the valley axis reflecting glacial movement. Soil horizon boundaries in all three slope positions appear to have at least moderate degrees of waviness which might result from frost heave processes or from differential leaching (Mahaney & Fahey, 1980).

Particle size

The particle size data shown in table 1 is useful in determining: (a) if there is any evidence for air-fall influx of material (loess); and (b) if fine-grained materials (silt and clay) move downslope. The data for profiles STR1 and STR16 show higher silt in the upper solum of both profiles (when compared with the till parent material). In the case of the soil at the mid-slope position (STR16, fig. 3b) it may have received some silt reworked from upslope. The pronounced increase in silt at site STR17 is likely the result of downward accumulation of sediments derived from upslope sites by slope wash processes. The overall tendency for clay to accumulate downslope, reaching the highest amount at site STR17, is seen as a result of movement through the catena. Increases of clay in the A11/A12 horizon complex of the slope soil member may be related to thickness of the upper solum or to root frequency (no data available on root systems).

Available soil moisture was calculated from field capacity (1/3 bar) – permanent wilting point (PWP = 15 bar) (table 2). Values are noticeably higher for the low soil member suggesting that higher silt and clay and organic matter contents are responsible for the increase in available moisture. The higher available moisture in the low soil member may have influenced weathering rates as discussed later on.

Site[a]	Horizon	Depth cm	Sand, % 2mm-63µm	Silt, % 63-2 µm	Clay, % <2 µm
STR1	A	0- 5	51.7	46.1	2.2
	B	5-18	59.0	37.0	4.0
	IIC1ox	18-35	74.1	20.9	5.0
	IIC2ox	35-63	72.0	22.3	5.7
	IICu	63+	54.6	42.4	3.0
STR16	A11	0- 7	48.9	32.6	18.5
	A12	7-14	53.6	30.9	15.5
	IIB	14-26	76.3	16.2	7.5
	IICox	26-52	64.6	29.4	6.0
	IICu	52+	70.9	23.1	6.0
STR17	A1	0- 4	38.1	46.9	15.0
	B	4-18	37.8	45.2	17.0
	Ab	18-22	32.9	46.1	21.0
	Bb	22-30	56.1	30.9	13.0
	IIC1box	30-43	78.6	16.4	5.0
	IIC2box	43-56	90.9	6.9	2.2
	IICub	56+	90.0	8.0	2.0

A. Soil profile sites are on fig. 2.

Table 1. Particle-size distribution for the soil profiles in the Stroud Basin toposequence.

Mineralogy

Analysis of the clay and primary minerals in the ⟨2 μm grain size (table 3) reveals some important differences between the three soil systems. In the primary mineral group quartz is unvarying (both in the loess and till) in large quantities, while orthoclase tends to increase in the sola of the slope and low members, which may reflect movement along the slope or aeolian input and/or differential weathering in the soil sola of the three profiles. Plagioclase feldspar distributions for the three profiles show the lowest quantities in the solum of the low soil member, which further suggests that weathering may proceed at a faster rate in the swale positions.

The clay mineral content for the three profiles shows similar distributions for the 1:1 (Si:Al) group (kaolinite and halloysite) across the catena. Within the 2:1 (Si:Al) group illite and illite-smectite tend to dominate in the subsoil and parent materials of the three sites, undergoing transformations to vermiculite (and possibly smectite) in the soil solum. Smectite is present in all three soil parent materials (Cu horizons) suggesting that it is inherited from the tills. Vermiculite is generally not present in the parent material, confirming that it is largely the product of either pedogenesis or possibly of air-fall influx. Chlorite, a 2:1:1 (Si:Al:Mg) clay mineral, is uniformly distributed in the high soil member increasing in the sola of both the slope and low members, suggesting that at least some of the amount present forms as a result of pedogenesis.

Soil	Horison	Depth cm	1/3 Bar Field Capacity	15 Bar Permanent Wilting Point	Available H_2O (FC=PWP)
STR1	A1	0- 5	26.6	19.4	7.2
	B	5-18	13.2	6.2	7.0
	IIClox	18-35	8.3	2.6	5.7
	IIC2ox	35-63	9.9	2.6	7.3
	IICu	63+	9.6	2.5	7.1
STR16	A11	0- 7	22.2	15.3	6.9
	A12	7-14	17.2	10.3	6.9
	IIB	14-26	9.5	4.7	4.8
	IICox	26-52	11.4	3.7	7.7
	IICu	52+	9.0	2.5	6.5
STR17	A	0- 4	33.2	21.9	11.3
	B	4-18	25.3	10.6	14.7
	Ab	18-22	35.5	10.0	25.5
	Bb	22-30	17.9	5.1	12.8
	IIClbox	30-43	6.5	2.4	4.1
	IIC2box	43-56	2.4	1.1	1.3
	IICub	56+	2.4	1.1	1.3

Table 2. Field capacities, permanent wilting points and available moistures for three Inceptisols, Stroud Basin toposequence, Wind River Mountains, Wyoming.

