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AMORPHOUS MATERIAL IN PENNSYLVANIA SOILS

by

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and
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Introduction

The term amorphous has been used in soil mineralogy to identify inorganic material that does not diffract x-rays. This material is important in soils because even in small quantities it can contribute significantly to the physical and chemical properties of soils (Fey and LeRoux, 1977). Its effect is primarily through its (1) high cation exchange capacity, (2) high surface area, and (3) high reactivity with phosphate and organics (Jackson et al., 1986).

Most mineralogical studies in Pennsylvania have been done on the crystalline, clay size (< 2 μm) material, and a significant amount of data have accumulated (Ciolkosz and Dobos, 1989). With the exception of the study of Johnson and Chu (1983) there are no data on the quantity of amorphous material in Pennsylvania soils. To alleviate this major shortcoming, a study was initiated to determine the amount of amorphous material in the A and two subsurface horizons of soils of various drainage classes developed in common Pennsylvania parent materials.

Materials and Methods

One hundred and four soil samples were selected from the Penn State University library of characterized soils (Ciolkosz and Dobos, 1989). Selected data for these samples is given in Table 1. As recommended by Hodges and Zelazny (1980), the entire fine earth (< 2 mm) material was used, not just the clay size (< 2 μm) material that has been commonly used in other studies (Nash et al., 1983). The soil samples were extracted with acid ammonium oxalate in the dark (AOD), following the method of Zelazny as presented in Jackson et al. (1986). In this method the amorphous material is determined by weight loss of

the AOD extracted sample. In addition, a second estimate of the amorphous material was made by the oxide addition method. In this method the Fe, Al, Si, and Mn in the AOD extract was determined by atomic absorption (Searle and Daly, 1977), and a weight percentage was calculated based on the sum of Fe_2O_3 + Al_2O_3 + SiO_2 + Mn_2O_4 ÷ the oven-dried weight of the sample (oven-dried samples were not used, a moisture correction factor was used on air-dried samples). All samples were run in duplicate.

Results and Discussion

The data for amorphous content by the weight loss method (weight) and the oxide addition method (chem) are given in Table 1. The data for the oxides on an individual basis are given in Table 2. An examination of the data shows with numerous exceptions the following trends:

1. Pennsylvania soils do not have large quantities of amorphous materials. It ranges from about 0.5 to 3.5%.
2. There is, in general, a decrease in the amount of the amorphous material from the surface downward.
3. There is some indication of lower amounts of amorphous material in wetter soils.
4. The basic crystalline rocks have a greater total profile (all 3 horizons) amorphous material content than the other parent materials.
5. With many exceptions, the weight loss method gave larger values than the chem method.
6. The major element in the amorphous material was Fe. Al was second in abundance and only small (< 0.1%) amounts of Si and Mn were present.

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Table 1. Selected soil characterization data and amorphous data for the soil samples used in this study. Characterization data from Ciolkosz and Dobos (1989).

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent				Percent Amorphous					
				Sand	Silt	Clay	Fe_2O_3	Chem		Weight		Mean	
								1	2	1	2	Chem	Weight
Grayish-Brown Wisconsinan Glacial Till													
Bath	08-11-01	0-7	Ap	28.2	56.8	15.1	1.5	2.40	2.30	1.60	2.04	2.35	1.82
(well drained)	08-11-03	12-17	Bw2	36.6	50.3	13.2	1.6	2.14	2.00	1.03	2.10	2.07	1.56
	08-11-06	27-42	Bx3	40.9	45.6	13.5	1.7	1.03	1.11	0.65	1.29	1.07	0.97
Volusia	08-14-01	0-8	Ap	24.4	53.7	21.9	1.6	2.02	2.03	1.96	2.15	2.02	2.05
(somewhat	08-14-03	11-14	Bw2	24.9	53.8	21.3	1.8	0.97	1.24	0.61	0.66	1.11	0.63
poorly drained)	08-14-06	29-38	Bxg3	24.5	48.0	27.5	2.1	0.89	0.93	1.22	1.14	0.91	1.18
Chippewa	08-16-01	0-6	Ap	11.6	63.4	25.0	2.2	3.89	3.64	2.89	2.11	3.77	2.50
(poorly drained)	08-16-03	12-17	Bwg	14.2	60.7	25.1	2.4	3.00	2.65	2.56	2.31	2.83	2.43
	08-16-06	37-51	Bxg3	20.0	69.2	10.7	1.4	0.85	0.73	0.63	0.96	0.79	0.79
Red Wisconsinan Glacial Till													
Lackawanna	45-80-01	0-7	Ap	42.3	45.6	12.1	0.7	0.87	1.09	1.37	1.62	0.98	1.49
(well drained)	45-80-03	14-20	Bw2	44.4	43.9	11.7	0.8	0.57	0.56	1.11	1.07	0.56	1.09
	45-80-05	28-53	Bx1	51.7	37.6	10.7	0.8	0.45	0.49	0.84	1.00	0.47	0.92
Morris	58-03-01	0-7	Ap	34.1	44.9	21.0		2.94	3.09	3.63	3.38	3.01	3.50
(somewhat	58-03-03	11-17	BA	45.9	42.3	11.8		1.63	1.84	1.89	1.92	1.73	1.90
poorly drained)	58-03-07	31-46	Bx4	41.5	45.2	13.3		0.82	0.73	1.14	1.34	0.77	1.24
Pre-Wisconsinan Glacial Till													
Allenwood	13-61-01	0-7	Ap	26.2	56.7	17.1	2.2	0.94	0.82	1.64	1.12	0.88	1.38
(well drained)	13-61-04	24-33	Bt3	31.2	32.2	36.6		0.43	0.34	1.06	0.57	0.39	0.81
	13-61-07	61-75	Bt5	45.6	37.9	16.5	3.2	0.32	0.19	0.64	0.21	0.25	0.42
Watson	55-02-01	0-9	Ap	26.5	52.5	20.9	2.5	0.69	0.70	1.28	1.18	0.69	1.23
(Moderately	55-02-03	18-27	Bt2	28.6	28.9	42.5	3.8	0.39	0.39	1.43	1.29	0.39	1.36
well drained)	55-02-05	35-45	Bx2	42.3	30.7	27.0	2.2	0.34	0.33	1.09	0.88	0.33	0.98

