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TOTAL POROSITY AND RANDOM ROUGHNESS OF THE INTERROW ZONE AS INFLUENCED BY TILLAGE

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TOTAL POROSITY AND RANDOM ROUGHNESS OF THE INTERROW ZONE AS INFLUENCED BY TILLAGE [1]

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INTRODUCTION

Soil conditions produced by a given tillage implement or combination of tillage implements differ markedly depending on other factors such as soil type, soil moisture content at time of tillage, and cropping history. Tillage practices can, therefore, be more thoroughly analyzed by an assessment of the resulting soil conditions than by description of the tillage operations only. When it is known what soil conditions are necessary for optimum plant growth and soil and water management, practices can be designed and altered to produce the required soil conditions.

The required soil conditions for corn growth and soil and water management in the Corn Belt have been discussed by Larson (*4, 5, 6*).[3] For analysis he divided a row-cropped field into two zones: (1) the zone between the rows, the interrow, where water management is a major concern; and (2) the zone in the row, where soil conditions favorable for germination and early growth are of paramount importance. The two-zone concept permits modification of soil conditions to meet one or more objectives. Depending on the soil management problem, interrow soil conditions may be modified for enhanced infiltration, water conservation, or surface drainage.

Two parameters of soil condition that are important to management of soil water in the interrow zone are the porosity of the tilled soil layer and the roughness of the soil surface.

When a soil layer is loosened or packed by a tillage operation, the total porosity and thickness of the layer are changed. The average size of the soil pores is related to the total porosity of the tilled layer because the absolute volume of solids remains the same. Hence, an increase in total porosity may increase the rate and amount of infiltration of water into the soil because of more rapid water conduction and temporary water storage in large pores. Water conservation and evaporation may be affected by the relation of total porosity and thermal properties of the soil. Even though porosity is an important parameter in a tilled soil, it has not been measured throughout the growing season in the Corn Belt. It has usually been measured by sampling the undisturbed soil in a cylinder. Accurate measurement of porosity in recently tilled soil layers is difficult because of the looseness of the soil and the consequent difficulty of retaining the sample in the cylinder.

The roughness of the surface in a tilled soil influences the amount of water that can be trapped in the depressions during an intense rain. Surface roughness is also related to the ease with which the soil surface seals during a rain, to the strength of the surface crust, and to exchanges of heat, air, and water between the soil and the atmosphere.

Two types of roughness are produced by tillage implements. The first type, oriented roughness, may be illustrated by ridges and furrows occurring between the rows of lister and ridge planting, respectively. Undulations in surface relief, such as plow furrow slices and cultivator furrows, are also an oriented roughness. The second type, random roughness, is merely a random occurrence of surface peaks and depressions, in which it is impossible to distinguish the direction in which tillage operations were performed. In the present study, only random roughness was considered because tillage practices that produce significant amounts of oriented roughness were not included in the study and because random roughness is more closely related to the phenomena enumerated in the previous paragraph.

In the present study, the total porosity of the tilled layer of the interrow zone was estimated from changes in elevation of the soil surface, which were referenced by estimating total porosity in undisturbed cores of the plow layer taken at one time during the season (usually before tillage).

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[3] Italic numbers in parentheses refer to Literature Cited, p. 15.

Random roughness of the interrow zone was estimated from a description of the microrelief of the soil surface. These two parameters were evaluated by consideration of: (1) the accuracy of their estimation, (2) their magnitudes, as influenced by tillage systems, and (3) their variation, as affected by other factors such as crop history, moisture content at tillage time, and soil type.

Working drawings of the microrelief meter used to measure changes in elevation of the soil surface (from which total porosity and random roughness were estimated) are included in the appendix.

PROCEDURES

Tillage Treatments and Measurements

The interrow soil conditions, total porosity and random roughness, were estimated from measurements in tillage experiments performed in 1961, 1962, and 1963 in western Minnesota and in 1963 in eastern South Dakota. Three preplanting and planting tillage treatments were performed to provide a range of interrow soil conditions. These treatments are designated as untilled, plow, and plow-disk-harrow. These designations correspond, respectively, to untilled, wheel-track, and conventional, the usual designations. The first set of designations is used in this report to emphasize the interrow soil conditions resulting from tillage. In the untilled treatment, no plowing or other tillage was performed and the seed was placed in a ¾-inch-diameter hole surrounded by untilled soil; in the plow-disk-harrow treatment, the sequence of operations was plowing, disking, harrowing, and surface planting; and in the plow treatment, the sequence was plowing and planting in the tractor wheel track. Plowing to a 6-inch depth was done with a turnplow having 14- or 16-inch moldboards; disking was done with a tandem disk having 16-inch notched disks on the first gang and 16-inch smooth disks on the second gang; and harrowing was done with a spring-tooth harrow pulled behind the disk. In nearly all cases only a single pass was made with the disk and harrow. Weeds were controlled with herbicides in all treatments.

The tillage experiments are listed in appendix table 14. There were two categories of experiments, based on crop grown and number of measurements taken. In the experiments of the first category, identified by a letter and a number after the year in the experiment number description, corn was planted and estimates of total porosity and random roughness were made throughout the growing season. Besides the preplanting and planting tillage, these experiments had two levels of postplanting tillage: (1) no cultivation after planting; and (2) two or more cultivations with shovels. Thus, in each experiment of the first category, there were six tillage treatments; each was replicated three times.

In the experiments of the second category, identified only by numbers after the year in the experiment number description, no crop was planted and random roughness and total porosity were measured only once—immediately after simulated planting. There were only three tillage treatments in each experiment of this category. The preplanting and planting tillage treatments were not replicated except in experiments 1962–24 and 1963–25, where the tillage treatments were replicated two and three times, respectively. Experiments 1963–5, 1963–6, 1962–24, and 1963–25 were begun in late summer and fall. In experiments 1962–24 and 1963–25, the sequence of tillage operations was completed within a day on the plow-disk-harrow and plow treatments, but in experiments 1963–5 and 1963–6, plowing was performed in the fall and the remaining operations in the plow-disk-harrow and plow treatments were performed during the following spring.

The area per single replication of a treatment ranged from 800 to 1,300 square feet; there were either four or six 40-inch rows in each plot.

The soils ranged from a loam to a clay loam and had a large range in soil moisture content at tillage time (see appendix table 14). Prior to initiation of these experiments, the previous crop was most frequently corn, alfalfa-brome, or alfalfa (see appendix table 14). Alfalfa and alfalfa-brome were killed with herbicides prior to tillage.

Total porosity and random roughness were estimated from height measurements over the entire 40-inch distance between adjacent rows, except where there was tractor-wheel traffic during any tillage operations that followed plowing. This consideration was important in the plow-disk-harrow treatment and all treatments receiving postplanting cultivation. However, in the plow treatment, the wheel track incurred during planting was centered over the row. The estimated total porosity of the interrow zone of the plow treatment then included the effect of one wheel track width, while that of the plow-disk-harrow did not. Conceptually, the interrow zone does not include all the area between centers of rows. Hence, in relation to concept the total porosity as estimated in the plow and plow-disk-harrow tillage treatments had a small negative bias because of the wheel track plus the planter and planter packing, respectively. The bias introduced into the random roughness estimate was of a smaller order of magnitude.

Total Porosity Estimates With Undisturbed Cores

Where estimates of total porosity are desired, the total porosity must be estimated from undisturbed cores sometime during the period over which total porosity is to be described. (Otherwise only changes in elevation can be estimated.) One set of the soil surface height readings must also be taken at the time that the undisturbed cores are taken; thus, height readings will give total porosity estimates when referred to measurements from undisturbed cores. Soil conditions most favorable for accurate undisturbed core sampling usually occur in the fall or spring after periods of about 6 months without tillage. Prior to tillage, soil surface height readings were made with the microrelief meter and undisturbed cores were taken. The depth of sampling was equal to the depth to which the tillage was to be performed—6 inches. Where the preplanting tillage involved plowing to a 6-inch depth, the 0- to 6-inch surface layer was sampled in 3-inch increments by use of a 3-inch Uhland core sampler (*9*). In the experiments described herein, at least three cores from the 0- to 3- and 3- to 6-inch layers were taken randomly within a single replication of a treatment. For a tillage experiment (such as listed in appendix table 14), the initial total porosity was estimated from a composite of cores from at least three treatments. Hence, the coefficient of variation for this estimate was 2 percent or less.

Surface Elevation Measurements

The Microrelief Meter

A microrelief meter was used to measure time changes in elevation of the soil surface. Random roughness was also estimated from these measurements. The microrelief meter was designed to measure surface elevations on a 2- by 2-inch grid over a 40- by 40-inch area (see fig. 1). The construction details of this point quadrant device are shown in appendix figures 8 through 10. These dimensions may easily be altered for other row spacings or physical layouts of experiment.

The microrelief meter consists of three major units: (1) the scaleboard-and-measuring-pins unit, (2) the scaleboard support frame and (3) the support pins (steel rods, ⅝ inch in diameter and 18 inches long). During the measurement operation, the scaleboard support frame was maintained in a fixed position on the four support pins. The scaleboard and measuring pins constitute a single unit, which moves horizontally over the scaleboard support frame. The starting position for taking measurements is illustrated in figure 1. Twenty measuring pins spaced 2 inches apart are supported by pin guides attached to the scaleboard. When the measuring pins are resting on the soil surface, heights at the top of the pins are read to the nearest 0.1 inch on the scaleboard. The

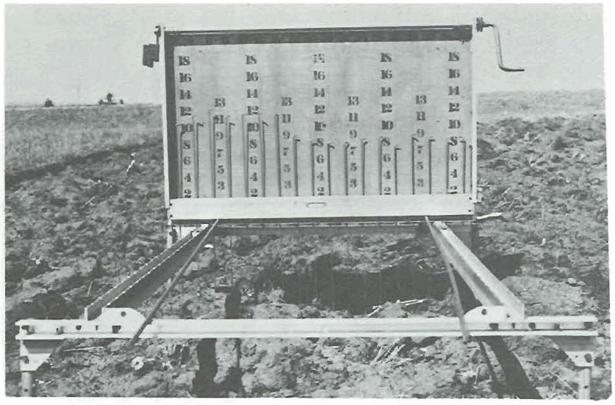

FIGURE 1.—Microrelief meter in field measuring position.

measuring pins are then raised, the scaleboard-and-measuring-pins unit is moved 2 inches horizontally toward the observer on the scaleboard support frame, the measuring pins are lowered, and heights are again read. At each setting at which measurements were taken in this study, the procedure was continued until 20 measurements were made at each of the 20 positions of the scaleboard-and-measuring-pins unit on the scaleboard support frame. Thus, 400 height readings were obtained on a 2- by 2-inch grid over a 40- by 40-inch area between rows spaced 40 inches apart.

Placement of Support Pins

The location and placement of the support pins depends on the physical layout of the field experiment and on convenience for tillage operations. The following location and placement procedure was used for the experiments described in this paper. Bench marks (each was 6 to 7 feet long, embedded in the ground at a 5- to 6-foot depth, and used for the alinement and elevation setting of the support pins) were located in accessible border areas and were protected from disturbance. Alinement of two or more bench marks parallel to the long side of the plots provided an axis for locating the support pins.

An engineer's level was plumbed over one of the bench marks and the telescope was alined over the other bench marks on the same side of the experiment. The telescope was then turned 90° from the line of sight. The support pin placement guide (see fig. 2) was placed on the plot of interest in a manner such that two corners were in the line of sight and at a specified distance from the bench mark. The specified distance located the support pins in the crop row. The four support pins were then placed inside the guide and driven firmly into the soil; the guide was then removed. The support pins were leveled with respect to each other at approximately 6 inches above the soil surface. The elevation of the top of the pins was determined and recorded

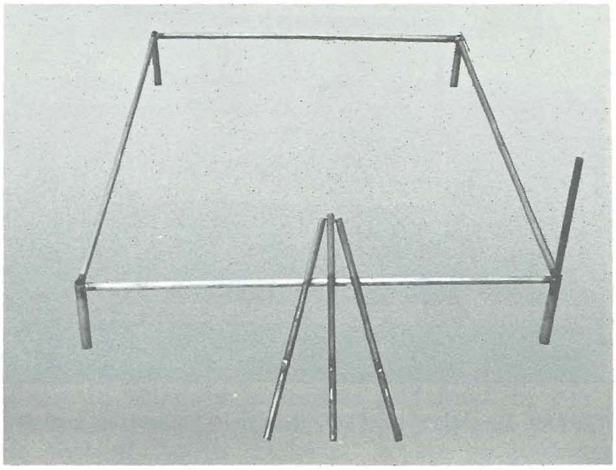

FIGURE 2.—Support pin placement guide and support pins. (One pin is shown in driving position.)

for releveling. Soil height readings taken with the microrelief meter were then recorded.

After the initial soil height readings were made with the microrelief meter (as described in the previous section) the support pins were removed and tillage and planting operations performed. The support pins were then put back in the same location and elevation plane as for the initial setting, in the manner described for their initial placement prior to tillage. Height readings were again taken with the microrelief meter. The support pins remained in this position throughout the remainder of the season. Before height readings were made at a later time, the elevation of the support pins was checked. This procedure permitted adjustment of heights (obtained with the microrelief meter) when the support pin height was different from that in the initial placement. Usually, the support pins did not change elevation during the growing season.

Orientation of Height Readings

The starting position of the microrelief meter for a series of measurements for one setting in the field is illustrated in figure 1. The measuring pins were gently lowered by a reel arrangement that lowers the upper pin guide bar. The height measurements were read and recorded manually from left to right on the top line (i.e., 20 readings) of a data sheet. The pins were raised, the scaleboard-and-measuring-pins unit was moved toward the observer 2 inches, the pins were lowered, and the heights were recorded from left to right on the next lower line. This procedure was continued until 20 rows of heights (each having 20 readings) were recorded. Thus, the left-to-right rows of height readings extended in a direction perpendicular to the rows in the field, and the columns of height readings extended in a direction parallel to the rows in the field. Consistency in orientation of height records is necessary for making the random roughness computations.

CALCULATION OF PARAMETERS OF SOIL CONDITION

Total Porosity

From the undisturbed cores obtained before tillage, the initial total porosity, P_i, for the layer to be tilled was calculated as follows:

$$P_i=\frac{2.65-D_b}{2.65}\times W \tag{1}$$

where D_b is the average bulk density in g./cc. obtained from undisturbed cores, and W is the thickness of the sampled layer in inches. In the experiments described herein the plowing depth was 6 inches, W was 6 for all computations of P_i, and P_i has units of inches and may be defined as "inches of initial porosity per initial 0- to 6-inch layer."

For any arbitrary time, t_a, at which microrelief readings were taken, the total porosity was computed in the following manner. First, the average height of the measuring pins at a single setting of the scaleboard support frame before tillage and at the time the undisturbed cores were taken was computed as:

$$\bar{h}_i=\frac{1}{n}\sum_{i=1}^{n} h_i \tag{2}$$

where h_i is the individual height reading in inches taken before tillage and n is the number of readings (400). Then the average height of the measuring pins at a single setting of the scaleboard support frame taken at a later time, t_a, was computed as:

$$\bar{h}_a=\frac{1}{n}\sum_{a=1}^{n} h_a \tag{3}$$

where h_a was the individual height reading in inches taken at time t_a.

The total porosity at time, t_a, was then given by:

$$P_a=P_i+\bar{h}_a-\bar{h}_i \tag{4}$$

P_a has units of inches, and may be defined as "inches of porosity per initial 0- to 6-inch soil layer." For the experiments of this study one setting of the microrelief meter was made for each replication of a tillage treatment.

From measurements performed on replications of the same tillage treatment, the standard error of P_a was approximately 0.28 inch (a coefficient of variation of about 6 to 10 percent). A number of factors caused a loss of precision and accuracy. The precision errors that arose from determining

P_t were about 10 percent of the standard error of P_a. Likewise the errors in determining the average elevation from a given setting of the microrelief meter (see table 2, p. 7) were about 10 percent of the standard error of P_a. The remaining variation in P_a was about 1.5 times the variation that could be accounted for by a 0.02-foot error in surveying. The influence of differential movement of support pins and the reference pin has been discussed previously (*2*); however, it was not a cause of the precision loss in the above observed 0.28-inch standard error of P_a. Two other factors that probably decreased precision and accuracy were (1) increased or decreased average elevation of the microrelief area due to horizontal displacement of soil during tillage operations, and (2) variations in depth of plowing

Random Roughness

The random roughness was computed from the 400 readings of height observed with one setting of the microrelief meter and oriented as specified in the "Orientation of Height Readings" section. Essentially, the random roughness index is the standard error among heights and has units of inches. Before the standard error was computed, the heights were expressed logarithmically and then adjusted both for tillage tool marks extending in a direction parallel to the row and for differences of elevation due to slope in the direction of the row.

Appendix figure 11 gives a typical computer printout of information from a single set of 400 height readings.[4] The first item of the second line indicates the mean and is either $\bar{h}_a$ or $\bar{h}_t$ of equation 4. In lines 3 through 6 are given the 20 parallel means and the 20 perpendicular means. They were not used in later computations, but described the general shape of the surface. The j^{th} parallel mean, $\bar{h}_{.j}$, was obtained by summing in the direction of the row:

$$\bar{h}_{.j}=\frac{1}{20}\sum_{i=1}^{20} h_{ij}; \qquad j=1, 2, \ldots, 20 \qquad (5)$$

The h_{ij} are the original height readings in inches, and the dot in the subscript signifies sum over all i. The i^{th} perpendicular mean, $\bar{h}_{i.}$, was obtained by summing in a direction perpendicular to the row:

$$\bar{h}_{i.}=\frac{1}{20}\sum_{j=1}^{20} h_{ij}; \qquad i=1, 2, \ldots, 20 \qquad (6)$$

The h_{ij} was defined above, and the dot in the subscript signifies sum over all j.

