

the ranges in soil characteristics of the official soil series. Use of these series for naming and interpreting map units in second-order soil surveys portrays a degree of precision to users that we have not attained in most instances and can result in credibility problems for soil surveys. We conclude that attempts to make ranges in soil properties in map units correspond to ranges defined for official soil series are pointless because distributions of soil properties do not lend themselves to hierarchical arrangement (Webster, 1968) and small map scales prevent their being mapped. The concepts of similar and dissimilar soils and inclusions are helpful to soil surveyors and correlators, but are not understood by many users since the tabulated interpretations of use and management for the map units in published soil survey reports are reported by the soil series.

It would be better to map whatever is mappable at a given scale and adjust series concepts to correspond to map units or to record the proportion and pattern of occurrence of soils in the map unit by any convenient method as suggested by Beckett and Webster (1971). Fordham and Green (1980) provide an example of listing several principal soil series within their map units as evidence of internal variability. This approach is feasible since second-order soil surveys are not site specific. There are other alternatives that should be explored by research that may provide more useful soils information than research to decide the placement of a typical soil profile or "pedon" in *Soil Taxonomy* selected on the basis of field criteria and

allowing the range in soil properties specified for that taxon to determine interpretations for the map unit.

REFERENCES

- Allmaras, R.R. 1965. Bias. In C.A. Black et al. (ed.) *Methods of soil analysis*, Part 1. *Agronomy* 9:24-42.
- Barr, A.J., J.H. Goodnight, J.P. Sall, W.H. Blair, and D.M. Chilko. 1979. *SAS user's guide*. 1979 ed. SAS Inst. Inc., Raleigh, NC.
- Beckett, P.H.T., and R. Webster. 1971. Soil variability: a review. *Soils Fert.* 34:1-15.
- Butts, C. 1940. *Geology of the Appalachian Valley in Virginia*, Part I — Geologic text and illustrations. Va. Geol. Surv. Bull. 52.
- Edmonds, W.J. 1983. Grouping of soil profiles in three mapping units by conventional and numerical classifications. Ph. D. thesis. Virginia Polytechnic Inst. and State Univ., Blacksburg. (Diss. Abstr. 83-16872).
- Edmonds, W.J., S.S. Iyengar, L.W. Zelazny, M. Lentner, and C.D. Peacock. 1982. Variability in family differentia of soils in a second-order soil survey mapping unit. *Soil Sci. Soc. Am. J.* 46:88-93.
- Fordham, S.J., and R.D. Green. 1980. *Soils of Kent*. Soil Survey Bull. no. 9. Rothamsted Exp. Station, Harpenden, UK.
- Schelling, J., 1970. Soil genesis, soil classification and soil survey. *Geoderma* 4:165-193.
- Soil Conservation Service, USDA. 1983. *National soils handbook*. (430-VI-NSH, July 1983). U. S. Government Printing Office, Washington, DC.
- Soil Conservation Service, USDA-SCS. 1984. *Soil survey manual*. (430-V-SSM, January 1984). U. S. Government Printing Office, Washington, DC.
- Soil Survey Staff. 1975. *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys*. USDA-SCS Agric. Handb. 436. U. S. Government Printing Office, Washington, DC.
- Sokal, R.R., and F.J. Rohlf. 1969. *Biometry*. W.H. Freeman and Co., San Francisco.
- Webster, R., 1968. Fundamental objections to the 7th Approximation. *J. Soil Sci.* 19:354-365.
- Webster, R., 1977. *Quantitative and numerical methods in soil classification and survey*. Clarendon Press, Oxford, UK.

Application of a Statistical Soil-Landscape Model to an Order III Wildland Soil Survey¹

H. F. SHOVIC AND C. MONTAGNE²

ABSTRACT

Data organization, analysis, and documentation have long been a concern in the soil survey process. Existing computer aided systems are often either not widely available, not "user friendly," or not very applicable to field mapping situations. These concerns are addressed using a simulation approach. A statistical model of the landscape and soils in the survey area is described. The data base used in the soil-landscape model consists of discrete sample points that are randomly distributed (for soil taxa only), mutually exclusive, and independent. The data are representative of other site characteristics. The concepts of statistical estimation, conditional probability, quantified prediction improvement, and selective sorting are applied to use the model in the mapping process. Applications include systematic development of soil-landscape relationships and legends; documented justification for decisions as to data adequacy, soil interpretations, map unit differentia, variability, and taxonomic descriptions; and increasing accuracy of soil correlation. Programs are standard and widely available.

Additional Index Words: computer applications, simulation, soil mapping.

¹ Contribution from the Gallatin Nat. Forest, U. S. Forest Service, USDA, Bozeman, MT. Received 5 Apr. 1984. Approved 19 Feb. 1985.

² Forest Soil Scientist, Gallatin Nat. Forest, Box 130, Bozeman, MT, and Assoc. Professor of Soil Science, Montana State Univ., Bozeman, MT, respectively.

Shovic, H.F., and C. Montagne. 1985. Application of a statistical soil-landscape model to an order III wildland soil survey. *Soil Sci. Soc. Am. J.* 49:961-968.

THE MOST IMPORTANT purposes of a soil survey are to show the geographic distribution of soils and other important landscape properties, and to interpret these for specified uses. In the Rocky Mountains, forest uses generally are more varied and less intensive than those on agricultural or urban land. Therefore, soil surveys are often at the Order III level, at scales ranging from 1:24 000 to 1:63 000 and at taxonomic levels above the soil series. Soil-landscape relationships are complex because of large variation in local climates, vegetation, parent materials, and topography. Landform, vegetation, or geologic characteristics are more often used for phase criteria than in detailed surveys. Finally, limited access reduces the efficiency of conventional mapping techniques. Not all map unit boundaries are verified by transecting or traversing. Remote sensing and widely spaced observations with some traversing are used to predict soil and landscape features and for delineation of most map units. The maximum use should be made of all data, since it is

of limited extent and must represent large areas of the soil and landscape.

Systems simulation is a collection of techniques used to represent complex reality with models. We manipulate and observe the models as they operate to help us learn about reality. They can be analytical (deterministic) or statistical, but are often numerical, complex, and computer based. In the past, the lack of easily accessible computing power has limited modeling efforts in field survey situations. However, computing power is now becoming available to field scientists and uses are increasing.

