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WITHIN-FIELD VARIABILITY OF PLANT AND SOIL PARAMETERS

3. Brian Brisco, Fawwaz T, Ulaby and Craig Dobson

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For research and development as well as applications-oriented studies in remote sensing, sub-units, called test sites, are used to describe the areas being studied. It is desirable to obtain enough measurements for any given variable to be able to confidently describe the mean and standard deviation. The results reported in this paper indicate that eight samples may be adequate for plant height determinations whereas approximately 20 samples are needed for plant- and soil-moisture characterization. A sampling intensity of 18 was found to be suitable for detecting within-field variability over time and between-field variability for the same crop. Although the gathering of this many samples may be impractical, it appears to be necessary to confidently describe the means and standard deviations of the variables measured in this experiment. The results also indicate that the necessary sample sizes may vary according to (1) the physiological growth stage of the crop, and (2) recent weather events that may affect the moisture and/or height characteristics of the field in question.

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December 1981

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ABSTRACT

For research and development as well as applications-oriented studies in remote sensing, sub-units, called test sites, are used to describe the areas being studied. It is desirable to obtain enough measurements for any given variable to be able to confidently describe the mean and standard deviation. The results reported in this paper indicate that eight samples may be adequate for plant height determinations whereas approximately 20 samples are needed for plant- and soil-moisture characterization. A sampling intensity of 18 was found to be suitable for detecting within-field variability over time and between-field variability for the same crop. Although the gathering of this many samples may be impractical, it appears to be necessary to confidently describe the means and standard deviations of the variables measured in this experiment. The results also indicate that the necessary sample sizes may vary according to (1) the physiological growth stage of the crop, and (2) recent weather events that may affect the moisture and/or height characteristics of the field in question.

1.0 INTRODUCTION

The value of using remote sensing techniques to monitor the earth's surface has received much attention in the past decade. Applications related to studies of snow, soil moisture, agricultural productivity, geology, etc., have been proposed, and in some cases implemented during this period of rapid development. In the future, continued development and increased use of these techniques can be expected.

Ground investigations of the area to be remotely sampled are used to evaluate the sensor's output for both research and development and applications-oriented studies. The types of ground investigations performed in support of remote sensing studies are summarized by Reeves (1975). In general, small areas are selected from the entire area to serve as test sites for sampling purposes. Therefore, an important question to consider is whether the test sites adequately represent the entire area being investigated. For any given variable to be measured, statistical procedures can be used to determine the sampling intensity required to describe the mean and standard deviation. However, constraints on manpower, time, equipment, and other resources usually prevent this approach.

The Remote Sensing Laboratory (RSL) has been investigating the microwave interaction with vegetation media for the past eight years. Radar backscatter behavior as a function of the geometrical and electrical properties of vegetation, and the use of radar for crop identification have been studied (Ulaby, 1981). Although the sampling techniques for ground-truth data acquisition in soil moisture studies have been evaluated (Rao, 1976), a similar study has not been conducted for the vegetation experiments.

This report investigates the variability of ground-truth data collected for vegetation experiments conducted at the RSL. Two different fields of wheat and a field of corn were sampled on two dates to provide a data base for this study. The variability of crop- and soil-parameters within a field, between two fields of the same crop type, and within a field over time were compared statistically. The results were used to evaluate ground-truth sampling programs carried out in support of vegetation studies and to make recommendations for future experiments.

2.0 GROUND TRUTH DATA COLLECTION

The test site used for this experiment is located in the Kansas River floodplain near the confluence of the Kansas River and the Wakarusa River east of Lawrence, Kansas. This area is characterized by a diverse assemblage of soils with a variety of crop types present, and is the site of current RSL experiments involving crop-discrimination and soil-moisture studies. Wheat 4 and Corn 6 were both located on a silt-loam soil while Wheat 8 was on a sandy-loam soil. The two wheat fields were sampled on June 10 and 17, 1981, while the corn field was visited on June 17 and 30.

Each field was sampled in the same way, as follows: A 40-meter swath was identified on the road-side of the field by means of surveyor flags. The ground-truth team was composed of six individuals split into three groups of two individuals each. From the start of the identified swath they proceeded directly into the field for a distance of 35 meters. Using this location as a reference point, three plots of 10 m x 10 m, each separated by 5 meters, were marked out. One team then proceeded to each of these plots to sample plant height, soil moisture, and plant moisture. For the wheat fields both spike height and leaf height were recorded. Figure 1 illustrates the plot- and sampling-locations within a field.

Each field worker sampled each variable three times, giving rise to six samples per plot and eighteen samples per field. Sample locations were randomly chosen by each individual within his respective plot. Plant- and spike-heights were measured to the nearest CM using a meter stick. Soil samples were collected with a trowel for the 0-5-cm depth and stored in plastic coffee cups for later gravimetric moisture analysis. One corn plant per sample location was obtained for gravimetric moisture determination while half a linear-foot of row was sampled in the wheat fields.