Soil chemistry

A number of soil chemical and organic properties were studied for the three soil members to determine the overall effect of topographic position on soil chemistry. The range in pH throughout the three soil systems shows that

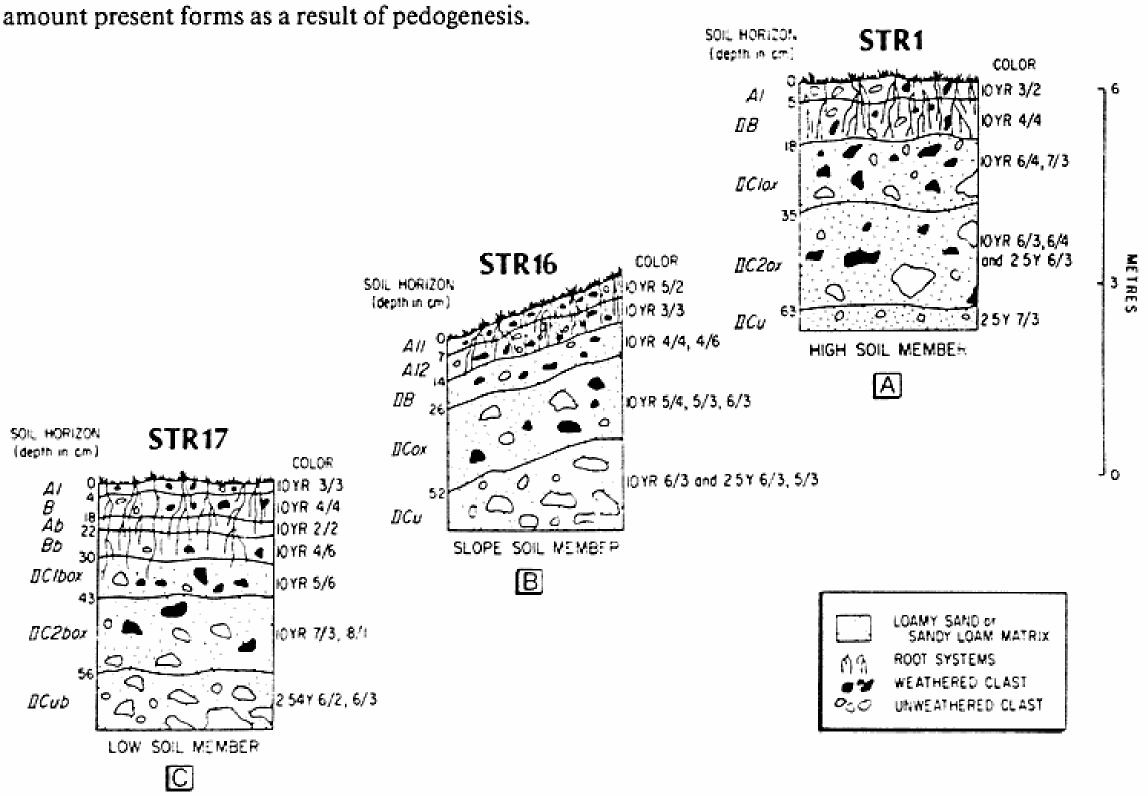

Fig. 3. Sketches of A) high soil member (STR1), B) slope soil member (STR16), and C) low soil member (STR17).

Site	Horizon	Depth cm	Clay Minerals K	H	I	S	I-S	V	C	Primary Minerals Q	O	F
STR1	A1	0- 5	-	-	-	-	-	-	-	xxx	-	xx
	B	5-18	x	-	xx	x	xx	x	x	xxx	x	x
	IIClox	18-35	x	tr	xx	x	xx	x	x	xxx	x	xx
	IIC2ox	35-63	x	tr	xx	x	xx	tr	x	xxx	-	xx
	IICu	63+	x	tr	x	x	x	tr	x	xxx	-	xx
STR16	A11	0- 7	tr	tr	tr	tr	x	tr	x	xxx	xx	xx
	A12	7-14	tr	-	-	-	tr	-	-	xxx	x	xx
	IIB	14-26	tr	?	tr	x	x	xx	x	xxx	-	xx
	IICox	26-52	x	tr	x	tr	xx	x	tr	xxx	-	xx
	IICu	52+	tr	tr	xxx	tr	xxx	-	tr	xxx	x	xxx
STR17	A1	0- 4	-	-	x	tr	x	-	tr	xxx	x	x
	B	4-18	x	-	tr	tr	tr	tr	-	xxx	x	x
	Ab	18-22	tr	tr	tr	tr	x	tr	x	xxx	tr	x
	Bb	22-30	x	x	tr	tr	x	xx	tr	xxx	xx	x
	IIC1box	30-43	tr	?	tr	tr	x	xx	tr	xxx	x	xx
	IIC2box	43-56	x	tr	xx	tr	xx	x	x	xxx	xx	xxx
	IICub	56+	tr	tr	x	tr	x	-	-	xxx	x	xx