[4] The computer program (Program Tillage), written in FORTRAN, is available upon request from the North Central Soil Conservation Research Center, Morris, Minn.

Earlier tests (*2*) concerning the distributional nature of the height readings revealed that the logarithms of the heights were more nearly normally distributed than were the arithmetic heights. Hence, each of the 400 observations of height was logarithmically expressed, after which the effect of slope and oriented tillage tool mark was mathematically removed as a component of variation among logarithm of heights. The following model represents the components of a natural logarithm of observed height, $\ln h_{ij}$:

$$\ln h_{ij}=m+A_i+B_j+e_{ij} \qquad (7)$$

where m is the average logarithm of height, A_i is the component of variation due to slope (or previous cross tillage), B_j is the component of variation due to tillage tool orientation, and e_{ij} is the residual variation among logarithms of heights. The e'_{ij} were estimated from the expression:

$$e'_{ij}=\overline{\ln h}_{..}+e_{ij}=\ln h_{ij}-(\overline{\ln h}_{.j}-\overline{\ln h}_{..}) -(\overline{\ln h}_{i.}-\overline{\ln h}_{..}) \qquad (8)$$

In this expression $\overline{\ln h}_{..}$ is the average of 400 logarithms of heights and was retained as a part of e'_{ij} to avoid negative numbers in the computations. The $\overline{\ln h}_{.j}$ is obtained by summing in the direction of tillage (the direction of the row) for the j^{th} tillage tool mark, while $\overline{\ln h}_{i.}$ is obtained by summing perpendicular to the row for the i^{th} station.

After the 400 e'_{ij} were arranged in order of increasing magnitude, the first upper limit of e'_{ij} was set by the smallest e'_{ij} value and each subsequent upper limit was determined by adding the product, 0.005 times the range of e'_{ij} values, to the preceding upper limit. For each upper limit, the proportion of e'_{ij} values having magnitudes less than or equal to the upper limit was ascertained. Where $0.10 \leq$ fraction undersize ≤ 0.90, the upper limits of e'_{ij} and the respective proportion undersize were used in the ensuing computations. Data with the above restrictions were chosen because each set of 400 observations could not individually be examined for erratic points that sometimes occur above 0.90-fraction undersize and below 0.10-fraction undersize in a plot of e'_{ij} versus normalized fraction undersize. These erratic points (due to erratic height readings) would unduly enlarge the random roughness index just as they would strongly inflate the variance when it is calculated by squaring and summing the deviations from the mean.

After the proportion of e'_{ij} values having magnitudes less than or equal to the upper limits of e'_{ij} was obtained, the standard deviation among logarithms of heights was estimated mathematically from the relation of normalized fraction undersize versus e'_{ij}. For the k^{th} e'_{ij} upper limit, the following relation was used to obtain the normalized fraction undersize, Y', for a given fraction undersize, Y:

$$Y'=Pr(Z\leq Z_k)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{Z_k} e^{-(Z^2/2)}dZ \qquad (9)$$

where $Z_k=(Y-0.5)/\sqrt{Y(1-Y)}$, and Pr indicates probability. In appendix figure 11, Y' of equation 9 is labeled NFU, and Y is labeled FRACTION UNDER. Both are given for each value of e'_{ij}; e'_{ij} is represented as LOG in appendix figure 11. The linear relation of Y' and e'_{ij} ($Y'=\alpha+\beta e'_{ij}$) was then obtained; it is equivalent to a best fit of the points between 0.10 and 0.90 fraction undersize in a plot of normalized fraction undersize versus e'_{ij}. The standard deviation among logarithms of heights was then estimated as $0.34/\beta$, where β is a parameter estimated in the relation $Y'=\alpha+\beta e'_{ij}$, and 0.34 is the fractional area under the normal curve corresponding to one standard deviation from the mean.

An example of the graphical relation of fraction undersize (and normalized fraction undersize) versus e'_{ij} is shown in appendix figure 12. The values were taken from the data of appendix figure 11.

The random roughness index σ_y was then estimated as follows:

$$\sigma_y\cong\sigma_x\bar{h} \qquad (10)$$

where σ_y is the standard error among heights in inches, σ_x is the standard error among logarithms of heights given in appendix figure 11, and $\bar{h}$ is the mean height given as MEAN in appendix figure 11. The approximation (see *3*) involved in equation 10 estimates σ_y within 2 percent.

Although a log-normal distribution of heights was assumed in the calculation of random roughness, more information about the validity of the assumption was sought by making tests of goodness of fit. For the k^{th} value of e'_{ij} (represented as LOG, see appendix fig. 11), a $\hat{Y}'$ (EST NFU) was computed using the linear relation $Y'=\alpha+\beta e'_{ij}$. Then for each $\hat{Y}'$ an estimated fraction undersize (EST FRACTION UNDER) was computed by reverse solution in equation 9 and compared with the observed fraction undersize (FRACTION UNDER). The greatest absolute difference was designated MAX ABS DIFF. The Kolmogorov-Smirnov test for goodness of fit (*7*, *8*) was used to compare the maximum absolute difference with a tabled value, D, such that

$$D=\max|F(x)-S_m(x)|$$

In the comparison, $F(x)$ is the theoretical distribution function and $S_m(x)$ is the sample distribution function. In terms of the example here, $\hat{Y}'$ is the theoretical distribution having parameters estimated from the sample and Y is the sample distribution. With 400 observations and a rejection level of 0.20, D is 0.053. Only in a few cases in at least 200 estimates of random roughness did the maximum absolute difference exceed 0.053. Except for a few cases, then, the null hypothesis of a log-normal distribution could not be rejected even at the probability level of 0.20. With a probability level of 0.01, the tabular value of D is 0.081.

In the routine measurements made for the random roughness index estimations, the horizontal spacing between the pins was 2 inches both parallel and perpendicular to the row. In October 1962, the effect of spacing on the estimation was evaluated on three surfaces: an untilled surface; a plowed surface; and a surface after it had been plowed, disked, and harrowed. Observations were made on a horizontal spacing of 1 inch. From this systematic arrangement of height readings, readings were selected to simulate reading on a 1- x 1-, 2- x 2-, 3- x 3-, or a 4- x 4-inch pin spacing. Little change occurred in the random roughness estimate with increasing pin spacing (table 1), and the variability of the estimates with increasing pin spacing was not significant. This observation indicates that the proximity of pin spacing had little disturbing influence on the estimation of random roughness. Table 2, however, reveals that the error of estimating the average elevation of a 40- x 40-inch area becomes significant when the pin spacing is greater than 2 inches on a freshly plowed surface.

RESULTS AND DISCUSSION

Effects of Tillage on Total Porosity and Random Roughness Throughout the Growing Season

The effects of tillage on total porosity and random roughness were observed in experiments 1961–M34, 1962–L1, and 1962–M34 (see appendix table 14). The soil management history was similar for all tillage treatments within each experiment, and was alfalfa-nurse crop, alfalfa-brome, or alfalfa. The total porosity (estimated as indicated by equation 4) is given in tables 3, 4, and 5. In all three experiments, large and statistically significant total porosity increases resulted from preplanting tillage. Usually, but not always, the total porosity on the plow-disk-harrow treatment was less than that on the plow treat-

TABLE 1.—*Random roughness as affected by horizontal pin spacing in 40- x 40-inch surface of measurement*

Horizontal pin spacing	Sets of height readings analyzed	Height observations per 40- x 40-inch area	Random roughness index[1] on—		
			Untilled plot	Plowed plot	Plowed, disked, and harrowed plot
Inches			*Inches*	*Inches*	*Inches*
1 x 1	1	1,600	0.24	1.85	0.82
2 x 2	4	380 to 400	0.24 ± 0.01	1.86 ± 0.05	0.82 ± 0.06
3 x 3	4	169	0.24 ± 0.02	1.85 ± 0.18	0.84 ± 0.02
4 x 4	4	100	0.25 ± 0.02	1.89 ± 0.12	0.88 ± 0.04

[1] Standard error of an estimate found by relation $\frac{\sigma}{\text{range}}=0.486$, when $n=4$ sets of height readings. Tabulated values of σ/range are given by Ostle (*7, p. 63*).