Table 1. Selected soil characterization data for the soil samples used for amorphous material determinations. Data from Ciolkosz and Dobos (1989). (Continued)

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent				Percent Amorphous					
				Sand	Silt	Clay	Fe_2O_3	Chem		Weight		Mean	
								1	2	1	2	Chem	Weight
Acid Grayish-brown Shale and Sandstone Colluvium													
Laidig	14-31-03	0-3	A	34.2	49.7	16.0	1.4	3.22	3.19	3.28	3.30	3.20	3.29
(well drained)	14-31-06	20-23	Bt2	42.8	37.4	19.8		0.65	0.72	1.55	1.57	0.68	1.56
	14-31-10	40-59	Bx1	43.3	36.1	20.7	1.9	0.99	1.19	0.95	2.08	1.09	1.51
Andover	18-13-01	0-9	Ap	29.6	46.6	23.8		3.50	3.44	3.62	3.56	3.47	3.59
(poorly drained)	18-13-03	14-18	Bt1	33.5	42.4	24.1		0.68	0.82	1.73	1.39	0.75	1.56
	18-13-06	32-38	Bx2g	41.0	39.5	19.5		1.01	1.15	1.52	1.49	1.08	1.50
Brown Wisconsinan Loess													
Duncannon	09-05-01	0-10	Ap	8.6	74.0	17.4	1.6	1.81	1.74	2.35	2.23	1.77	2.29
(well drained)	09-05-03	17-24	Bt1	7.9	69.9	22.2	3.0	1.14	0.93	1.70	1.59	1.03	1.64
	09-05-05	34-45	BC	6.6	83.0	10.4	2.5	1.13	0.97	1.35	1.33	1.05	1.34
Lawrenceville	09-03-01	0-11	Ap	11.6	73.0	15.4	1.4	1.69	1.55	1.95	2.04	1.62	1.99
(Moderately	09-03-03	19-25	Bt2	8.6	73.4	18.1	2.0	0.99	0.91	1.47	1.57	0.95	1.52
well drained)	09-03-05	34-40	Bx2	12.0	73.4	14.6	2.6	1.11	0.94	0.00	0.05	1.03	0.02
Doylestown	09-11-01	0-7	Ap	9.2	76.6	14.2	1.7	1.27	1.25	1.76	1.92	1.26	1.84
(poorly drained)	09-11-02	7-15	Btg2	4.8	71.6	23.6	1.4	1.01	0.80	1.75	1.93	0.90	1.84
	09-11-04	18-27	Bxtg2	14.8	55.3	29.9	2.6	1.02	1.06	1.52	1.30	1.04	1.41
Residual Acid Sandstone													
Hazleton	17-12-02	0-2	A	26.6	52.3	21.1	2.4	1.94	1.92	2.81	2.83	1.93	2.82
(well drained)	17-12-05	13-24	Bw2	37.3	43.4	19.3	2.4	1.08	0.94	1.38	1.17	1.01	1.27
	17-12-08	41-50	Bw5	45.1	41.1	13.9	2.2	0.85	0.82	0.85	1.08	0.83	0.96
Cookport	17-15-02	2-6	BA	31.1	47.4	21.5	3.0	2.47	2.29	2.61	1.92	2.38	2.26
(Moderately	17-15-04	10-15	Bt2	35.0	44.8	20.3	2.7	1.55	1.47	1.53	1.67	1.51	1.60
well drained)	17-15-07	33-47	Bx3	35.5	43.7	20.8	2.8	0.79	0.61	0.98	1.07	0.70	1.02

Table 1. Selected soil characterization data for the soil samples used for amorphous material determinations. Data from Ciolkosz and Dobos (1989). (Continued)

