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Soil Moisture

Technical Memorandum

SOIL MOISTURE VARIATION PATTERNS OBSERVED IN HAND COUNTY, SOUTH DAKOTA

E. Bruce Jones, Manfred Owe and Thomas J. Schmugge

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August 1981

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ABSTRACT

Soil moisture data were taken during 1976 (April, June, October), 1977 (April, May, June), and 1978 (May, June, July) in selected fields in Hand County, South Dakota as part of the ground truth used in NASA's aircraft experiments studying the use of microwave radiometers for the remote sensing of soil moisture. This portion of the study dealt only with the spatial variability observed on the ground during each of the sampling events. The measurements were taken along the same 40 km's of flight line during each of the 9 flights. The data were reported as the mean gravimetric soil moisture contained in three surface horizon depths: 0 - 2.5, 0 - 5 and 0 - 10 cm. The overall moisture levels ranged from extremely dry conditions in June 1976 to very wet in May 1978, with a relatively even distribution of values within that range. The coefficient of variation for these was generally less than $e^{(-5.85\overline{x})}$, where $\overline{x}$ is the mean soil moisture for the field. The results indicate that one must partition well drained sites from imperfectly drained areas when attempting to characterize the general moisture profile throughout an area of varying soil and cover type conditions. It was also found that the variability in moisture content was greatest in the 0 - 2.5 cm measurements and decreased as the measurements were integrated over a greater depth. In addition, it was determined that the sampling intensity of 10 measurements per km was adequate to estimate the mean moisture with an uncertainty of ± 3 percent under average moisture conditions in areas of moderate to good drainage.

SOIL MOISTURE VARIATION PATTERNS OBSERVED IN HAND COUNTY, SOUTH DAKOTA

INTRODUCTION

Ground truth continues to be an important link between the acquisition of remotely sensed data and its interpretation. In this program, soil moisture was being analyzed by microwave radiometers flown in NASA aircraft over a study site in Hand County, South Dakota. The variability of the soil moisture and hence the acquisition of sufficient ground-truth data is but one, albeit important, aspect of this program.

Other investigators have viewed the problem of soil moisture variability. *Rao and Ulaby* (1977) have reported on results obtained near Perry-Topeka, Kansas, in connection with remote sensing experiments on soil moisture. They demonstrated how estimates of the number of soil moisture samples for an area can be prespecified for various layers of soil. *Bell et al.* (1980) have investigated variations in surface soil moisture for various sites. They also show approaches for prespecifying the number of samples. However, unlike *Rao and Ulaby* (1977), their findings indicate that the variation in sample size requirement is more a function of moisture content than depth.

The work in Hand County utilized 3 East-West flight lines, with sampling conducted only along these flight lines. Thus, the goal of the sampling was to characterize the soil moisture throughout three variably-deep surface horizons within individual fields along these flight lines for comparison with the radiometric data acquired from aircraft over these fields. The minimum field size was 400 by 400 m (40 acres) and the surface conditions included: bare, pasture, wheat and alfalfa. Samples were taken to three depths, 0 - 2.5 cm, 0 - 5 cm and 0 - 10 cm, and the mean gravimetric moisture content of the individual fields determined at each horizon.

One of the products of the soil moisture ground truth taken over the past three years at the Hand County, South Dakota site was a better understanding of the relationships between the mean soil moisture of a section of a field and the corresponding coefficient of variation. The supporting data for these analyses are contained in various reports previously submitted to NASA/GSFC (*Jones* 1976a, 1976b, 1976c, 1977a, 1977b, 1977c, 1978a, 1978b, 1978c)) and have recently been summarized in a report to NASA (*Jones*, 1978d).

SITE LOCATION AND DESCRIPTION

The Hand County study site is a 77.7 square kilometer area (approximately 9.7 kilometers E-W and 8.0 kilometers N-S) located just north of the town of Miller, South Dakota, as shown in Figure 1. The detailed location of the site and the North, Middle, and South flight lines are shown in Figure 2 along with the field numbering scheme used. Only the southern 60 percent of this site was used in the soil moisture experiments.

The topography of the site is characterized by only limited vertical relief. Although the drainage pattern in portions of the site is poorly defined, the small creeks that drain the area tend to flow in a generally northeastern direction. The topographic high for the site is located in the extreme southwest corner.

The soils are of the Houdek-Bonilla association which are generally level to slightly undulating, loamy soils of glacial origin and of the Houdek-Cavour-Miranda association which are similar but tend to be somewhat heavier and may contain impervious clay layers. The heavier soils tend to be located in the western third and in the extreme eastern portions of the site (*White, Westin & Buntley*, 1963). There are numerous small depressions or potholes on the test site that fill with water during wet years. The region is predominantly a dry-land farming region in which the majority of the fields are sowed to wheat or lie fallow. In those areas with the heavier soils, the land remains in pasture grass as it has for many decades.

The monthly precipitation patterns, along with the monthly normals, for Miller, South Dakota, are shown in Figure 3 for the period January 1975 through August 1978. Attention is called to the wide deviations in precipitation from the normal amounts. The yearly rainfall totals for the years 1975, 1976, and 1977 were 17.4, 7.6, and 23.4 inches respectively compared to the 30 year average of 19.9 inches. In particular, note that the 19 month period from July 1975 to Jan-

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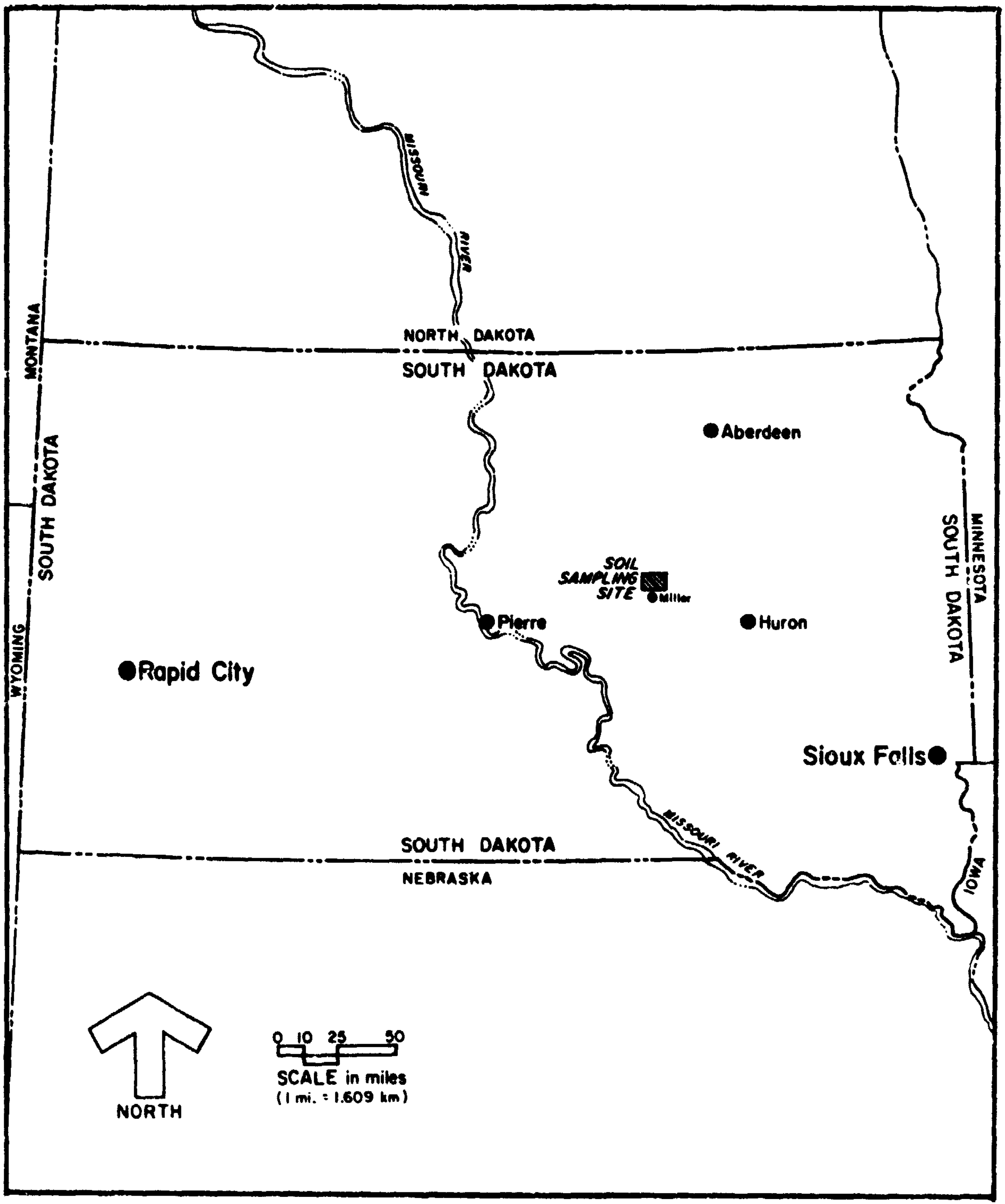