3.0 STATISTICAL ANALYSIS

Due to the paucity of data points (3) per individual, within-plot variability could not be evaluated. The data collected by each pair of individuals were then pooled on a plot basis. The same pair of individuals visited the same plots in each field so that the comparison of the six samples for each variable from any given plot would be valid. All statistical analyses were performed using the SPSS system of computer programs (Nie et al., 1975; Nie and Hall, 1981).

Nonparametric statistics were used as there were not enough observations to specify the distributions of the variables. The one-way analysis of variance developed by Kruskal and Wallis (1952) was used to determine whether all plots within a field were from the same populations. To

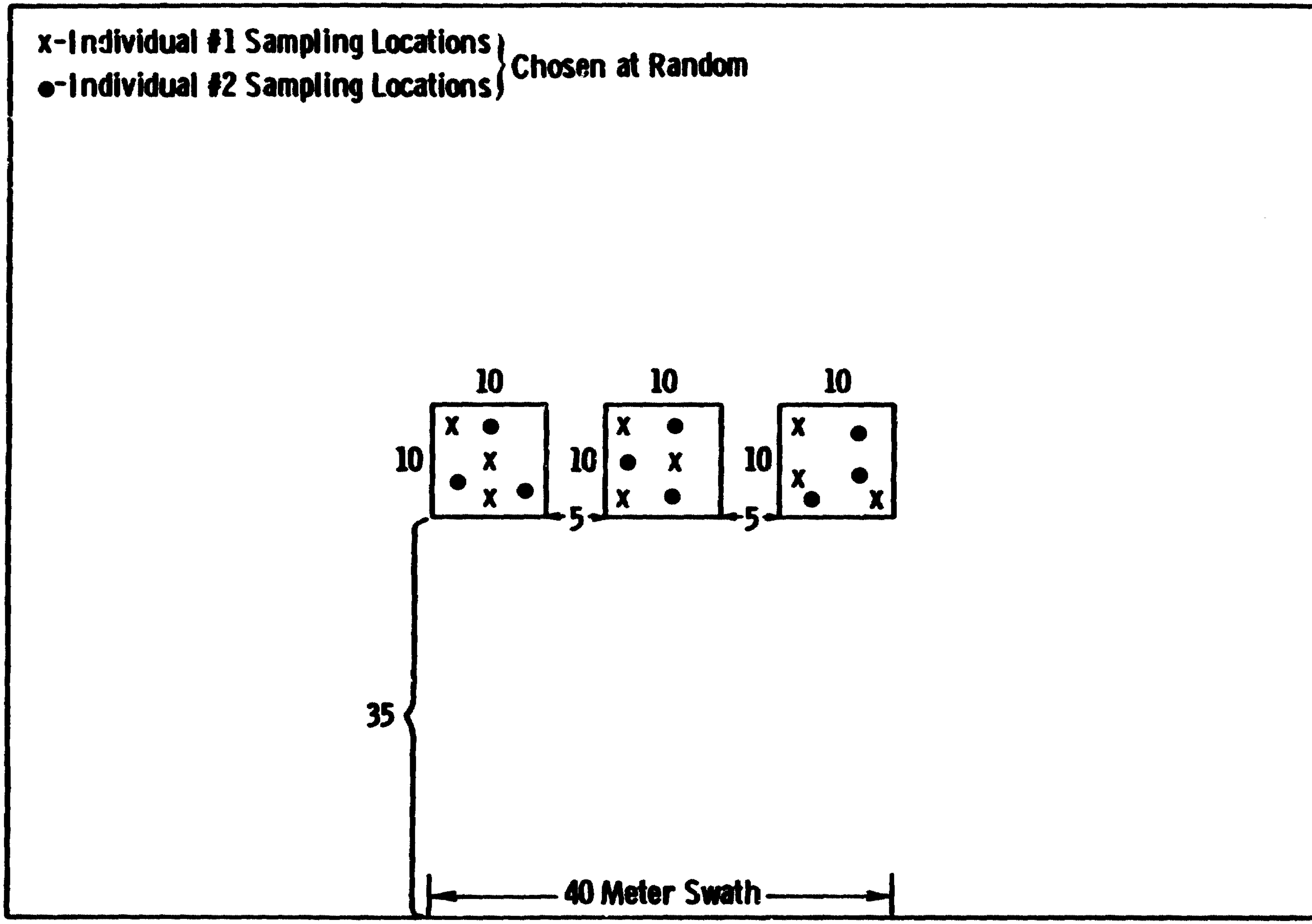

Figure 1. Location of Plots and Sampling Sites Within a Field. (All Distances in Meters)

find out if there were significant differences in a variable between the two wheat fields, the Mann-Whitney mean test (Mann and Whitney, 1947) was applied. The Wilcoxon matched-pairs ranked-signs test was used to checked for differences between the same variable in a field on two different dates (Wilcoxon, 1945). Between-field differences for the wheat fields were also determined using the classical T-test for independent samples. Similarly, the T-test for dependent samples was employed to further investigate differences between the same variable in one field at two different times.

4.0 RESULTS AND DISCUSSION

The field data for the wheat fields are presented in Table 1 and for the corn field in Table 2. Computer outputs for the various statistical tests can be found in Appendix I. Results from the Kruskal-Wallis one-way ANOVA (Table 3) indicate that in approximately half of the cases there was a significant difference between plots within a field. Spike height exhibited the greatest variability, with four out of the six cases indicating significant differences. Plant water content, leaf height, and soil moisture were significantly different 50 percent of the time.

The results in Table 3 also indicate that Wheat 8 changes from conditions of low variability on June 10 to high variability on June 17 for the variables measured. Wheat 4 shows mixed results, with similar field variability between the two dates, but for exactly opposite plant/soil variables. Corn 6 exhibits high variability on both dates for the three variables measured. These results indicate that a sample size greater then six per field is needed to confidently determine the mean of the variables observed in this experiment.

The calculated means (M) and standard deviations ($\overline{sd}$) reported in Tables 1 and 2 can be used to estimate the sampling intensity required to accurately determine the mean 90 percent of the time. The formula used to calculate this sampling intensity is

$$N = \left(\frac{\sqrt{18} \times \overline{sd}}{M \times .1} \right)^2$$

where

N = estimated sampling intensity

$\sqrt{18}$ = sample size for estimates of M and $\overline{sd}$

$\overline{sd}$ = standard deviation from Tables 1 and 2

M = mean from Tables 1 and 2

Table 4 presents the estimated sampling intensities obtained using this expression.

These results indicate that 68 percent of the variables measured during this experiment require a sample size of fewer than 18 for estimating the mean and standard deviation. The average estimated sample size for these variables is 8. In general, smaller sample sizes are needed for plant-height measurements compared to plant- or soil-moisture observations. Soil moisture is quite variable and thus a larger sample size is needed to estimate the mean and standard deviation. Rao (1976) reports sample sized of 11-32 for the 0-5-cm depth in a 2½-acre field, which is similar to the average number of 20 reported in Table 4. Crop moisture in the corn fields is quite uniform during the growth stage (vegetative) that the plants were in during this experiment. Thus, small sample-sizes will adequately describe the mean and standard deviation. However, the wheat fields were maturing during this experiment and thus moisture conditions were changing. This is reflected in the sample sizes reported in Table 4.

Since the means and standard deviations used to estimate the sample sizes reportes above are based on a small sample-size (18), the estimated sampling intensity must not be considered absolute. However, the results indicate approximately the number of samples that is required to accurately describe the variables measured in this experiment. It appears that height characteristics should be estimated using sample sizes of 6-10 while the moisture estimates require more samples (12-20) for accurate determinations. The sampling intensity will also be a function of the growth stage of the crop in question, as well as recent weather events.

Between-field variability for the two wheat fields was assessed using both nonparametric tests and the classical T-test procedure for independent samples. The results (Table 4) are the same for both approaches and indicate no significant difference between fields for spike height and leaf height on June 10. In all other cases, the means for the observed variables are significantly different at the 99-percent confidence level.

At this time of year, the wheat crops are approaching maturity and little change in plant growth is expected. The significant difference in the plant-height variables found on June 17, but not on June 10, may be due to crop damage caused by bad weather in late May and early June. More damage, from wind and rain, was observed in Wheat 4 than in Wheat 8 on the June 10 sample data. By June 17, Wheat 8 had recovered to a greater extent than had Wheat 4. Although the sample size appears to be too small for within-field variability analysis of plant- and soil-moisture differences, the highly significant results reported in Table 4 indicate that the pooled samples are sufficient to detect between-field differences.

The results of the comparisons within a field over time are presented in Table 5. Very similar results are found using parametric versus nonparametric statistical procedures. The argument presented above for between-field variability in wheat-plant height variables can be applied to the results in Table 5. Similarly, it appears that the pooled sampling intensity is large enough to detect differences in the other variables within a field over time. This is expected for the moisture variables, as rainfall events and changes in plant maturity occurred during the time period of the experiment. Corn is in a vegetative stage of growth at this time of year and thus is rapidly increasing in height. This change is readily detected using the sampling intensity method and methods reported above, as the 99-percent significant level in Table 5 indicates.

Thus it appears that six samples per field is an inadequate number to determine the mean of the plant-soil variables observed in this experiment. Height characteristics can be estimated with approximately eight samples while approximately 20 samples are needed for moisture estimates of plants and soil. These sample sizes may vary according to (1) the growth stage of the field in question, and (2) recent environmental events such as rainfall. A sample size of 18 appears to be suitable for detecting between-field variability and temporal within-field variability of the measured plant-soil variables. Although this sampling intensity might often be impractical, it may be necessary to produce reliable quantitative results. An experiment needs to be conducted, with a larger sample size than was used in this effort, to more accurately determine within-field variability for these plant-soil parameters.