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent				Percent Amorphous					
				Sand	Silt	Clay	Fe_2O_3	Chem		Weight		Mean	
								1	2	1	2	Chem	Weight
Residual Acid Sandstone													
Nolo	17-19-02	0-4	A	27.2	63.2	9.5	0.3	0.42	0.48	0.76	0.93	0.45	0.84
(poorly drained)	17-19-04	11-14	Btg	37.5	43.2	19.3	3.1	0.67	0.63	1.19	0.93	0.65	1.06
	17-19-06	31-49	Bxg2	47.3	37.2	15.4	1.8	0.64	0.59	0.68	0.64	0.61	0.66
Residual Acid Gray Shales													
Gilpin	32-54-01	0-9	Ap	41.6	52.5	5.9		1.68	1.62	2.13	2.15	1.65	2.14
(Well drained)	32-54-03	14-23	Bt	27.3	50.1	22.6		0.66	0.66	1.23	1.21	0.66	1.22
	32-54-05	26-30	C	25.9	53.3	20.8		0.56	0.54	1.29	1.37	0.55	1.33
Rayne	56-02-01	0-9	Ap	30.5	46.5	23.0	2.4						
(Well drained)	56-02-04	26-38	Bt3	29.9	29.5	40.6		0.47	0.50	1.22	1.68	0.49	1.45
	56-02-07	66-82	C1	47.4	28.5	24.1	3.5	0.79	0.81	1.44	1.64	0.80	1.54
Wharton	32-53-01	0-10	Ap	17.3	69.7	13.0		2.14	1.87	1.83	2.03	2.01	1.93
(Moderately	32-53-04	19-24	Bt2g	10.3	62.5	27.2		1.08	1.25	1.22	1.51	1.17	1.36
well drained)	32-53-06	36-54	C	21.7	56.7	21.6		1.03	0.89	1.15	1.21	0.96	1.18
Cavode	10-39-01	0-11	Ap	20.1	52.3	27.6	2.6	1.51	1.68	2.43	2.35	1.59	2.39
(Somewhat	10-39-04	21-27	Bt3g	3.6	40.1	56.3	3.1	0.86	0.81	2.44	2.20	0.83	2.32
poorly drained)	10-39-07	41-51	2Btbg	30.9	46.1	23.0	2.3	0.50	0.36	0.68	0.52	0.43	0.60
Cavode	32-59-01	0-11	Ap	22.8	61.5	15.7		1.87	1.92	2.64	2.36	1.89	2.50
(Somewhat	32-59-03	16-21	Bt1	12.4	48.4	39.2		1.17	0.87	1.76	1.99	1.02	1.87
poorly drained)	32-59-06	47-57	Cg	28.3	50.6	21.2		0.95	0.44	1.75	1.34	0.69	1.54
Residual Calcareous Red Shales													
Upshur	02-23-01	0-8	Ap	13.6	66.2	20.2	3.4	1.70	1.71	1.62	1.68	1.70	1.65
(Well drained)	02-23-03	16-25	Bt2	0.9	32.2	67.0	4.5	1.66	1.43	4.20	3.24	1.54	3.72
	02-23-07	46-56	C1	2.2	66.4	31.4		0.48	0.46	0.55	0.48	0.47	0.51

Table 1. Selected soil characterization data for the soil samples used for amorphous material determinations. Data from Ciolkosz and Dobos (1989). (Continued)