Figure 1. Locations of the Test Site in Central South Dakota

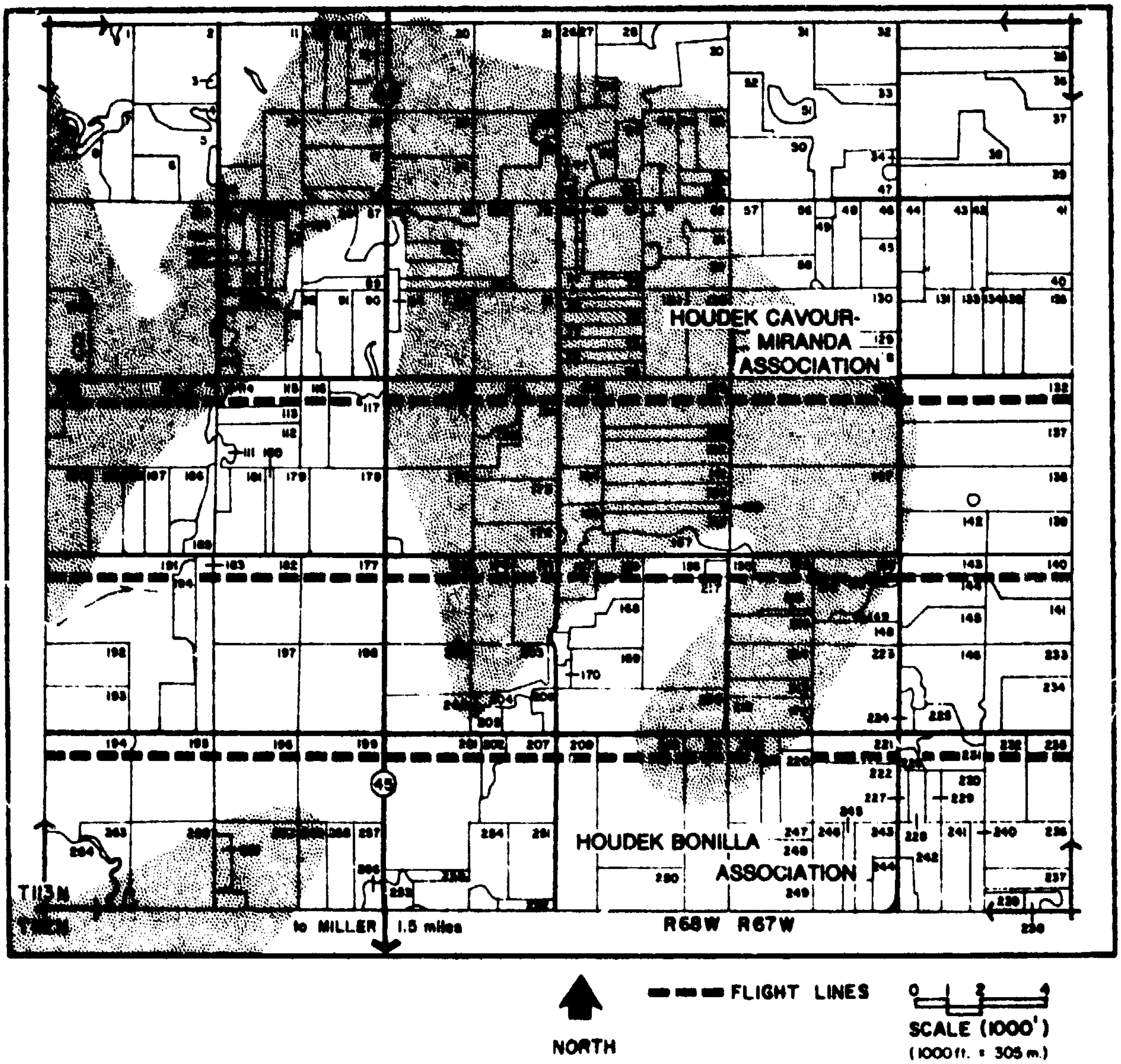

Figure 2. Map of Hand County Test Site Showing the Distribution of the Two Dominant Soil Associations and the Field Numbering Scheme Used During Experiment

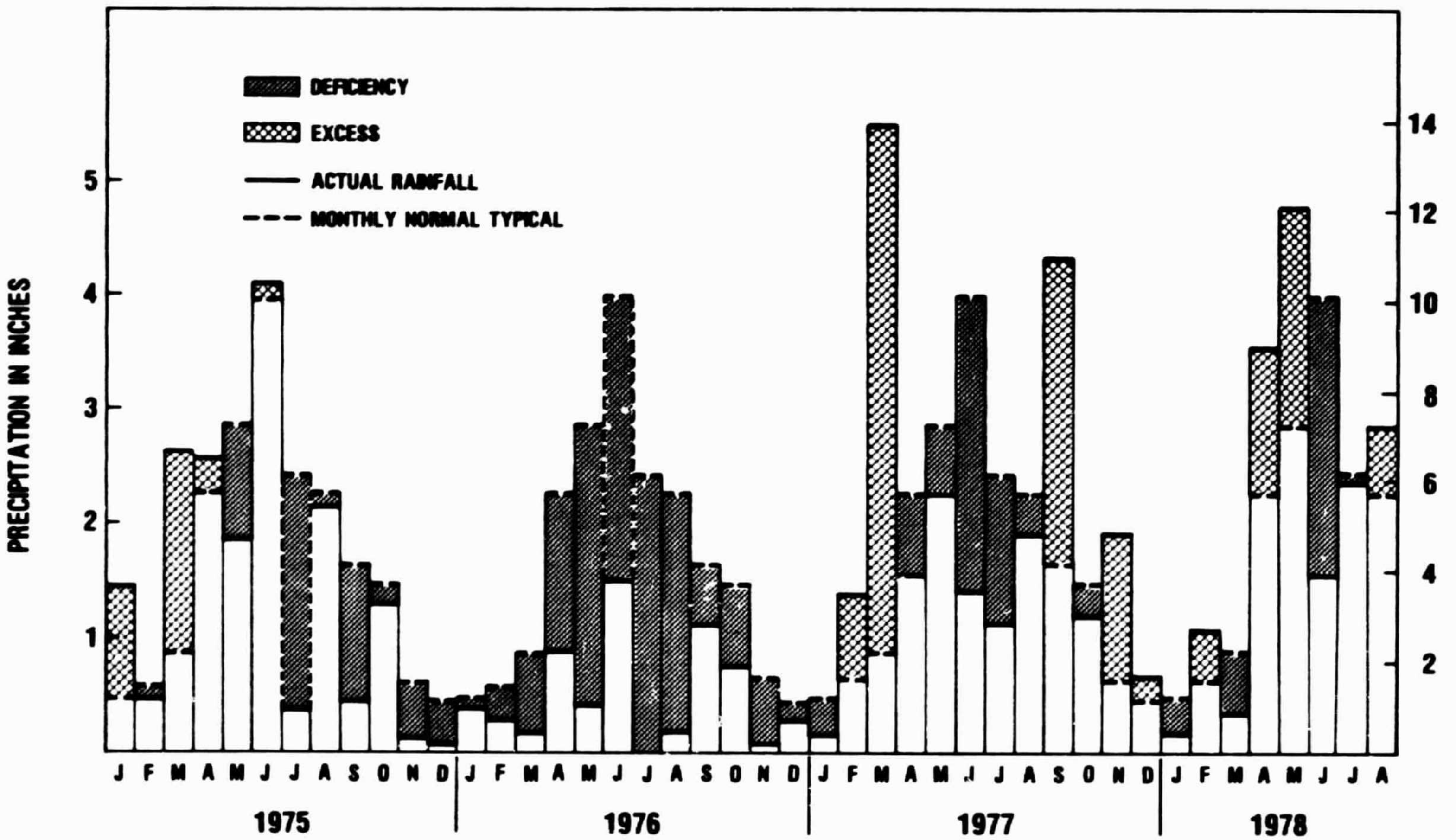

Figure 3. Monthly Precipitation Values for the Period of Interest at the Hand County, South Dakota Test Site

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uary 1977 was one of continuous rainfall deficiency resulting in a deficit of 17 inches over this period. The period from September 1977 to May 1978 was one of excess rainfall in the amount of 6.8 inches. Thus a wide range of moisture conditions was present during the study period from extremely dry in 1976 to very wet in the spring of 1978.

BASIC SAMPLING PROCEDURES

The fields that were to be sampled on each mission were selected on the basis of surface cover condition and accessibility. The sampling conducted in each field generally followed the pattern shown in Figure 4. In cases where higher degrees of soil moisture variability were suspected, three points were selected, rather than the standard two, within the 5-foot radius, i.e., points A, B, and C were sampled at the three horizons of 0–2.5 cm, 0–5 cm, and 0–10 cm. The pattern shown in Figure 4 was initially selected because the soils were generally quite uniform across individual fields. This pattern also allowed one to reoccupy the same sites year after year with only minimal effort since the area is divided on a section, range, and township basis.

The decision to conduct horizon sampling, i.e., 0 to 2.5 cm, 0 to 5 cm, and 0 to 10 cm, rather than a layered sampling, i.e., 0 to 2.5 cm, 2.5 cm to 5 cm, and 5 cm to 10 cm, was made in an attempt to match as closely as possible what the microwave radiometers would be sensing.

All fields in the study area were numbered in 1976. These numbers were maintained throughout the soil moisture portion of the work. Figure 2 shows the field numbering system. During the nine missions (1976 through 1978) over 4,500 individual soil moisture samples were taken and gravimetrically analyzed. All soil moisture data reported are on a percent by weight basis. These data, along with other mission specific data, are reported by *Jones* (1976a, 1976b, 1976c, 1977a, 1977b, 1977c, 1978a, 1978b, 1978c).

The flight lines were 200 meters (1/8 mile) south of the East-West road at miles 1, 2, and 3, as indicated in Figure 2. The particular fields chosen were at least 400 meters long and 400 meters wide. Thus most of the fields at the eastern ends of the South and Middle flight lines were rejected as being too small. These dimensions were chosen to provide several seconds of data over a relatively

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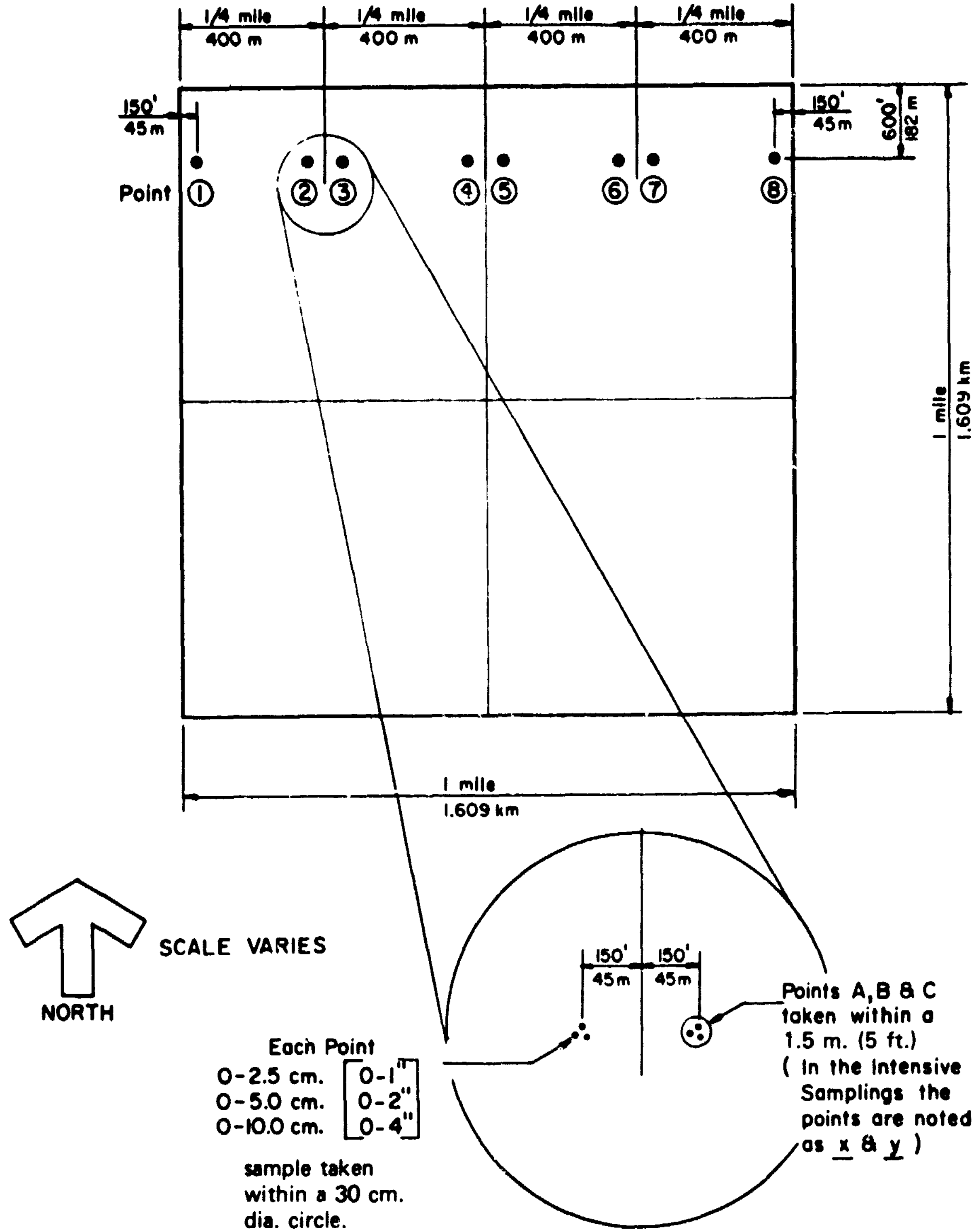

Figure 4. Typical Sampling Pattern Hand County, South Dakota

uniform scene for a radiometer with an 80-meter field of view traveling at a ground speed of 75 to 80 meters per second (150 knots).

The data were analyzed by inspecting the field mean soil moistures, their respective standard deviations and coefficients of variation. After some consideration, it was decided not to further inspect the standard deviation. When comparing means over a wide range of values, this statistic is inappropriate since it is inherent for σ to vary directly with the mean.

To overcome this difficulty, the coefficient of variation (CV) was used. This value is defined as the standard deviation divided by the mean ($\sigma/\bar{x}$). The value is expressed either as a fraction or a percentage of the sample mean. Since both the mean and the standard deviation generally vary together, this value is a good comparative measure of their relative magnitudes. Being a dimensionless parameter, it also permits one to compare sample populations involving different units of measure. Each sampling day was analyzed independently to maintain some consistency, at least with respect to the antecedent meteorological conditions.

The first objective of the analysis was to attempt to determine the relative uncertainties associated with each sampling depth. The first value to be inspected was the coefficient of variation (CV) calculated for each mean field soil moisture value at each of the three sampling depths. This parameter is an indication of the within-field variability of the soil moisture measurements. Table 1 indicates the frequency of occurrence that each horizon possessed the lowest CV value for a field.

Table 1
Frequency of occurrence of low field CV value at each horizon across the entire study site.

Sampling Date	Horizon (cm) 0-2.5	0-5	0-10	No Difference
April 76	0	9	20	2
June 76	4	5	9	1
October 76	3	8	2	6
April 77	3	5	5	9
May 77	5	6	19	0
June 77	9	7	9	4
May 78	0	4	12	0
June 78	2	5	11	5
July 78	1	6	16	0
	27	55	103	27

Analyses of variance and subsequent paired T-tests were performed on the field CV values, using horizon depth as the grouping variable. Table 2 lists the mean CV values for each sampling day at each of the three depths. Any statistically significant differences observed between them is indicated.

Table 2
Mean CV values (percent) for the entire study site at each of the three samples depths.

Sampling Date	Horizon (cm) 0-2.5	0-5	0-10	Statistically Significant Difference
April 76	27	18	14	Yes**
June 76	28	25	23	no
October 76	24	21	24	no
April 77	11	10	10	no
May 77	43	36	24	Yes**
June 77	13	14	14	no
May 78	31	23	17	Yes**
June 78	15	13	12	no
July 78	29	22	17	Yes**
	25%	20%	17%	

* .05 level
** .01 level

In those instances where a significant difference exists between the three sampling horizons, level 10, or the average moisture throughout the top 10 cm possessed the lowest mean coefficient of variation. Those cases that did not demonstrate a statistically significant difference in variation between horizons were generally at the extremes (high or low) of the soil moisture scale. Several sampling events occurred during periods of extended severe moisture stress. Several others were conducted outside the peak growing season with subsequent minimal evapotranspiration and the presence of a soil moisture surplus. These periods were generally characterized by a relatively uniform soil moisture profile and somewhat stable meteorological conditions, rarely creating a situation for concern with respect to plant–soil–water relationships.

The mean moisture values obtained for each sampling interval were also compared. Differences in the overall test site mean as estimated by each horizon were compared by analyses of variance (Table 3). The coefficient of variation corresponding to each of the overall site means is indicated in parenthesis. The least variation across the entire sample site is contained in the 10 cm horizon. This is also shown to be the case when the moisture profile is relatively constant throughout the three sample depths.

Table 3. Differences in Overall Site Soil Moisture Means

		Horizon (cm)		
Date	0-2.5	0-5	0-10	Significant
April 76	11.1 (48)	15.4 (28)	17.1 (19)	Yes**
Jun 76	1.8 (29)	2.6 (29)	4.6 (35)	Yes**
Oct 76	24.2 (16)	22.5 (12)	18.4 (10)	Yes**
Apr 77	30.8 (14)	30.3 (12)	29.9 (12)	No
May 77	4.8 (45)	9.1 (35)	14.0 (28)	Yes**
Jun 77	19.1 (22)	18.2 (16)	15.8 (22)	Yes**
May 78	23.8 (48)	25.8 (30)	25.8 (20)	No
Jun 78	30.5 (20)	30.3 (16)	30.5 (14)	No
Jul 78	11.3 (41)	13.8 (24)	15.6 (20)	Yes**

* .05 level
** .01 level

The data shows the greatest moisture variability to be contained in the 0-2.5 cm samples, both within the individual fields, and across the entire test site.

Intuitively, this is what one would generally expect. The surface is highly variable with respect to its inherent physical properties, and also the most vulnerable to external influences such as meteorological conditions and general physical disturbances. As a result, the soil surface experiences the greatest spatial and temporal variability with respect to both moisture, temperature and other factors. As one integrates over a greater depth, the more uniform all aspects of the soil become, and the less susceptable the mean moisture content is to rapid fluctuation.

DETERMINATION OF SAMPLING CONSIDERATIONS

To determine essential future sampling criteria, the relationship between the mean field soil moisture ($\overline{X}$) and the coefficient of variation (CV) was investigated. This would provide an indication of the general variation one would expect to encounter at various soil moisture ranges.