Computers are now widely used in the soil survey for manuscript preparation, statistical studies of individual soil properties or taxonomic limits, list processing, summaries of interpretations or other properties by taxonomic class, or soil pedon data bases (Soil Survey Staff, 1982). Various computer aided map processing systems have been developed (Giltrap, 1983b; Amidon, 1978; Nelson and Johnson, 1976; Ragg, 1977). Mathematical techniques of classification and mapping have been explored (Giltrap, 1983a, 1981; Webster, 1978). There are numerous data handling systems, e.g., Kosaki et al. (1980), Bie and Schelling (1977), or Haantjens, et al., (1975). Most of the above techniques, though, are either not widely available, not friendly enough for field scientist use, or are too cumbersome for day to day use. The purpose of this paper is to report on the application of computer oriented simulation techniques to the soil mapping process. A statistical model of the soil and landscape is proposed to serve as an interactive, field oriented aid in making maximum use of limited data.

METHODS

The Soil Survey of the Gallatin National Forest Area (SW Montana) was begun in 1975 and field work was completed in 1981 (Davis and Shovic, 1985). The area surveyed is about 600 000 ha, of which about 100 000 ha has road access. The proposed models were developed and tested concurrently with this survey. Precipitation ranges from 50 to 100 cm. Vegetation ranges from grassland through Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) forests, to alpine tundra. Elevations are from 1800 to over 3600 m. Landforms include steep stream break lands, rolling hills, glaciated lands, and broad, gently rolling plateaus. Geologic materials include igneous intrusions, folded limestones, sandstones, shales, crystalline basement rocks, and volcanic flows.

Soil properties vary widely in response to this variance in soil forming factors. Cryoborolls and Cryochrepts are most common where parent materials are weathered or eroded from rocks of acid composition. Cryoboralfs are associated with more basic rocks. Mode of deposition, age, and weathering regimes often control particle size class. Soils formed in glacial till are often very cobbly, while those formed in outwash are sandy. Soils formed in material weathered from limestone can be calcareous and medium textured, or non-calcareous and moderately fine textured depending on relative age of bedrock exposure. Soils under grassland vegetation generally have mollic epipedons. However, they can also have paleo-argillic horizons that may reflect previous cycles of forest vegetation.

The philosophy of the system involves developing a model that represents soils and their relationships to landscapes. This model of reality is viewed in different ways that are useful to the soil surveyor. The various "views" are gener-

ated by programs that manipulate the data in different ways to represent "viewpoints". Each viewpoint depicts reality somewhat differently and is biased toward the objectives of the surveyor.

The model is represented by a data base which represents estimates of the actual occurrence of soils on the landscape. The data base contains a serial listing of summaries of soils, vegetation, parent material, and landform data for sample sites. It is updated as data are gathered during the survey, to advance the model toward a more accurate estimate of "reality".

The soil and site data represent discrete areas or points on the landscape. They are accurately located on maps or on air photos and fit into existing systems for describing and classifying soils, geology, landform, and vegetation. The data are entered serially, each record representing a sample site. There are no restrictions on the types of data collected except that it be tied to a specific sample site. Continuous data is classed, either during data input or during computer runs, since all statistics are based on discrete or "frequency" data. The need to assign all site data to discrete units encourages the scientist to develop significant and important limits for each class to enable the development of discrete map units and interpretations. *Soil Taxonomy* (Soil Survey Staff, 1975) is used for soil classification at the family level. The series level is excluded because of the difficulty of interpreting quantitative limits from series descriptions, the large number of potential classifications, and the lack of established series in the survey area. The data base is designed to be a random sample of soils or soil characteristics. This means there is no concerted effort during sampling to look for a certain soil. Theoretically the only controls on the kinds of soils found on a site are the site features, which predict soil features to a greater or lesser extent depending on their relationships to soil forming factors. Therefore, the site features that control site selection must be representative of the area as a whole. They are not clustered on or biased towards any criterion except on that of the feature's areal extent.

The sample base must be large enough to provide an adequate random sample of the characteristics of interest. The achievable precision of predictions is directly related to the data base size, the variability of soils, and the survey objectives. There were 1594 total sites in the Gallatin data base at the end of the survey process (380 ha per site or 2.6 map unit delineations per observation). Data are entered as the survey progresses and are analyzed during the survey process. Therefore, later predictions are more detailed and/or more reliable than earlier ones.

There are four analytical concepts used in dealing with the model, three statistical and one organizational. The first concept is that the relative frequencies of soil feature occurrence are unbiased estimators of their probabilities. This is valid because the sample sites are randomly distributed, discrete, mutually exclusive, and are assumed to be independent. (Steel and Torrie, 1960), (Miller and Freund, 1965, p. 39, 186-187).

The second is the concept of conditional probability (Miller and Freund, 1965, p. 25-28). When the symbol $P(A)$ is used for the probability of A, the symbol implies "given some sample space S". For example, if only volcanic terrain is sampled then the probability of finding a given soil type may be different than if the entire survey area is the sample space. This equates to the conditional probability of a soil type given the "volcanic rock" subset of all potential rock types. This is calculated as

$$P(A|B) = P(A \text{ and } B)/P(B) \quad [1]$$

where $P(A|B)$ is the probability of A given B, $P(A \text{ and } B)$ is the probability of A and B, and $P(B)$ is the probability of B alone. $P(B)$ cannot be calculated directly using the data base described above because site features such as rock type are

not sampled randomly. $P(A|B)$ is therefore estimated using a random sample of soils within a subset of the entire sample space, i.e. a given rock type. Cross tabulations of sample site data are used to estimate these probabilities.

The third concept is that of prediction improvement. One of the most important reasons for mapping landscape features is to predict the soils beneath them. Any differentiating feature selected for this reason should improve the prediction of soils. To express this numerically we propose a prediction improvement factor (PIF). It is calculated by comparing the probability of a soil's occurrence when a site feature is used to select the sample site, to the probability of the soil's occurrence without selection of any site feature. It is calculated as:

$$\text{PIF} = P(A|B)/P(A) \text{ if } P(A|B) \geq P(A) \quad [2]$$

or

$$\text{PIF} = -P(A)/P(A|B) \text{ if } P(A|B) < P(A) \quad [3]$$

where PIF = prediction improvement factor, and $P(A)$ = probability of the occurrence of "A" alone.

The larger the absolute value of the PIF is, the larger the improvement in predictivity is for the soil feature A using that site feature B. If PIF is near 1.0, there is little improvement in prediction over not using the site feature or "predictor variable". If the PIF is positive and large, the prediction of the soil type is improved and the soil is more likely to occur than if no predictors are used. If the PIF is negative but large, prediction is still improved, but the soil type or predicted variable is less likely to occur where that site feature is present than if no predictors are used. Since all PIFs are calculated from random estimates of actual probabilities sample size is important. Accurate interpretations are unlikely with small samples because of random variation. Also, small differences in frequencies may make a disproportionately large difference in the PIF. Of course, if there are too few observations at a given level of generalization, the level can be raised until sufficient.

The fourth concept deals with nonnumerical analysis of information in the data base. The mapping process is by nature probabilistic and the criteria for development of mapping differentia are often complex. Also, the occurrence of individual soils is controlled by many factors that vary in importance in different areas. No individual predictor is sufficient for all soil features. Therefore, the above analytical concepts cannot be used alone without judgement and observation of other data. If data are also organized and displayed in a nonnumerical manner, the soil surveyor can make use of his capacity for synthesis. Soil and site information in the data base is selectively sorted at different levels and displayed in an easily scanned format to make a synthetic analysis and to verify that the numerical analysis is realistic.

A UNIVAC series 1100 mainframe computer was used with a data base management system (SPSS or Statistical Package for the Social Sciences) (Nie, et al., 1975; Hull and Nie, 1979). This set of programs allows great flexibility in output format and data transformations. It has standardized control card formats for all programs, which simplifies data manipulation. Finally, it uses natural language control statements, and variable labeling is extensive and easily understood. Programs used are noted in the figures.

DISCUSSION

The landscape model represents the soil and landscape of the survey area. The surveyors' objective is to differentiate this reality into meaningful areas on the land (map units). To do this, the model is viewed from different viewpoints in the context of the soil survey process. Relevant steps in this process are:

Table 1. Frequencies of soil site data: great group (modified from output of FREQUENCIES program).

Great group	Absolute frequency	Frequency (%)
Cryoboralfs	507	31.8
Eutroboralfs	44	2.8
Glossoboralfs	9	0.6
Cryorthents	14	0.9
Cryochrepts	295	18.5
Cryumbrepts	27	1.6
Ustochrepts	44	2.8
Argiborolls	133	8.3
Cryoborolls	369	23.1
Haploborolls	76	4.8
Other	76	4.8
Total	1594	100.0

1. Compilation of existing data.
2. Preliminary field studies and initial stratifications.
3. Development of initial mapping legend.
4. Production field mapping including further sampling of soils.
5. Interim correlation and remapping.
6. Iteration of steps 4 and 5 until field mapping is finished, mapping accuracy is adequate, and mapping legend is complete.
7. Final correlation and writeup.

In step 2 above, data are collected for sample sites representing groups of apparent soil forming factors. For the Gallatin Forest, data was entered in 80 column records. Codes were used for geology, vegetation groups, and landforms.

In Steps 2 and 3, soil-landscape relationships are developed. Three analytical tools are used. First, frequency tables are generated that show estimates of the relative extent and importance of soils in the survey area, i.e. Great Groups (Table 1). The most extensive great groups that occur in the survey area are Cryoboralfs, Cryochrepts, and Cryoborolls. If these all differ in management implications, they are likely to be the ones that should be analyzed in more depth. Other tables are used to assure adequate representation of different site features.

Second, conditional probabilities and prediction improvement factors (PIFs) are evaluated (Table 2). Since all soil order occurrences are based on a random sample, the probability of any order's occurrence is given by the right hand P column, i.e. 35% for Alfisols. The conditional probabilities of a soil order, given a specific geologic group is known, are in the CP rows. For example, the probability of finding Alfisols, given the geology group crystalline rock is 15%. The PIF for Alfisols using crystalline rock as a predictor is then $-35/15$ or -2.3 . This means that it is 2.3 times less likely to find Alfisols in crystalline rock than if no rock type is known. Similarly, Inceptisols are twice as likely to occur in crystalline rock. The rock type is a good predictor for these two soil orders, but is not for Molisols (PIF = -1.1).

Since all PIFs are calculated from estimators of actual probabilities, sample size is important. Experience indicates accurate interpretations are unlikely below $n = 10$ for predicted variable classes and below 50 for predictor variable classes. In Table 2, the classes Histosols, and Obsidian sand are disregarded. Also, since zero cell values may lead to undefined PIFs they

Table 2. Cross-tabulations and prediction improvement factors (PIF) of soil orders with geology groupings (modified from output of CROSSTABS program).

Soil order	Geology groups									Total P
	Crystalline rock	Rhyolite	Other volcanic rock	Shale	Shale: volcanic	Limestone	Sand-stone: soft	Sand-stone: hard	Obsidian sand	
Alfisol										
Count	61	35	158	40	103	48	74	43	0	562
CP†	15%	49%	45%	49%	43%	29%	43%	36%	0%	35%‡
PIF	-2.3	1.4	1.3	1.4	1.2	-1.2	1.2	1.0	†	
Entisol										
Count	10	1	2	4	0 (1)	3	3	4	0	27
CP	3%	1%	1%	5%	0% (0.4%)	2%	2%	3%	0%	2%
PIF	1.5	-2.0	-2.0	2.5	-4.8	1.0	1.0	1.5	†	
Histosol										
Count	1	0	0	0	0	0	0	0	0	1
CP	0.3%	0%	0%	0%	0%	0%	0%	0%	0%	0.3%
PIF	†	†	†	†	†	†	†	†	†	
Inceptisol										
Count	179	30	44	5	11	34	42	27	1	373
CP	45%	42%	13%	6%	5%	20%	24%	22%	100%	23%
PIF	2.0	1.8	-1.8	-3.8	-4.6	-1.2	1.0	1.0	†	
Mollisol										
Count	144	5	141	32	125	83	54	47	0	631
CP	36%	8%	40%	40%	52%	49%	31%	39%	0%	39.7%
PIF	-1.1	-5.0	1.0	1.0	1.3	1.2	-1.3	1.0	†	
Column total	395	71	345	81	239	168	173	121	1	1594
Average PIF	1.7	2.6	1.5	2.2	3.0	1.2	1.1	1.1		

† PIF not calculated; sample size inadequate.

‡ "Conditional" probability of occurrence of soil order given site in specified rock type (CP).

§ Probability of occurrence of soil order, given no other information (P).

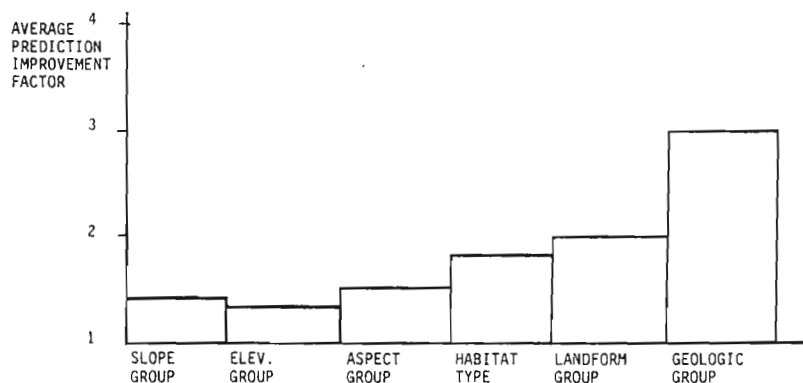


Fig. 1. Average prediction improvement factors for various predictor groups for soil particle size class.

are changed to "1s" for calculation, i.e. for the Entisol — shale-volcanic cell, the value used for the PIF calculations is 1/239, not 0/239.

PIFs are averaged to give an average PIF for the predictors (Table 2). Note that Rhyolite and Volcanic Shale are good predictors of soil orders (2.6 and 3.0 respectively). PIFs are also averaged for predicted variable classes to justify the use of various predictor groups (Fig. 1). Note that geologic group is the best predictor of particle size class. This analysis helps in the selection of certain features as mapping criteria. Interactions between predictors are not evaluated in this level of analysis, but probably are important in multiple factor prediction.

The third tool is selective sorting by tentative mapping criteria. Any sample site data categories can be used for sort keys. The sorts are evaluated by inspection for their quality in predicting soils. Figure 2 depicts part of a sort by landform for sample sites in the geologic group Rhyolite. Note that Cryochrepts are a small part of the soils formed in glacial deposits (glacial depos) but they make up a large part of the soils

on ridgetops (frost churn). Cryoboralfs make up a much larger part of the glacier derived soils. Also, the AW/VASC habitat type dominates the ridgetops while AF habitat types occur on glacial deposits. These sorts suggest relationships that can then be tested and applied in mapping to predict soils, in this case Cryochrepts vs. Cryoboralfs. Also, meaningful and consistent phases can be developed, in this case, AW/VASC (noncommercial forest) vs. AF types which are usually commercial forestland.

Sample site data are added to the landscape data base and the appropriate programs are run against it until the surveyor is satisfied relationships are adequately defined. In step 3, the mapping legend is developed using map unit differentia and soil taxa that are important to soil prediction and interpretations. Tools such as Table 1 and 2, and Fig. 1 and 2 are used to help make these decisions. Laboratory data are also used. In this survey area 77 sample sites were classified in the Unified system (Sowers and Sowers, 1970). Figure 3 depicts some relationships of soil features to this engineering data. For example, the loamy skeletal

GEOLOGIC GROUP	LANDFORM	PHOTO IDEN	MTN RANGE	TRNSCT OR MAP	TYPE OF STOP	CLASSIFICATION			SUR HOR	SEC HOR	ELE VA	SLP TION	ASP	UT	HG	HABITAT TYPE		
RHYOLITE	FROST CHURN	62-155-M6	H8GN	H95	R	TYPIC	CRY	OCHR	EFTL-SK	OCH	CAM	7200	25	E	1	Q	AFVAGL	
		62-153-M4	H8GN	H88	R	TYPIC	CRY	OCHR	EPTF-L	OCH	CAM	7700	45	N	1	Q	AFVASC	
		62-155-2	H8GN	174	D	MOLLIC	CRY	BOR	ALFL-SK	OCH	ARG	6600	22	W	1	U	AWVASC	
		62-162-A	HILGD	H52	R	TYPIC	CRY	BOR	ALFL-SK	OCH	ARG	8600	1	FL	1	U	AWVASC	
		63-139-4	HILGD	83	D	LITHIC	CRY	OCHR	EFTL-SK	OCH	CAM	8700	5	SE	1	U	AWVASC	
		NO OF ST		5														
		N OF ELV																
		N OF SLP																
		ELV MN		7760														
		SLP MN		20														
MIN		6600																
MAX		8700																
GLACIAL DEPOS																		
		62-162-9	HILGD	61	D	TYPIC	CRY	BOR	ALFL-SK	OCH	ARG	7300	5	N	1	T	AFARCO	
		63-145-10B2	H8GN	154	D	GLOSSIC	CRY	BOR	ALFF-L	OCH	ARG	6680	1	FL	1	Q	AFCARU	
		62-155-M12	H8GN	H101	R	TYPIC	CRY	BOR	ALFF-L	OCH	ARG	6720	15	N	1	Q	AFCARU	
		62-155-M13	H8GN	H102	R	TYPIC	CRY	OCHR	EFTL-SK	OCH	CAM	6680	10	N	1	Q	AFCARU	
		62-162-13	HILGD	65	D	GLOSSIC	CRY	BOR	ALFL-SK	OCH	ARG	6950	25	N	1	T	AFLIBO	
		61-206-5	HILGD	39	D	MOLLIC	CRY	BOR	ALFL-SK	OCH	ARG	7860	25	E	1	T	AFLIBO	
		62-162-AB7	HILGD	H54	R	TYPIC	CRY	BOR	ALFF	OCH	ARG	7200	10	W	1	Q	AFLIBO	
		63-145-10B1	H8GN	153	D	GLOSSIC	CRY	BOR	ALFL-SK	OCH	ARG	6720	9	E	1	Q	AFVASC	
		63-145-18	H8GN	180	D	MOLLIC	CRY	BOR	ALFC-L	OCH	ARG	6800	15	E	1	Q	AFVASC	
		63-145-12	H8GN	156	D	MOLLIC	CRY	BOR	ALFF-L	OCH	ARG	6900	9	N	1	Q	AFVASC	
		61-206-3	HILGD	37	D	DYSTRIC	CRY	OCHR	EFTL-SK	OCH	CAM	8170	12	E	1	Q	AFVASC	
		62-155-M14	H8GN	H103	R	TYPIC	CRY	BOR	ALFF-L	OCH	ARG	6840	10	N	1	N	Q	AFVAGL
		62-155-M11	H8GN	H100	R	TYPIC	CRY	BOR	GLLL-SK	MOL	CAM	6680	5	FL	4	I	NFMM	

Fig. 2. Sort of sample site data by geologic group and landform (partial output of SORT CASES/REPORT programs).