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TABLE 1

Field Data for Wheat Fields # 4 and 8

FIELD #	PLOT #	SAMPLE #	June 10 SPIKE HEIGHT	June 10 LEAF HEIGHT	June 10 PLANT H_2O	June 10 SOIL H_2O	June 17 SPIKE HEIGHT	June 17 LEAF HEIGHT	June 17 PLANT H_2O	June 17 SOIL H_2O
W4	1	1	96	70	47.57	33.79	106	66	37.14	37.00
		2	98	70	55.24	31.83	92	61	35.25	34.72
		3	105	70	52.65	33.33	103	72	42.11	40.71
		4	97	65	52.39	29.90	98	66	37.88	36.17
		5	96	73	54.60	31.92	105	73	67.24	42.22
		6	94	67	55.20	35.22	100	78	55.29	38.83
	2	1	97	72	51.17	27.32	111	74	32.49	37.50
		2	98	70	51.02	36.73	95	68	35.50	35.51
		3	102	78	53.02	33.02	91	63	40.45	36.90
		4	105	75	56.13	36.17	95	75	37.47	37.38
		5	104	82	51.87	34.16	95	74	40.08	36.53
		6	98	72	61.48	32.92	96	73	34.93	35.91
	3	1	105	74	55.87	38.80	93	74	40.38	41.12
		2	101	76	54.81	35.48	91	64	41.99	36.18
		3	106	75	55.80	37.80	92	67	43.27	39.12
		4	105	79	56.41	36.61	85	65	37.06	36.97
		5	99	69	53.32	33.95	88	68	43.73	39.98
		6	98	76	53.69	36.63	92	67	41.15	38.00
MEAN			99.94	72.94	54.01	34.20	96.0	69.33	41.30	37.82
STANDARD DEV.			4.17	4.36	2.93	2.87	6.73	4.85	8.16	2.09
W8	1	1	100	70	43.27	20.64	70	57	13.08	36.89
		2	98	63	45.40	24.41	78	48	12.16	24.12
		3	95	73	44.16	17.77	80	54	16.41	25.23
		4	94	58	49.29	22.24	85	49	18.37	24.44
		5	97	69	49.19	21.06	67	41	8.50	20.96
		6	102	68	48.31	19.58	74	46	6.57	24.07
	2	1	92	65	54.84	21.38	91	60	16.79	22.96
		2	99	60	55.41	19.38	82	63	21.90	22.61
		3	97	55	50.26	21.90	80	58	24.37	24.08
		4	108	79	44.46	19.71	90	61	20.60	24.60
		5	98	75	43.98	20.94	77	64	21.02	23.31
		6	101	72	47.09	21.51	84	62	17.97	22.63
	3	1	89	63	43.99	20.82	86	60	17.98	23.82
		2	111	74	53.82	21.65	92	73	27.78	24.31
		3	113	86	53.31	25.03	83	63	20.74	22.93
		4	100	70	46.99	21.56	91	66	31.26	22.95
		5	111	81	50.95	17.63	95	68	27.41	22.48
		6	108	78	45.39	24.89	96	68	30.14	22.42
MEAN			100.72	69.94	48.34	21.20	83.39	58.94	19.58	24.16
STANDARD DEV.			6.89	8.31	4.03	2.08	8.29	8.48	6.95	3.34

TABLE 2

Field Data for Corn Field #6

FIELD #	PLOT #	SAMPLE #	June 17 SPIKE HEIGHT	June 17 PLANT H_2O	June 17 SOIL H_2O	June 30 SPIKE HEIGHT	June 30 PLANT H_2O	June 30 SOIL H_2O
C6	1	1	188	89.73	21.99	275	82.22	24.82
		2	191	90.73	22.01	273	81.65	24.77
		3	186	91.33	19.57	274	81.94	30.76
		4	195	91.07	23.20	285	82.14	28.13
		5	175	91.54	22.22	283	91.63	31.24
		6	190	92.01	22.19	280	81.75	28.82
	2	1	195	90.90	22.42	264	83.89	25.93
		2	192	92.43	24.77	255	82.00	26.81
		3	193	93.03	25.40	270	80.60	22.86
		4	185	92.46	19.99	268	83.82	23.09
		5	200	92.41	19.24	260	83.21	21.77
		6	179	92.12	20.72	290	83.00	23.28
	3	1	161	93.79	19.69	264	79.91	24.91
		2	183	90.80	20.04	256	83.88	28.52
		3	181	90.72	17.02	265	83.81	27.32
		4	169	91.57	20.66	270	82.44	24.17
		5	163	90.42	17.70	267	81.43	28.50
		6	161	92.12	15.52	250	79.59	28.02
	MEAN		182.61	91.62	20.80	269.39	82.76	26.32
	STANDARD DEV.		12.29	1.02	2.55	10.76	2.58	2.77

TABLE 3

Kruskal-Wallis One-Way ANOVA Results
for Wheat Fields #4 and #8 and Corn Field #6

FIELD & DATE	SPIKE HEIGHT	LEAF HEIGHT	% PLANT MOISTURE	% SOIL MOISTURE
W4 - June 10	NS	S**	NS	S**
W4 - June 17	S**	NS	S*	NS
W8 - June 10	NS	NS	NS	NS
W8 - June 17	S***	S***	S***	NS
C6 - June 17	S***	--	S*	S**
C6 - June 30	S**	--	NS	S**

