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A Field Measurement of Total Porosity and Surface Microrelief of Soils[1]

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ABSTRACT

Total porosity of the layer to be plowed was estimated from undisturbed cores collected before primary tillage. Using a point quadrant instrument, soil surface elevation measurements were made before and after preplant tillage, and after each cultivation to determine the effects of tillage on total porosity of the plowed layer. Large apparent differences in capacity to detain water, as inferred from total porosity, were observed among preplant tillages and among particular combinations of preplant and postplant tillage that are used in the western Corn Belt.

When total porosity of the plowed layer was measured in the ensuing fall and spring, relatively small changes in total porosity were observed. This result suggests that this physical property persists over a long time in a Barnes loam.

To evaluate the effects of tillage on surface geometry and temporary water storage in surface depressions, macro and random surface roughness as measured by the point quadrant instrument are considered. Estimates of the standard error among logarithm of the elevation heights differed among tillage treatments. The standard error is suggested as an index of random roughness.

Various tillage practices used in the Corn Belt can create different soil physical conditions in the tilled layer. These soil physical conditions may be important both for plant growth and for proper soil and water management.

Total porosity and surface microrelief may vary markedly among soils and among tillage systems within a given soil. As considered by Larson (4), a method is needed to provide simple measurements of soil porosity and surface microrelief throughout the cropping season. Such measurements are needed to evaluate tillage practices as they relate to principles of soil and water management of the inter-row area of row crops.

Within a growing season, air porosity and surface microrelief are subject to change by rainfall action, plant canopy, tillage, soil moisture changes and perhaps other factors. This paper describes a field method for measuring changes that occur in total porosity and in surface microrelief characteristics of plowed soils. Representative data obtained with the method are presented and discussed relative to the evaluation of the several tillage methods studied.

REVIEW OF LITERATURE

The total porosity of portions of the tilled layer of soil has been measured by air pycnometry (3, 6, 8). Kummer and Parks (3) and Page (6) measured noncapillary pore volume on undisturbed soil cores in the laboratory. They found that the greatest increase in noncapillary pore volumes resulted from tillage operations such as moldboard and disc plows, and that an ensuing gradual decrease of noncapillary pore volume occurred during the growing season (3). Total porosity changes were noted due to management in long-term field experiments (6). Such pore volume estimations have been made by determining the dry bulk density of undisturbed cores from portions of tilled layers. The chief limitation of these methods for estimating total porosity is that undisturbed cores are required for each measurement. Frequently, these cores are obtained under conditions of high soil moisture content and low bulk density-conditions not ideal for accurate sampling. Furthermore, the arbitrary depth selected for each time of measurement often may not include the total layer of tilled soil.

A description of the distribution of heights of constant length pins impinging on the soil surface has been used to measure soil compaction (7), lateral soil movement during tillage operations (5), and surface roughness of seedbeds (2). Kuipers (2) formulated a roughness index as 100 times the logarithm of the standard deviation of arithmetic heights. Thus far, most of the applications of this measurement principle have not been carefully evaluated, nor has the distribution of measured heights been carefully considered.

METHODS AND MATERIALS

Most of this study was conducted during the 1961 growing season at Morris, Minnesota, on a Barnes loam, having a 0 to

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1% slope. In 1959 and 1960 the area was in corn and flax, respectively. The flax residue was removed prior to tillage in 1961. Corn was grown in 1961 during the experiment.

Six tillage treatments, consisting of 3 preplant tillages each with and without postplant cultivations, were replicated 3 times. The preplant tillage treatments were: *(a)* "conventional" (turn-plowing, discing, harrowing, surface planting); *(b)* wheel-track planting (turn-plowing, planting in tractor wheel track); and *(c)* "unplowed" (seed placed in a ