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Quantitative Field Estimations of Stickiness and Plasticity for Predicting WEPP Model Parameters

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ABSTRACT

Precise and accurate pedon descriptions prepared by field soil scientists using standard techniques and defined terminology are essential to soil survey. The accuracy of field measurements are generally defined in terms of how the soil scientist's determinations agree with objective criteria, usually laboratory analyses, such as mechanical analysis for soil texture. Stickiness and plasticity are included as part of pedon descriptions, and the skill of 26 professional soil scientists to determine the stickiness and plasticity of 18 WEPP soils were evaluated. A numerical range of 0-1, 1-2, 2-3, and 3-4 were assigned to the four stickiness and plasticity classes, and soil scientist evaluated each soil using this criteria. A rating of 2.5 identifies that soil as being in the middle of the moderately sticky or moderately plastic class. The mean S.D. for the soil scientists estimations of each soil were .65 and .60, and they agreed on the correct class 58 and 61%, for stickiness and plasticity, respectively. For each soil scientist a regression correlating his/her estimates verses the mean of all soil scientists estimates were computed, and the r^2 were .75 and .84 for stickiness and plasticity, respectively. The regression slopes and intercepts were quite different, indicating a wide range of soil scientist skills. Correlation coefficients to relate the mean stickiness and plasticity for each soil to the Ke, Ki, Kr, and Tc soil erodibility WEPP parameters were -0.70 and 0.71, -0.64 and -0.58, -0.56 and -0.55, and 0.73 and 0.69 for stickiness and plasticity, respectively. We recommend that stickiness and plasticity be more quantitative rather than using the four classes. Models used to predict soil erodibility or make other interpretations could include these field measurements as additional parameters, utilizing the "expert opinion" of field soil scientists.

INTRODUCTION

Precise and accurate pedon descriptions prepared by field soil scientists using standard techniques and defined terminology are essential to the soil survey program (Soil Survey Division Staff, 1993a,b). The confidence limits placed on soil interpretations are directly related to the accuracy by which soil properties are estimated or measured. Accuracy of field measurements are generally defined in terms of the extent to which soil scientists' judgements agree with objective criteria, usually laboratory analyses.

The research community develops algorithms or models to predict the soil erodibility or the hydraulic conductivity of soils, and they require soil input parameters. The Water Erosion Prediction Project (WEPP) (Nearing et al., 1989, 1990 and Laflen et al., 1991) is an example of such a model, and the effective hydraulic conductivity (Ke), interill erodibility (Ki), rill erodibility (Kr), and critical hydraulic shear (Tc) are basic input parameters. These parameters are determined (predicted) from soil characteristics, usually measured in the laboratory, but estimates by field soil scientists of soil properties such as stickiness, plasticity, structure, and others could also be used.

These data are generally obtained from Natural Resources Conservation Service (NRCS) soil maps, and from soil interpretation tables that accompany these maps (Soil Survey Division Staff, 1993a,b). The NRCS has national guidelines to make soil interpretations; however local adjustments to these guidelines can be made to refine local predictions. These guides list a series of soil properties and site characteristics that impact a given soil use, and generally three or four category ratings (or more) are noted.

Recently much has been written about soil quality (Karlen et al., 1997; Sims et al., 1997; Wagenet and Hutson, 1997 and Bouma, 1997), which is defined in simplest terms as "the capacity (of soil) to function." (Often the term soil health is used in conjunction with soil quality.) The NRCS has stated that soil quality is the foundation of a productive nation in harmony with a quality environment. The National Soil Survey is responsible for providing the soils database and soil evaluations (soil interpretations and/or soil quality information) to the policy-decision makers in the USA. Any soil quality or soil health evaluation uses the soil survey, which is based on the measurement of soil properties. These basic data are required to make soil interpretations for different land uses, or predict the susceptibility to land degradation, such as erosion, salinization, compaction, etc.

Soil morphology characteristics determined by field soil scientists are very basic information used in soil survey. Foss et al. (1975), Post et al. (1986) and Levine et al. (1989) and others have evaluated soil scientists' and students' abilities to estimate soil texture. Post et al. (1993) and Cooper (1989) have studied individual's skills at estimating soil color. Levine et al. (1989) concluded that the average junior-senior or graduate student enrolled in a soil morphology class are capable of almost reaching the skill level in texture determinations of professional field soil

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scientists in three to four weeks of class time. Their success is greatly dependent upon the availability of many reference samples to practice on. As expected, the more conscientious, capable students do better than the less motivated ones. Soil colors are more precisely/accurately measured than soil texture, because it is a matching process, whereas the estimation of sand, silt, and clay and the determination of textural classes are based on "standards" that correlates the feel of the soil sample with a "reference" recorded in the evaluators' brain. There are however, no studies that evaluated the skill of soil scientists to determine stickiness and plasticity.

We believe more precise estimations of stickiness and plasticity should be made to compliment other soil morphology data collected when preparing a pedon description. The Unified Engineering System for classifying soil materials (Soil Survey Division Staff, 1993a, b) uses particle size analyses and liquid and plastic limit soil moisture data, which is related to a soils stickiness and plasticity. These measurements are made by manipulating the soil with different soil moisture contents, somewhat like the procedure used to determine stickiness and plasticity.

The objectives of this research are to

1. Demonstrate that soil stickiness and plasticity as evaluated by soil scientists in the field should be more quantitative.
2. Evaluate soil scientists' skills in determining stickiness and plasticity.
3. Investigate if stickiness and plasticity soil morphology field data can be used with laboratory analyses in the WEPP model to predict soil erodibility parameters.

METHODOLOGY

The methodology for determining the stickiness and plasticity of soils is described in the Soil Survey Manual (Soil Survey Staff, 1993a). Stickiness refers to the capacity of a soil to adhere to other objects, and plasticity is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. There are four classes for each, and the description and terminology for placing them into one of the classes is presented in Table 1. All determinations are made on < 2 mm soil material.

In this study we asked soil scientists to make these estimates quantitatively. We assigned a numerical range to each class, namely: 0 to 1—non-sticky or non-plastic; 1 to 2—slightly sticky or slightly plastic; 2 to 3—moderately sticky or moderately plastic, and 3 to 4—very sticky or very plastic. The soil scientist were first asked to place each soil into one of the four classes, and then record a number, indicating where it most likely fit in the 0-1, 1-2, 2-3, and 3-4 ranges. For example, if a soil was determined to be moderately plastic, and it is identified as being in the middle of that class, they recorded a 2.5. If the sample trended toward the slightly plastic class, they recorded a 2.2 or 2.3.

Eighteen Ap horizons from the WEPP cropland soil erodibility study sites were evaluated (Laflen et al., 1991, and the WEPP user summary report edited by Flanagan and Livingston, 1995). Twenty-six soil scientists completed the project. Eleven in March 1999 when attending the NRCS Soils Institute at North Carolina State University, and 5 from Arizona and 10 from Ohio in 1995. Other soil science institute scientists completed the evaluations; however their estimations were less quantitative, choosing only the probable correct class, so they are not included.

The mean stickiness and plasticity of the 26 observations per sample was computed, and this determines the correct class placement for that soil. Regression analyses related these means to the individual evaluation for each soil scientist for each sample. The number of times each soil scientist placed the soil in the correct class was tallied, and reported as % agreement. Regression relations between stickiness and plasticity and the Ke, Ki, Kr, and Tc parameter for the 18 WEPP soils were also evaluated. The units and numerical results for each of these parameters are listed in the National Soil Erosion Laboratory Report No. 11 (1995) edited by Flanagan and Livingston, or in the paper by Laflan et al. (1991).

RESULTS AND DISCUSSION

Estimations of Stickiness and Plasticity

Table 2 lists the mean stickiness and plasticity values for the 18 WEPP soils. The mean, S. D. and % of soil scientists who placed the sample in the correct class is also listed. The mean S. D. for stickiness and plasticity were 0.65 and 0.60, respectively. This is equal to a C. V. of 44% and 32%; the % soil scientists agreement on the correct four classes were 58 and 61% for stickiness and plasticity, respectively.

A simple linear regression plotting the individual soil scientist estimation on the Y-axis and the mean stickiness or plasticity on the X-axis was calculated. The coefficient of determination (r^2) ranged from 0.28 to 0.88 with a mean r^2 of 0.75 for stickiness (Table 3). The r^2 for plasticity ranged from 0.53 to 0.94 with a mean r^2 of 0.84. The slopes and intercepts were quite different for the 26 soil scientists, with the intercepts ranging from -0.54 to 1.95 for stickiness and -0.63 to 0.88 for plasticity. The slopes ranged from -0.45 to 1.46 for stickiness and 0.54 to 1.29 for plasticity. Since the mean of all estimations for each soil was reported as the correct answer, the mean slope for all regression equations would be 1.0, and the intercept zero. These results show soil scientists estimations are quite variable, and estimations of stickiness are somewhat less precise/accurate than for plasticity.

Table 3 summarizes soil scientist's precision in estimating stickiness and plasticity as measured by the r^2 value, and they are slightly more precise (.75 and .84) when compared to % clay and % sand field estimations (.74 and .77 Post et al., 1986). It is also similar to color estimating of hue, value and chroma, which is .74, .79, and .55, respectively (Post et al., 1993). The percentage of agreement with the classes of each soil parameter, namely the four stickiness and plasticity classes, 12 and 21 textural classes, and the same color chip, is better than the textural classes, but not as good as the color evaluations. There is a disadvantage of placing a soil into a specific class, because the data is really a continuum, not discrete categories.

Table 1. Description of criteria for placing soils into the four stickiness and plasticity classes.

Classes	Test Description
Non-sticky (NS)	After release of pressure, practically no soil material adheres to thumb or forefinger.
Slightly sticky (SS)	After release of pressure, soil material adheres perceptibility to both digits. As the digits are separated, the material tends to come off one or the other rather cleanly. The material does not stretch appreciably on separation of the digits.
Moderately sticky (MS)	After release of pressure, soil material adheres to both digits and tends to stretch slightly rather than pull completely free from either digit.
Very sticky (VS)	After release of pressure, soil material adheres so strongly to both digits that it stretches decidedly when the digits are separated. Soil material remains on both digits.
Non-plastic (NP)	A roll 4 cm long and 6 mm thick that supports its own weight held on end cannot be formed.
Slightly plastic (SP)	A roll 4 cm long and 6 mm thick can be formed and, if held on end, will support its own weight. A roll 4 mm thick will not support its own weight.
Moderately plastic (MP)	A roll 4 cm long and 4 mm thick can be formed and will support its own weight, but a roll 2 mm thick will not support its own weight.
Very plastic (VP)	A roll 4 cm long and 2 mm thick can be formed and will support its own weight.

Table 2. Stickiness and plasticity characteristics of the WEPP soils and the standard deviation (S.D.) and percent agreement for each soil.

Soil Series and State Location	Soil Texture	Stickiness				Plasticity			
		Clas s	Mean	S. D.	Agreement (%)	Class	Mean	S.D.	Agreement (%)
Amarillo, TX	LFS	NS*	0.38	0.38	88	NP*	0.27	0.22	100
Barnes, MN	L	SS	1.79	0.60	65	MP	2.42	0.78	38
Bonifay, GA	S	NS	0.27	0.48	92	NP	0.22	0.21	100
Caribou, ME	L	SS	1.32	0.52	62	SP	1.33	0.57	62
Gaston, NC	C-CL	MS	2.81	0.73	46	VP	3.37	0.52	77
Hersh, NE	FSL	NS	0.32	0.33	92	NP	0.33	0.25	100
Hiawasee, GA	SL	SS	1.25	0.87	35	SP	1.02	0.84	27
Lewisberg, IN	CL	MS	2.19	0.80	42	MP	2.92	0.68	35
Loring, MS	SiL	SS	1.86	0.88	54	MP	2.43	0.88	38
Mexico, MO	SiL	SS	1.69	0.64	50	MP	2.54	0.81	35
Miami, IN	SiL	SS	1.93	0.79	46	MP	2.58	0.85	27
Miamian, OH	L-CL	MS	2.30	0.92	46	VP	3.04	0.71	58
Nansene, WA	SiL	NS	0.91	0.55	62	SP	1.31	0.75	50
Pierre, SD	SiC-C	MS	2.73	0.80	31	VP	3.38	0.68	81
Portneuf, ID	SiL	SS	1.06	0.70	46	SP	1.41	0.62	54
Sharpsburg, NE	SiC	MS	2.63	0.76	38	VP	3.33	0.55	77
Sverdrup, MN	SL	NS	0.50	0.51	88	NP	0.43	0.30	92
Woodward, OK	L	NS	0.83	0.44	65	SP	1.12	0.59	54
Mean - All soils			1.49	0.65	58	SP	1.86	0.60	61

*Abbreviations defined in Table 1.

Table 3. Summary of soil scientists's precision in determining soil morphologic properties.

Soil Property	r^2 values		% Agreement
	Range	Mean	
Stickiness	.28-.88	.75	58 (4 Stickiness Classes)
Plasticity	.53-.94	.84	61 (4 Plasticity Classes)
Clay†	.24-.90	.74	36 (21 Textural Classes)
Sand†	.36-.92	.77	46 (12 Textural Classes)
Silt†	.24-.85	.61	
Hue‡		.74	71 (Same hue color chip)
Value‡		.79	72 (Same value color chip)
Chroma‡		.55	70 (Same chroma color chip)
Same Color Chip‡			52 (Same chip)

Table 4. Simulator measured effective hydraulic conductivity (Ke), rill erodibility (Kr), interill erodibility (Ki) and critical hydraulic shear (Tc) for the 18 WEPP cropland soils.

Soil I.D.	Ke	Kr	Ki	Tc
	(cm/hr)	(sec/m)	(kg/sec/m4)	(Pascals)
Amarillo, TX	1.50	0.0453	9261962	1.66
Barnes, MN	1.91	0.0063	4696644	3.96
Bonifay, GA	3.48	0.0179	5470062	1.02
Caribou, ME	0.81	0.0045	2634362	4.25
Gaston, NC	0.36	0.0049	3310538	4.37
Hersh, NE	1.58	0.0112	8412926	1.70
Hiawasee, GA	1.36	0.0103	3145089	2.33
Lewisburg, IN	0.37	0.0059	3978307	3.41
Loring, MS	0.34	0.0073	4595726	4.47
Mexico, MO	0.62	0.0036	5855134	0.69
Miami, IN	0.09	0.0095	3607881	3.32
Miamian, OH	0.44	0.0096	3242856	5.45
Nansene, WA	0.53	0.0307	6978966	3.05
Pierre, SD	0.24	0.0117	4475042	4.80
Portneuf, ID	0.79	0.0106	3596739	3.11
Sharpsburg, NE	0.73	0.0053	3409795	3.18
Sverdrup, MN	2.03	0.0100	6611372	1.37
Woodward, OK	1.20	0.0250	11156412	1.31

Table 5. Correlation coefficients (r values) relating soil morphologic properties to erodibility parameters.

Erodibility Parameters	Stickiness	Plasticity	% Clay	% Sand	% O.M.	CEC
Ke	-0.70**	-0.71**	-0.64**	0.82**	-0.36	-0.48*
Ki	-0.64**	-0.58*	-0.46	0.42	-0.46	-0.26
Kr	-0.56*	-0.55*	-0.45	0.40	-0.51*	-0.32
Tc	0.73**	0.69**	0.55*	-0.50*	0.54*	0.40

r > 0.47 and 0.59 significance at the 5% and 1% levels.

Relationship of Stickiness and Plasticity to Soil Erodibility Parameters

Table 4 lists WEPP rainfall simulator measured effectivehydraulic conductivity (Ke), rill erodibility (Kr), interill erodibility (Ki) and critical hydraulic shear (Tc) values for the 18 WEPP cropland soils we studied. If stickiness and plasticity estimations were more quantitative, they could be included in algorithms used to predict these parameters. The baseline soil erodibility parameter estimations are currently estimated using equations presented in the WEPP User Summary (Flanagan and Livingston, 1995), and only the textural characteristics (% clay and % sand, total and very fine sand), % organic matter, and cation exchange capacity soil properties are included in these equations. Elliot et al., 1989 and 1990 also evaluated the relationships between the soil erodibility parameters and laboratory measured soil properties, and they also considered the classification, mineralogy, climate and topography of the WEPP soils; however these results were inconclusive.

Table 5 presents the correlation coefficients for the mean stickiness and plasticity of each soil, and % clay, % sand, % organic matter and cation exchange capacity, correlating each to Ke, Ki, Kr, and Tc. For the Ke parameter only % sand has a greater r-value than the mean stickiness and plasticity reported in Table 2 for each soil. For Ki, Kr, and Tc all r-values correlating stickiness and plasticity are higher than % clay, % sand, % organic matter and cation exchange capacity. Figures 1 and 2 present the scattergrams relating Ke, Ki, Kr and Tc to stickiness and plasticity. We assumed all relationships were linear; however there is a tendency to be somewhat curvilinear in some cases.

To further evaluate this a step-wise multiple linear regression was computed. In addition to stickiness and plasticity, clay, sand, organic matter, and the cation exchange capacity of the soils were included. The latter four parameters are commonly included in equations presented in the WEPP User Summary (Flanagan and Livingston, 1995).

$$Ke = -0.153 - 0.143(Stick) + 0.412(Plast) - 0.047(\%Clay) + 0.028(\%Sand) - 0.115(O.M.) + 0.051(CEC), \quad R^2 = 0.71 \tag{1}$$

$$Ki = 7{,}796{,}146 - 1.1E + 07(Stick) + 4{,}814{,}903(Plast) + 267{,}800(\%Clay) + 11{,}991(\%Sand) + 279{,}862(O.M.) - 71{,}835(CEC), \quad R^2 = 0.67 \tag{2}$$

$$Kr = 0.025 - 0.002(Stick) - 0.001(Plast) - 0.0002(\%Clay) + 1.539\ E\text{-}05(\%Sand) - 0.005(0.0005(CEC), \quad R^2 = 0.42 \tag{3}$$