TABLE 2.—*Average height as affected by horizontal pin spacing in a 40- x 40-inch surface of measurement*

Horizontal pin spacing	Sets of height readings analyzed	Height observations per 40- x 40-inch area	Average height of pins[1] on—		
			Untilled plot	Plowed plot	Plowed, disked, and harrowed plot
Inches			*Inches*	*Inches*	*Inches*
1 x 1	1	1,600	7.46	8.93	8.95
2 x 2	4	380 to 400	7.46 ±0.005	8.94 ±0.068	8.95 ±0.045
3 x 3	4	169	7.46 ±0.045	8.90 ±0.102	8.95 ±0.058
4 x 4	4	100	7.45 ±0.049	8.87 ±0.262	8.94 ±0.078

[1] Standard error of an estimate found by relation $\frac{\sigma}{\text{range}}=0.486$, when $n=4$ sets of height readings. Tabulated values of σ/range are given by Ostle (*7, p. 63*). Heights are given in inches above a datum.

TABLE 3.—*Effect of preplanting and postplanting tillage on total porosity of a Barnes loam (experiment 1961–M34) in 1961*

Tillage treatment		Total porosity[1] on—				
Preplanting	Postplanting	May 29 (before tillage)[2]	June 8 (after preplanting tillage)	June 22 (after first cultivation)	July 5 (after second cultivation)	July 17 (after third cultivation)
		Inches[3]	*Inches*[3]	*Inches*[3]	*Inches*[3]	*Inches*[3]
Plow-disk-harrow	Cultivated	3.20	4.39 a	4.36 a	3.62 ab	3.66 ab
	Noncultivated			4.29 a	3.94 bc	4.04 b
Plow	Cultivated		5.06 b	5.13 b	4.56 cd	4.26 b
	Noncultivated			5.03 b	4.99 d	5.03 c
Untilled	Cultivated		3.20 c	3.66 c	3.63 ab	3.23 a
	Noncultivated			3.27 c	3.24 a	3.30 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as evaluated by the Duncan Multiple Range Test.
[2] Average porosity estimated from 54 Uhland core samples. The standard error of this average is 0.011 inch.
[3] Inches of porosity per initial 0- to 6-inch layer.

TABLE 4.—*Effect of preplanting and postplanting tillage on total porosity of a Barnes loam (experiment 1962–M34) in 1962*

Tillage treatment		Total porosity [1] on—				
Preplanting	Postplanting	May 13 (before tillage) [2]	June 13 (after preplanting tillage)	July 10 (after first cultivation)	July 25 (after second cultivation)	Sept. 25 (end of season)
		Inches [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]
Plow-disk-harrow	Cultivated	3.22	4.44 b	4.09 b	3.69 bc	4.05 bc
	Noncultivated			4.36 b	4.22 cd	4.25 bc
Plow	Cultivated		4.84 b	4.60 b	3.95 cd	4.36 c
	Noncultivated			4.52 b	4.31 d	4.36 c
Untilled	Cultivated		3.18 a	3.55 a	3.38 ab	3.76 b
	Noncultivated			3.21 a	3.12 a	3.20 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as evaluated by the Duncan Multiple Range Test.
[2] Average porosity estimated from 54 Uhland core samples. The standard error of this average is 0.020 inch.
[3] Inches of porosity per initial 0- to 6-inch layer.

TABLE 5.—*Effect of preplanting and postplanting tillage on total porosity of a Nicollet silt loam (experiment 1962–L1) in 1962*

Tillage treatment		Total porosity [1] on—					
Preplanting	Postplanting	May 21 (before tillage) [2]	May 25 (after preplanting tillage)	June 14 (after first cultivation)	June 26 (before second cultivation)	June 30 (after second cultivation)	Sept. 20 (end of season)
		Inches [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]
Plow-disk-harrow	Cultivated	3.14	4.91 c	4.42 b	4.25 cd	3.76 b	3.71 bc
	Noncultivated			4.75 b	4.58 d	4.58 d	4.36 d
Plow	Cultivated		4.46 b	4.60 b	4.45 d	4.17 c	4.22 d
	Noncultivated			4.25 b	4.10 c	4.10 bc	3.96 cd
Untilled	Cultivated		3.14 a	3.55 a	3.47 b	3.13 a	3.40 ab
	Noncultivated			3.08 a	3.05 a	3.05 a	3.05 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as evaluated by the Duncan Multiple Range Test.
[2] Average porosity estimated from 54 Uhland core samples. The standard error of this average is 0.025 inch.
[3] Inches of porosity per initial 0- to 6-inch layer.

ment. In most instances, there were no significant changes in total porosity due to a post-planting cultivation (compare cultivated and noncultivated for a given date), nor were the indicated changes consistent on all preplanting tillage treatments for a given cultivation.

The random roughness of the interrow surface corrected for tillage tool marks is shown in tables 6, 7, and 8. Plowing (plow treatment) significantly increased random roughness, but a subsequent disking and harrowing operation (plow-disk-harrow treatment) reduced the roughness to those levels observed on untilled surfaces. Postplanting cultivation also resulted in significant increases of roughness on all preplanting tillage treatments. When there was no postplanting cultivation, there were usually no differences of roughness among preplanting tillage treatments at the end of the growing season.

Estimates of random roughness and total porosity in this study were sufficiently precise to enable one to distinguish differences in interrow soil conditions. To assess the importance of these differences as measures of real factors in soil and water management will require further experimentation. Preliminary experimentation has revealed, however, that these differences in random roughness are associated with significant differences of infiltration, and that these differences

TABLE 6.—*Effect of preplanting and postplanting tillage on random roughness of a Barnes loam (experiment 1961–M34) in 1961*

Tillage treatment		Random roughness index[1] on—				
Preplanting	Postplanting	May 29 (before tillage)[2]	June 8 (after preplanting tillage)	June 22 (after first cultivation)	July 5 (after second cultivation)	July 17 (after third cultivation)
		Inches	*Inches*	*Inches*	*Inches*	*Inches*
Plow-disk-harrow	Cultivated	0.34	0.44 a	0.54 a	0.88 b	0.78 b
	Noncultivated			0.33 a	0.35 a	0.32 a
Plow	Cultivated		0.86 b	1.11 c	1.15 c	1.01 c
	Noncultivated			0.80 b	0.87 b	0.72 b
Untilled	Cultivated		0.34 a	0.78 b	1.08 c	1.14 c
	Noncultivated			0.34 a	0.34 a	0.34 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as determined by Duncan Multiple Range Test.
[2] Standard error of this value is 0.019 and is an average of 18 values.

TABLE 7.—*Effect of preplanting and postplanting tillage on random roughness of a Barnes loam (experiment 1962–M34) in 1962*

Tillage treatment		Random roughness index[1] on—				
Preplanting	Postplanting	May 13 (before tillage)[2]	June 13 (after preplanting tillage)	July 10 (after first cultivation)	July 25 (after second cultivation)	Sept. 25 (end of season)
		Inches	*Inches*	*Inches*	*Inches*	*Inches*
Plow-disk-harrow	Cultivated	0.25	0.40 b	0.84 b	0.92 b	0.42 b
	Noncultivated			0.23 a	0.20 a	0.23 a
Plow	Cultivated		0.75 c	0.95 bc	0.92 b	0.34 a
	Noncultivated			0.35 a	0.30 a	0.29 a
Untilled	Cultivated		0.26 a	1.00 c	0.95 b	0.51 b
	Noncultivated			0.26 a	0.23 a	0.26 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as determined by Duncan Multiple Range Test.
[2] Standard error of this value is 0.018 and is an average of 15 values.

in total porosity cause significant differences in soil thermal properties and water conservation.

Residual Effects of Tillage on Total Porosity and Random Roughness

In 1962 a number of tillage treatments were compared on each of experiments 1962–L1 and 1962–M34 (see appendix table 14). The same treatments were again repeated on the same plots in 1963 and are designated 1963–L1 and 1963–M34. The total porosity and random roughness estimates are shown in tables 9 through 12. The generalizations made in the previous section concerning the effect of tillage treatment on total porosity and random roughness are also illustrated in these 1963 experiments.

No significant change was found in total porosity of the untilled treatment for the period of May 1962 through September 1963 on both the Barnes and Nicollet soil (tables 4 and 9, and 5 and 10). Moreover, the total porosity obtained for September 1962 from the application of the relation of equation 4 agreed with the measurements from undisturbed samples taken in April 1963. Porosity was reduced on all other treatments during the period of September 1962 to April 1963. At the end of the 1962 and 1963 growing seasons, the total porosity was nearly the same. Furthermore, the differences in total porosity among tillage treatments from the time of preplanting tillage to the end of the growing season remained nearly the same. These observations are of interest because the 1962 season represented one year of row-crop tillage following alfalfa, and the

TABLE 8.—*Effect of preplanting and postplanting tillage on random roughness of a Nicollet silt loam (experiment 1962–L1) in 1962*

Tillage treatment		Random roughness index [1] on—				
Preplanting	Postplanting	May 21 (before tillage) [2]	May 25 (after preplanting tillage)	June 14 (after first cultivation)	June 26 (after second cultivation)	Sept. 20 (end of season)
		Inches	*Inches*	*Inches*	*Inches*	*Inches*
Plow-disk-harrow	Cultivated	0.38 a	0.31 b	0.86 c	0.83 d	0.22 a
	Noncultivated			0.24 a	0.20 a	0.19 a
Plow	Cultivated		0.66 c	0.93 c	0.88 d	0.27 a
	Noncultivated			0.50 b	0.38 b	0.31 a
Untilled	Cultivated		0.20 a	0.88 c	0.69 c	0.24 a
	Noncultivated			0.18 a	0.18 a	0.19 a

[1] Within a column, values not followed by the same letter are significantly different ($p=0.05$) as determined by Duncan Multiple Range Test.
[2] Standard error of this value is 0.015 and is an average of 12 values.