NS = no significant difference between plots

S*, S**, S*** = 90, 95, 99% significance levels respectively

TABLE 4

Sample Size Estimates from Field Standard Deviation and Mean

FIELD #	DATE	VARIABLE	SAMPLE SIZE
W4	June 10	Spike HT	3
		Leaf HT	6
		Plant H_2O	5
		Soil H_2O	13
	June 17	Spike HT	9
		Leaf HT	9
		Plant H_2O	70
		Soil H_2O	6
W8	June 10	Spike HT	8
		Leaf HT	25
		Plant H_2O	13
		Soil H_2O	17
	June 17	Spike HT	18
		Leaf HT	37
		Plant H_2O	227
		Soil H_2O	34
C6	June 17	Spike [illegible]	8
		Plant H_2O	1
		Soil H_2O	27
	June 30	Spike HT	3
		Plant H_2O	2
		Soil H_2O	20

TABLE 5(a)

Mann-Whitney U Test for Between-Field Variability of Wheat #4 and Wheat #8

DATE	SPIKE HEIGHT	LEAF HEIGHT	% PLANT MOISTURE	% SOIL MOISTURE
June 10	NS	NS	S***	S***
June 17	S***	S***	S***	S***

TABLE 5(b)

T-Test for Independent Samples of Wheat #4 and Wheat #8

DATE	SPIKE HEIGHT	LEAF HEIGHT	% PLANT MOISTURE	% SOIL MOISTURE
June 10	NS	NS	S***	S***
June 17	S***	S***	S***	S***

NS = no significant difference between means

S*** = 99% significance level

TABLE 6(a)

Wilcoxon Matched-Pairs Ranked-Signs Test
for Within-Field Variability Over Time

FIELD	SPIKE HEIGHT	LEAF HEIGHT	% PLANT MOISTURE	% SOIL MOISTURE
W4	NS	NS	S***	S***
W8	S***	S***	S***	S***
C6	S***	--	S***	S***

TABLE 6(b)

T-Test for Related Samples to Determine
Within-Field Variability Over Time

FIELD	SPIKE HEIGHT	LEAF HEIGHT	% PLANT MOISTURE	% SOIL MOISTURE
W4	NS	S**	S***	S***
W8	S***	S***	S***	S***
C6	S***	--	S***	S***

NS = no significant difference between means

S** = 95% significance level

S*** = 99% significance level

APPENDIX

SPSS Computer Outputs for Statistical Tests

```
SPSS G.T.VARIABILITY
FILE   NONAME   (CREATION DATE = 10-21-81)
- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    SH          SPIKEHT
 BY PLOT        PLOT

      PLOT          1          2          3
    NUMBER          6          6          6
MEAN RANKS       6.33      10.50      11.67
                                                   CORRECTED FOR TIES
     CASES     CHI-SQUARE  SIGNIFICANCE     CHI-SQUARE  SIGNIFICANCE
        18          3.310         0.191          3.390         0.184

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    LH          LEAFHT
 BY PLOT        PLOT

      PLOT          1          2          3
    NUMBER          6          6          6
MEAN RANKS       4.92      11.50      12.08
                                                   CORRECTED FOR TIES
     CASES     CHI-SQUARE  SIGNIFICANCE     CHI-SQUARE  SIGNIFICANCE
        18          6.670         0.036          6.760         0.034

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    PW          PLANTWATER
 BY PLOT        PLOT

      PLOT          1          2          3
    NUMBER          6          6          6
MEAN RANKS       7.83       8.33      12.33
                                                   CORRECTED FOR TIES
     CASES     CHI-SQUARE  SIGNIFICANCE     CHI-SQUARE  SIGNIFICANCE
        18          2.561         0.278          2.561         0.278
```

SPSS G.T.VARIABILITY

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SW SOILWATER
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	5.83	8.50	14.17

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	7.626	0.022	7.626	0.022

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SHB SPIKEHT2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	13.50	10.58	4.42

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	9.056	0.011	9.140	0.010

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

LHB LEAFHT2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	8.92	11.83	7.75

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	1.863	0.394	1.878	0.391

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SPSS G.T.VARIABILITY

- - - - - - KRUSKAL-WALLIS 1-WAY ANOVA

PWB PLANTWATER2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	11.00	5.67	11.83

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	4.713	0.095	4.713	0.095

- - - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SWB SOILWATER2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	10.17	6.50	11.83

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	3.135	0.209	3.135	0.209

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OF POOR QUALITY

SPSS G.T.VARIABILITY

FILE NONAME (CREATION DATE = 10-21-81)

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SH SPIKEHT
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	7.25	8.42	12.83

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	3.652	0.161	3.671	0.160

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

LH LEAFHT
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	7.17	8.50	12.83

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	3.696	0.158	3.704	0.157

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

PW PLANTWATER
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	7.50	10.67	10.33

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	1.275	0.529	1.275	0.529

SPSS G.T.VARIABILITY

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SW SOILWATER
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	8.67	8.17	11.67

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	1.509	0.470	1.509	0.470

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SHB SPIKEHT2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	4.75	9.33	14.42

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	9.845	0.007	9.865	0.007

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

LHB LEAFHT2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	3.50	10.50	14.50