First, plots (Appendix 1, Figures 1-9) of the individual sampling days were examined for possible trends. Each $\overline{X}$ was plotted against its corresponding CV value. It was noticed that the coefficient of variation displayed a general inverse relationship with the mean field soil moisture in some instances, while in others, no obvious trends were detectable. It appears that those cases possessing both a broad range of soil moistures, and a relatively even distribution across that range displayed the best relationship (App. 1, Figs. 1, 2, 5, 7 & 9). In the remainder of the sampling events, most of moisture values were clustered in narrow ranges, generally during a period when soil moisture was not limiting (App. 1, Figs. 3, 4, 6 & 8). In these latter instances, it appears that the field CV values corresponded randomly to the soil moisture measurements, although when several sampling sets were combined and the range of moisture values increased, the relationship would again become apparent. When the plots for all nine sample events were combined, the relationship became very evident (Figure 5).

Using the equation for the standard exponential decay function (Snedecor and Cochran, 1967)

$$Y = A\,(e^{-CX}) \qquad (1)$$

an approximately 90 percent inclusive envelope curve was fitted to the entire set of points. The equation for this line is

$$CV = e^{-5.85\overline{X}} \tag{2}$$

where $\overline{X}$ is the mean field soil moisture expressed as a fraction. Although a true envelope curve generally includes all data, such a curve would not depict what appears to be the relationship exhibited by the data points. Justification for exclusion of approximately 10 percent of the data points will be discussed shortly.

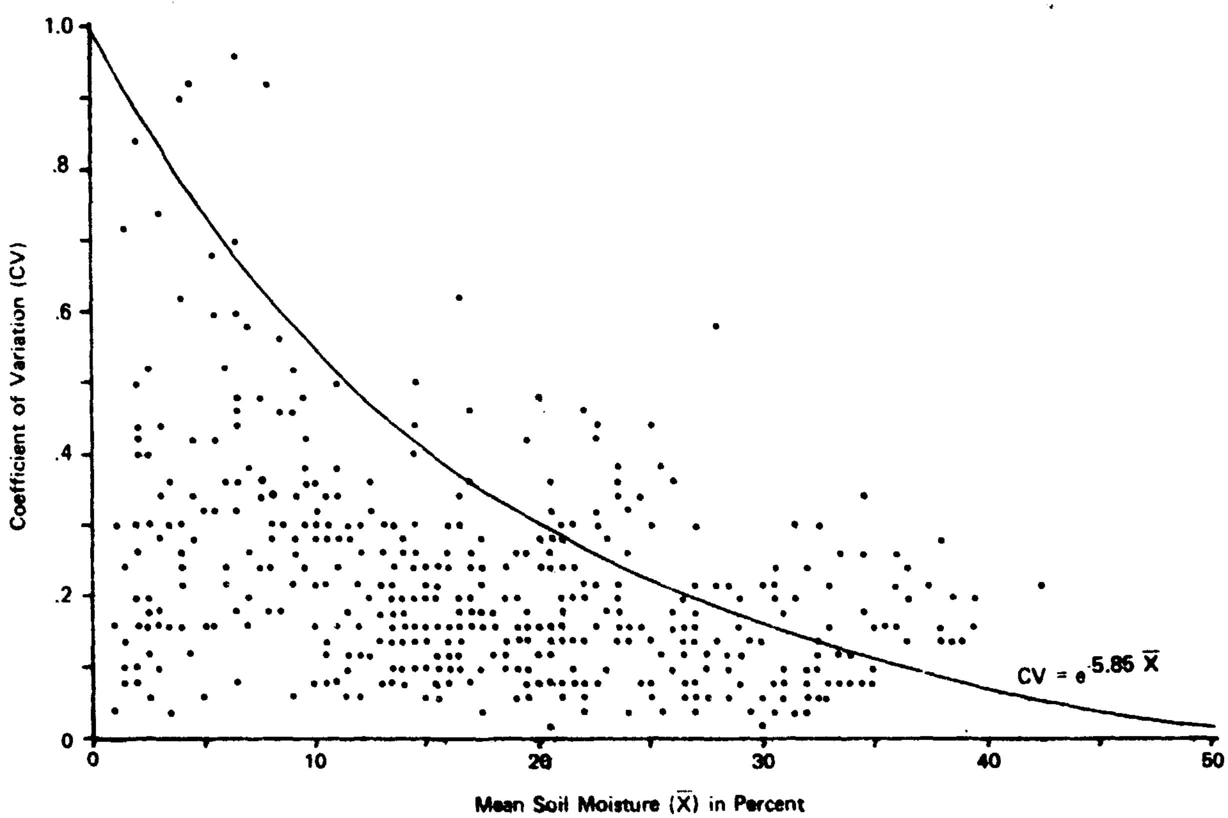

Figure 5. Coefficient of variation versus the mean field soil moisture for all 9 sampling events.

The above curve is plotted on all three years of data (Figure 5). Of the 75 points falling outside the curve, 55 occurred during three of the sampling events, October 1976, May 1978 and June 1978. A precise compilation of the excluded points, with respect to field, cover, horizon and date is presented in Tables 4 and 5.

Table 4
Fields, Horizons, and Sampling Dates with Coefficients of Variation
Above that Predicted by Equation (2)

1976 Field Nos.	Cover1/			Horizon (cm)	1976			1977			1978 May/		
	1976	1977	1978		Apr	Jun	Oct	Apr	May	Jun	May	Jun	Jul
110	Wheat	Fallow	Fallow	0–2.5			x				2/	x	2/
				0–5							2/	x	2/
				0–10							2/	x	2/
115			Wheat	0–2.5							2/	x	
				0–5							2/		
				0–10							2/		
118	Pasture	Fallow	Wheat	0–2.5	2/	2/	x	x			2/		
				0–5	2/	2/	x	x			2/		
				0–10	2/	2/	x	x	x		2/	x	
122	Pasture	Pasture	2/	0–2.5			2/	2/			2/	2/	2/
				0–5			2/	2/		x	2/	2/	2/
				0–10			2/	2/			2/	2/	2/
126	Fallow	Wheat	Wheat	0–2.5			2/	2/					
				0–5		x	2/	2/	x				
				0–10			2/	2/			x		
191	– Native Pasture –			0–2.5	x		x	x			x	x	
				0–5	x		x				x	x	
				0–10	x						x	x	
182	Wheat	Fallow	Wheat	0–2.5			x						
				0–5			x						
				0–10						x			
177	Fallow	Wheat	Wheat	0–2.5									
				0–5									
				0–10			x						
175	Wheat	Wheat	Fallow	0–2.5					x		x		
				0–5					x				
				0–10									
174	Alfalfa	Alfalfa	Wheat	0–2.5					x				
				0–5									
				0–10				x					
171	Alfalfa	Alfalfa	Alfalfa	0–2.5							x		
				0–5									
				0–10									

1/ Cover as of second mission each year.
2/ Not sampled.

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Table 4 (continued)

1976 Field Nos.	Cover 1/			Horizon (cm)	1976			1977			1978 May/			Total
	1976	1977	1978		Apr	Jun	Oct	Apr	May	Jun	May	Jun	Jul	
194	Pasture	Pasture	Pasture	0–2.5			2/	2/			x	x		
				0–5			2/	2/			x	x		
				0–10			2/	2/				x		
195	Wheat	Fallow	Wheat	0–2.5			2/	2/					x	
				0–5			2/	2/					x	
				0–10			2/	2/					x	
196	Wheat	Fallow	Wheat	0–2.5			2/	2/			x	x		
				0–5			2/	2/			x	x		
				0–10			2/	2/			x	x		
199	Wheat	Fallow	Wheat	0–2.5			2/	2/			x	2/		
				0–5			2/	2/				2/		
				0–10			2/	2/				2/		
201	Fallow	Wheat	Oats	0–2.5										
				0–5										
				0–10					x					
207	Fallow	Wheat	2/	0–2.5		2/	x	x		2/	2/	2/	2/	
				0–5		2/				2/	2/	2/	2/	
				0–10		2/				2/	2/	2/	2/	
209	Wheat	Wheat	Wheat	0–2.5		2/	x		x			x		
				0–5		2/	x							
				0–10		2/	x					x		
210	Wneat	Fallow	Fallow then Sorghum	0–2.5			x					x		
				0–5			x					x		
				0–10			x					x		
211	Pasture	Pasture	Pasture	0–2.5	x	2/	x				x			
				0–5		2/					x			
				0–10		2/					x			
232	Corn	Wheat	Alfalfa	0–2.5		2/	2/	2/			x			
				0–5		2/	2/	2/						
				0–10		2/	2/	2/						
235	Pasture	Pasture	Pasture	0–2.5		2/	2/	2/			x	x		
				0–5		2/	2/	2/			x	x		
				0–10		2/	2/	2/				x		
Distribution by horizons –				0–2.5	1	0	6	3	2	0	8	8	1	29
				0–5	1	1	5	1	1	1	6	7	1	24
				0–10	1	0	3	2	2	1	4	8	1	22
Total					3	1	14	6	5	2	18	23	3	75

1/ Cover as of second mission each year.
2/ Not sampled.

Table 5
Occurrence of Samples with Coefficient of Variation Greater than that Obtained From the Equation, $CV = e^{-5.85\bar{x}}$

Field Cover	Sampling Horizon (cm)			Total
	0–2.5	0–5	0–10	
Wheat	10	9	9	28
Fallow	4	4	5	13
Pasture	12	11	7	30
Alfalfa	3	0	1	4
Total	29	24	22	75

Several characteristics concerning those data points possessing excessive CV values continue to recur. Most of these points occurred during months which experienced excessive precipitation. Although the April 1977 data, which had the greatest overall mean soil moisture, only produced 6 data points outside the envelope curve. Precipitation in this case had occurred sufficiently far in advance of the sampling date to have permitted uniform distribution of the soil moisture throughout the individual fields.

Tables 4 and 5 indicate that the greatest number of points with coefficients of variation exceeding those predicted by equation (2) are related to fields of pasture and wheat cover, although more than two times as many wheat fields were sampled as pastures. An inspection of the wheat fields will indicate that many are in poorly drained areas, while several are actually plowed pastures. Pastures have traditionally been relegated to areas containing imperfectly drained soils, often in low lying areas adjacent to streams. In many instances, these areas are grazed. Pastures often suffer from severe compaction, contain impervious layers, and possess other physical parameters making them extremely marginal agricultural areas. Many pastures were found to contain extensive areas of free standing water, attesting to their lack of drainage and overall poor quality.

An additional observation indicates that many of the high CV values occur during a period when moisture is not limiting. Grouping by horizon shows that most of the excluded points are

2.5 cm samples, while the fewest in number are 10 cm measurements. It can be seen that while some of the high CV values are due to random variation and measurement error, most can be explained by a number of shared systematic physical properties.

Equation (2) was used to demonstrate the relationship between the coefficient of variation, mean soil moisture and the standard deviation. Figure 6 shows the greatest standard deviations to occur at soil moistures between 15 and 25 percent, or what is generally considered average conditions. At values above and below this range, the soil again becomes more spatially uniform with respect to its moisture content.

These relationships allow one to estimate the minimum sample size required per sampling unit (field, mile, etc.) at a given level of confidence. One approach to determining the number of samples is to assume that the data are normally distributed and use the procedure outlined by *Snedecor and Cochran* (1967). This procedure requires that one set the limits (L) in which the estimate would be correct and also the probability limits. Assuming a 95 percent probability the formula is

$$n = 3.84\sigma^2/L^2 \tag{3}$$

and for 99 percent probability is

$$n = 6.63\sigma^2/L^2 \tag{4}$$

Thus equations (3) and (4) indicate the number of samples required to be 95 or 99 percent confident that the true mean for the field is within plus or minus L of the observable mean.

These equations assume that the soil moisture values are normally distributed about the mean. Studies of intensively sampled fields by *Hills and Reynolds* (1969), *Nielsen et al.* (1973) and *Bell et al* (1980) have indicated that the assumption of a normal distribution is valid. Using this approach with a 95 percent probability and the further assumption that the error in soil moisture should not exceed 2 to 4 percent (percent here refers to the deviation from a measured percentage of soil moisture), sampling estimates have been summarized in Table 6. One could, of course, be more conservative and assume the 99 percent probability level, although this would require approximately twice as many samples. Should the question of normality be of concern, then a "t"-test approach could be utilized. However, assuming that the basis for Table 6 is acceptable, the

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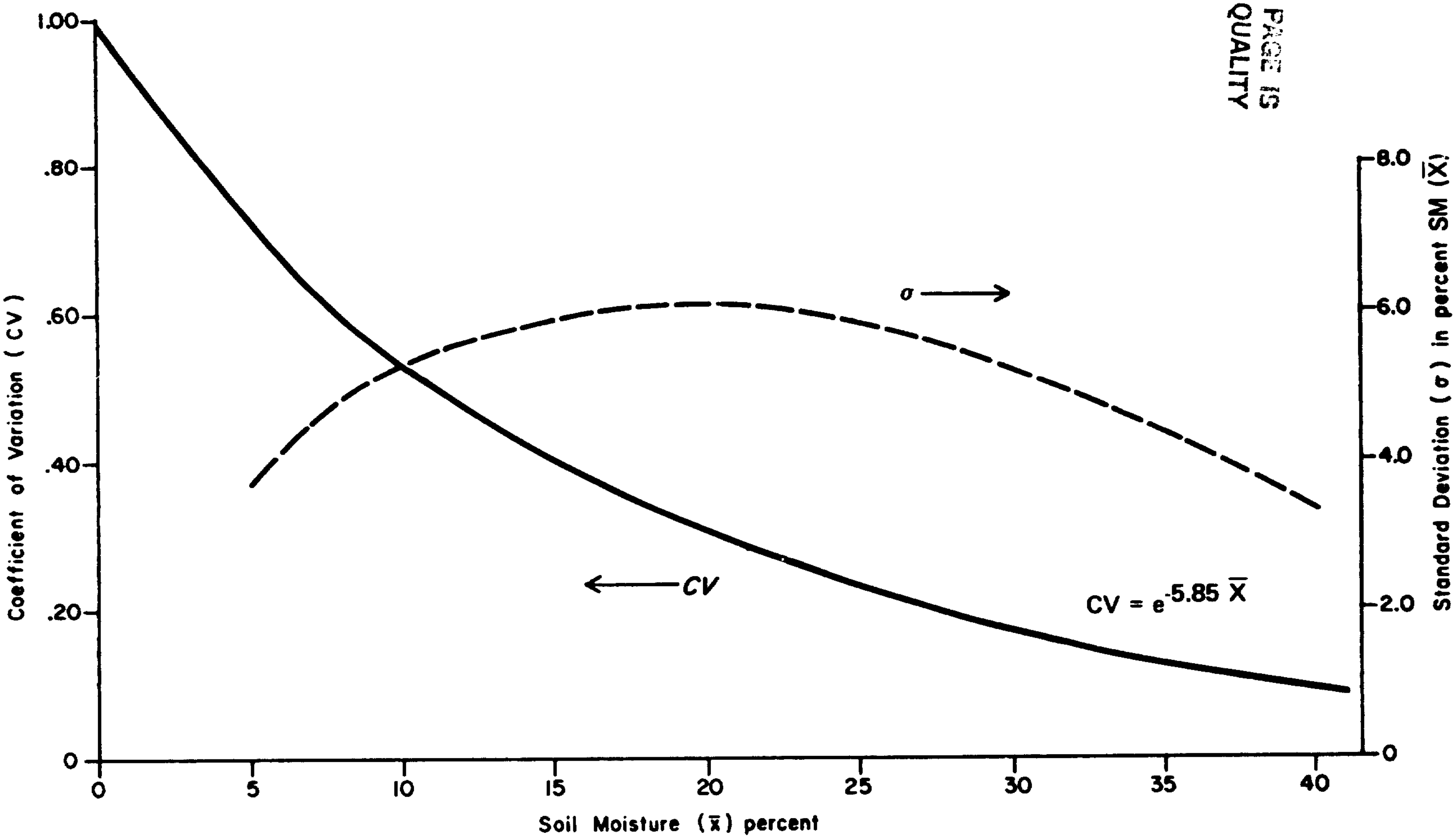

Figure 6. Relationship Between $\overline{x}$ and CV, and $\overline{x}$ and σ

sampling of 16 points per full field unit appears to be adequate. Looking at the field arrangement, one notices that a full field has a length of approximately 1.6 kilometers (1 mile). The sampling pattern described in Figure 4 produces 10 points per kilometer or 16 points per full field unit. If points A, B and C are all used, a sample size of 24 points per full field unit (1.6 km) will result. On this basis, one might conclude that the sampling pattern suggested earlier is justified for the larger field units, especially during average conditions. During dry periods, or when sampling fields of obvious high cover, topographic and/or soil variability, sound judgement might direct one to systematically increase the number of sample points.

Table 6
Estimates of Sample Size at 95% Probability Using the Relationship $CV = e^{-5.85\bar{x}}$

Soil Moisture (%)	Coefficient of Variation 1/	Estimate of σ 2/	Sample Size with Error Allowable		
			L=2%	L=3%	L=4% 3/
5	.75	3.7	13	6	4
10	.56	5.6	30	13	7
15	.42	6.2	37	17	9
20	.31	6.2	37	16	9
25	.23	5.8	32	14	8
30	.17	5.2	26	12	7
35	.13	4.5	20	9	5
40	.1	3.9	14	6	4

1/ From equation (2)   2/ $\sigma = CV(\bar{x})$

3/ 4 samples would be the minimum sample size permitted; a lesser number would imply sampling at only one location.

SUMMARY AND CONCLUSIONS

As with previous studies, soil moisture is again found to be highly variable, both vertically and laterally within a given field and between fields. The coefficient of variation was found to be inversely related to the moisture content of the soil. Variation was generally found to be highest in the 0-2.5 cm samples and least in the 0-10 cm measurements.

Horizontally within fields, pastures were found to be the most variable with respect to moisture content, although other fields displaying marginal physical properties such as poor drainage, depressions and high density soils were found to be equally variable. Variability between fields appears to be primarily due to cover, surface condition, drainage and soil type.

The standard deviation can be expected to be greatest at moisture contents between 15 and 25 percent. As $\bar{X}$ decreases below this range, soil moisture loss is increasingly affected by associated soil physical parameters, creating steep gradients within the soil moisture profile. As $\bar{X}$ increases beyond this range, subsurface moisture is transmitted more evenly and rapidly in all directions. Moisture loss is consequently more uniform throughout the profile resulting in smaller gradients.

The sampling scheme used in the study appears to be adequate when confronted with average moisture conditions in uniformly-textured, well-drained soils. Adjustments in sampling intensity to account for abnormal or poor physical conditions may be made in the field after careful evaluation by the observer.

Variability could be considerably reduced by exercising some discretion as to which fields are to be sampled, although this may tend to yield somewhat biased measurements, resulting in inadequate representation of the study site. One must reach a compromise during sampling, between the arbitrary exclusion of fields with potential high variability or increasing the number of measurements in these fields within the limits of one's available resources.

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APPENDIX 1

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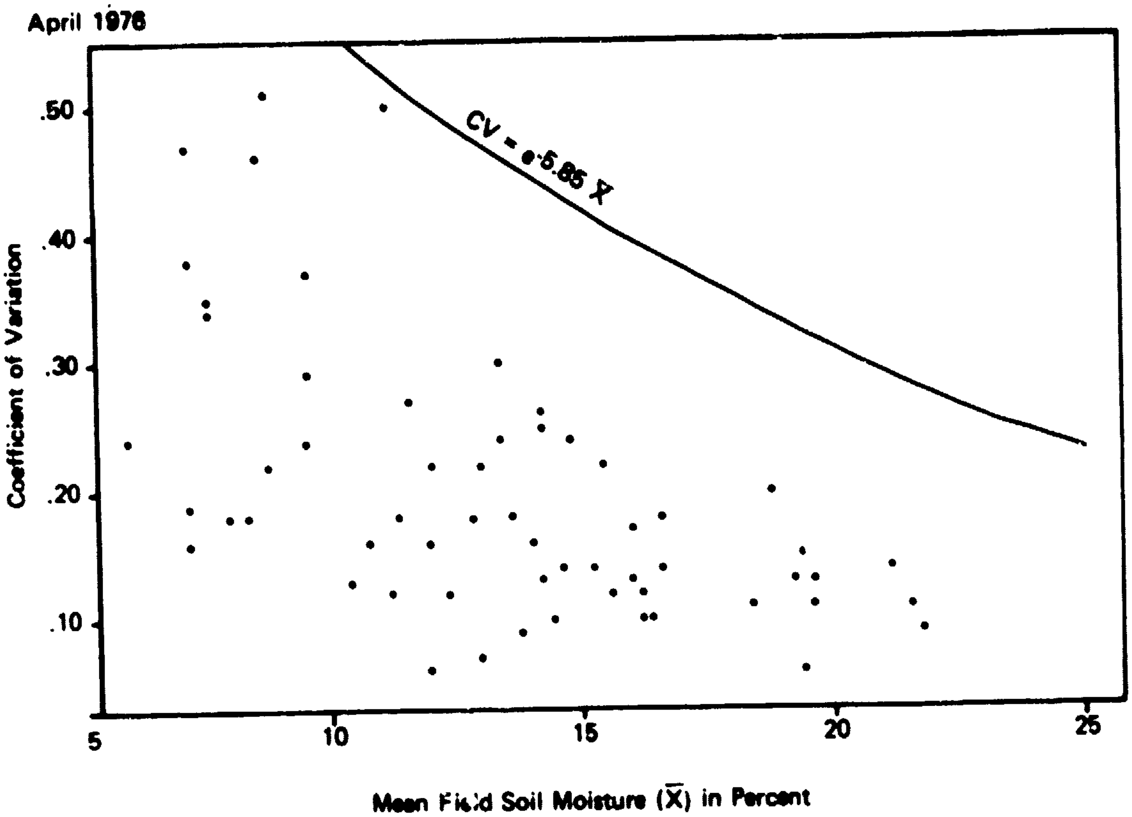

Figure 1. Coefficient of variation versus the mean field soil moisture for the April 1976 data.

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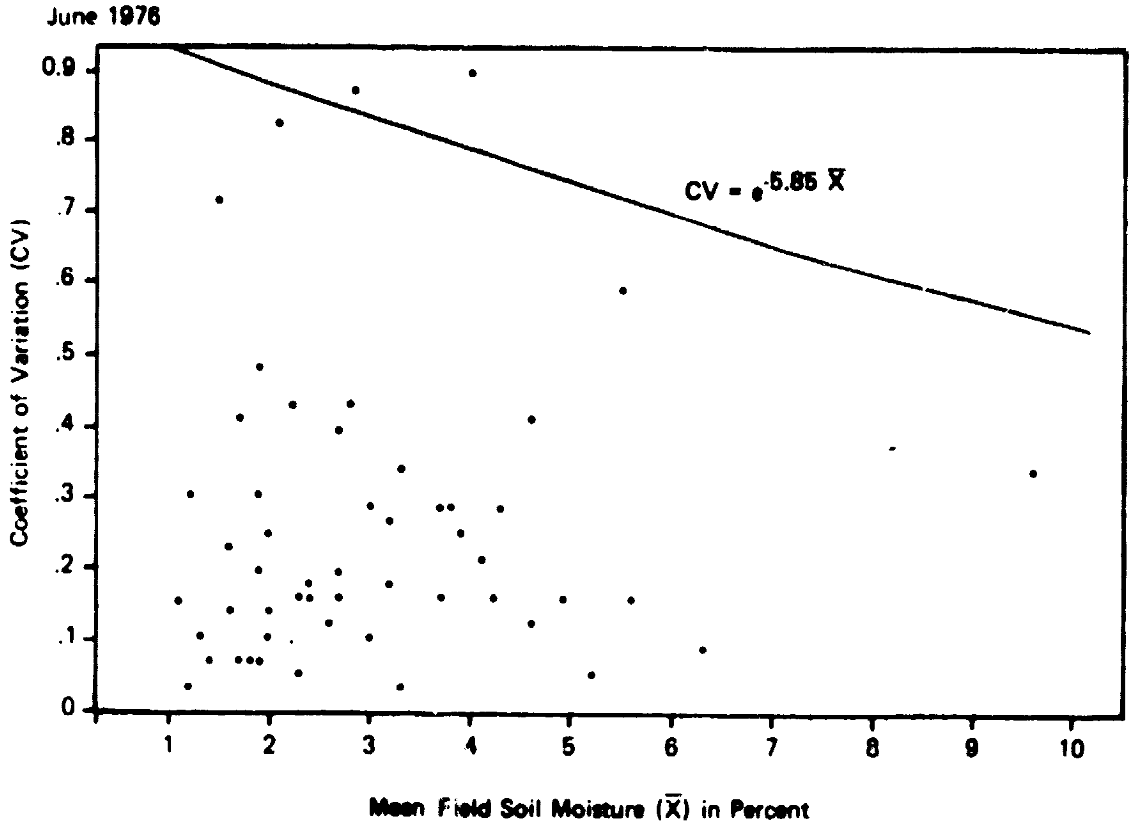

Figure 2. Coefficient of variation versus the mean field soil moisture for the June 1976 data.

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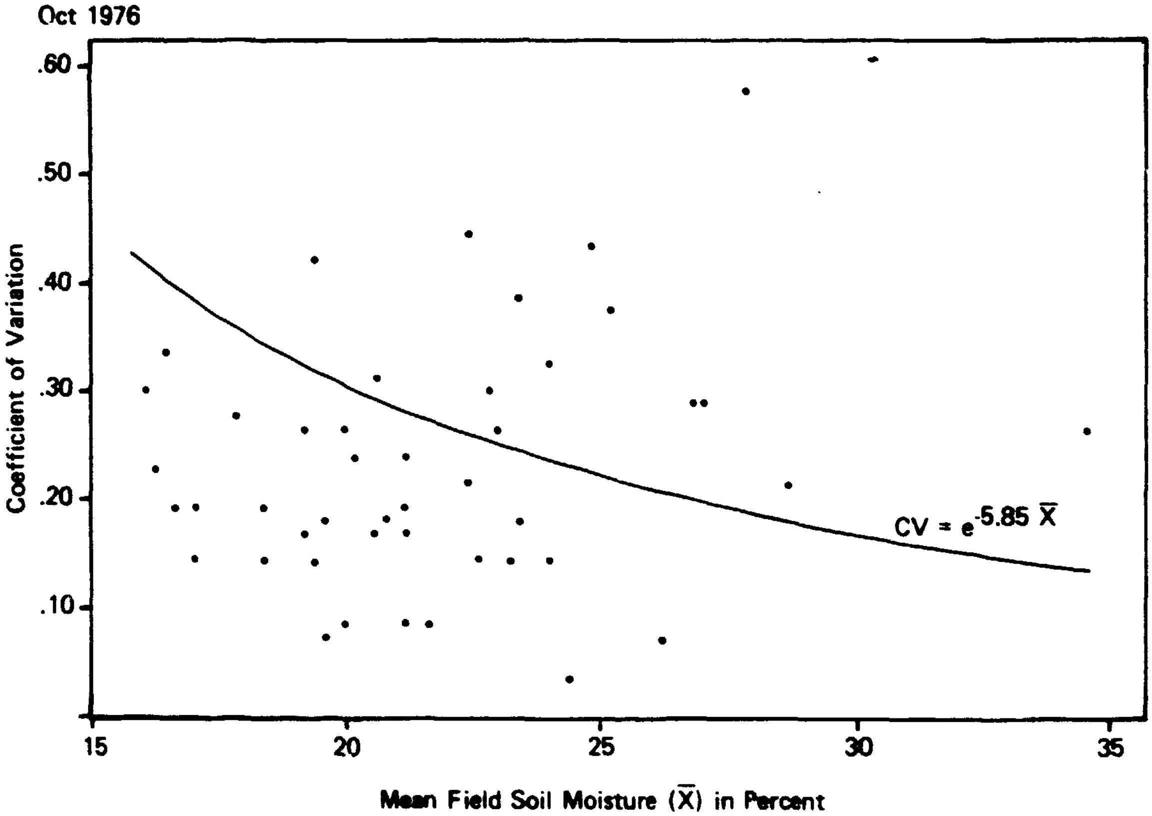

Figure 3. Coefficient of variation versus the mean field soil moisture for the October 1976 data.