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent				Percent Amorphous					
				Sand	Silt	Clay	Fe_2O_3	Chem		Weight		Mean	
								1	2	1	2	Chem	Weight
Residual Calcareous Red Shales													
Vandergrift	04-01-01	0-7	Ap	9.2	60.9	29.9	1.9	1.57	1.45	2.08	1.97	1.51	2.02
(Somewhat	04-01-04	16-22	Bt3	3.3	27.9	68.8	2.7	0.91	0.77	2.20	2.04	0.84	2.12
poorly drained)	04-01-08	58-71	C1	3.1	63.9	33.1	1.7	0.99		0.96	0.96		0.96
Residual Calcareous Gray Shales													
Westmoreland	63-43-01	0-10	Ap	12.8	71.6	15.6	1.8	1.59	1.80	2.13	2.21	1.69	2.17
(Well drained)	63-43-04	21-29	Bt2	21.0	48.6	30.5		1.37	1.37	2.04	2.32	1.37	2.18
	63-43-07	50-58	C	41.5	46.5	12.0	2.2	0.57	0.55	1.14	1.21	0.56	1.17
Dormont	02-07-02	0-7	Ap	9.7	68.6	21.7	3.1	1.78	1.83	1.75	1.52	1.80	1.63
(Moderately	02-07-05	19-23	Bt2	11.5	59.2	29.3	4.5	1.85	1.85	1.87	1.59	1.85	1.73
well drained)	02-07-08	40-52	Bt5	29.5	51.1	19.4	3.3	0.57	0.57	0.54	0.68	0.57	0.61
Library	63-45-01	0-10	Ap	9.1	68.8	22.0	2.0	2.04	2.21	2.81	2.83	2.13	2.82
(Somewhat	63-45-04	19-24	Bt3g	9.0	58.3	32.7		0.86	0.89	2.03	1.98	0.87	2.00
poorly drained)	63-45-08	49-52	C1g	5.0	39.5	55.5		0.56	0.51	1.24	1.57	0.53	1.40
Residual Limestones													
Duffield	36-17-01	0-7	Ap	11.7	69.9	18.4		1.55	1.48	2.04	2.22	1.51	2.13
(Well drained)	36-17-03	12-22	Bt1	10.9	54.7	34.4		0.66	0.58	1.74	1.48	0.62	1.61
	36-17-06	40-52	C	31.1	40.1	28.8		0.88	0.61	1.61	1.52	0.75	1.56
Hagerstown	36-19-01	0-10	Ap	11.2	64.3	24.5	3.2	1.16	1.01	1.94	1.33	1.09	1.63
(Well drained)	36-19-03	21-28	Bt2	6.6	39.9	53.5	4.4	0.93	0.68	2.05	1.80	0.80	1.92
	36-19-07	56-66	C1	9.0	47.7	43.4		0.82	0.69	1.86	2.34	0.75	2.10
Residual Acid Crystalline Rocks													
Manor	36-28-01	0-5	Ap1	38.1	45.4	16.5	2.9	0.70	0.70	1.34	1.17	0.70	1.25
(Well drained)	36-28-03	10-20	Bw	46.5	41.4	12.0	2.5	0.56	0.55	1.00	1.06	0.55	1.03
	36-28-06	33-37	C1	59.7	36.0	4.3	2.0	0.59	0.53	0.89	1.08	0.56	0.98

Table 1. Selected soil characterization data for the soil samples used for amorphous material determinations. Data from Ciolkosz and Dobos (1989). (Continued)

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent				Percent Amorphous					
				Sand	Silt	Clay	Fe_2O_3	Chem		Weight		Mean	
								1	2	1	2	Chem	Weight
Residual Acid Crystalline Rocks													
Chester (Well drained)	67-08-01	0-8	Ap	31.6	46.0	22.4		1.49	1.31	1.60	1.69	1.40	1.64
	67-08-04	21-26	Bt2	37.6	30.8	31.6		0.56	0.44	0.97	1.14	0.50	1.05
	67-08-06	28-34	C1	55.8	16.5	29.7		0.58	0.46	1.45	1.61	0.52	1.53
Glenelg (Moderately well drained)	36-27-01	0-10	Ap	51.6	34.2	14.2	2.3	0.50	0.63	1.91	2.01	0.57	1.96
	36-27-02	10-19	Bt1	35.1	41.0	23.9	3.9	0.43	0.44	1.09	0.95	0.43	1.02
	36-27-05	33-42	C1	61.0	35.3	3.8		0.19	0.19	1.44	1.05	0.19	1.24
Residual Basic Crystalline Rocks													
Neshaminy (Well drained)	09-51-01	0-7	Ap	20.2	57.4	22.3	2.4	1.90	1.51	2.47	2.09	1.70	2.28
	09-51-03	13-23	Bt2	29.0	37.2	33.9	4.0	1.95	1.52	2.59	2.03	1.73	2.31
	09-51-05	36-64	C	50.6	21.4	28.0	3.6	2.35	2.25	2.30	2.46	2.30	2.38
Neshaminy (Well drained)	46-13-01	0-6	Ap	25.4	57.2	17.4		1.54	2.14	2.63	2.78	1.84	2.70
	46-13-05	16-20	Bt2	38.2	34.0	27.8		2.39	2.42	3.52	3.45	2.41	3.48
	46-13-08	33-39	C1	60.4	25.2	14.4		1.76	1.72	2.71	2.51	1.74	2.61
Mount Lucas (Moderately well drained)	01-16-01	0-8	Ap	19.7	68.1	12.2		1.37	1.25	2.02	1.73	1.31	1.87
	01-16-04	18-24	Bt2	43.8	31.5	24.7		1.12	1.21	1.82	2.15	1.17	1.98
	01-16-06	28-39	C	79.7	14.1	6.2		0.54	0.45	1.08	0.87	0.49	0.97
Towhee (Poorly drained)	09-12-01	0-8	Ap	9.2	76.6	14.2	1.7	1.17	1.05	1.99	1.55	1.11	1.77
	09-12-04	21-28	Btg3	14.8	55.3	29.9	2.6	1.31	1.17	1.65	1.44	1.24	1.54
	09-12-06	39-53	Bx2	26.9	64.4	8.7	4.6	1.15	1.29	1.12	0.74	1.22	0.93
Towhee (Poorly drained)	09-13-01	0-7	Ap	5.6	70.0	24.4	2.3	1.77	1.77	3.17	2.94	1.77	3.05
	09-13-04	21-28	Btg2	19.7	57.6	22.7	5.5	1.64	1.92	2.06	1.74	1.78	1.90
	09-13-06	41-50	Bxg2	32.7	43.4	23.9	6.8	1.59	1.88	1.91	2.08	1.73	1.99

Table 2. Fe_2O_3, Al_2O_3, SiO_2, and MnO_2 data for the soil samples used in this study.