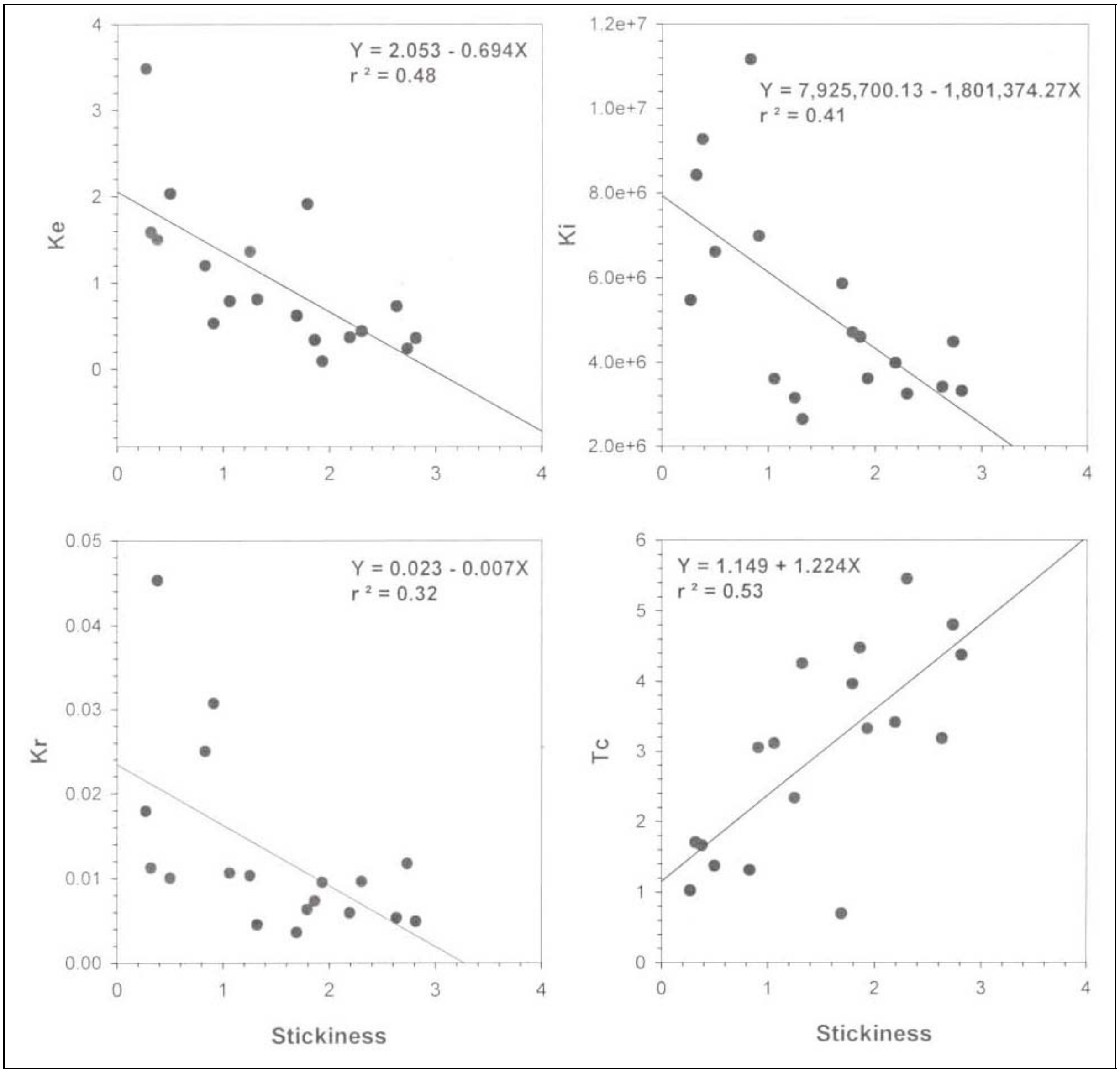

Figure 1. Regression relationships between soil stickiness and the Ke, Ki, Kr, and Tc for the 18 WEPP soils.

$$\text{Tc} = 0.607 + 5.593(\text{Stick}) - 1.787(\text{Plast}) - 0.165(\%\text{Clay}) + 0.001(\%\text{Sand}) - 0.186(\text{O.M.}) + 0.070(\text{CEC}), \quad R^2 = 0.69 \tag{4}$$

DISCUSSION AND CONCLUSIONS

A more quantitative method for making stickiness and plasticity evaluations has been presented in this paper, and the skill of soil scientists to estimate these parameters were measured. The stickiness and plasticity field evaluations routinely included as part of pedon descriptions should be more quantitative, because the four classes currently used are too general. The assignment of the 0-1, 1-2, 2-3, and 3-4 to the four classes, and then estimating to the nearest tenth presented in this paper, could be used. Soil scientists are not trained to make these refined estimations, and their skills should be tested and evaluated. This could be accomplished by doing a self-evaluation on test soils of known stickiness and plasticity characteristics. We believe the test description for the four classes presented in the Soil Survey Manual (Soil Survey Staff, 1993) are adequate; however a refinement of these estimations are needed to make this data more quantitative. There is an advantage in using stickiness and plasticity data rather than soil texture, because there are no treatments of the soil prior to analysis. In the laboratory mechanical analysis determination of soil texture procedure, the organic matter and soluble salts are removed (Soil Survey Staff, 1996), which is different than the condition of the soil as found in the field.

Soil characterization information determined in the laboratory for selected soil pedon properties are the basic measurements used to develop algorithms for predicting the “K” factors. These are objective measurements; however what is considered “less than objective” field