			CORRECTED FOR TIES	
CASES	CHI-SQUARE	SIGNIFICANCE	CHI-SQUARE	SIGNIFICANCE
18	13.053	0.001	13.093	0.001

SPSS G.T.VARIABILITY

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

PWB PLANTWATER2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	4.00	10.33	14.17

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	11.099	0.004	11.099	0.004

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

SWB SOILWATER2
BY PLOT PLOT

PLOT	1	2	3
NUMBER	6	6	6
MEAN RANKS	12.50	9.00	7.00

CASES	CHI-SQUARE	SIGNIFICANCE	CORRECTED FOR TIES CHI-SQUARE	CORRECTED FOR TIES SIGNIFICANCE
18	3.263	0.196	3.263	0.196

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SPSS G.T.VARIABILITY
FILE   NONAME   (CREATION DATE = 10-21-81)
- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

   SH           SPIKEHT
 BY PLCT        PLOT

       PLOT           1          2          3
     NUMBER           6          6          6
MEAN RANKS        11.25      13.08       4.17
                                                     CORRECTED FOR TIES
        CASES     CHI-SQUARE  SIGNIFICANCE       CHI-SQUARE  SIGNIFICANCE
           18          9.336         0.009            9.356         0.009

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

   PW           PLANTWATER
 BY PLCT        PLOT

       PLOT           1          2          3
     NUMBER           6          6          6
MEAN RANKS         6.67      13.42       8.42
                                                     CORRECTED FOR TIES
        CASES     CHI-SQUARE  SIGNIFICANCE       CHI-SQUARE  SIGNIFICANCE
           18          5.167         0.076            5.172         0.075

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

   SW           SOILWATER
 BY PLCT        PLOT

       PLOT           1          2          3
     NUMBER           6          6          6
MEAN RANKS        11.83      11.83       4.83
                                                     CORRECTED FOR TIES
        CASES     CHI-SQUARE  SIGNIFICANCE       CHI-SQUARE  SIGNIFICANCE
           18          6.877         0.032            6.877         0.032
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SPSS G.T.VARIABILITY

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    SHB            SPIKEHT2
 BY PLOT           PLOT

        PLOT          1            2           3
      NUMBER          6            6           6
MEAN RANKS        14.50         8.17        5.83
                                                      CORRECTED FOR TIES
           CASES     CHI-SQUARE   SIGNIFICANCE     CHI-SQUARE   SIGNIFICANCE
              18          8.468          0.014          8.485          0.014

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    PWB            PLANTWATER2
 BY PLOT           PLOT

        PLOT          1            2           3
      NUMBER          6            6           6
MEAN RANKS         9.17        11.33        8.00
                                                      CORRECTED FOR TIES
           CASES     CHI-SQUARE   SIGNIFICANCE     CHI-SQUARE   SIGNIFICANCE
              18          1.205          0.548          1.205          0.548

- - - - - KRUSKAL-WALLIS 1-WAY ANOVA

    SWB            SOILWATER2
 BY PLOT           PLOT

        PLOT          1            2           3
      NUMBER          6            6           6
MEAN RANKS        12.83         4.83       10.83
                                                      CORRECTED FOR TIES
           CASES     CHI-SQUARE   SIGNIFICANCE     CHI-SQUARE   SIGNIFICANCE
              18          7.298          0.026          7.298          0.026
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SPSS G.T.VARIABILITY
FILE  NONAME  (CREATION DATE = 10-21-81)
- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST

    SH           SPIKEHT
 BY FIELD        FIELD

      FIELD     =         4        FIELD     =         8
      MEAN RANK      NUMBER        MEAN RANK      NUMBER
         18.00           18            19.00          18

                                   EXACT           CORRECTED FOR TIES
          U              W     2-TAILED P           Z        2-TAILED P
        153.0        324.0         0.7905     -0.2859           0.7749

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST

    LH           LEAFHT
 BY FIELD        FIELD

      FIELD     =         4        FIELD     =         8
      MEAN RANK      NUMBER        MEAN RANK      NUMBER
         20.72           18            16.28          18

                                   EXACT           CORRECTED FOR TIES
          U              W     2-TAILED P           Z        2-TAILED P
        122.0        373.0         0.2142     -1.2697           0.2042

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST

    PW           PLANTWATER
 BY FIELD        FIELD

      FIELD     =         4        FIELD     =         8
      MEAN RANK      NUMBER        MEAN RANK      NUMBER
         25.00           18            12.00          18

                                   EXACT           CORRECTED FOR TIES
          U              W     2-TAILED P           Z        2-TAILED P
         45.0        450.0         0.0001     -3.7017           0.0002
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SPSS G.T.VARIABILITY

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
   SW          SOILWATER
BY FIELD       FIELD

     FIELD       =         4        FIELD       =         8
     MEAN RANK        NUMBER        MEAN RANK        NUMBER
        27.50             18             9.50            18

                                     EXACT            CORRECTED FOR TIES
          U              W        2-TAILED P           Z       2-TAILED P
          0.          495.0         0.0000        -5.1255         0.0000

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
   SHB         SPIKEHT2
BY FIELD       FIELD