a. Mineral abundance is based on peak height: nil (-); minor amount (tr); small amount (x); moderate amount (xx); abundant (XXX).
Clay minerals are: kaolinte (K), halloysite (H), illite (I), smectite (S), mixed layer illite-smectire (I-S), vermiculite (V), chlorite (C).
Primary minerals are: quartz (Q), orthoclase (O), plagioclase feldspar (F).

Table 3. Mineralogy of the ⟨2 μm fraction of soils in the late-Holocene toposequence in Stroud Basin, Wind River Mountains.

greater H+ ion concentration occurs in the low soil member. This suggests that hydrolysis might operate at a faster rate in the low soil member, provided that the site is periodically renewed with water from the water table, to increase the input of H+ and OH- ions and to remove the hydrolyzates by flushing. Such a condition should lead to greater feldspar weathering, and removal by leaching of Si from 2:1 (Si:Al) clay minerals, such as illite and smectite, a situation which is supported by the data in table 3.

The distribution of extractable cations among the three soil profiles suggests that only minor amounts of K+, Ca+2, and Mg+2 are accumulating in the low soil member. Overall the lower amount of Ca+2 throughout the low soil member probably represents the extent of removal by fluctuating ground water.

The degree of leaching in these soils can be deduced from the low total salt, base saturation, and pH values. The organic carbon and nitrogen depth distributions (table 4) show that organic materials penetrate or perhaps accumulate to different depths in the three profiles: 18 cm

Site[a]	Horizon	Depth cm	pH 1:1	Extractable Cations (meq/100 g) Na^+	K^+	Ca^{+2}	Mg^{+2}	Salts (mmhos/cm)	Organic carbon %	N %	Carbon/nitrogen %	Base saturation %	CEC (meg/100 g)
STR1	A1	0- 5	6.0	0.1	1.0	11.8	2.3	0.4	4.9	0.41	11.9	88.0	17.3
	B	5-18	6.0	<0.1	0.2	6.5	1.4	0.1	1.2	0.09	13.1	80.6	10.1
	IIClox	18-35	6.4	<0.1	<0.1	4.3	0.9	0.1	0.2	0.02	8.5	100.0	4.0
	IIC2ox	35-63	5.8	<0.1	<0.1	5.1	0.8	0.1	0.2	0.02	8.0	100.0	5.3
	IICu	63+	6.2	0.2	0.1	5.6	1.0	<0.1	0.1	0.02	6.0	100.0	5.0
STR16	A11	0- 7	5.2	<0.1	0.9	7.2	1.2	0.2	4.9	0.36	13.6	64.7	14.4
	A12	7-14	4.9	<0.1	0.4	4.3	0.9	0.1	2.5	0.21	11.9	47.2	12.0
	IIB	14-26	5.0	<0.1	0.1	1.3	0.2	0.1	1.1	0.12	9.0	26.0	6.2
	IICox	26-52	5.3	<0.1	<0.1	1.5	0.2	0.6	0.3	0.05	5.6	41.6	4.3
	IICu	52+	5.6	<0.1	0.1	1.6	0.2	0.8	0.3	0.03	10.3	45.5	4.2
STR17	A1	0- 4	4.5	0.2	1.3	9.0	1.9	0.4	7.5	0.59	12.6	48.2	24.7
	B	4-18	4.9	<0.1	0.2	1.8	0.3	<0.1	2.4	0.19	12.8	15.4	15.7
	Ab	18-22	5.2	0.1	0.2	1.9	0.3	<0.1	2.5	0.18	14.1	13.9	18.3
	Bb	22-30	4.8	0.1	<0.1	1.4	0.2	<0.1	0.9	0.05	18.0	18.8	9.6
	IIClbox	30-43	5.0	0.1	<0.1	0.9	<0.1	<0.1	0.2	0.03	7.0	26.7	4.2
	IIC2box	43-56	5.3	<0.1	<0.1	0.4	<0.1	<0.1	0.2	<0.1	9.5	46.0	1.6
	IICu	56+	5.5	<0.1	<0.1	0.4	<0.1	<0.1	0.2	<0.1	9.0	34.7	1.5

a. Location on fig. 2

Table 4. Selected chemical properties of the ⟨2 mm fractions of the material in soil horizons in the Stroud Basin toposequence.

Sample[a]	Topographic position	Depth cm	Elemental Analysis in %					
			CaO	MgO	K_2O	Na_2O	SiO_2	Al_2O_3
STR1-A		0- 5	3.01	1.61	2.52	1.82	63.13	16.33
STR1-B		5-18	3.54	2.14	2.33	2.12	64.91	18.04
STR1-IIClox	High	18-35	4.24	2.62	3.21	2.54	61.42	19.14
STR1-IIC2ox		35-63	4.03	3.73	2.21	2.13	62.93	18.72
STR1-IICu		63+	3.69	2.82	2.32	2.43	65.81	17.39
STR16-A11		0- 7	3.51	2.21	2.21	1.92	59.09	17.41
STR16-A12		7-14	3.22	2.34	2.21	2.04	62.02	18.03
STR16-IIB	Slope	14-26	3.31	2.54	1.81	2.43	63.01	18.82
STR16-IICox		26-52	3.21	2.82	1.91	2.43	64.04	18.61
STR16-IICu		52+	3.32	2.53	2.02	2.52	64.01	18.82
STR17-A1		0- 4	5.21	1.52	1.71	1.44	52.03	16.91
STR17-Bb		4-18	3.43	1.54	1.92	1.72	61.52	17.58
STR17-Ab	Low	18-22	2.64	1.62	1.61	1.64	61.01	20.01
STR17-Bb		22-30	3.21	1.71	1.62	2.33	63.03	19.92
STR17-IIClox		30-43	3.13	1.54	2.14	2.71	64.04	20.81
STR17-IICbox		43-56	2.09	0.73	2.01	2.53	70.01	18.42
STR17-IICub		56+	2.08	0.92	2.21	2.64	71.03	17.62

a. Soil catena location is shown on fig. 2; sketches of individual pedons are shown on fig. 3.

Table 5. Elemental analysis of soils in the Stroud Basin soil toposequence.

in STR1, 26 cm in STR16, and 30 cm in STR17. The downward movement of carbon and nitrogen through the toposequence is reflected in the C/N ratios shown in table 4.

Elemental chemistry

The data in tables 5 and 6 show some interesting trends for the total elemental content in each soil system. The Si/Al data (converted to molar ratios in table 6) show that while some mobility of SiO_2 occurs in the high and low soil members, there is relatively little movement of SiO_2 in the mid-slope position. Moreover, there is no evidence to show that SiO_2 moves through the toposequence into the low soil member. The data for total Fe_2O_3 show little variation between sites; however, there appears to be somewhat less Fe (˜2.0 %) in the low soil member. The refractory oxides (CaO, MgO, K_2O and Na_2O have depth distributions which reflect their relative mobilities. Data for the mobile elements CaO and Na_2O show that for calcium some movement occurs into the low soil member. Decreases in Na_2O from the slope member into the low soil member reflect either a fluctuating water table, or leaching, and its effect on removing sodium from the low member.

Iron distributions (table 7) for pyrophosphate-extractable Fe (Fep) (organically bound Fe), oxalate-extractable Fe (Feo) (organically bound and amorphous Fe), and dithionite-citrate extractable Fe (Fed) (organically bound

Site[b]	Horizon	Depth cm	SiO_2	Al_2O_3	SiO_2/ Al_2O_3
STR1	A1	0- 5	1.05	0.16	6.6
	B	5-18	1.08	0.18	6.0
	IIClox	18-35	1.02	0.19	5.4
	IIC2ox	35-63	1.04	0.18	5.8
	IICu	63+	1.09	0.17	6.4
STR16	A11	0- 7	0.98	0.17	5.8
	A12	7-14	1.03	0.18	5.7
	IIB	14-26	1.05	C.18	5.8
	IICox	26-52	1.07	0.18	5.9
	IICu	52+	1.07	0.18	5.9
STR17	A1	0- 4	0.87	0.17	5.1
	B	4-18	1.02	0.17	6.0
	Ab	18-22	1.02	0.20	5.1
	Bb	22-30	1.05	0.19	5.5
	IIClbox	30-43	1.07	0.20	5.4
	IIC2box	43-56	1.17	0.18	6.5
	IICub	56+	1.18	0.17	6.9

Table 6. Molar ratios for SiO_2 and Al_2O_3. The molar ratio for Si/Al is calculated from the %Si=2/molecular weight (60); $\%Al_2O_3$/molecular weight (102).

