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ESTIMATION OF SOIL TEXTURE AND PLANT AVAILABLE WATER BY CORRELATION WITH THE LASER LIGHT-SCATTERING METHOD

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INTRODUCTION

Particle-size distribution and plant available water are basic input to studies of range, forest and cultivated land. Since the conventional laboratory procedures for determining these parameters are time consuming, an improved method for making these measurements is desirable. Weiss and Frock (1976) reported results from an instrument employing the principle of laser light scattering to measure particle-size distribution. The instrument was reported to be of high precision, and yielded reproducible results. The laser light-scattering instrument used in this study is the *Microtrac Particle-size Analyzer Model 7991-0, manufactured by Leeds and Northrup. The particle-size analysis range of this model is from 1.9 to 176 μm, which does not correspond to the entire fine earth fraction (< 2 mm) usually characterized by soil scientists. It is, therefore, desirable to develop predictive equations to estimate the soil texture of the fine earth fraction. We believe data from this instrument could be used to predict other soil properties. This paper reports on using Microtrac data to estimate the plant available water holding capacity and soil texture of Arizona soils.

Two hundred and forty-seven Arizona soils were used in this study. Most of these soils (approximately 230 soils) are thermic or hyperthermic and arid or semiarid soils of dominantly mixed mineralogy, as described on the Arizona General Soils Map (Jay et al., 1975). An array of soil horizons are included, with approximately one half of the samples coming from the A or Ap surface horizons. The other half of the samples are from the subsurface B or C horizons.

METHODS AND MATERIALS

General Description and Operation of the Microtrac

A brief description of the operation and data output of the Microtrac, and some of the previous work with the instrument, is given below. The papers by Weiss and Frock (1976), Wertheimer et al. (1978), Haverland and Cooper (1981) and Cooper et al. (1984) describe, in greater detail, the operation of the instrument.

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*Trade names are included for information of the reader, and do not constitute endorsement by the United States Department of Agriculture or the University of Arizona.

Other research results have been published using data obtained from this same instrument. Cooper et al. (1984) compared the sieve-pipette and Microtrac methods of particle-size analysis for 10 soils representing a wide range of size distribution. They concluded that regression analysis may be used to convert Microtrac results to those of the sieve-pipette method with an acceptable degree of accuracy; however, this is best achieved when done by specific particle-size ranges. The agreement between the two methods was highest for the 62 and 31 μm and 31 to 16 μm particle size ranges. These workers also studied the effect of organic matter and soluble salts on Microtrac results, and they report a slight improvement in the data when these two components had been removed. Haverland and Cooper (1981) reported on the effect of sample dispersion techniques and sample concentrations on Microtrac analyses. They further studied the relationship between the specific surface data obtained from Microtrac and other specific surface measurements, and they reported an excellent correlation between the two methods.

The Microtrac measures particle size by low-angle forward-scattering of laser light which has passed through a sample cell (Wertheimer et al., 1978). The laser light is produced by a helium neon source of 0.6 μm wavelength, and the nature of scattering is dependent upon the ratio of particle diameter to the wavelength of the laser light. The relationship of particle size to the intensity and angle of scatter of the laser light, after light-particle interaction, is of prime importance in Microtrac theory. Light intensity is directly proportional to the particle diameter squared, whereas the angle of light scatter is inversely proportional to the diameter of the particle (Jenkins and White, 1975).

Following the interaction of light and particle in the sample cell, the light passes through a rotating Fraunhoffer plane optical filter, which has openings designed to accomodate light fluxes proportional to respective powers (d^2, d^3, and d^4) of the particle diameter. A photodetector and microcomputer convert the scattered light into numerical data describing particle-size distribution. The concentration is displayed visually, and data is recorded by a digital printer.

Samples are put in aqueous suspension, with two sample cells available for use, depending upon sample concentration. A 4-liter chamber is used for an approximate range of 2,000-40 mg/l, and a smaller 250-ml chamber can be used for an approximate range of 400-40 mg/l. In this research, we used only the 4-liter chamber.

Data is provided on 13 channels (size fractions) between 1.9 and 176 μm yielding both channel percent and cumulative percent less than (or cumulative percent greater than). These size ranges correspond to one half phi intervals of the Udden - Wentworth scale as expressed by Krumbein (1934) where phi = $-\log_2$ (diameter, mm). This notation is widely used in sediment analysis.

Output includes a cumulative graph, a relative volume graph, cumulative and histogram data, and summary data. Summary data consist of the values, in µm, at the 10th, 50th, and 90th percentile points, the mean diameter of the volume distribution (µm), the calculated mean specific surface area, and a value (dv) representative of sample concentration. All data, except the sample concentration term, were used in this study.

Sample Preparation and Data Computation

Sample preparation and dispersion remain important factors for precise and reproducible analysis. Our Microtrac sample dispersion was accomplished by a combination of two treatments, a chemical dispersant, and the subsequent application of ultrasonics immediately prior to analysis. The chemical dispersant consists of 53.52 g Na_2PO_7 and 4.24 g Na_2CO_3 in one liter of distilled water (C. L. Lameris, 1964), which is added to the soil at a ratio of 1 ml dispersant/1 gram soil. A 350 watt, 20 KHz ultrasonic probe, with a 1/2-inch disruptor horn, was submerged into the soil solution, and ultrasonics were applied for 30 seconds. Following this dispersion, each sample was wet-sieved with an ASTME No. 80, 180 µm sieve. Although 176 µm is the upper size limit of this Microtrac model, the difference between 180 µm and 176 µm is considered negligible. We included this gravimetric measurement (% > 180 µm) as an additional "channel of data". We further used this information to calculate a "corrected" Microtrac parameter for the 13 channels from 176 to 1.9 µm. The following computation corrects the Microtrac data for the sand fraction from 180 µm to 2 mm, which was not measured by Microtrac:

$$1-\left(\frac{\text{wt of sample} > 180\ \mu\text{m}}{\text{total sample wt.} < 2\text{mm}}\right)\left(\begin{matrix}\%\text{ Microtrac data for}\\ \text{each size category}\end{matrix}\right) = \begin{matrix}\text{sand "corrected"}\\ \text{Microtrac}\\ \text{data.}\end{matrix} \qquad (1)$$

The descriptions of all variables are given in Table 1. The 13 size categories from 176 to 1.9 µm are all "corrected" variables. The other variables-specific surface, mean diameter, 90th, 50th and 10th percentile were used as recorded by Microtrac. Two additional variables were generated from the basic data, and have been called "Microtrac sand" and "Microtrac silt". Microtrac sand = $(V4 + V5 + V6 + V7 + .67\ (V8))$, and Microtrac silt = $(.33(V8) + V9 + V10 + V11 + V12 + V13 + V14 + V15 + V16)$. These two variables very closely approximate the size of sand (2.00 -.05 mm) and silt (.05 -.002 mm) particles. However, these calculations cannot be corrected for that portion of the sample below the Microtrac Model 7991-0 sensitivity (< 1.9 µm); so the true value would be lower.

Microtrac data through correlation and regression analyses were related to the percent sand, silt, and clay determined by conventional procedures (Day, 1965) for pipette or hydrometer analyses. This textural data came from various sources, including analyses completed by the authors, by the National Soil Survey Characterization Laboratory, and soil and water science graduate students at the University of Arizona. The plant available water content was determined at 1/3 and 15 bars of tension, as described by Richards (1965). In the statistical analyses, Microtrac data was used as the set of 19 independent variables, and %

sand, % silt, % clay, % water at 15 bar, and % water at 1/3 bar were the dependent variables. Variables were retained in the multilinear regression equation which met the 90% confidence level, or which significantly increased the coefficient of determination.

RESULTS AND DISCUSSION

Relating Microtrac Results to Soil Texture

Correlations were performed in two ways, with the data from all 247 soils combined, and with the data stratified into the 12 textural classes as defined in USDA Handbook 18 (1951). The sample population did not include any silt textures, but there are data for the other 11 classes. Table 1 presents the means and standard deviations for each textural class for all variables used in this research. Table 2 presents the predictive equations for all soils and for each textural class, and lists the coefficient of determination (r^2) and significance level of each equation. These equations are produced by a series of computer generated step-wise multiple linear regressions. Generally, the correlations were lower in classes with a high number of samples, but the significance levels were improved.

Figures 1, 2, and 3 show, graphically, the relationship for all 247 soils between the conventionally determined sand, silt, and clay content versus the sand, silt, and clay content predicted from Microtrac data. The percent sand prediction was the best (r^2 = .82); silt was next (r^2 = .68); and clay was least accurate (r^2 = .63). All predictive equations are highly significant, except the sand determination for the sand textural class and the clay and sand determinations for both loamy sand and sandy clay textural classes, and although the Microtrac does not measure particles less than 1.9 µm, percent clay can still be estimated. The clay fraction is partially predictable from the variation of clay content with the data of the size fractions measured by the Microtrac.

The soil texture of an unknown sample may be estimated either by preliminary use of the qualitative "feel" method (hand manipulation of sample), or by preliminary use of the equation set developed for all soil textures (Table 2), to select the approximate soil texture. Then, the appropriate set of equations for that textural class should be used to improve the prediction.

Relating Microtrac Results to Plant Available Water

Ninety-one soils from the 247 total soils had plant available water information. Table 3 presents the correlation coefficient (r value) for each of the Microtrac size categories. We ran the correlations on both the "uncorrected" and "corrected" Microtrac data (Eq. 1), and the corrected data gave the better relationships, particularly for the wilting point (15 bars of tension). For the wilting-point (corrected) data, the 16 - 11 µm, 11 - 7.8 µm, 7.8 - 5.5 µm, 5.5 - 3.9 µm, and the 2.8 - 1.9 µm size channel, plus the mean diameter and 50th percentile data, showed

Table 1. Description of variables and the means and standard deviation (σ) by soil textural classes.

ID Number and description of variables	Sand n* = 5		Loamy sand n = 7		Sandy loam n = 50	
	Mean	σ	Mean	σ	Mean	σ
Conventional analysis						
V1 % sand	89.52	3.89	74.9	14.23	63.19	7.44
V2 % silt	5.54	2.75	17.93	9.44	24.80	6.37
V3 % clay	4.96	2.13	7.20	5.00	12.06	3.61
V4 % .176-2.0 mm	54.42	14.15	43.15	25.74	29.09	12.96
Microtrac Analysis						
V5 % 176-125 μm	12.01	4.12	10.84	6.49	8.98	3.75
V6 % 125-88	9.43	4.11	11.47	7.89	9.88	2.77
V7 % 88-62	5.71	2.75	8.18	4.59	7.90	3.34
V8 % 62-44	2.94	1.44	5.53	3.00	7.37	2.59
V9 % 44-31	2.87	2.50	4.93	3.32	5.66	2.23
V10 % 31-22	2.00	2.01	3.35	1.44	4.40	1.69
V11 % 22-16	0.64	0.96	1.23	0.92	3.02	1.67
V12 % 16-11	1.71	1.16	2.35	1.57	3.64	1.49
V13 % 11-7.8	1.30	1.35	1.53	1.26	3.51	1.62
V14 % 7.8-5.5	1.78	1.81	1.06	1.26	2.15	1.20
V15 % 5.5-3.9	1.76	0.92	2.16	0.93	4.59	1.37
V16 % 3.9-2.8	1.23	1.14	2.04	1.22	4.38	1.61
V17 % 2.8-1.9	1.98	1.41	1.81	1.57	4.98	1.89
V18 Specific surf.	0.35	0.14	0.35	0.10	0.54	0.14
V19 Mean diameter	79.64	10.92	70.60	11.58	54.70	9.08
V20 90 percentile	152.80	4.27	144.50	7.73	130.30	11.48
V21 50 percentile	77.28	15.25	62.21	18.87	40.68	12.50
V22 10 percentile	8.60	8.07	7.99	8.04	3.50	1.04
V24 Microtrac silt	14.26	5.93	20.50	8.92	33.81	6.54
V28 Microtrac sand	83.53	7.25	77.32	10.28	60.77	7.43

	Loam n = 60		Silt loam n = 11		Sandy clay loam n = 32	
Conventional analysis						
V1 % sand	45.85	9.34	21.85	8.38	51.65	10.09
V2 % silt	34.00	6.86	58.39	6.15	23.88	9.32
V3 % clay	20.17	4.41	18.92	6.32	24.38	3.55
V4 % .176-2.0 mm	20.90	9.31	13.35	14.49	27.94	10.99

*n is the number of samples in the given texture class.

Table 1. (Continued)

ID Number and description of variables		Loam n = 60		Silt loam n = 11		Sandy clay loam n = 32	
		Mean	σ	Mean	σ	Mean	σ
Microtrac Analysis							
V5	% 176-125 μm	6.27	2.49	2.86	1.97	5.43	2.52
V6	% 125-88	7.79	2.43	5.17	2.64	6.76	3.51
V7	% 88-62	7.90	2.49	5.79	2.67	7.19	3.31
V8	% 62-44	7.58	2.07	7.40	3.07	6.09	2.52
V9	% 44-31	6.33	2.11	8.76	2.86	4.86	2.09
V10	% 31-22	4.86	1.58	8.06	1.85	4.07	1.93
V11	% 22-16	3.63	1.94	7.61	2.38	3.27	2.35
V12	% 16-11	4.89	1.93	8.00	2.21	4.28	1.96
V13	% 11-7.8	4.59	1.74	6.81	2.63	3.97	2.04
V14	% 7.8-5.5	2.94	1.64	5.11	1.56	2.77	1.69
V15	% 5.5-3.9	6.84	2.47	7.17	2.64	7.12	1.50
V16	% 3.9-2.8	6.99	2.93	6.55	2.92	7.15	1.73
V17	% 2.8-1.9	7.97	3.13	6.83	2.67	8.42	2.19
V18	Specific surf.	0.69	0.17	0.67	0.17	0.78	0.14
V19	Mean diameter	43.78	10.31	32.66	9.77	40.69	10.41
V20	90 percentile	112.41	15.79	84.75	25.83	107.48	24.75
V21	50 percentile	26.32	14.82	19.33	7.84	22.64	10.69
V22	10 percentile	3.05	0.98	3.41	1.19	2.60	0.14
V24	Microtrac silt	43.61	8.42	60.52	12.67	39.52	9.89
V28	Microtrac silt	47.91	10.42	32.10	14.75	51.39	11.04

		Clay loam n = 57		Silty clay loam n = 6		Sandy clay n = 5	
Conventional analysis							
V1	% sand	35.89	5.93	11.82	4.41	50.57	4.65
V2	% silt	30.50	6.00	54.80	2.75	11.40	1.95
V3	% clay	33.08	3.33	33.17	3.28	38.03	3.18
V4	% .176-2.0 mm	17.10	5.18	4.95	5.67	32.73	19.98
Microtrac Analysis							
V5	% 176-125 μm	3.92	1.64	0.85	0.87	1.45	1.22
V6	% 125-88	5.28	1.57	2.51	1.64	3.39	2.24
V7	% 88-62	6.54	2.54	5.41	2.88	5.01	4.22
V8	% 62-44	6.51	2.07	5.35	1.19	3.83	1.77
V9	% 44-31	5.52	2.06	6.62	1.77	4.85	4.40
V10	% 31-22	4.57	1.81	7.88	1.76	2.64	1.10
V11	% 22-16	4.63	1.94	8.04	2.04	4.69	1.07
V12	% 16-11	5.77	1.87	9.95	1.54	5.47	0.51
V13	% 11-7.8	5.34	2.10	9.67	0.98	4.36	1.49
V14	% 7.8-5.5	3.69	1.92	6.76	0.82	3.51	0.57

Table 1. (Continued)

ID Number and description of variables	Clay loam n = 57		Silty clay loam n = 6		Sandy clay n = 5	
	Mean	σ	Mean	σ	Mean	σ
Microtrac Analysis						
V15 % 5.5-3.9	9.43	2.24	10.93	3.03	9.05	1.07
V16 % 3.9-2.8	9.80	3.04	10.24	3.21	9.48	2.34
V17 % 2.8-1.9	11.39	3.75	10.36	2.79	9.19	4.66
V18 Specific surf.	0.88	0.14	0.87	0.14	0.97	0.10
V19 Mean diameter	32.34	5.51	21.90	5.69	24.80	7.39
V20 90 percentile	92.82	14.98	57.97	16.89	70.93	23.98
V21 50 percentile	12.78	5.29	11.22	3.19	9.60	3.03
V22 10 percentile	2.61	0.39	2.73	0.24	2.53	0.14
V24 Microtrac silt	50.91	5.71	71.87	5.96	45.32	8.18
V28 Microtrac sand	37.18	6.65	17.28	7.51	45.13	12.79

	Silty clay n = 3		Clay n = 11	
Conventional analysis				
V1 % sand	7.00	3.36	17.11	11.21
V2 % silt	45.00	3.22	31.66	7.50
V3 % clay	48.00	5.02	50.32	12.33
V4 % .176-2.0 mm	8.44	12.62	14.28	5.88
Microtrac Analysis				
V5 % 176-125 µm	1.41	1.94	2.65	2.27
V6 % 125-88	1.00	2.04	4.02	2.99
V7 % 88-62	1.24	1.47	5.56	2.02
V8 % 62-44	2.20	2.29	5.23	2.22
V9 % 44-31	2.78	3.34	5.18	1.91
V10 % 31-22	3.85	3.26	4.43	2.02
V11 % 22-16	4.97	3.56	5.66	1.30
V12 % 16-11	8.00	2.09	7.19	1.49
V13 % 11-7.8	9.81	1.79	6.92	2.77
V14 % 7.8-5.5	7.38	1.36	5.06	2.11
V15 % 5.5-3.9	15.74	5.73	10.62	2.98
V16 % 3.9-2.8	15.91	6.99	10.97	3.80
V17 % 2.8-1.9	16.84	7.36	11.73	4.74
V18 Specific surf.	1.20	0.30	0.94	0.20
V19 Mean diameter	14.48	9.13	26.62	9.34
V20 90 percentile	38.50	10.99	76.27	27.52
V21 50 percentile	6.57	2.61	10.67	5.15
V22 10 percentile	2.42	0.17	2.61	0.30
V24 Microtrac silt	69.18	11.44	57.76	7.73
V28 Microtrac sand	13.57	16.68	30.00	10.32

Table 2. Predictive equations for % sand, % silt, and % clay by textural class.

Texture class	Dependent variable	Predictive equation	r^2	Significance level
All texture classes	Clay	$Y = 12.18 + .90(V14) + 1.65(V15) + .07(V19) - .24(V21)$	.63	$< .01$
	Silt	$Y = 12.04 -.46(V5) + .95(V10) - 17.84(V18) + .67(V24)$	.68	$< .01$
	Sand	$Y = - 20.71 + .76(V5) + 1.30(V16) + 1.11(V28)$	.82	$< .01$
Sand	Clay	$Y = 6.21 +.51(V13) - .22(V22)$	.99	.55
	Silt	$Y = 1.39 + .74(V7) + 2.08(V12) -.10(V22)$	.99+	.29
	Sand	$Y = 82.33 - .48(V7) + 11.71(V18) + .68(V22)$	.99+	3.54
Loamy sand	Clay	$Y = 4.93 - .48(V7) + .25(V9) + 1.86(V12)$	.84	9.96
	Silt	$Y = 26.05 - 1.96(V7) + .91(V8) + 4.90(V12) - 26.85(V18)$	.99	1.17
	Sand	$Y = 63.16 + 2.05(V7) - 6.84(V12) + 37.37(V18)$	.71	23.69
Sandy loam	Clay	$Y = 7.70 + .44(V13) + 1.08(V17) - .73(V22)$	.62	$< .01$
	Silt	$Y = 30.03 + .56(V6) + 1.01(V8) + .95(V10) - .23(V20) + .21(V24)$	.72	$< .01$
	Sand	$Y = 25.54 + .41(V5) - 1.05(V8) + .69(V28)$	.77	$< .01$
Loam	Clay	$Y = - 4.81 - 1.69(V5) + .31(V7) + .50(V17) + .29(V20) - .15(V21)$	.64	$< .01$
	Silt	$Y = 103.22 - 55.47(V18) - .38(V19) - .53(V21)$	.74	$< .01$
	Sand	$Y = - 33.42 - .46(V7) + 1.66(V12) - 2.02(V15) + 85.38(V18) + 1.12(V21)$	.76	$< .01$
Silt loam	Clay	$Y = 40.58-2.07(V7) + 1.79(V8) - .84(V12) - .84(V21)$	.93	.11
	Silt	$Y = 3.11 + 7.04(V10) - 2.87(V11) - 7.22(V13) + 13.57(V15) - 5.46(V17) + 1.75(V19) - 2.47(V21)$	.98	1.02
	Sand	$Y = - 7.37 + .88(V11) + 6.60(V22)$	.82	.12

Table 2. (Continued)

Texture class	Dependent variable	Predictive equation	r^2	Significance level
Sandy clay loam	Clay	$Y = 47.27 + .58(V12) - 22.98(V18) - .33(V21)$	.50	.02
	Silt	$Y = 1.62 + .33(V21) - 9.21(V22) + .98(V24)$	.93	$< .01$
	Sand	$Y = 2.81 - 1.16(V12) + 17.48(V18) + 0.78(V28)$	.94	$< .01$
Clay loam	Clay	$Y = 56.09 + 1.39(V17) - 38.00(V18) - 0.40(V21)$	.23	.27
	Silt	$Y = 22.46 + 1.82(V6) + 1.49(V10) - .87(V19) + 7.58(V22)$	.51	$< .01$
	Sand	$Y = -28.90 + 1.06(V16) - 1.38(V17) + 40.32(V18) + .93(V28)$	.74	$< .01$
Silty clay loam	Clay	$Y = 39.97 + .43(V7) - 3.06(V8) + 1.07(V14)$	.99+	.14
	Silt	$Y = 52.02 + .46(V5) - 2.20(V8) + 1.20(V9) + .78(V10)$	.99+	.10
	Sand	$Y = 9.49 + 5.51(V8) - 2.66(V9) - 1.41(V14)$	.99+	.47
Sandy clay	Clay	$Y = 57.51 - 5.54(V14)$	.99	6.14
	Silt	$Y = 5.64 + .08(V20)$	.99+	1.56
	Sand	$Y = 55.95 - 3.72(V5)$	.95	14.54
Silty clay	Clay	$Y = 60.90 - 1.51(V11) - .55(V13)$	.99+	.08
	Silt	$Y = 43.63 + 1.89(V5) - 1.30(V6)$	.99+	.47
	Sand	$Y = 4.71 + 1.23(V10) + .71(V13)$	.99+	.29
Clay	Clay	$Y = 168.89 + 5.70(V5) - 6.63(V8) - 6.74(V12) + 121.47(V18) + 66.47(V22)$	.94	.46
	Silt	$Y = 3.37 - 9.12(V5) + 6.49(V10) + 7.48(V15) - 5.27(V16) + .86(V20) - 24.20(V22)$	.99	.04
	Sand	$Y = 2.69 + 2.83(V8) + 2.43(V9) + 2.98(V11) - 2.26(V14) - .45(V20) + .52(V28)$	.97	.35

Microtrac predicted clay = 12.18 +.90(%7.8 -5.5 μm) + 1.65(%5.5 -3.9 μm) + .07(mean diameter, μm) -.24 (50th percentile, μm)

$r^2 = .63$

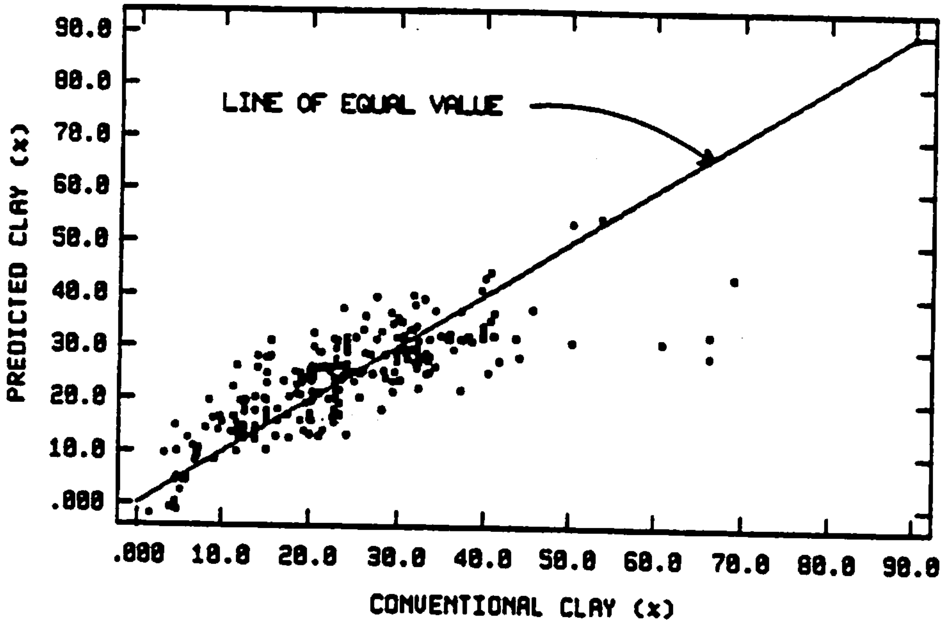

Figure 1. Plot of Microtrac predicted percent clay (from multiple regression analysis given above) with the conventionally determined percent clay.