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent								Mean			
				Fe_2O_3		Al_2O_3		SiO_2		MnO_2					
				1	2	1	2	1	2	1	2	Fe_2O_3	Al_2O_3	SiO_2	MnO_2
Grayish-Brown Wisconsinan Glacial Till															
Bath	08-11-01	0-7	Ap	1.60	1.56	0.73	0.71	0.03	0.00	0.04	0.03	1.58	0.72	0.01	0.03
(well drained)	08-11-03	12-17	Bw2	1.23	1.24	0.80	0.74	0.10	0.00	0.01	0.02	1.23	0.77	0.05	0.01
	08-11-06	27-42	Bx3	0.64	0.70	0.29	0.34	0.05	0.02	0.05	0.05	0.67	0.31	0.03	0.05
Volusia	08-14-01	0-8	Ap	1.36	1.38	0.58	0.62	0.05	0.00	0.03	0.03	1.37	0.60	0.03	0.03
(somewhat	08-14-03	11-14	Bw2	0.65	0.85	0.32	0.38	0.00	0.01	0.00	0.00	0.75	0.35	0.01	0.00
poorly drained)	08-14-06	29-38	Bxg3	0.59	0.66	0.27	0.22	0.00	0.01	0.03	0.04	0.63	0.25	0.01	0.03
Chippewa	08-16-01	0-6	Ap	2.96	2.90	0.58	0.64	0.08	0.05	0.05	0.05	2.93	0.61	0.07	0.05
(poorly drained)	08-16-03	12-17	Bwg	2.31	2.06	0.63	0.54	0.01	0.00	0.06	0.05	2.19	0.59	0.01	0.05
	08-16-06	37-51	Bxg3	0.60	0.53	0.16	0.17	0.06	0.00	0.03	0.03	0.57	0.17	0.03	0.03
Red Wisconsinan Glacial Till															
Lackawanna	45-80-01	0-7	Ap	0.35	0.47	0.51	0.57	0.00	0.04	0.01	0.01	0.41	0.54	0.02	0.01
(well drained)	45-80-03	14-20	Bw2	0.23	0.18	0.29	0.33	0.03	0.03	0.02	0.02	0.21	0.31	0.03	0.02
	45-80-05	28-53	Bx1	0.20	0.21	0.21	0.19	0.00	0.03	0.04	0.06	0.21	0.20	0.01	0.05
Morris	58-03-01	0-7	Ap	2.02	1.89	0.79	1.01	0.06	0.10	0.07	0.09	1.95	0.90	0.08	0.08
(somewhat	58-03-03	11-17	BA	1.12	1.32	0.42	0.44	0.00	0.00	0.09	0.08	1.22	0.43	0.00	0.09
poorly drained)	58-03-07	31-46	Bx4	0.60	0.47	0.19	0.19	0.00	0.03	0.03	0.04	0.53	0.19	0.01	0.03
Pre-Wisconsinan Glacial Till															
Allenwood	13-61-01	0-7	Ap	0.39	0.32	0.53	0.45	0.00	0.03	0.02	0.02	0.35	0.49	0.01	0.02
(well drained)	13-61-04	24-33	Bt3	0.10	0.08	0.26	0.26	0.07	0.00	0.00	0.00	0.09	0.26	0.03	0.00
	13-61-07	61-75	Bt5	0.11	0.02	0.19	0.17	0.02	0.00	0.00	0.00	0.07	0.18	0.01	0.00
Watson	55-02-01	0-9	Ap	0.35	0.37	0.28	0.27	0.03	0.03	0.03	0.03	0.36	0.27	0.03	0.03
(Moderately	55-02-03	18-27	Bt2	0.09	0.06	0.30	0.30	0.00	0.03	0.00	0.00	0.07	0.30	0.01	0.00
well drained)	55-02-05	35-45	Bx2	0.07	0.03	0.27	0.27	0.00	0.03	0.00	0.00	0.05	0.27	0.01	0.00

Table 2. Fe_2O_3, Al_2O_3, SiO_2, and MnO_2 data for the soil samples used in this study. (Continued).