Site[a]	Horizon	Depth cm	Fe_p	Fe_o	Fe_d	Fe_o/Fe_d
STR1	A	0- 5	0.07	0.29	0.87	0.33
	B	5-18	0.12	0.29	0.78	0.37
	IIClox	18-35	0.06	0.23	0.39	0.59
	IIC2ox	35-63	0.06	0.27	0.51	0.53
	IICu	63+	0.06	0.36	0.34	1.05
STR16	A11	0- 7	0.19	0.35	0.54	0.65
	A12	7-14	0.18	0.38	0.68	0.56
	IIB	14-26	0.15	0.30	0.48	0.63
	IICox	26-52	0.08	0.22	0.42	0.52
	IICu	52+	0.07	0.28	0.38	0.74
STR17	A1	0- 4	0.28	0.40	0.71	0.56
	B	4-18	0.27	0.59	1.09	0.54
	Ab	18-22	0.34	0.60	1.14	0.53
	Bb	22-30	0.15	0.40	0.79	0.51
	IIClbox	30-43	0.13	0.27	0.39	0.69
	IIC2box	43-56	0.05	0.18	0.30	0.60
	IICub	56+	0.02	0.09	0.18	0.50

a. Location on fig. 2

Table 7. Extractable Fe and Al in the Stroud Basin toposequence.

and amorphous plus crystalline Fe) (Blume & Schwertmann, 1969) show some interesting trends, both with depth in the profiles, and with respect to movement within the toposequence.

Within the profiles, the greatest movement in Fep occurs in the low soil member. Overall more amorphous and organically-bound Fe forms in the slope and low soil members, with slightly higher amounts occurring in the A1 and Ab horizons. The Fed trends show slightly higher amounts in the high and low soil members, and correspondingly lower amounts in the slope soil member. The slope soil member contains mainly higher organically-bound and amorphous Fe, and less crystalline Fe when compared with the high soil member. While it is possible that some of the Fe increase in the slope soil member is due to weathering in situ, it is more probable that input from upslope is increasing the amount of organically bound Fe, and that higher surface runoff across the slope reduces soil moisture in the pedon, thus slowing the conversion of amorphous Fe to crystalline Fe.

COMPARISON WITH THE TITCOMB BASIN TOPOSEQUENCE

In comparison with an older soil toposequence of early-Holocene age in nearby Titcomb Basin (Mahaney & Sanmugadas, 1983), a number of similarities and differences emerge. While the soil systems reported on here are younger, and less deeply weathered, they are nonetheless dynamic in terms of the amount of weathering that has occurred, and of their response to the topographic factor as a major force in promoting profile changes. Their morphological properties are subject to similar fluctuations observed in the Titcomb toposequence, namely, variable depth of solum, waviness of horizon boundaries in the soil sola, and mottling which occurs in the low soil member. Moreover, in the Stroud Basin toposequence, a compound paleosol formed in the swale position, shows that input of material from upslope stopped long enough for a soil to form, which was later buried by sediment transported from upslope. Because the buried soil contains a B horizon it is likely that it formed over about ˜2000 yrs BP (see Mahaney, 1981, 1984b; Mahaney et al., 1984a, 1984b for a discussion of the properties of soils formed in deposits of Audubon age).

An analysis of sand-silt-clay ratios shows similar trends between the two toposequences, but with overall lower clay and silt in the younger Stroud Basin toposequence. In addition, the high silt content provides evidence for loess in the STR1 profile, and for reworked loess in the slope (STR16) and low (STR17) soil members.

Comparison of the mineralogical data for the two catenas highlights some interesting variations. Both quartz and feldspar trends show a greater tendency for weathering in the older Titcomb Basin toposequence. Smectite which is absent in the older toposequence appears in the younger one, along with greater amounts of vermiculite (see Mahaney, 1984a, 1984b for a discussion of these relative stratigraphic differences). Overall, the trend in the Stroud toposequence where clay mineral amounts decrease in the low soil member, parallels a similar trend in the older Titcomb toposequence (Mahaney & Sanmugadas, 1983).

In both the Stroud and Titcomb toposequences chemical properties provide equivocable evidence for downslope movement. While extractable cations and salts show little if any evidence for movement, increases in organic carbon and nitrogen in the downslope direction suggest that some movement occurs. The elemental trends with depth across the toposequence show little variation in most oxides, and in general these younger soils have somewhat fewer weathered products and less tendency for them to concentrate in the B horizons. The oxalate-extractable Fe trends are similar but slightly higher in the older Titcomb toposequence, while the amount of dithionite-citrate extractable Fe is 2 to 3 times greater in the older catena. As in the older toposequence dithionite-citrate extractable Fe increases in the low soil member, probably as a result of a fluctuating water table bringing in water with a lower pH, and hence, higher oxidizing potential.