TABLE 9.—*Total porosity of a Barnes loam as affected by 1962 preplanting and postplanting tillage treatments, 1963 preplanting tillage, and 1963 postplanting cultivation* [1]

Tillage treatment in 1962 and 1963		Total porosity [2] on—						
Preplanting	Postplanting	Sept. 25 (end of 1962 season)	Apr. 24 (before 1963 tillage)	May 29 (after preplanting tillage)	June 14 (before first cultivation)	June 17 (after first cultivation)	July 5 (after second cultivation)	Sept. 20 (end of season)
		Inches [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]
Plow-disk-harrow	Cultivated	4.05	3.64	4.34	4.28	4.44	4.36	4.14
	Noncultivated	4.25	3.62	4.38	----------	----------	----------	4.11
Plow	Cultivated	4.36	3.56	4.43	4.36	4.32	4.06	3.83
	Noncultivated	4.36	3.60	4.22	----------	----------	----------	3.84
Untilled	Noncultivated	3.20	3.20	----------	----------	----------	----------	3.18

[1] Data for Sept. 25, 1962, are from experiment 1962–M34; other data are from experiment 1963–M34.
[2] Values for Apr. 24 are direct estimates from undisturbed cores; values for Sept. 25 are from application of equation 4 during 1962 season; and all other values are from application of equation 4 during 1963 season using the values for Apr. 24 as estimates of P_i.
[3] Inches of porosity per initial 0- to 6-inch layer.

1963 season represented two years of the same tillage treatment following alfalfa. Hence, the total porosity due to a tillage operation did not change markedly during row cropping for a 2-year period. The residual effect of the tillage operations on total porosity was apparent during the fall and spring prior to spring tillage but was not additive to the treatment effect the following year.

The estimation of total porosity using equation 4 was attempted for the growing season following the growing season in which the bench mark was placed, but it was inaccurate in most cases. The causes of the inaccuracies, some of which have previously been discussed (*2*), are being investigated. The application of equation 4 to obtain the estimates of tables 9 and 10 was limited to the same growing season as when the bench marks were placed. Corrections in elevation of the support pins were made only when the support pins had accidentally been changed from the set elevation.

Values of the random roughness index (tables 11 and 12) at the end of the 1963 season were generally lower than those observed in 1962. Hence, the random roughness decreased with an additional year of row cropping following alfalfa sod.

Variability of Tillage Effects

Repeated experiments using two different tillage treatments gave values of total porosity (or random roughness index) that did not repeatedly rank the tillage treatments similarly. Apparently,

TABLE 10.—*Total porosity of a Nicollet silt loam as affected by 1962 preplanting and postplanting tillage treatments, 1963 preplanting tillage, and 1963 postplanting cultivation* [1]

Tillage treatment in 1962 and 1963		Total porosity [2] on—						
Preplanting	Postplanting	Sept. 20 (end of 1962 season)	Apr. 26 (before 1963 tillage)	May 14 (after preplanting tillage)	June 17 (before first cultivation)	June 18 (after first cultivation)	July 1 (after second cultivation)	Sept. 29 (end of season)
		Inches [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]	*Inches* [3]
Plow-disk-harrow	Cultivated	3.71	3.42	4.02	3.84	3.74	3.50	3.64
	Noncultivated	4.36	3.11	3.57				3.23
Plow	Cultivated	4.22	3.48	4.40	4.28	4.18	4.07	3.98
	Noncultivated	3.96	3.08	3.98				3.93
Untilled	Noncultivated	3.05	3.13	3.13				3.14

[1] Data for Sept. 20, 1962, are from experiment 1962–L1; other data are from experiment 1963–L1.
[2] Values for Apr. 26 are direct estimates from undisturbed cores; values for Sept. 20 are from application of equation 4 during 1962 season; all other values are from application of equation 4 during 1963 season using the values for Apr. 26 as estimates of P_i.
[3] Inches of porosity per initial 0- to 6-inch layer.

TABLE 11.—*Random roughness of a Barnes loam as affected by 1962 preplanting and postplanting tillage treatments, 1963 preplanting tillage, and 1963 postplanting cultivation* [1]

Tillage treatment in 1962 and 1963		Random roughness index on—					
Preplanting	Postplanting	Apr. 24 (before tillage)	May 29 (after preplanting tillage)	June 14 (before first cultivation)	June 17 (after first cultivation)	July 5 (after second cultivation)	Sept. 20 (end of season)
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Plow-disk-harrow	Cultivated	0.25	0.53	0.25	0.57	0.44	0.26
	Noncultivated	0.20	0.51				0.19
Plow	Cultivated	0.34	0.68	0.41	0.66	0.52	0.36
	Noncultivated	0.28	0.54				0.25
Untilled	Noncultivated	0.19					0.19

[1] Data are from experiment 1963–M34 and may include residual from respective tillage treatments in experiment 1962–M34. Values in the table have a standard error of 0.030 inch.

soil type, soil management history, and moisture content at tillage time account for much of this failure to achieve similar magnitudes of total porosity or random roughness from a specified preplanting and planting tillage. Appendix table 14 shows that the tillage experiments were conducted on a number of soil types and that there was a variation in crop management history and soil moisture content at time of tillage. Although the number of experiments is not sufficient for a complete accounting, trends in the effect of these management factors can be evaluated.

In each of the experiments listed in appendix table 14, random roughness index and total porosity were estimated on each of three preplanting tillage treatments: (1) untilled, (2) plow-disk-harrow and (3) plow. The measurements in all of the experiments were taken on the untilled treatment prior to tillage and within a week following tillage on the plow and plow-disk-harrow treatments.

In figures 3, 4, and 5, the total porosity and the random roughness index are each plotted as departures (three per experiment) from their respective experiment mean value. The experiments for the Barnes-Aastad, Kranzburg-Poinsett, and Nicollet-Webster soil associations are plotted in figures 3, 4, and 5, respectively. The method of plotting is similar to superimposing values from 21 experiments on the same coordinates by alining so that the experiment mean values of total porosity coincide on the ordinate and random roughness on the abscissa.

General separation of tillage methods is shown on the abscissa. Thus, about three ranges of random roughness occurred, corresponding to unversus porosity change suggest that when the moisture ratio approaches 1.0 (the point of plastic consistence) disking and harrowing increase total porosity. Under friable consistency conditions (when the moisture ratio is less than 1.0) disking and harrowing decrease total porosity. The causes for the relation between soil moisture content at tillage time and the resulting porosity are being investigated further.

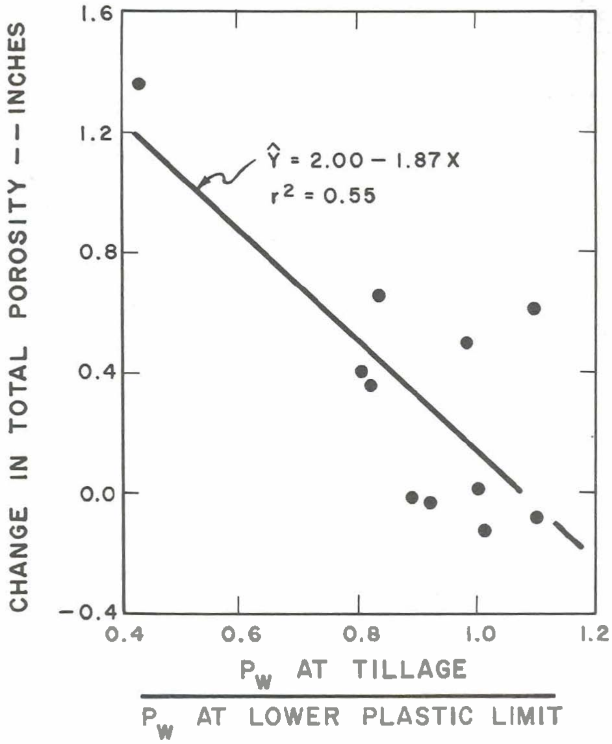

FIGURE 7.—Moisture ratio of the soils of Barnes-Aastad soil association at time of tillage and change in interrow porosity resulting from disking and harrowing the freshly plowed surface. Total porosity changes are differences between values for plow and plow-disk-harrow treatments; a positive value indicates greater total porosity in the plow than in the plow-disk-harrow treatment.