***** C R O S S T A B U L A T I O N O F *****

UNIFIED BY PRTS PARTICLE SIZE CLASS

***** PAGE 1 OF 2

UNIFIED	COUNT I	ROW PCT I	PRTS								ROW TOTAL
			IS-SK	L-SK	CL-SK	C-L	F-L	F	VF	S	
			TOT PCT I	2.I	3.I	4.I	5.I	6.I	10.I	11.I	
CH	0	0	0	0	0	0	0	0	1	0	1
	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	1.3
	.0	.0	.0	.0	.0	.0	.0	.0	33.3	.0	
	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.0	
CL	0	1	0	0	4	10	0	0	0	0	15
	.0	6.7	.0	.0	26.7	66.7	.0	.0	.0	.0	19.5
	.0	3.7	.0	.0	25.0	62.5	.0	.0	.0	.0	
	.0	1.3	.0	.0	5.2	13.0	.0	.0	.0	.0	
GC	0	2	0	0	1	0	0	0	0	0	3
	.0	66.7	.0	.0	33.3	.0	.0	.0	.0	.0	3.9
	.0	7.4	.0	.0	6.3	.0	.0	.0	.0	.0	
	.0	2.6	.0	.0	1.3	.0	.0	.0	.0	.0	
GM	0	19	0	0	3	0	0	0	0	0	22
	.0	86.4	.0	.0	13.6	.0	.0	.0	.0	.0	28.6
	.0	70.4	.0	.0	18.8	.0	.0	.0	.0	.0	
	.0	24.7	.0	.0	3.9	.0	.0	.0	.0	.0	
GW	1	0	0	0	0	0	0	0	0	0	1
	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3
	20.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	
	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	
MM	0	0	0	0	0	3	2	0	0	0	5
	.0	.0	.0	.0	.0	60.0	40.0	.0	.0	.0	6.5
	.0	.0	.0	.0	.0	18.8	66.7	.0	.0	.0	
	.0	.0	.0	.0	.0	3.9	2.6	.0	.0	.0	
ML	0	2	1	0	0	1	0	0	0	0	4
	.0	50.0	25.0	.0	.0	25.0	.0	.0	.0	.0	5.2
	.0	7.4	100.0	.0	.0	6.3	.0	.0	.0	.0	
	.0	2.6	1.3	.0	.0	1.3	.0	.0	.0	.0	
COLUMN TOTAL	5	27	1	8	16	16	3	1	77		
TOTAL	6.5	35.1	1.3	10.4	20.8	20.8	3.9	1.3	100.0		

Fig. 3. Cross tabulation of soil particle size class with unified classifications (partial output of CROSSTABS program) S-SK = sandy-skeletal; L-SK = loamy-skeletal; CL-SK = clayey-skeletal; C-L = coarse-loamy; F-L = fine-loamy; F = fine; VF = very fine; S = sandy.

particle size class tends to have GM soils, while the Fine class has more CL soils. Cross tabulations with these and other soil and site features were examined to determine the best predictors of the C horizons' Unified classifications.

Soil taxonomic units at the family level and above are described by the subset of soil sample sites occurring within their class limits. Figure 4 is a sort by soil family. It is used to select all pedon descriptions occurring within the family limits and to describe the

CLASSIFICATION	MAP UNIT	PHOTO IDEN	MTN RANGE	TRNSCT OR MAP	TYPE OF STOP	SUR HOR	SBC HOR	ELE-VATION	SLOPE	ASPECT	LFRM, GEOL, V TYP	HT GP	HABITAT TYPE
MOLLIC	CRY BOR ALFCL-SK												
	46.2A	70-223-3	CRAZY	61	D	OCH	ARG	6600	5	E	D82	A	AGGR
	53.3C	213-131	GALTN	T3-1	R	OCH	ARG	6800	26	N	C31	T	AFLIBO
	71.1C	65-154	BRDGR	T2-7	R	OCH	ARG	6600	99		C51		AF
	72.2D	218-100	GALTN	T1-1	D	OCH	ARG	7350	15	NW	C31	B	S SMST
	82.2B	62-162-1	HILGD	52	D	OCH	ARG	7920	15	NW	I71	Q	AFVASC
NO OF ST				5									
N OF ELV								5					
N OF SLP									4				
ELV MN								7054.0					
SLP MN									15.25				
MIN								6600					
MAX								7920					
MOLLIC	CRY BOR ALFF												
	35.4B	62-155-3	HGBN	165	D	OCH	ARG	7100	20	E	C51	Q	AFVAGL
	53.3C	213-131	GALTN	T3-3	R	OCH	ARG	6700	7	S	C31	Q	AFVAGL
	54.5C	213-114-5	ABSBR	A105	R	OCH	ARG	6600	50	N	E41	Q	AFVAGL
	54.5C	213-114-5A	ABSBR	A105B	R	OCH	ARG	6600	50	N	E41	Q	AFVAGL
	71.1A	64-139	BRDGR	T5-1	R	OCH	ARG	7000	15	E	H51	G	AFCACA
	71.1A	213-129-27	GALTN	106	D	OCH	ARG	6200	20	W	H61	T	S GATR
	72.2A	216-156-8A	GALTN	77	D	OCH	ARG	7100	40	W	H31	T	AFLIBO
	72.2D	218-100	GALTN	T1-4	R	OCH	ARG	7640	10	SW	C31	CC	AFVASC
	82.2A	213-129-15	GALTN	8 *	D	OCH	ARG	7440	1	FL	I54	I	NFMM
	84.1A	64-139-16	BRDGR	90	D	OCH	ARG	6775	10	SE	I51	Q	AFVAGL
	84.1A	65-152-2	BRDGR	38	D	OCH	ARG	6500	12	N	I41	Q	AFVAGL
	86.2A	213-129-23	GALTN	16 *	D	OCH	ARG	6800	35	SW	I51	S	AFGATR
	86.2E	62-159-2	HGBN	201	D	OCH	ARG	8500	10	S	I54	G	NFMM
	86.2E	63-139-1C	HILGD	H433	R	OCH	ARG	8320	15	S	I51	DD	DFARCO
	86.3B	69-204-13	CRAZY	65	D	OCH	ARG	6880	12	W	I41	Q	AFVACA
	87.2A	64-139-20	BRDGR	8200	R	OCH	ARG	7500	50	NE	I52	CC	AFVAGL
	87.2D	213-129-29	GALTN	112 *	D	OCH	ARG	6480	30	NE	I51	T	AFLIBO
NO OF ST				17									
N OF ELV								17					
N OF SLP									17				
ELV MN								7066.8					
SLP MN									22.76				
MIN								6200					
MAX								8500					

Fig. 4. Sort of sample site data by soil family (partial output of SORT CASES/REPORT programs) (CL-SK=clayey-skeletal; F=fine).

associated site features, to estimate extent (by relative frequency) and to write the taxonomic descriptions for the survey area. Finally, it is used to verify that the soil pedons used for taxonomic descriptions are in map unit delineations named for the soils.

Steps 4 through 6 include the physical mapping process and associated analysis. Sample data are taken as delineations are observed on the ground (transects, traverses, or single observations). This information is added to the data base, and is used to verify that mapping criteria and soil landscape relationships are still adequate in new areas. Mapping reliability and quality of map unit concepts are assessed by field inspection and iterative analysis. Viewing data sorted by map unit illustrates this analysis (Fig. 5). The concept of map unit 12-1C is described in the mapping legend as midelevation, gently sloping to rolling ridgetops (LFRM = A) underlain by hard crystalline rocks (GEOL = 1). Soils are predicted to be Typic Cryochrepts, loamy-skeletal (L-SK), mixed, with AF/VASC and AF/VAGL habitat types. Note that the concepts fit well with the field data, though there is some variation. Dystric subgroups occur in some areas but these are similar soils for most purposes. Cryoboralfs and Cryoborolls, though, are dissimilar soils, having higher fertility and water holding capacity. Either these soils are considered limiting inclusions and are described as such, or they are designated as mapping error and corrected.

Soil correlation is "the process of maintaining consistency in naming, classifying, and interpreting kinds of soils and of the units delineated on maps." (Soil Survey Staff, 1982). The mapping legend and maps are modified (in step 5) during mapping to maintain adequate consistency using field checks and outputs such as Fig. 5.

The final field review and final correlation (Step 7) are the official presentation and review of the survey. The tables and figures described above are used to document and demonstrate concepts used in the survey. Figure 5 shows the basic data taken for each map unit, which can be compared to the map unit descriptions. Inclusions can be identified and discussed. Figure 4 is used to show the data used in the taxonomic descriptions. Figure 3 is used to justify interpretive value of soil taxa used in mapping. Any pedon description is easily located for more detailed discussion. Tables 1 and 2, and Fig. 2 are used to justify differentiating criteria. Table 2 and Fig. 1 are used to quantitatively justify the quality of the soil site relationships that were used in developing those criteria. Finally, the tables and figures are used to guide the final narratives on map units, soils, and interpretations.

CONCLUSIONS

We have proposed a statistical model and a system for viewing it that replaces the soil surveyor's memory