     FIELD       =         4        FIELD       =         8
     MEAN RANK        NUMBER        MEAN RANK        NUMBER
        25.50             18            11.50            18

                                     EXACT            CORRECTED FOR TIES
          U              W        2-TAILED P           Z       2-TAILED P
        36.0          459.0         0.0000        -3.9950         0.0001

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST
   LHB         LEAFHT2
BY FIELD       FIELD

     FIELD       =         4        FIELD       =         8
     MEAN RANK        NUMBER        MEAN RANK        NUMBER
        25.17             18            11.83            18

                                     EXACT            CORRECTED FOR TIES
          U              W        2-TAILED P           Z       2-TAILED P
        42.0          453.0         0.0001        -3.8040         0.0001
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SPSS G.T.VARIABILITY

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST

PWB PLANTWATER2
BY FIELD FIELD

FIELD = 4		FIELD = 8	
MEAN RANK	NUMBER	MEAN RANK	NUMBER
27.50	18	9.50	18

U	W	EXACT 2-TAILED P	CORRECTED FOR TIES Z	2-TAILED P
0.	495.0	0.0000	-5.1255	0.0000

- - - - - MANN-WHITNEY U - WILCOXON RANK SUM W TEST

SWB SOILWATER2
BY FIELD FIELD

FIELD = 4		FIELD = 8	
MEAN RANK	NUMBER	MEAN RANK	NUMBER
27.17	18	9.83	18

U	W	EXACT 2-TAILED P	CORRECTED FOR TIES Z	2-TAILED P
6.0	489.0	0.0000	-4.9356	0.0000

SPSS G.T.VARIABILITY

FILE NONAME (CREATION DATE = 10-21-81)

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SH SPIKEHT
WITH SHB SPIKEHT2

CASES	TIES	13 -RANKS MEAN	5 +RANKS MEAN	Z	2-TAILED P
18	0	9.65	9.10	-1.742	0.082

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

LH LEAFHT
WITH LHB LEAFHT2

CASES	TIES	10 -RANKS MEAN	5 +RANKS MEAN	Z	2-TAILED P
18	3	9.40	5.20	-1.931	0.053

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

PW PLANTWATER
WITH PWB PLANTWATER2

CASES	TIES	16 -RANKS MEAN	2 +RANKS MEAN	Z	2-TAILED P
18	0	10.06	5.00	-3.288	0.001

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SW SOILWATER
WITH SWB SOILWATER2

CASES	TIES	1 -RANKS MEAN	17 +RANKS MEAN	Z	2-TAILED P
18	0	4.00	9.82	-3.549	0.000

SPSS G.T.VARIABILITY

FILE NONAME (CREATION DATE = 10-21-81)

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SH SPIKEHT
WITH SHB SPIKEHT2

CASES	TIES	18 -RANKS MEAN	0 +RANKS MEAN	Z	2-TAILED P
18	0	9.50	0.	-3.724	0.000

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

LH LEAFHT
WITH LHB LEAFHT2

CASES	TIES	16 -RANKS MEAN	2 +RANKS MEAN	Z	2-TAILED P
18	0	10.31	3.00	-3.462	0.001

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

PW PLANTWATER
WITH PWB PLANTWATER2

CASES	TIES	18 -RANKS MEAN	0 +RANKS MEAN	Z	2-TAILED P
18	0	9.50	0.	-3.724	0.000

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SW SOILWATER
WITH SWB SOILWATER2

CASES	TIES	4 -RANKS MEAN	14 +RANKS MEAN	Z	2-TAILED P
18	0	4.50	10.93	-2.940	0.003

SPSS G.T.VARIABILITY

FILE NONAME (CREATION DATE = 10-21-81)

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SH SPIKEHT
WITH SHB SPIKEHT2

CASES	TIES	0 -RANKS MEAN	18 +RANKS MEAN	Z	2-TAILED P
18	0	0.	9.50	-3.724	0.000

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

PW PLANTWATER
WITH PWB PLANTWATER2

CASES	TIES	17 -RANKS MEAN	1 +RANKS MEAN	Z	2-TAILED P
18	0	10.00	1.00	-3.680	0.000

- - - - - WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

SW SOILWATER
WITH SWB SOILWATER2

CASES	TIES	1 -RANKS MEAN	17 +RANKS MEAN	Z	2-TAILED P
18	0	3.00	9.88	-3.593	0.000

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FILE NONAME (CREATION DATE = 10-21-81)

T - T E S T

GROUP 1 - FIELD EQ 4.
GROUP 2 - FIELD EQ 8.