SUMMARY AND CONCLUSIONS

Total porosity and random roughness were estimated for the area between 40-inch corn rows (the interrow). These estimates were developed and tested in tillage experiments conducted on Barnes-Aastad, Nicollet-Webster, and Kranzburg-Poinsett soil associations in western Minnesota and eastern South Dakota. The tillage treatments were chosen to give a wide variation of total porosity and random roughness. The total porosity is the inches of porosity per initial 0- to 6-inch layer of soil, and random roughness is an index of the microvariations of elevation of the soil surface in an interrow area where there are no directional tillage tool marks.

Large and statistically significant differences in total porosity occurred between a freshly plowed and a plowed-disked-harrowed interrow area. The freshly plowed surface had a greater porosity in the majority of trials. However, the opposite result was observed consistently in the Kranzburg-Poinsett and in some cases in the Nicollet-Webster and Barnes-Aastad associations. Much of the difference in porosity resulting from the freshly plowed and plowed-disked-harrowed treatments was explained by the soil moisture content at tillage time in relation to the moisture content at the lower plastic limit. Disking and harrowing decreased the porosity when performed on soil in the friable or harsh range of consistency, but increased the porosity when performed on soil in the plastic range of soil consistency. Hence, in row-crop tillage the interrow total porosity cannot be completely specified by the tillage operation, but is greatly affected by the soil type and soil moisture content at tillage time.

The random roughness following preplanting tillage was usually associated with the type of tillage treatment. There was evidence that the previous crop affected the random roughness of the plowed interrow areas but did not significantly affect the random roughness of the plowed-disked-harrowed interrow areas.

Frequently, the random roughness index value for spring-plowed interrow areas and the interrow areas that were spring plowed, disked, and harrowed was not different from the value for untilled soil at the end of the growing season. This agreement occurred in two growing seasons during which the two tillage treatments were each sequentially the same. Usually the total porosity resulting from these treatments was greater than the total porosity of the untilled soil at the end of the growing season, but at the end of each growing season there was little difference between treatments involving spring plowing. In an investigation consisting of two years of tillage following alfalfa, two seasons of the same tillage did not give additive effects on total porosity.

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APPENDIX

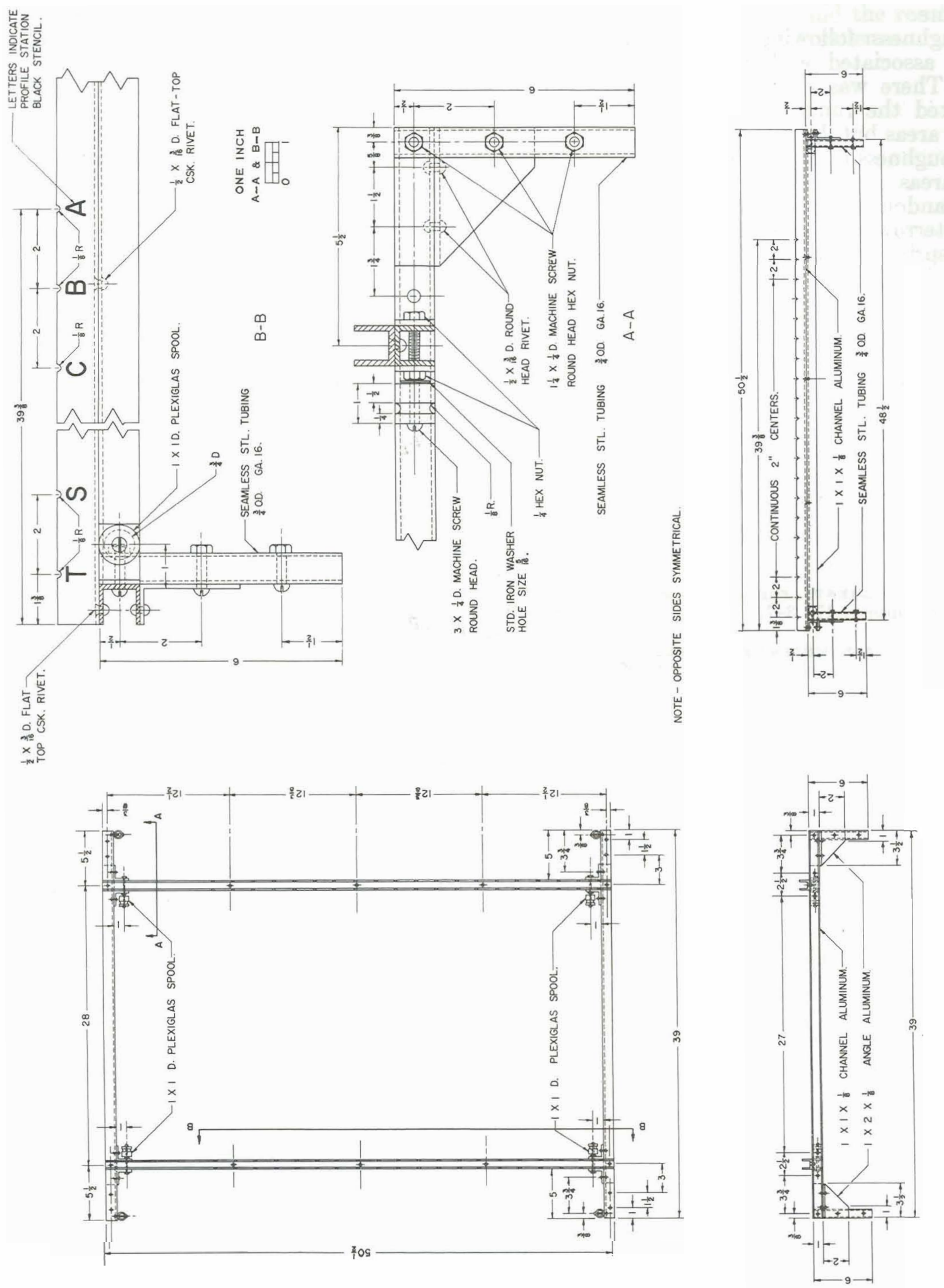

FIGURE 8.—Microrelief meter scaleboard support frame.

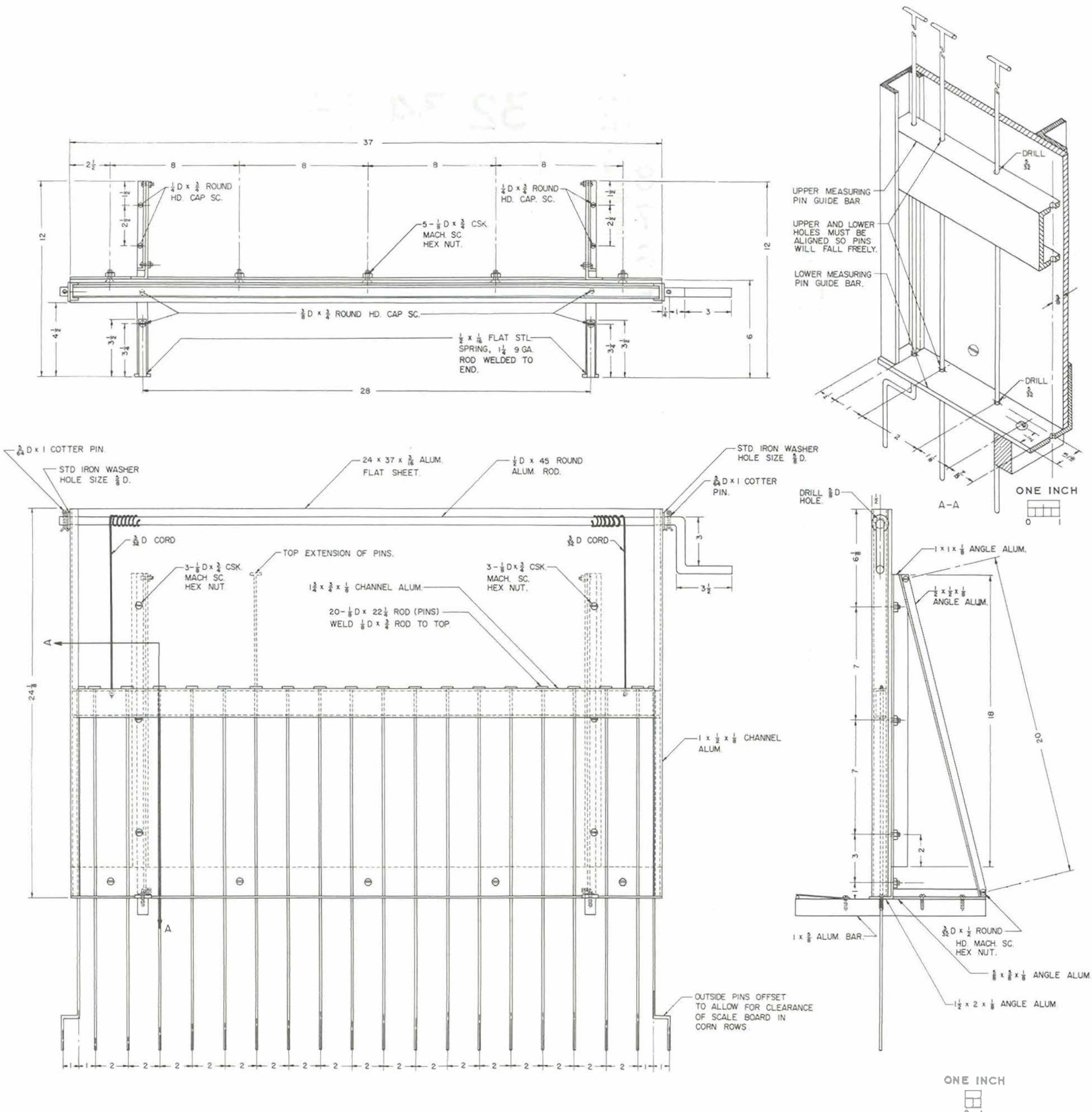

FIGURE 9.—Microrelief meter scaleboard-and-measuring-pins unit.