MAP UNIT	PHOTO IDEN	MTN RANGE OR MAP	TRNSCT OR MAP	TYPE OF STOP	CLASSIFICATION	SUR HOR	SBC HOR	ELE- VATION	SLOPE	ASPECT	LFOM, GEOL, V TYP	HT	GP	HABITAT TYPE		
12.1C	61-200-H7	H8GN	H128	R	TYPIC	CRY	BOR	ALFC-L	OCH	ARG	8000	1	FL	171	Q	AFVASC
	213-131-23	GALTN	18	D	TYPIC	CRY	BOR	ALFF-L	OCH	ARG	7000	50	N	A11	Q	AFVAGL
	213-131-26	GALTN	20	D	TYPIC	CRY	BOR	ALFF-L	OCH	ARG	6750	20	E	A11	Q	AFCARU
	218-100	GALTN	T2-6	R	TYPIC	CRY	BOR	ALFL-SK	OCH	ARG	7500	10	SW	D31	Q	AFVASC
	218-100	GALTN	T2-5	R	TYPIC	CRY	BOR	ALFL-SK	OCH	ARG	7500	3	W	D31	Q	AFVASC
	60-121-7	HILGD	181	D	TYPIC	CRY	BOR	ALFL-SK	OCH	ARG	7100	35	NE	B11	Q	AFVASC
	60-121-2	HILGD	5	D	MOLLIC	CRY	BOR	ALFC-L	OCH	ARG	7400	3		B11	S	AFCAEA
	213-131	GALTN	T1-4	R	MOLLIC	CRY	BOR	ALFF-L	OCH	ARG	6600	3	W	C11	Q	AFVASC
	218-100	GALTN	T2-4	R	MOLLIC	CRY	BOR	ALFL-SK	OCH	ARG	7500	15	W	D31	T	AFLIBO
	59-126-1	HILGD	1	D	TYPIC	CRY	AQU	EPTF-L	OCH	CAM	7700	1	NE	C16	K	DCHD
	60-123-A11	HILGD	H401	R	TYPIC	CRY	AQU	EPTL-SK	OCH	CAM	7580	1	FL	B11	S	AFCAEA
	60-123-A7	HILGD	H10	R	TYPIC	CRY	OCHR	EPTC-L	OCH	CAM	7500	38	N	B11	Q	AFVAGL
	62-153-M4	H8GN	H88	R	TYPIC	CRY	OCHR	EPTF-L	OCH	CAM	7700	45	N	A21	Q	AFVASC
	62-155-M6	H8GN	H95	R	TYPIC	CRY	OCHR	EPTL-SK	OCH	CAM	7200	25	E	A21	Q	AFVAGL
	62-157-H11	H8GN	H107	D	TYPIC	CRY	OCHR	EPTL-SK	OCH	CAM	7600	8	SW	A11	Q	AFVASC
	62-157-H12	H8GN	H108	D	TYPIC	CRY	OCHR	EPTL-SK	OCH	CAM	7900	12	S	A11	Q	AFCARU
	62-157-H14	H8GN	H110	D	TYPIC	CRY	OCHR	EPTL-SK	OCH	CAM	7700	18	SW	A11	Q	AFCARU
	60-121-4	HILGD	119	D	TYPIC	CRY	OCHR	EPTS	OCH	CAM	7100	20	NE	B11	Q	AFVASC
	60-123-A11	HILGD	H14	R	TYPIC	CRY	OCHR	EPTS	OCH	CAM	7580	15	N	B11	S	AFCAEA
	59-126-A3	HILGD	H3	R	TYPIC	CRY	OCHR	EPTS-SK	OCH	CAM	7780	5	S	B11	Q	AFCARU
	213-131	GALTN	T1-1	R	DYSTRIC	CRY	OCHR	EPTC-L	OCH	CAM	6600	15	NE	A11	Q	AFVAGL
	214-22-4	GALTN	53	D	DYSTRIC	CRY	OCHR	EPTC-L	OCH	CAM	7840	30	NW	A11	U	AFVASC
	213-131	GALTN	T1-2	R	DYSTRIC	CRY	OCHR	EPTL-SK	OCH	CAM	6600	20	E	C11	Q	AFVAGL
	213-131	GALTN	T1-3	R	DYSTRIC	CRY	OCHR	EPTL-SK	OCH	CAM	6600	17	N	A11	Q	AFVAGL
	213-131	GALTN	T1-5	R	DYSTRIC	CRY	OCHR	EPTL-SK	OCH	CAM	6600	35	W	A11	Q	AFVAGL
	213-131	GALTN	T1-5	R	DYSTRIC	CRY	OCHR	EPTL-SK	OCH	CAM	6600	20	NE	A11	S	AFCAEA
	60-123-4	HILGD	11	D	DYSTRIC	CRY	OCHR	EPTL-SK	OCH	CAM	7600	30	NW	A11	Q	AFVASC
	59-126-2	HILGD	2	D	DYSTRIC	CRY	OCHR	EPTS	OCH	CAM	7700	10	N	C11	Q	AFVASC
	60-123-A8	HILGD	H11	R	DYSTRIC	CRY	OCHR	EPTS-SK	OCH	CAM	7950	26	SE	B11	Q	AFVASC
	61-200-16	H8GN	195	D	ENTIC	CRY	UMBR	EPTS-SK	UMB	CAM	8000	15	NE	A11	Q	AFVAGL
	63-141-1	HILGD	88	R	TYPIC	CRY	UMBR	EPTL-SK	UMB	CAM	8720	15	W	A11	U	AFVASC
	63-141-B	HILGD	H428	R	TYPIC	CRY	UMBR	EPTL-SK	UMB	CAM	8500	10	N	B11	U	AFVASC
	214-22-8A	GALTN	57	D	TYPIC	CRY	UMBR	EPTS	UMB	CAM	7600	45	N	F11	Q	AFVAGL
	59-126-A2	HILGD	H2	R	TYPIC	CRY	AQU	OLLL-SK	MOL	CAM	7480	18	E	B11	Q	AFVASC
	62-157-H15	H8GN	H111	R	ARPC	CRY	BOR	OLLL-SK	MOL	ARG	8600	22	S	A11	Q	AFCARU
	218-100	GALTN	T2-1	R	ARGIC	CRY	BOR	OLLL-SK	MOL	ARG	7500	15	NW	C31	T	AFLIBO
	218-100	GALTN	T2-2	R	ARGIC	CRY	BOR	OLLL-SK	MOL	ARG	7500	15	NW	C31	T	AFLIBO
	218-100	GALTN	T2-3	R	ARGIC	CRY	BOR	OLLL-SK	MOL	ARG	7500	65	S	C31	Q	AFCAEA
	60-123-1	HILGD	8	D	TYPIC	CRY	BOR	OLLS	MOL	CAM	7440	10	E	B11	Q	AFVASC

NO OF ST	39	
N OF ELV		39
N OF SLP		39
ELV MN		7469.7
SLP MN		19.64
MIN	6600	1
MAX	8720	65

Fig. 5. Sort of sample site data by map unit (12-1C illustrated here) (partial output of SORT CASES/ REPORT programs).

as the central location for site data and its analysis. We have shown via examples, applications of the system in the soil survey process. We emphasize that it does not replace the surveyors' judgement and experience in analysis of the landscape, map unit design, or correlation. It enhances the process by using the computer models to visualize, recognize, and document relationships that might otherwise be obscured or lost, to more fully utilize soil site data, and to perform tracking functions that would otherwise consume a large part of the survey staff's time and resources. With all the basic documentation for the survey being organized and readily available after the survey is completed, revisions or evaluations are easily accomplished. The information can aid in soil correlation and interpretation when an old survey is to be updated and can provide initial data for future adjacent surveys.

REFERENCES

Amidon, E.L. 1978. Computer mapping systems for integrated resource inventories. p. 354-359. *In* Integrated inventories of renewable natural resources Proc. of the Workshop, Tucson, AZ, 8-12 Jan. 1978. Gen. Tech. Rep. RM-55, USDA, FS, PSW FRES, Berkeley.

Bie, S.W., and J. Schelling. 1977. An integrated (computer based) information system for soil survey in factual data banks in agriculture: p. 45-53. *In* Pro. Symp. organized by the Committees of the European Communities, Luxembourg. 12-13 July 1977. Centre for Agricultural Publishing and Documentation, Wagen-

ingen, The Netherlands.

Davis, C.E., and H.F. Shovic. 1985 Soil survey of the gallatin forest area, Southwestern Montana. USDA-SCS. U.S. Government Printing Office, Washington, DC. (in press).

Giltrap, D.J. 1981. A practical application of spatial interpolation for the rapid production of a wide range of special purpose soil maps. p. 73-82. *In* A.W. Moore et al. (ed.) Information systems for soil and related data, Wageningen, The Netherlands.

Giltrap, D.J. 1983a. Computer production of soil maps. I. Production of grid maps by interpolation. *Geoderma* 29:295-311.