Microtrac predicted silt = 12.04 -.46(176 -125 μm)+ .95(31 -22 μm) -17.84 (specific surface) + .67(% Microtrac silt)

$r^2 = .68$

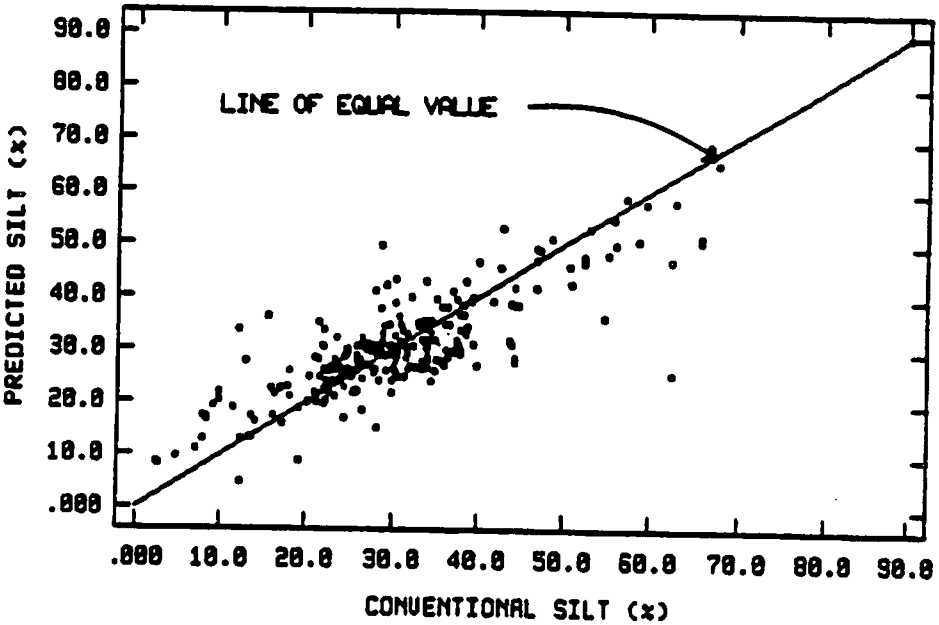

Figure 2. Plot of Microtrac predicted percent silt (from multiple regression analysis given above) with the conventionally determined percent silt.

Microtrac predicted sand =-20.71 +.76(%176 -125 µm) + 1.30(%3.9 -22 µm) + 1.11 (% Microtrac sand)

$r^2 = .82$

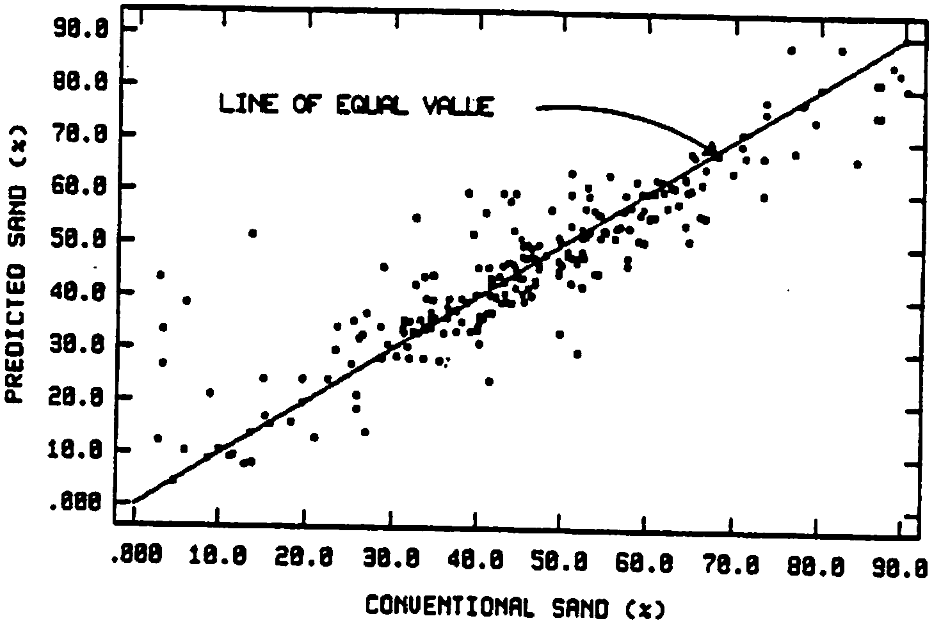

Figure 3. Plot of Microtrac predicted percent sand (from multiple regression analysis given above) with the conventionally determined percent sand.