Comparison with other environments

Research with soil toposequences in many climatic regions has been published by numerous workers including Abtahi (1980), Al-Janabi & Drew (1967), Dan et al. (1968), and Nettleton et al. (1968). All these researchers stress the dynamic processes at work in tropical and temperate climates, ranging from wet to dry. In the arctic, Tedrow and Brown (1967) investigated the arctic brown tundra and arctic bog soils forming prominent catenas in the landscape. While work of this nature in North American alpine areas remains woefully neglected (Mahaney & Sanmugadas, 1983), the results of this paper show that soils in a young toposequence (˜3000 yr BP) produce trends where different soil properties vary from summit to depression paralleling changes in similar situations in other climate zones.

CONCLUSIONS

A soil toposequence dated at ˜3000 yr BP yields variations in profile morphology, particle size, clay and primary mineralogy, and soil chemistry which support the hypothesis that alpine soils forming in a middle latitude, continental, alpine area are dynamic entities which assume new shapes in different topographic situations. Inceptisols, making up this sequence, show differences in horizon development, increases in clay and silt size particles downslope, accumulations of some total and extractable elements (cf. CaO and Fep in the low soil member, and pH that appear to be the product of movement along and through the toposequence.

ACKNOWLEDGEMENTS

I thank the students in my Mountain Geomorphology field school (1980) and L. Gowland for assistance in the field. Funds were provided by minor research grants from York University. Research was carried out in the Geomorphology and Pedology Laboratory at York University. C. Sorensen (University of Kansas) and an anonymous reviewer provided critiques of the manuscript.

References

Abtahi, A. (1980): Soil genesis as affected by topography and time in highly calcareous parent materials under semiarid conditions in Iran. Soil Sci. Soc. Amer. Journ., 44:329-336.

Al-Janabi, A.M. & Drew, J.V. (1967): Characterization and genesis of Sharpsburg-Wymore soil sequence in southeastern Nebraska. Soil Sci. Soc. Amer. Proc., 31:238-244.

Barry, R.G. & Chorley, R.J. (1970): Atmosphere, Weather and Climate. New York: Holt, Rinehart and Winston, 320 pp.

Birkeland, P.W. (1984): Soils and Geomorphology. New York: Oxford. 372 pp.

Blume, H.P. & Schwertmann, U. (1969): Genetic evaluation of profile distribution of aluminium, iron and manganese oxides, Soil Sci. Soc. Amer. Proc., 33:438-444.

Bouyoucos, G.J. (1962): Hydrometer method improved for making particle size analysis of soil. Agr. Journ., 54:464-465.

Bower, C.A. & Wilcox, L.V. (1965): Soluble Salts. In Black, C.A., (ed.)., Methods of Soil Analysis. Agr. Mon. 9. Madison, Wisconsin. Amer. Soc. Agr.: 933-951.

Bremner, J.R. (1965): Total nitrogen. In Black, C.A., (ed.), Methods of Soil Analysis. Agr. Mon. 9. Madison: Wisc. Amer. Soc. Agr.: 1149-1176.

Coffin, E.E. (1963): A method for the determination of free iron in soils and clays. Can. Journ. Soil Sci., 43:7-17.

Dan, J., Yaalon, D.H. & Koyumdjisky, H. (1968): Caternary soil relationship in Israel, 1. The Netanya catena on coastal dunes of the Sharon. Geoderma, 2:95-120.

Day, P. (1965): Particle fractionation and particle size analysis. In Black, C.A (ed.), Methods of Soil Analysis. Agr. Mon. 9. Madison: Wisc., Amer. Soc. Agr.: 545-567.

Folk, R.L (1968): Petrology of Sedimentary Rocks. Austin: Texas, Hamphill Press, 170 pp.

Hodson, J.M. (1976): Soil Survey Field Handbook. Soil Surv. Tech. Mon. 5. Rothamsted Exp. Station, Harpenden, Herts, U.K.: 99 pp.

Jackson, M.L. (1956): Soil Chemical Analysis – Adv. Course. Publ. by the author, Dep. Soil Sci., Univ. Wisconsin, U.S.A.

Mahaney, W.C. (1975): Soils of post-Audubon age, Teton Glacier Area, Wyoming. Arctic and Alpine Research: 7:141-154.

Mahaney, W.C. (1978): Late Quaternary stratigraphy and soils in the Wind River Mountains, Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Soils. Norwich, U.K., Geoabstracts Ltd.: 223-264.

Mahaney, W.C. (1981): Paleoclimate reconstructed from paleosols: evidence from the Rocky Mountains and East Africa. In Mahaney, W.C. (ed.), Quaternary Paleoclimate, Norwich, U.K., Geoabstracts Ltd.: 227-247.

Mahaney, W.C. (1984a): Superposed Neoglacial and late Pinedale (Wisconsinan) tills, Titcomb Basin, Wind River Mountains, Western Wyoming. Palaeogeography, Palaeoclimatology, Palaeoecology, 45:149-163.

Mahaney, W.C. (1984b): Indian Basin advance: new name for Early Neoglacial till in Western and Northwestern Wyoming. Northwest Science, 58: no. 2:94-102.