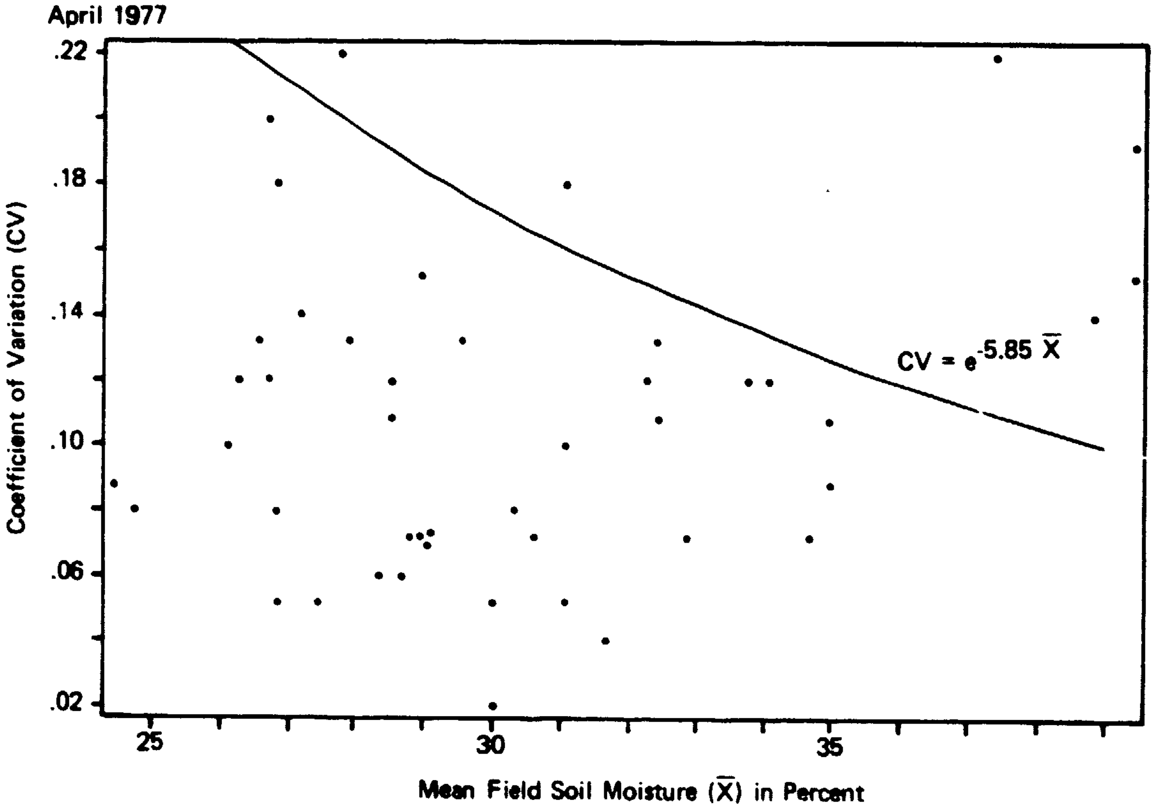

Figure 4. Coefficient of variation versus the mean field soil moisture for the April 1977 data.

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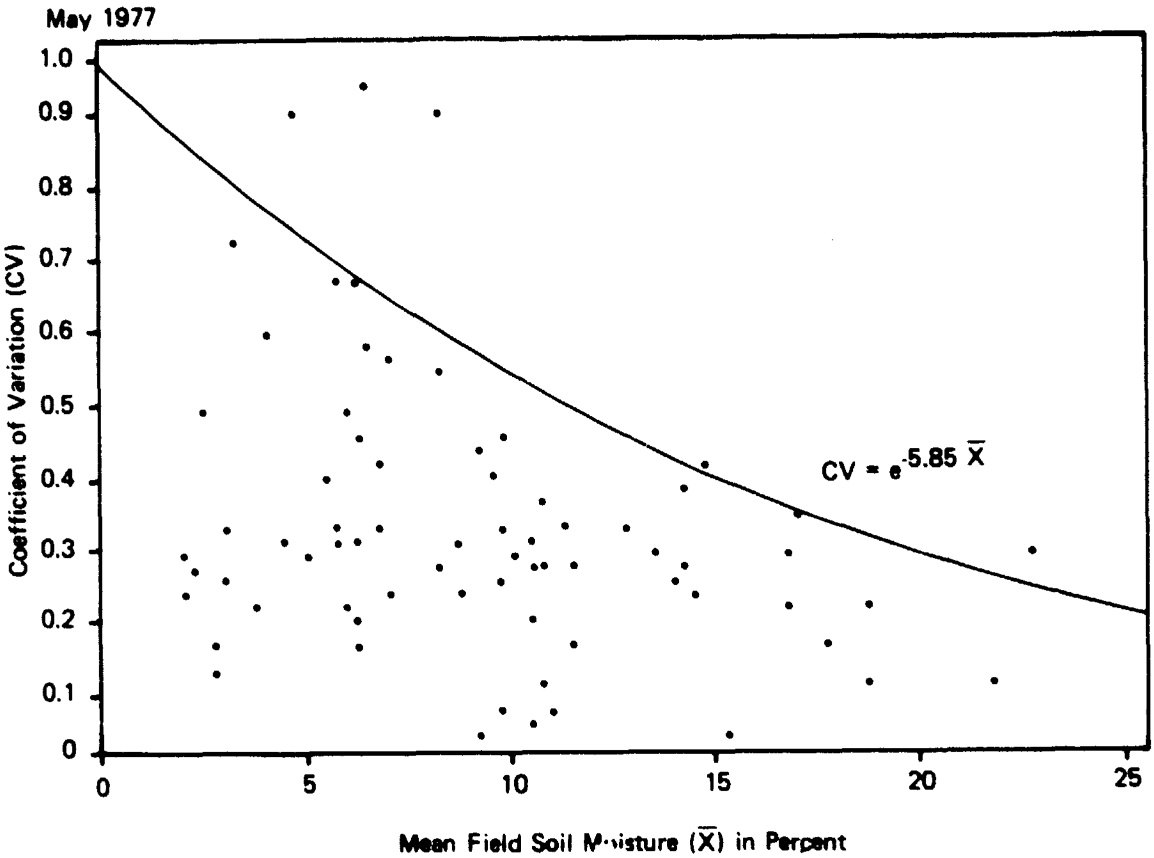

Figure 5. Coefficient of variation versus the mean field soil moisture for the May 1977 data.

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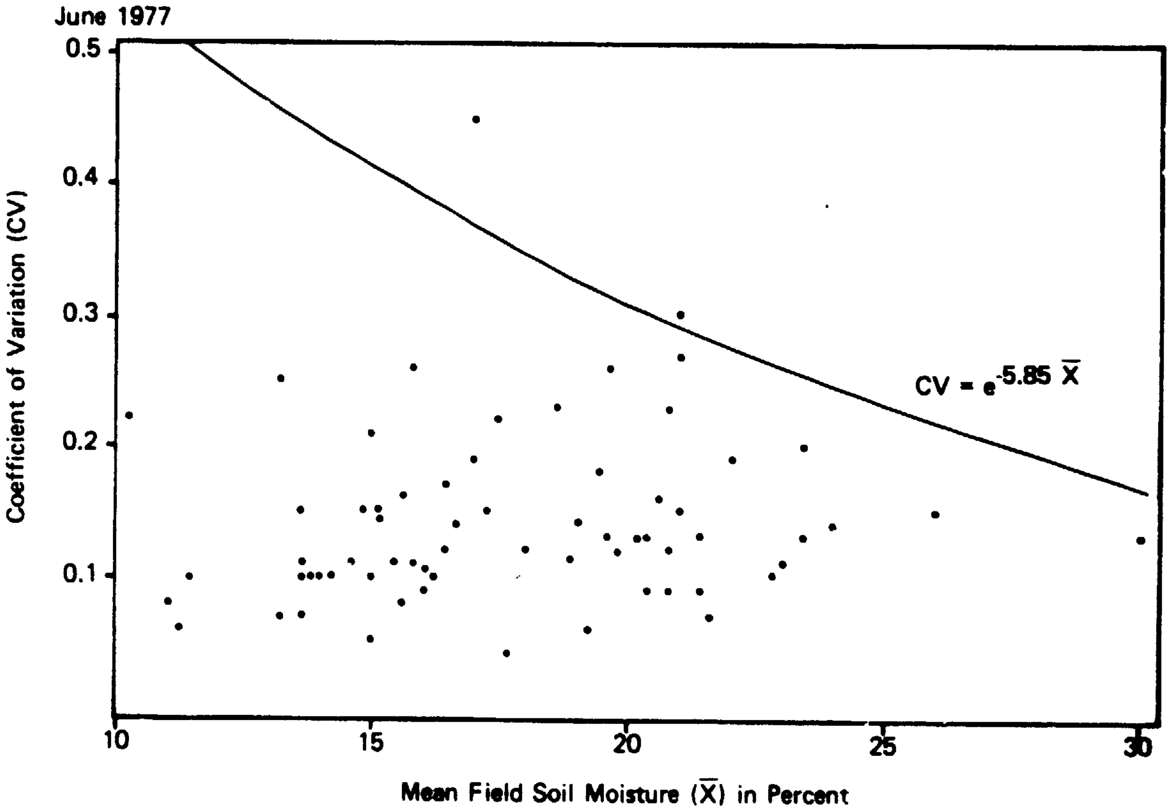

Figure 6. Coefficient of variation versus the mean field soil moisture for the June 1977 data.