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent								Mean			
				Fe_2O_3		Al_2O_3		SiO_2		MnO_2					
				1	2	1	2	1	2	1	2	Fe_2O_3	Al_2O_3	SiO_2	MnO_2
Acid Grayish-brown Shale and Sandstone Colluvium															
Laidig	14-31-03	0-3	A	1.96	1.83	0.99	1.08	0.00	0.00	0.27	0.28	1.89	1.03	0.00	0.27
(well drained)	14-31-06	20-23	Bt2	0.18	0.25	0.46	0.47	0.00	0.00	0.01	0.00	0.21	0.47	0.00	0.01
	14-31-10	40-59	Bx1	0.40	0.57	0.51	0.44	0.00	0.08	0.08	0.10	0.49	0.47	0.04	0.09
Andover	18-13-01	0-9	Ap	2.38	2.20	0.78	0.99	0.06	0.00	0.28	0.25	2.29	0.89	0.03	0.27
(poorly drained)	18-13-03	14-18	Bt1	0.34	0.48	0.33	0.34	0.00	0.00	0.01	0.00	0.41	0.33	0.00	0.01
	18-13-06	32-38	Bx2g	0.62	0.73	0.35	0.29	0.00	0.08	0.04	0.05	0.67	0.32	0.04	0.05
Brown Wisconsinan Loess															
Duncannon	09-05-01	0-10	Ap	0.83	0.78	0.88	0.87	0.00	0.00	0.10	0.09	0.81	0.87	0.00	0.09
(well drained)	09-05-03	17-24	Bt1	0.55	0.46	0.58	0.46	0.00	0.00	0.01	0.01	0.51	0.52	0.00	0.01
	09-05-05	34-45	BC	0.73	0.61	0.37	0.34	0.00	0.00	0.03	0.02	0.67	0.35	0.00	0.03
Lawrenceville	09-03-01	0-11	Ap	0.79	0.71	0.83	0.73	0.00	0.05	0.07	0.06	0.75	0.78	0.03	0.07
(Moderately	09-03-03	19-25	Bt2	0.64	0.52	0.35	0.39	0.00	0.00	0.00	0.00	0.58	0.37	0.00	0.00
well drained)	09-03-05	34-40	Bx2	0.79	0.60	0.29	0.31	0.00	0.00	0.03	0.03	0.69	0.30	0.00	0.03
Doylestown	09-11-01	0-7	Ap	0.85	0.82	0.35	0.40	0.02	0.00	0.05	0.03	0.83	0.37	0.01	0.04
(poorly drained)	09-11-02	7-15	Btg2	0.35	0.28	0.53	0.47	0.13	0.05	0.00	0.00	0.31	0.50	0.09	0.00
	09-11-04	18-27	Bxtg2	0.71	0.74	0.26	0.27	0.02	0.02	0.03	0.03	0.73	0.27	0.02	0.03
Residual Acid Sandstone															
Hazleton	17-12-02	0-2	A	1.23	1.51	0.56	0.17	0.00	0.08	0.15	0.16	1.37	0.37	0.04	0.15
(well drained)	17-12-05	13-24	Bw2	0.54	0.40	0.50	0.46	0.00	0.05	0.04	0.03	0.47	0.48	0.03	0.03
	17-12-08	41-50	Bw5	0.47	0.33	0.31	0.39	0.00	0.04	0.07	0.06	0.40	0.35	0.02	0.07
Cookport	17-15-02	2-6	BA	1.70	1.72	0.77	0.57	0.00	0.00	0.00	0.00	1.71	0.67	0.00	0.00
(Moderately	17-15-04	10-15	Bt2	0.90	0.79	0.65	0.64	0.00	0.04	0.00	0.00	0.85	0.65	0.02	0.00
well drained)	17-15-07	33-47	Bx3	0.52	0.35	0.22	0.21	0.00	0.00	0.05	0.05	0.43	0.21	0.00	0.05
Nolo	17-19-02	0-4	A	0.21	0.23	0.21	0.25	0.00	0.00	0.00	0.00	0.22	0.23	0.00	0.00
(poorly drained)	17-19-04	11-14	Btg	0.39	0.39	0.28	0.24	0.00	0.00	0.00	0.00	0.39	0.26	0.00	0.00
	17-19-06	31-49	Bxg2	0.37	0.33	0.19	0.17	0.07	0.07	0.01	0.02	0.35	0.18	0.07	0.01

Table 2. Fe_2O_3, Al_2O_3, SiO_2, and MnO_2 data for the soil samples used in this study. (Continued).