Giltrap, D.J. 1983b. Computer production of soil maps. II. Interactive map display. *Geoderma* 29:313-325.

Haantjens, H.A., P. Blecker, and L.G.N. Cook. 1975. Procedures for computer storage of soil and landscape data from Papua, New Guinea. I. General introduction and input of descriptive soil observation data. *Geoderma* 13(2):105-113.

Hull, C.H., and N.H. Nie. 1979. SPSS update: new procedures and facilities for releases 7 and 8. McGraw-Hill, New York.

Kosaki, T., K. Kyuma, and H. Furukawa. 1980. Computer-based soil data management system (COSMAS): its function and use (remote sensing) p. 135. *In* symposium on Machine Processing of Remotely Sensed Data. 3-6 June 1980. Lab. for applications of remote sensing, West Lafayette, IN 47907.

Miller, I. and J.E. Freund. 1965. Probability and statistics for engineers. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Nelson, W.C., and J.E. Johnson. 1976. Resource inventory, information management, and monitoring system. North Dakota Farm Research. Nov-Dec, 34 (2):20-22.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. Statistical package for the social sciences. McGraw-Hill, New York.

Ragg, J.M. 1977. The recording and organization of soil field data for computer aerial mapping. *Geoderma* 19:81-89.

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agri. Handb. 436. U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 1982. Soil Survey manual. USDA-SCS. Draft 430-

V-SSM, August 1982. U.S. Government Printing Office, Washington, DC.
 Sowers, G.B., and G.F. Sowers. 1970. Introductory soil mechanics and foundations, 3rd ed. Macmillan Publ. Co. New York.
 Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of

statistics, p. 31-32. McGraw-Hill, New York.
 Webster, R. 1978. Mathematical treatment of soil information, Soil survey of England and Wales, Rothamsted Exp. Stn., Harpenden, Herts, AL5 2JQ, UK. Trans., Int. Cong. Soil Sci., 11th 3:161-190.

DIVISION S-6—SOIL AND WATER MANAGEMENT AND CONSERVATION

Tillage Effects on Soil Thermal Properties¹

K. N. POTTER, R. M. CRUSE, AND R. HORTON²

ABSTRACT

Theoretical considerations indicate soil thermal properties may be altered by tillage, but few field studies have been conducted to compare soil thermal properties as affected by conservation or no-till management systems. Surface-soil thermal properties were determined in the row zone for three soils in three tillage systems: conventional till, chisel plow, and no-till. The apparent thermal diffusivity was determined by harmonic analysis of soil temperature data, volumetric heat capacity from the volume fraction of the soil components, and thermal conductivity by the line source heat-probe method. Soil volumetric heat capacity was similar for all tillage treatments. Thermal diffusivity was significantly greater in the no-till system than in conventional and chisel plow tillage systems, indicating that thermal conductivity also was greater in the no-till system. Direct determination of thermal conductivity by the line source heat-probe method at one site indicated that thermal conductivity was more than 20% greater in no-till than in the conventional till system. Percentage surface residue cover had a greater influence on soil temperature and soil heat flux than soil thermal properties.

Additional Index Words: harmonic analysis, soil heat flux, soil heat transfer, thermal conductivity, thermal diffusivity.

Potter, K.N., R.M. Cruse, and R. Horton. 1985. Tillage effects on soil thermal properties. *Soil Sci. Soc. Am. J.* 49:968-973.

TILLAGE INFLUENCES soil temperature by altering soil thermal properties, the surface configuration, and percentage surface residue cover. There have been many experiments concerning surface residue and surface configuration effects on soil temperature. For a review, see Willis and Amemiya (1973) and Voorhees et al. (1981). The general consensus is that spring soil temperatures are reduced with increasing amounts of surface residue. There is evidence, however, that the use of ridge planting may reduce differences in soil temperature between tillage systems while maintaining surface residue cover (Radke, 1982).

The increasing interest in computer modeling of tillage effects on soil temperature makes knowledge of

soil thermal properties important (Cruse et al., 1982). Van Duin (1956) discussed the theoretical implications of tillage on soil thermal properties. Decreasing soil porosity or increasing soil water content increased thermal conductivity (λ). Soil heat flux was reduced by loosening the surface soil layer.

Tillage effects on soil thermal properties have been considered in only a few field studies. Thermal diffusivity (α) was larger in a direct-drilled barley field as compared with a plowed field throughout the growing season in England (Hay et al., 1978). The difference in α was attributed to the greater soil bulk density in the direct-drilled field. Allmaras et al. (1977) found λ increased with increasing amounts of secondary tillage following plowing.

With the wide variety of tillage systems available, it is important to understand the effect of tillage on physical properties and processes occurring in the soil. The objective of this study was to determine the effect of widely used tillage systems on soil thermal properties for a variety of soils. Soil heat flux also was determined to compare the effects of ridged and flat no-till systems with other tillage systems.

THEORETICAL BACKGROUND

The method of determining λ , α , and soil heat flux used in this study is based upon solutions to the heat conduction equation. A brief review of the concepts involved is presented.

An equation describing one-dimensional heat transfer in a homogeneous media is:

$$\partial C_v T / \partial t = \partial (\lambda \partial T / \partial z) / \partial z \quad [1]$$

where T is the temperature, t is the time, z the depth, C_v the volumetric heat capacity, and λ the apparent thermal conductivity. Assuming that C_v and λ are independent of depth and time, Eq. [1] may be rewritten as:

$$\partial T / \partial t = \alpha \partial^2 T / \partial z^2 \quad [2]$$

where α is the apparent thermal diffusivity ($\alpha = \lambda / C_v$).

With boundary conditions

$$T(0,t) = \bar{T} + \sum_{n=1}^m A_{on} \sin(n\omega t + \phi_{on}) \quad [3]$$

and
$$\lim_{z \rightarrow \infty} T(z,t) = \bar{T} \quad [4]$$

¹ Journal paper no. J-11502 of the Iowa Agriculture and Home Econ. Exp. Stn., Ames, IA. Project 2423. This research was supported in part by USDA-SEA Agreement no. 58-519B-0-885. Received 25 June 1984. Approved 14 Mar. 1985.

² Research Associate, Associate Professor and Assistant Professor, respectively. Agronomy Dep., Iowa State Univ., Ames, IA.