VARIABLE		NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	F VALUE	2-TAIL PROB.	POOLED VARIANCE ESTIMATE T VALUE	POOLED VARIANCE ESTIMATE DEGREES OF FREEDOM	POOLED VARIANCE ESTIMATE 2-TAIL PROB.	SEPARATE VARIANCE ESTIMATE T VALUE	SEPARATE VARIANCE ESTIMATE DEGREES OF FREEDOM	SEPARATE VARIANCE ESTIMATE 2-TAIL PROB.
SN	SPIKENT												
	GROUP 1	18	99.9444	4.165	0.982	2.74	0.045	-0.41	34	0.685	-0.41	27.96	0.685
	GROUP 2	18	100.7222	6.892	1.625								
LN	LEAFNT												
	GROUP 1	18	72.9444	4.359	1.027	3.63	0.011	1.36	34	0.184	1.36	25.70	0.186
	GROUP 2	18	69.9444	8.306	1.958								
PW	PLANTWATER												
	GROUP 1	18	54.0133	2.928	0.690	1.89	0.198	4.83	34	0.000	4.83	31.04	0.000
	GROUP 2	18	48.3394	4.029	0.950								
SW	SOILWATER												
	GROUP 1	18	34.2017	2.867	0.676	1.90	0.195	15.58	34	0.000	15.54	31.00	0.000
	GROUP 2	18	21.2080	2.078	0.490								
SNB	SPIKENT2												
	GROUP 1	18	96.0000	6.730	1.586	1.52	0.399	5.01	34	0.000	5.01	32.62	0.000
	GROUP 2	18	83.3889	8.290	1.954								
LNB	LEAFNT2												
	GROUP 1	18	69.3333	4.851	1.143	3.06	0.027	4.51	34	0.000	4.51	27.05	0.000
	GROUP 2	18	58.9444	8.482	1.999								
PWB	PLANTWATER2												
	GROUP 1	18	41.5006	8.163	1.924	1.38	0.515	8.59	34	0.000	8.59	33.16	0.000
	GROUP 2	18	19.5833	6.951	1.638								

FILE NONAME (CREATION DATE = 10-21-81)

T - TEST

GROUP 1 - FIELD EQ 4.
GROUP 2 - FIELD EQ 8.

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	F VALUE	2-TAIL PROB.	POOLED VARIANCE ESTIMATE T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.	SEPARATE VARIANCE ESTIMATE T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
SUB SOILWATER2												
GROUP 1	18	37.8194	2.089	0.492	2.55	0.061	14.72	34	0.000	14.72	28.56	0.000
GROUP 2	18	24.1561	3.340	0.787								

FILE NONAME (CREATION DATE = 10-21-81)

- T - T E S T -

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	(DIFFERENCE) MEAN	STANDARD DEVIATION	STANDARD ERROR	CORR.	2-TAIL PROB.	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
SW	SPIKENT	99.9444	4.165	0.982	3.9444	9.076	2.140	-0.353	0.151	1.44	17	0.085
	18											
SWB	SPIKENT2	96.0000	6.730	1.586								
LW	LEAFNT	72.9444	4.359	1.027	3.6111	6.740	1.589	-0.069	0.787	2.27	17	0.036
	18											
LWB	LEAFNT2	69.3333	4.851	1.143								
PW	PLANTWATER	54.0133	2.928	0.690	12.7128	8.421	1.985	0.098	0.724	6.40	17	0.000
	18											
PWB	PLANTWATER2	41.3006	8.163	1.924								
SW	SOILWATER	34.2017	2.867	0.676	-3.6178	3.236	0.763	0.176	0.484	-4.74	17	0.000
	18											
SWB	SOILWATER2	37.8194	2.089	0.492								

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FILE NONAME (CREATION DATE = 10-21-81)

T - T E S T

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	(DIFFERENCE) MEAN	STANDARD DEVIATION	STANDARD ERROR	[illegible]	2-TAIL PROB.	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
SH	SPIKEHT	100.7222	6.892	1.625								
	18				17.3333	8.630	2.034	0.365	0.136	8.52	17	0.000
SHB	SPIKEHT2	83.3889	8.290	1.954								
LH	LEAFHT	69.9444	8.306	1.958								
	18				11.0000	8.872	2.091	0.442	0.067	5.26	17	0.000
LHB	LEAFHT2	58.9444	8.482	1.999								
PW	PLANTWATER	48.3394	4.029	0.950								
	18				28.7561	7.390	1.742	0.177	0.482	16.51	17	0.000
PWB	PLANTWATER2	19.5833	6.951	1.638								
SW	SOILWATER	21.2000	2.078	0.490								
	18				-2.9561	4.133	0.974	-0.116	0.645	-3.03	17	0.007
SWB	SOILWATER2	24.1561	3.340	0.787								

FILE NONAME (CREATION DATE = 10-21-81)

T - T E S T

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	(DIFFERENCE) MEAN	STANDARD DEVIATION	STANDARD ERROR	CORR.	2-TAIL PROB.	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
SW	SPIKENT	182.6111	12.258	2.889								
	18				-86.7778	14.862	3.503	0.171	0.497	-24.77	17	0.000
SWG	SPIKENT2	269.3889	10.760	2.536								
PW	PLANTWATER	91.6211	1.016	0.239								
	18				8.8983	2.968	0.700	-0.218	0.384	12.72	17	0.000
PWB	PLANTWATER2	82.7228	2.576	0.607								
SW	SOILWATER	20.7972	2.548	0.601								
	18				-5.5261	4.039	0.952	-0.153	0.546	-5.81	17	0.000
SWB	SOILWATER2	26.3233	2.769	0.653								

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