Table 3. Correlation coefficients (r values) between Microtrac variables and the wilting point and available water-holding capacity of 91 Arizona soils.

	Wilting point		Plant available water	
	Uncorrected	Corrected	Uncorrected	Corrected
.176 - 2.0 mm		-.50		-.28
176 - 125 µm	-.59	-.48*	-.43	-.40*
125 - 88 µm	-.62	-.46	-.40	-.33
88 - 62 µm	-.51	-.33	-.33	-.23
62 - 44 µm	-.37	-.17	.01	.03
44 - 31 µm	-.24	-.02	-.02	.10
31 - 22 µm	-.03	.20	.27	.30
22 - 16 µm	.40	.46	.54	.52*
16 - 11 µm	.59	.65*	.46	.51
11 - 7.8 µm	.53	.64*	.32	.38*
7.8 - 5.5 µm	.52	.66*	.14	.30*
5.5 - 3.9 µm	.54	.65*	.19	.28*
3.9 - 2.8 µm	.49	.58	.16	.24
2.8 - 1.9 µm	.50	.60	.08	.18
Specific surface	.57	**	.19*	**
Mean diameter	-.65*	**	-.39	**
90th percentile	-.57	**	-.34	**
50th percentile	-.65*	**	-.44*	**
10th percentile	-.39	**	-.30	**

*Variables selected for the step-wise multiple linear regression equation.

**These variables were not corrected for the 176 - 2000 µm fraction.

the best correlations, having r values of .60 or better. The multiple regression relationship is:

$$\%\ \text{Water at the Wilting Point} = -13.88 - .46(\%176 - 125\ \mu\text{m}) + .60(\%16 - 11\ \mu\text{m}) + .41(\%11 - 7.8\ \mu\text{m}) + .62(\%7.8 - 5.5\ \mu\text{m}) + .83(\%5.5 - 3.9\ \mu\text{m}) + .55\ (\text{mean diameter}) - .30\ (\text{50th percentile}). \tag{2}$$

This relationship has an r value of .75, and a significance level of < 0.01% (very highly significant).

The correlation coefficients for plant available water, defined as the % water at .33 bar minus the % water at 15 bars of tension, are less than those for the wilting point alone. Only the 22-16 µm and 16 -11 µm size fractions have an r value greater than .50, and there is less difference between the uncorrected and corrected data. The multiple regression relationship is:

$$\%\ \text{Plant Available Water} = 17.21 + .10(\%\ 176 - 2000\ \mu\text{m}) + .39(\%22 - 16\ \mu\text{m}) + .36(\%11 - 7.8\ \mu\text{m}) - .31(\%7.8 - 5.5\ \mu\text{m}) + 1.03(\%5.5 - 3.9\ \mu\text{m}) - 19.89\ (\text{specific surface area}) - .14(\text{50th percentile}). \tag{3}$$

This relationship has an r value of .67 and a significance level of < 0.01%.

SUMMARY AND CONCLUSIONS

Microtrac analysis is very rapid, requiring less than 5 minutes per sample. The 13 particle-size ranges, plus the other data, provide a detailed particle-size distribution look at the soil. The predictive equations for each of the textural classes are quite different, and these should be used to better estimate the percentage of soil separates. Percent sand can be predicted the most accurately. However, corrected data (for the .176 - 2.0 mm fraction not analyzed by the Microtrac) should be used rather than the uncorrected data.

Perhaps the greatest future use of Microtrac data will be in predicting soil properties other than soil texture, like plant available water. The relationships presented in this paper show there is potential, but additional research and evaluation are needed. These equations are not intended for general usage, but rather may be useful criteria in judging the feasibility of using such an approach. The number of samples in certain texture classes is low, and it may be found that other stratifications of the data, such as by sample source area, may be more useful. The variability in the conventional analyses of % sand, % silt, % clay, plant available water and water content at wilting point needs to be studied. We believe there is a significant coefficient of variability in these laboratory measurements that has affected our results. It is expected that Microtrac models capable of analyzing particles of smaller size should produce somewhat higher correlations, particularly for predicted % clay.

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