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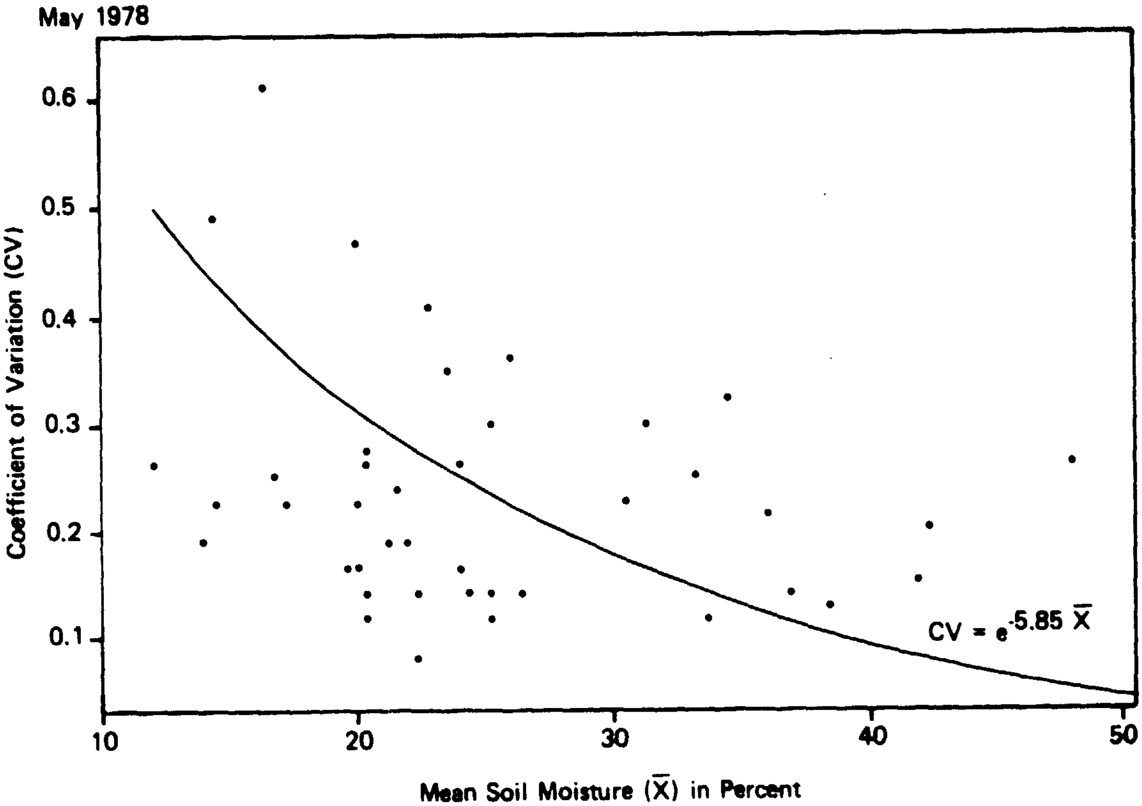

Figure 7. Coefficient of variation versus the mean field soil moisture for the May 1978 data.

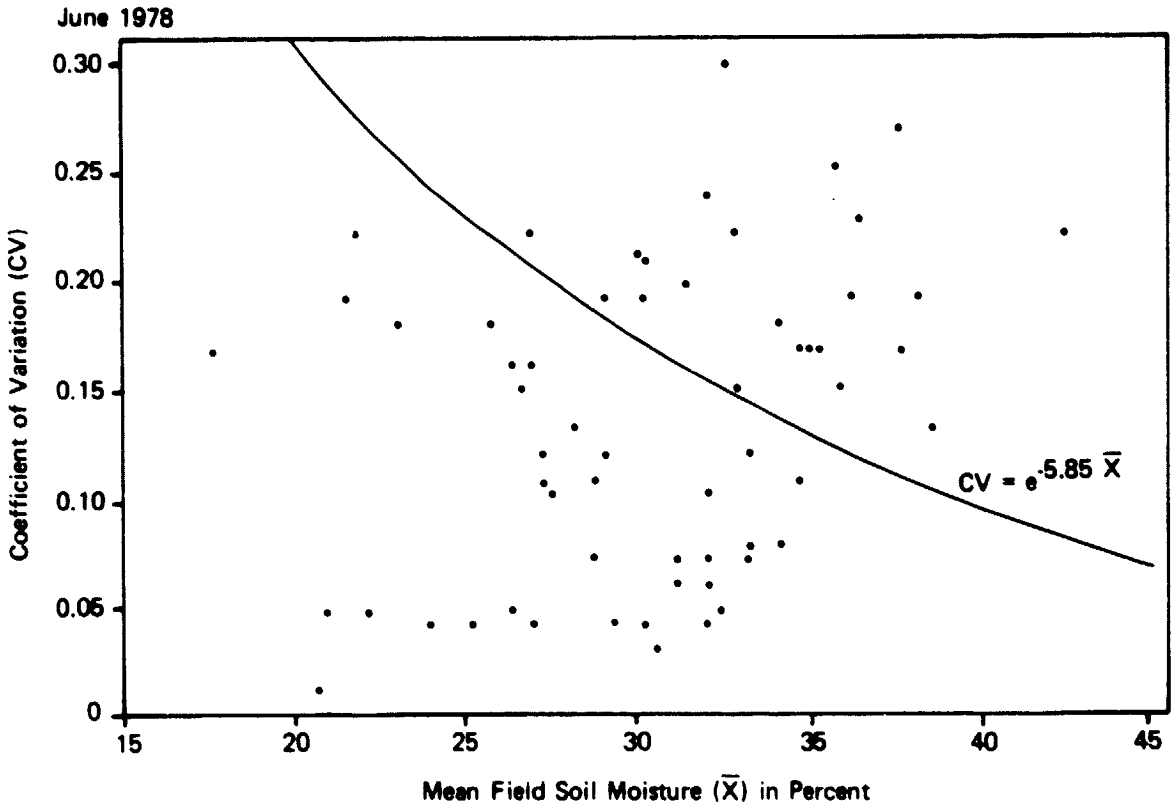

Figure 8. Coefficient of variation versus the mean field soil moisture for the June 1978 data.

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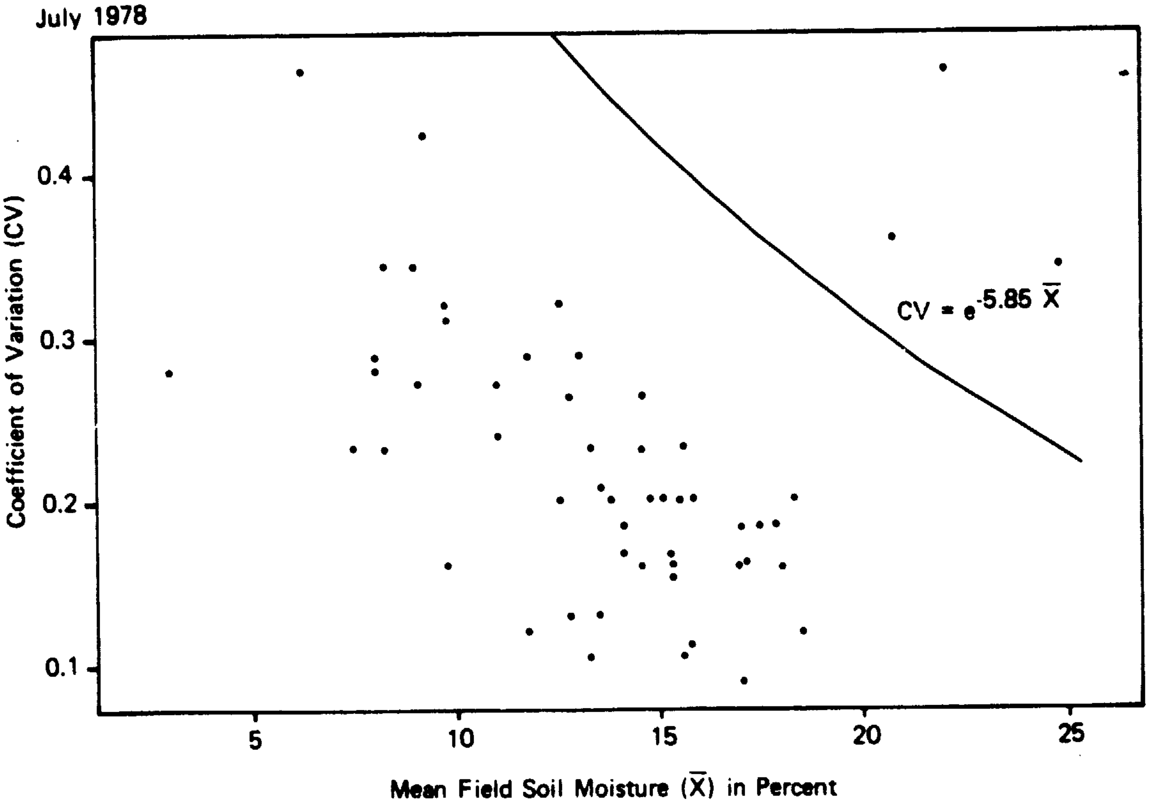

Figure 9. Coefficient of variation versus the mean field soil moisture for the July 1978 data.