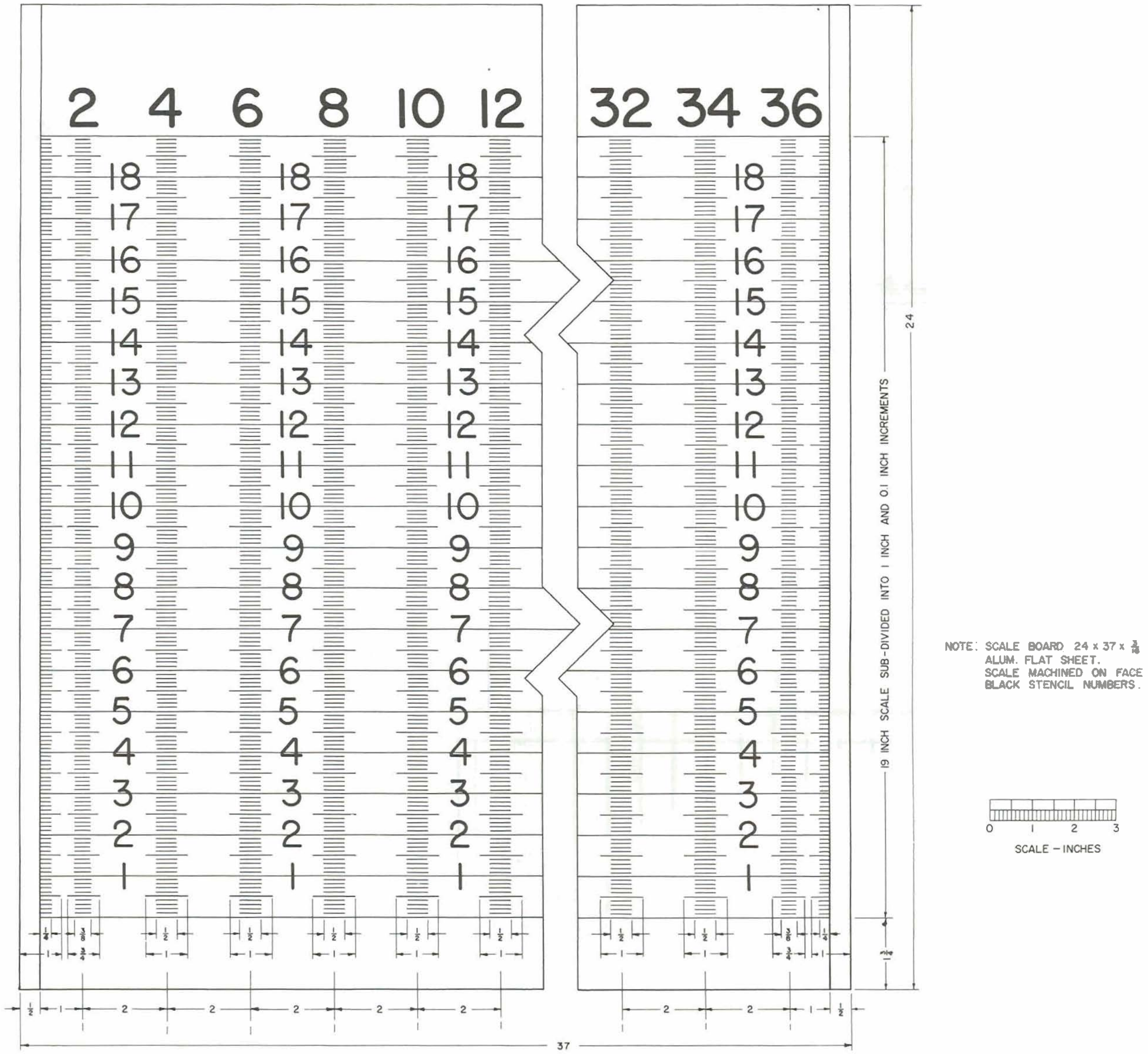

FIGURE 10.—Microrelief meter scaleboard.

Minn—34 Plot 20 July 13, 1962

Mean 9.00 Parallel sigma .8482885 Perpendicular sigma .3184191 Ratio 2.6640628

Parallel means	8. 76	10. 16	10. 07	8. 99	8. 82	9. 70	9. 94	9. 65	9. 39	8. 46
	8. 62	9. 27	10. 01	9. 89	8. 46	7. 26	7. 58	8. 30	8. 51	8. 14
Perpendicular means	8. 84	8. 86	9. 31	8. 90	8. 93	9. 12	8. 84	8. 68	8. 98	8. 61
	8. 44	8. 85	9. 06	9. 12	8. 91	9. 34	9. 50	9. 85	8. 93	8. 89

No. classes between 10 and 90 percent undersize 69 Std. error among logs .10374

MAX ABS DIFF=.02619 Random roughness=.934 Y=−6.65546+3.27739(x)

CLASS	LOG	FRACTION UNDER	NFU	EST NFU	EST FRACTION UNDER
1	2. 04759	0. 10250	0. 09500	0. 05530	0. 07631
2	2. 05140	. 10750	. 10255	. 06779	. 08459
3	2. 05521	. 11500	. 11375	. 08027	. 09279
4	2. 05902	. 12250	. 12478	. 09276	. 10100
5	2. 06283	. 12500	. 12842	. 10525	. 10928
6	2. 06664	. 13000	. 13562	. 11774	. 11768
7	2. 07045	. 13500	. 14273	. 13022	. 12624
8	2. 07426	. 14250	. 15322	. 14271	. 13498
9	2. 07807	. 14500	. 15667	. 15520	. 14393
10	2. 08189	. 15250	. 16687	. 16769	. 15312
11	2. 08570	. 17000	. 18983	. 18017	. 16255
12	2. 08951	. 17750	. 19932	. 19266	. 17225
13	2. 09332	. 19000	. 21470	. 20515	. 18222
14	2. 09713	. 19250	. 21771	. 21764	. 19249
15	2. 10094	. 19500	. 22071	. 23012	. 20305
16	2. 10475	. 21250	. 24109	. 24261	. 21392
17	2. 10856	. 22250	. 25233	. 25510	. 22510
18	2. 11237	. 23250	. 26329	. 26759	. 23659
19	2. 11618	. 24000	. 27133	. 28007	. 24841
20	2. 11999	. 25750	. 28959	. 29256	. 26055
21	2. 12380	. 26250	. 29467	. 30505	. 27300
22	2. 12761	. 26500	. 29720	. 31754	. 28577
23	2. 13142	. 29000	. 32175	. 33002	. 29885
24	2. 13523	. 29500	. 32653	. 34251	. 31224
25	2. 13904	. 29500	. 32653	. 35500	. 32591
26	2. 14285	. 31750	. 34751	. 36748	. 33986
27	2. 14666	. 32750	. 35660	. 37997	. 35408
28	2. 15047	. 33250	. 36109	. 39246	. 36855
29	2. 15428	. 36750	. 39173	. 40495	. 38324
30	2. 15809	. 37000	. 39386	. 41743	. 39814

FIGURE 11.—Typical printout of information from a single set of 400 height readings (computer program "Program Tillage").