Mahaney, W.C. (1986): Growth curve for Rhizocarpon geographicum s.l. in the Wind River Range, Western Wyoming, Northwest Science, 61 (1):13-19.

Mahaney, W.C. & Fahey, B.D. (1980): Morphology, composition and age of a buried paleosol on Niwot Ridge, Front Range, Colorado, U.S.A. Geoderma, 23:209-218.

Mahaney, W.C. & Sanmugadas, K. (1983): Early Holocene soil catena in Titcomb Basin, Wind River Mountains, Western Wyoming. Zeitschr. f. Geomorph. 27: no. 3:265-281.

Mahaney, W.C., Halvorson, D., Piegat, J. & Sanmugadas, K. (1984a): Evaluation of dating methods used to differentiate quaternary deposits in the Wind River and Teton Ranges, Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Dating Methods. Amsterdam, Elsevier: 355-374.

Mahaney, W.C., Boyer, M.G., Halvorson, D.L. & Sanmugadas, K. (1984b): Glacial chronology of the Rocky Mountains: some problems from observations in Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Chronologies. Norwich, U.K., GeoBooks: 225-241.

McKeague, A. & Day, J. (1966): Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soils. Can. Journ. of Soil Sci., 46:13-22.

Nettleton, W.C., Flach, K.W. & Borst, G.W. (1968): A toposequence of soils on tonalite grus in the southern California Peninsular Range. U.S. Dep. Agr. Soil Conserv. Serv., Soil Surv. Invest. Rep. 21: 41 pp.

Oyama, M. & Takehara, H. (1970): Standard Soil Color Charts. Japan Res. Council Agric.

Peech, M.L., et al. (1947): Methods of soil analyses for soil fertility investigations. U.S. Dep. of Agric. Circ. 757: 25 pp.

Schollenberger, C.J. & Simon, R.H. (1945): Determination of exchange capacity and exchangeable bases in soils-ammonium acetate method. Soil Sci. 49:13-24.

Soil Survey Staff: (1951): Soil Survey Manual. Washington, D.C., U.S. Govern. Print. Office: 503 pp.

Soil Survey Staff (1975): Soil Taxonomy. Washington, D.C., U.S. Govern. Print. Office: 754 pp.

Tedrow, J.C.F. & Brown, J. (1967): Arctic and Alpine Environments. Bloomington, Ind., Indiana Univ. Press.

Walkley, A. & Black, I.A. (1934): An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci., 34:29-38.

Whittig, L.E (1965): X-ray diffraction techniques for mineral identification and mineralogical composition. In Black, C.A. (ed.), Methods of Soil Analysis. Agron. Mon. 9. Madison, Wisc., Amer. Soc. Agr.: 671-696.

that appear to be the product of movement along and through the toposequence.

ACKNOWLEDGEMENTS

I thank the students in my Mountain Geomorphology field school (1980) and L. Gowland for assistance in the field. Funds were provided by minor research grants from York University. Research was carried out in the Geomorphology and Pedology Laboratory at York University. C. Sorensen (University of Kansas) and an anonymous reviewer provided critiques of the manuscript.

References

Abtahi, A. (1980): Soil genesis as affected by topography and time in highly calcareous parent materials under semiarid conditions in Iran. Soil Sci. Soc. Amer. Journ., 44:329-336.

Al-Janabi, A.M. & Drew, J.V. (1967): Characterization and genesis of Sharpsburg-Wymore soil sequence in southeastern Nebraska. Soil Sci. Soc. Amer. Proc., 31:238-244.

Barry, R.G. & Chorley, R.J. (1970): Atmosphere, Weather and Climate. New York: Holt, Rinehart and Winston, 320 pp.

Birkeland, P.W. (1984): Soils and Geomorphology. New York: Oxford. 372 pp.

Blume, H.P. & Schwertmann, U. (1969): Genetic evaluation of profile distribution of aluminium, iron and manganese oxides, Soil Sci. Soc. Amer. Proc., 33:438-444.

Bouyoucos, G.J. (1962): Hydrometer method improved for making particle size analysis of soil. Agr. Journ., 54:464-465.

Bower, C.A. & Wilcox, L.V. (1965): Soluble Salts. In Black, C.A., (ed.)., Methods of Soil Analysis. Agr. Mon. 9. Madison, Wisconsin. Amer. Soc. Agr.: 933-951.

Bremner, J.R. (1965): Total nitrogen. In Black, C.A., (ed.), Methods of Soil Analysis. Agr. Mon. 9. Madison: Wisc. Amer. Soc. Agr.: 1149-1176.

Coffin, E.E. (1963): A method for the determination of free iron in soils and clays. Can. Journ. Soil Sci., 43:7-17.