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent								Mean			
				Fe_2O_3		Al_2O_3		SiO_2		MnO_2					
				1	2	1	2	1	2	1	2	Fe_2O_3	Al_2O_3	SiO_2	MnO_2
				Residual Acid Gray Shales											
Gilpin	32-54-01	0-9	Ap	0.63	0.49	0.93	1.04	0.09	0.00	0.03	0.09	0.56	0.99	0.05	0.06
(Well drained)	32-54-03	14-23	Bt	0.26	0.28	0.39	0.35	0.00	0.02	0.01	0.01	0.27	0.37	0.01	0.01
	32-54-05	26-30	C	0.22	0.21	0.34	0.33	0.00	0.00	0.00	0.00	0.21	0.33	0.00	0.00
Rayne	56-02-01	0-9	Ap												
(Well drained)	56-02-04	26-38	Bt3	0.11	0.13	0.36	0.37	0.00	0.00	0.00	0.00	0.12	0.36	0.00	0.00
	56-02-07	66-82	C1	0.36	0.27	0.39	0.44	0.00	0.06	0.04	0.04	0.31	0.41	0.03	0.04
Wharton	32-53-01	0-10	Ap	1.08	0.89	0.90	0.80	0.06	0.07	0.10	0.11	0.99	0.85	0.07	0.11
(Moderately	32-53-04	19-24	Bt2g	0.41	0.72	0.62	0.49	0.04	0.00	0.01	0.04	0.57	0.55	0.02	0.03
well drained)	32-53-06	36-54	C	0.57	0.53	0.43	0.27	0.00	0.06	0.03	0.03	0.55	0.35	0.03	0.03
Cavode	10-39-01	0-11	Ap	0.91	0.99	0.48	0.54	0.05	0.08	0.07	0.07	0.95	0.51	0.07	0.07
(Somewhat	10-39-04	21-27	Bt3g	0.51	0.32	0.33	0.38	0.02	0.11	0.00	0.00	0.41	0.35	0.07	0.00
poorly drained)	10-39-07	41-51	2Btbg	0.19	0.16	0.25	0.18	0.03	0.00	0.03	0.02	0.17	0.21	0.01	0.03
Cavode	32-59-01	0-11	Ap	0.93	0.99	0.75	0.76	0.02	0.00	0.17	0.17	0.96	0.75	0.01	0.17
(Somewhat	32-59-03	16-21	Bt1	0.41	0.38	0.67	0.49	0.09	0.00	0.00	0.00	0.39	0.58	0.05	0.00
poorly drained)	32-59-06	47-57	Cg	0.22	0.21	0.64	0.21	0.09	0.00	0.00	0.02	0.21	0.43	0.05	0.01
				Residual Calcareous Red Shales											
Upshur	02-23-01	0-8	Ap	1.10	1.26	0.49	0.31	0.00	0.00	0.11	0.14	1.18	0.40	0.00	0.13
(Well drained)	02-23-03	16-25	Bt2	1.04	0.84	0.51	0.54	0.11	0.05	0.00	0.00	0.94	0.53	0.08	0.00
	02-23-07	46-56	C1	0.24	0.23	0.15	0.20	0.08	0.02	0.01	0.01	0.23	0.17	0.05	0.01
Vandergrift	04-01-01	0-7	Ap	0.95	0.89	0.47	0.44	0.03	0.00	0.12	0.12	0.92	0.45	0.01	0.12
(Somewhat	04-01-04	16-22	Bt3	0.45	0.43	0.34	0.31	0.12	0.03	0.00	0.00	0.44	0.33	0.07	0.00
poorly drained)	04-01-08	58-71	C1	0.79		0.12		0.08		0.00					

Table 2. Fe_2O_3, Al_2O_3, SiO_2, and MnO_2 data for the soil samples used in this study. (Continued).

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent												Mean			
				Fe_2O_3		Al_2O_3		SiO_2		MnO_2									
				1	2	1	2	1	2	1	2	Fe_2O_3	Al_2O_3	SiO_2	MnO_2
Residual Calcareous Gray Shales															
Westmoreland (Well drained)	63-43-01	0-10	Ap	0.82	0.97	0.60	0.67	0.00	0.00	0.17	0.16	0.89	0.63	0.00	0.17
	63-43-04	21-29	Bt2	0.58	0.60	0.67	0.67	0.00	0.00	0.12	0.10	0.59	0.67	0.00	0.11
	63-43-07	50-58	C	0.29	0.24	0.27	0.28	0.00	0.00	0.01	0.03	0.27	0.27	0.00	0.02
Dormont (Moderately well drained)	02-07-02	0-7	Ap	1.14	1.18	0.50	0.52	0.03	0.00	0.11	0.13	1.16	0.51	0.01	0.12
	02-07-05	19-23	Bt2	1.29	1.44	0.44	0.37	0.09	0.00	0.03	0.04	1.37	0.41	0.05	0.04
	02-07-08	40-52	Bt5	0.30	0.34	0.21	0.19	0.03	0.01	0.03	0.03	0.32	0.20	0.02	0.03
Library (Somewhat poorly drained)	63-45-01	0-10	Ap	1.34	1.54	0.49	0.49	0.07	0.05	0.14	0.13	1.44	0.49	0.06	0.13
	63-45-04	19-24	Bt3g	0.44	0.59	0.27	0.25	0.06	0.00	0.09	0.05	0.51	0.26	0.03	0.07
	63-45-08	49-52	C1g	0.25	0.30	0.17	0.13	0.06	0.00	0.08	0.08	0.27	0.15	0.03	0.08
Residual Limestones															
Duffield (Well drained)	36-17-01	0-7	Ap	0.49	0.49	0.83	0.81	0.07	0.00	0.16	0.18	0.49	0.82	0.03	0.17
	36-17-03	12-22	Bt1	0.28	0.25	0.37	0.33	0.00	0.00	0.01	0.00	0.27	0.35	0.00	0.01
	36-17-06	40-52	C	0.36	0.25	0.44	0.31	0.07	0.03	0.01	0.02	0.31	0.37	0.05	0.01
Hagerstown (Well drained)	36-19-01	0-10	Ap	0.49	0.38	0.57	0.56	0.03	0.03	0.07	0.04	0.43	0.57	0.03	0.05
	36-19-03	21-28	Bt2	0.27	0.21	0.66	0.44	0.00	0.03	0.00	0.00	0.24	0.55	0.01	0.00
	36-19-07	56-66	C1	0.24	0.18	0.56	0.47	0.01	0.03	0.01	0.01	0.21	0.51	0.02	0.01
Residual Acid Crystalline Rocks															
Manor (Well drained)	36-28-01	0-5	Ap1	0.26	0.26	0.39	0.37	0.00	0.03	0.05	0.04	0.26	0.38	0.01	0.05
	36-28-03	10-20	Bw	0.20	0.13	0.28	0.37	0.05	0.00	0.03	0.05	0.17	0.33	0.03	0.04
	36-28-06	33-37	C1	0.25	0.24	0.20	0.22	0.03	0.00	0.11	0.07	0.25	0.21	0.01	0.09
Chester (Well drained)	67-08-01	0-8	Ap	0.55	0.55	0.82	0.65	0.00	0.00	0.12	0.11	0.55	0.73	0.00	0.11
	67-08-04	21-26	Bt2	0.15	0.15	0.40	0.28	0.00	0.00	0.01	0.01	0.15	0.34	0.00	0.01
	67-08-06	28-34	C1	0.15	0.13	0.41	0.31	0.00	0.00	0.02	0.02	0.14	0.36	0.00	0.02
Glenelg (Moderately well drained)	36-27-01	0-10	Ap	0.20	0.20	0.25	0.36	0.00	0.00	0.05	0.07	0.20	0.31	0.00	0.06
	36-27-02	10-19	Bt1	0.14	0.16	0.29	0.28	0.00	0.00	0.00	0.00	0.15	0.29	0.00	0.00
	36-27-05	33-42	C1	0.07	0.06	0.11	0.11	0.00	0.00	0.01	0.02	0.07	0.11	0.00	0.01