CLASS	LOG	FRACTION UNDER	NFU	EST NFU	EST FRACTION UNDER
31	2. 16190	0. 38000	0. 40237	0. 42992	0. 41323
32	2. 16571	. 40500	. 42327	. 44241	. 42847
33	2. 16952	. 41500	. 43152	. 45490	. 44384
34	2. 17333	. 44500	. 45594	. 46738	. 45931
35	2. 17714	. 45500	. 46400	. 47987	. 47486
36	2. 18095	. 47000	. 47603	. 49236	. 49045
37	2. 18476	. 47250	. 47804	. 50485	. 50606
38	2. 18857	. 48750	. 49002	. 51733	. 52165
39	2. 19238	. 51750	. 51397	. 52982	. 53721
40	2. 19619	. 53500	. 52797	. 54231	. 55271
41	2. 20000	. 55250	. 54204	. 55480	. 56810
42	2. 20381	. 58250	. 56643	. 56728	. 58338
43	2. 20762	. 59000	. 57260	. 57977	. 59850
44	2. 21143	. 59750	. 57880	. 59226	. 61344
45	2. 21524	. 63250	. 60827	. 60475	. 62818
46	2. 21905	. 64000	. 61473	. 61723	. 64270
47	2. 22286	. 65500	. 62781	. 62972	. 65698
48	2. 22667	. 67500	. 64566	. 64221	. 67099
49	2. 23048	. 68250	. 65249	. 65470	. 68473
50	2. 23429	. 70250	. 67110	. 66718	. 69818
51	2. 23810	. 72750	. 69531	. 67967	. 71133
52	2. 24191	. 74500	. 71298	. 69216	. 72417
53	2. 24572	. 75500	. 72338	. 70464	. 73669
54	2. 24953	. 76500	. 73402	. 71713	. 74890
55	2. 25334	. 78000	. 75046	. 72962	. 76079
56	2. 25715	. 79500	. 76753	. 74211	. 77236
57	2. 26096	. 79750	. 77044	. 75459	. 78361
58	2. 26477	. 80750	. 78229	. 76708	. 79455
59	2. 26858	. 81750	. 79446	. 77957	. 80517
60	2. 27239	. 82250	. 80068	. 79206	. 81550
61	2. 27620	. 83250	. 81338	. 80454	. 82554
62	2. 28001	. 83750	. 81987	. 81703	. 83530
63	2. 28382	. 84250	. 82645	. 82952	. 84479
64	2. 28763	. 85250	. 83990	. 84201	. 85403
65	2. 29144	. 86500	. 85727	. 85449	. 86303
66	2. 29525	. 87750	. 87522	. 86698	. 87182
67	2. 29906	. 89250	. 89745	. 87947	. 88042
68	2. 30287	. 89500	. 90122	. 89196	. 88885
69	2. 30669	. 90000	. 90879	. 90444	. 89716

FIGURE 11.—(Continued) Typical printout of information from a single set of 400 height readings (computer program "Program Tillage").

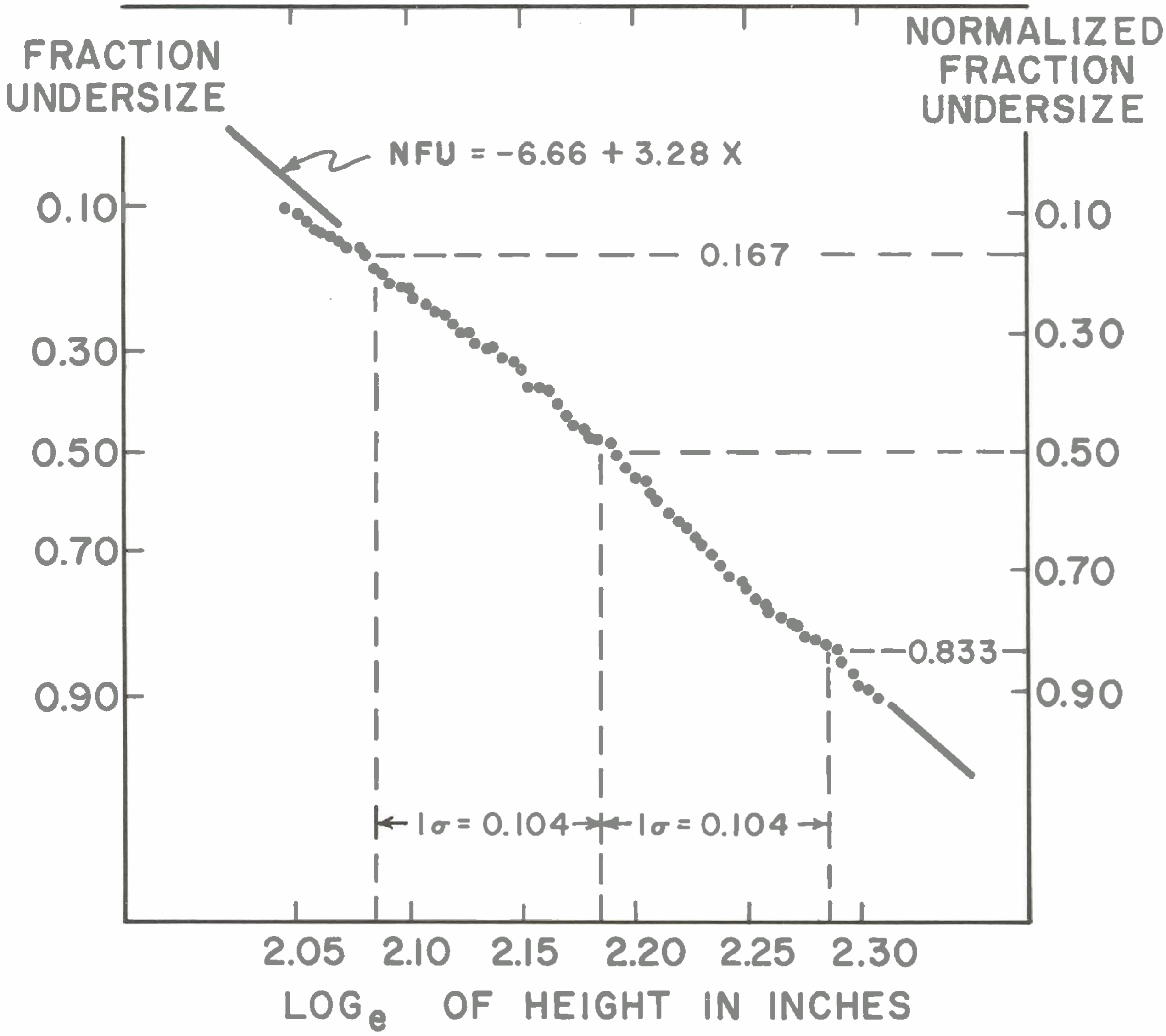

FIGURE 12.—Graphical representation of calculation of standard deviation among logarithms of height (data from appendix fig. 11).

TABLE 14.—*Experimental conditions for the 25 tillage experiments involving estimation of total porosity and random roughness* [1]

Experiment number [1]	Previous year's crop	Clay content [2]	Soil texture [2]	Moisture content [2]	
				P_w [3] at time of tillage	P_w [3] of lower plastic limit [4]
NICOLLET-WEBSTER ASSOCIATION					
		Percent		*Percent*	*Percent*
1963–1	Alfalfa-brome	36.2	Clay loam	24.6	25.8
1963–2	Alfalfa-brome	34.0	Sandy clay loam	22.6	22.1
1963–3	Corn	36.2	Clay loam	25.4	24.3
1963–4	Corn	33.0	Clay loam	24.9	23.2
1963–5	Corn	29.0	Sandy clay loam	23.5	23.5
1963–6	Corn	29.0	Clay loam	24.9	25.0
1962–L1	Alfalfa-brome	30.0	Sandy clay loam	23.9	23.1
1962–L2	Alfalfa-brome	30.0	Sandy clay loam	24.5	23.1
1963–L1	Corn	30.0	Sandy clay loam	21.1	23.1
KRANZBURG-POINSETT ASSOCIATION					
1963–10	Alfalfa	38.1	Silty clay loam	29.0	29.0
1963–11	Alfalfa	39.2	Silty clay loam	28.1	28.2
1963–12	Alfalfa	34.2	Silty clay loam	30.6	30.2
1963–13	Corn	34.3	Silty clay loam	31.8	30.7
1963–14	Corn	34.1	Silty clay loam	29.5	30.7
BARNES-AASTAD ASSOCIATION					
1963–15	Oats-sweet clover	35.2	Clay loam	24.5	26.6
1963–16	Oats-sweet clover	35.2	Clay loam	27.3	27.1
1963–19	Alfalfa	25.0	Loam	32.4	29.7
1963–20	Alfalfa	18.9	Loam	29.9	27.1
1963–21	Alfalfa	21.8	Loam	24.6	24.7
1961–M34	Flax-alfalfa	---	---	21.5	25.9
1962–M34	Alfalfa	24.0	Loam	22.3	27.9
1963–M34	Corn	24.0	Loam	24.8	27.9
1962–23	Alfalfa	24.0	Loam	22.8	27.9
1962–24	Alfalfa	24.0	Loam	27.3	27.9
1963–25	Alfalfa	24.0	Loam	12.1	27.9

[1] Experiments identified by a letter and a number after the year were in corn, and total porosity and random roughness estimates were made throughout the growing season. Experiments identified by numbers only after the year had no crop and estimates were made only once—after simulated planting. See page 21 for further discussion of experimental conditions.

[2] Clay content, texture, and moisture contents observed from samples of the 0- to 6-inch soil layer.

[3] P_w is percent of water by weight.

[4] Determined by rolling out into wire as described by Baver (*1*).

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