Dan, J., Yaalon, D.H. & Koyumdjisky, H. (1968): Caternary soil relationship in Israel, 1. The Netanya catena on coastal dunes of the Sharon. Geoderma, 2:95-120.

Day, P. (1965): Particle fractionation and particle size analysis. In Black, C.A (ed.), Methods of Soil Analysis. Agr. Mon. 9. Madison: Wisc., Amer. Soc. Agr.: 545-567.

Folk, R.L (1968): Petrology of Sedimentary Rocks. Austin: Texas, Hamphill Press, 170 pp.

Hodson, J.M. (1976): Soil Survey Field Handbook. Soil Surv. Tech. Mon. 5. Rothamsted Exp. Station, Harpenden, Herts, U.K.: 99 pp.

Jackson, M.L. (1956): Soil Chemical Analysis – Adv. Course. Publ. by the author, Dep. Soil Sci., Univ. Wisconsin, U.S.A.

Mahaney, W.C. (1975): Soils of post-Audubon age, Teton Glacier Area, Wyoming. Arctic and Alpine Research: 7:141-154.

Mahaney, W.C. (1978): Late Quaternary stratigraphy and soils in the Wind River Mountains, Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Soils. Norwich, U.K., Geoabstracts Ltd.: 223-264.

Mahaney, W.C. (1981): Paleoclimate reconstructed from paleosols: evidence from the Rocky Mountains and East Africa. In Mahaney, W.C. (ed.), Quaternary Paleoclimate, Norwich, U.K., Geoabstracts Ltd.: 227-247.

Mahaney, W.C. (1984a): Superposed Neoglacial and late Pinedale (Wisconsinan) tills, Titcomb Basin, Wind River Mountains, Western Wyoming. Palaeogeography, Palaeoclimatology, Palaeoecology, 45:149-163.

Mahaney, W.C. (1984b): Indian Basin advance: new name for Early Neoglacial till in Western and Northwestern Wyoming. Northwest Science, 58: no. 2:94-102.

Mahaney, W.C. (1986): Growth curve for Rhizocarpon geographicum s.l. in the Wind River Range, Western Wyoming, Northwest Science, 61 (1):13-19.

Mahaney, W.C. & Fahey, B.D. (1980): Morphology, composition and age of a buried paleosol on Niwot Ridge, Front Range, Colorado, U.S.A. Geoderma, 23:209-218.

Mahaney, W.C. & Sanmugadas, K. (1983): Early Holocene soil catena in Titcomb Basin, Wind River Mountains, Western Wyoming. Zeitschr. f. Geomorph. 27: no. 3:265-281.

Mahaney, W.C., Halvorson, D., Piegat, J. & Sanmugadas, K. (1984a): Evaluation of dating methods used to differentiate quaternary deposits in the Wind River and Teton Ranges, Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Dating Methods. Amsterdam, Elsevier: 355-374.

Mahaney, W.C., Boyer, M.G., Halvorson, D.L. & Sanmugadas, K. (1984b): Glacial chronology of the Rocky Mountains: some problems from observations in Western Wyoming. In Mahaney, W.C. (ed.), Quaternary Chronologies. Norwich, U.K., GeoBooks: 225-241.

McKeague, A. & Day, J. (1966): Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soils. Can. Journ. of Soil Sci., 46:13-22.

Nettleton, W.C., Flach, K.W. & Borst, G.W. (1968): A toposequence of soils on tonalite grus in the southern California Peninsular Range. U.S. Dep. Agr. Soil Conserv. Serv., Soil Surv. Invest. Rep. 21: 41 pp.

Oyama, M. & Takehara, H. (1970): Standard Soil Color Charts. Japan Res. Council Agric.

Peech, M.L., et al. (1947): Methods of soil analyses for soil fertility investigations. U.S. Dep. of Agric. Circ. 757: 25 pp.

Schollenberger, C.J. & Simon, R.H. (1945): Determination of exchange capacity and exchangeable bases in soils-ammonium acetate method. Soil Sci. 49:13-24.

Soil Survey Staff: (1951): Soil Survey Manual. Washington, D.C., U.S. Govern. Print. Office: 503 pp.

Soil Survey Staff (1975): Soil Taxonomy. Washington, D.C., U.S. Govern. Print. Office: 754 pp.

Tedrow, J.C.F. & Brown, J. (1967): Arctic and Alpine Environments. Bloomington, Ind., Indiana Univ. Press.

Walkley, A. & Black, I.A. (1934): An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci., 34:29-38.

Whittig, L.E (1965): X-ray diffraction techniques for mineral identification and mineralogical composition. In Black, C.A. (ed.), Methods of Soil Analysis. Agron. Mon. 9. Madison, Wisc., Amer. Soc. Agr.: 671-696.