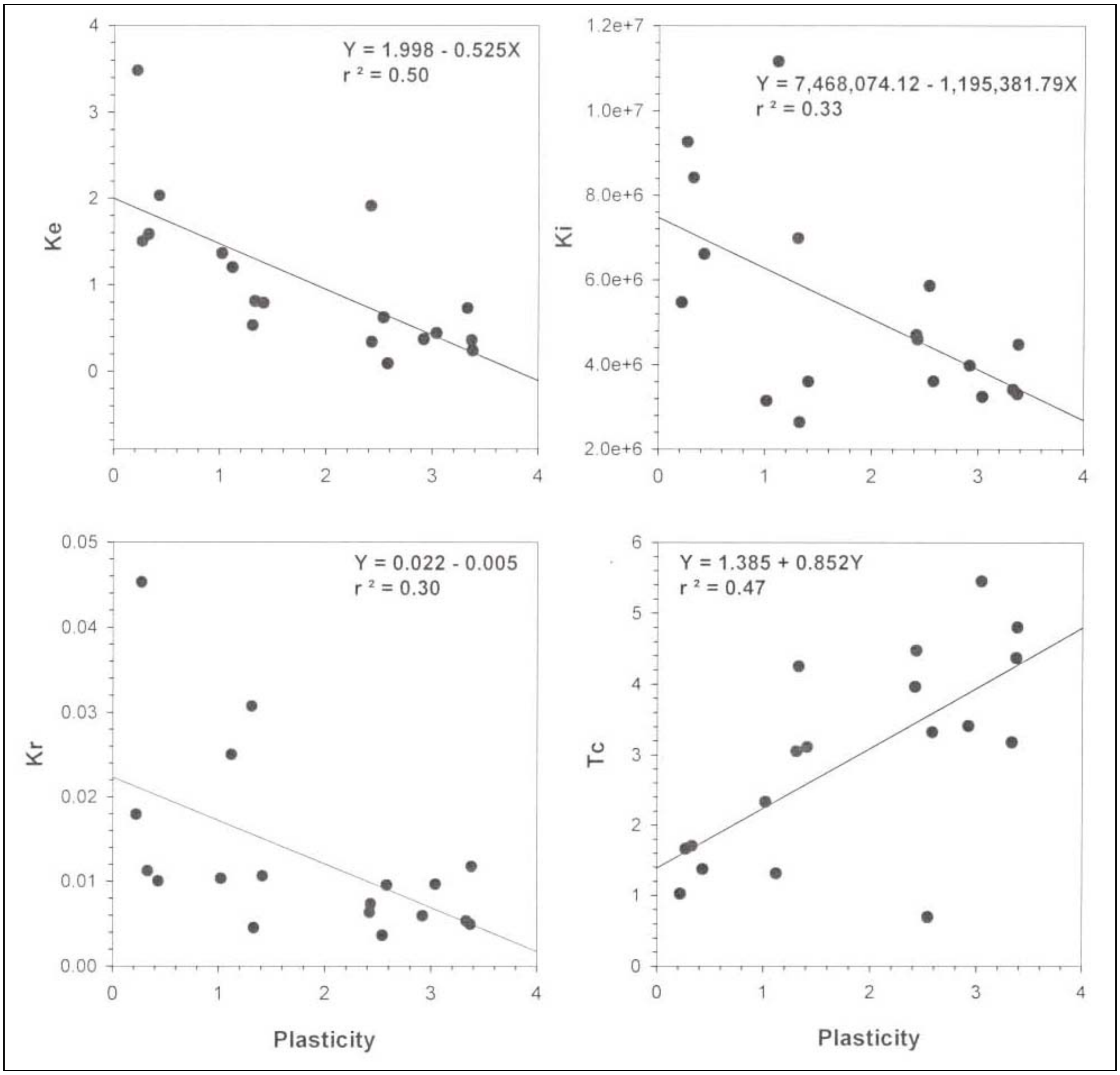

Figure 2. Regression relationships between soil plasticity and the Ke, Ki, Kr and Tc for the 18 WEPP soils.

morphology data is generally not considered. The incorporation of "collective soil scientists' wisdom or expert opinion," that is not available from laboratory analyses are also important, and could be used to improve algorithms that predict these input parameters. The development of natural resource management systems must often rely on the use of expert opinions or professional judgment, because research results do not exist for solving the problem. Lawrence (1996) states the role of the expert is to enlighten the planning process by providing knowledge directly to problem solving situations through group interaction. The USDA-ARS has developed a computer-based multi-objective decision support system (Yakowitz et al., 1992a, b) that has the capability of accepting data sources from simulation models and measured data, as well as expert opinion. This research attempts to better quantify stickiness and plasticity data by utilizing the collective wisdom of field soil scientist (expert opinions) to refine models that currently only use laboratory analyses.

The correlation coefficients relating Ke, Ki, Kr, and Tc to soil scientists mean estimation of stickiness and plasticity for the 18 WEPP cropland soils were all significant relationships (the r value ranged from -0.55 to 0.73). The laboratory measurements for % clay, % sand, % silt, % O.M. and CEC related to these same erodibility parameters ranged from -0.26 to 0.82. Overall, the stickiness and plasticity correlation coefficients were more strongly correlated suggesting these could be used in algorithms to predict these parameters.

Assuming the relationships between the erodibility and morphologic soil properties are linear, the step-wise multiple linear regression (Eq. 1, 2, 3, and 4) gave good R^2 for Ke - 0.71, Ki - 0.67, and Tc = 0.69; however Kr was 0.42.. These regressions need further studies and all WEPP cropland soils should be included; however, we conclude that field soil morphologic "expert opinion" data should be used in models or algorithms to predict soil erodibility.

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