Table 2. Fe_2O_3, Al_2O_3, SiO_2, and MnO_2 data for the soil samples used in this study. (Continued).

Soil and Drainage Class	Number	Depth (inches)	Horizon	Percent								Mean			
				Fe_2O_3		Al_2O_3		SiO_2		MnO_2					
				1	2	1	2	1	2	1	2	Fe_2O_3	Al_2O_3	SiO_2	MnO_2
Residual Basic Crystalline Rocks															
Neshaminy (Well drained)	09-51-01	0-7	Ap	1.06	1.02	0.71	0.45	0.08	0.00	0.05	0.04	1.04	0.58	0.04	0.05
	09-51-03	13-23	Bt2	0.82	0.77	0.78	0.68	0.31	0.04	0.04	0.03	0.79	0.73	0.17	0.03
	09-51-05	36-64	C	1.30	1.12	0.84	0.91	0.21	0.18	0.04	0.04	1.21	0.87	0.19	0.04
Neshaminy (Well drained)	46-13-01	0-6	Ap	0.38	1.02	0.91	0.92	0.10	0.07	0.15	0.13	0.70	0.91	0.09	0.14
	46-13-05	16-20	Bt2	1.19	1.25	0.80	0.92	0.31	0.15	0.09	0.10	1.22	0.86	0.23	0.09
	46-13-08	33-39	C1	0.80		0.73		0.16		0.07					
Mount Lucas (Moderately well drained)	01-16-01	0-8	Ap	1.03	0.88	0.25	0.33	0.05	0.00	0.04	0.04	0.95	0.29	0.03	0.04
	01-16-04	18-24	Bt2	0.65	0.72	0.37	0.43	0.08	0.05	0.02	0.01	0.69	0.40	0.07	0.01
	01-16-06	28-39	C	0.26	0.21	0.20	0.21	0.06	0.02	0.02	0.01	0.23	0.21	0.04	0.01
Towhee (Poorly drained)	09-12-01	0-8	Ap	0.78	0.74	0.32	0.29	0.05	0.00	0.02	0.02	0.76	0.31	0.03	0.02
	09-12-04	21-28	Btg3	0.85	0.67	0.36	0.40	0.10	0.10	0.00	0.00	0.76	0.38	0.10	0.00
	09-12-06	39-53	Bx2	0.69	0.72	0.34	0.43	0.11	0.13	0.01	0.01	0.71	0.39	0.12	0.01
Towhee (Poorly drained)	09-13-01	0-7	Ap	1.15	1.23	0.49	0.51	0.11	0.00	0.02	0.03	1.19	0.50	0.05	0.02
	09-13-04	21-28	Btg2	1.07	1.29	0.43	0.52	0.13	0.07	0.01	0.04	1.18	0.47	0.10	0.03
	09-13-06	41-50	Bxg2	0.97	1.04	0.47	0.62	0.13	0.19	0.02	0.03	1.01	0.55	0.16	0.03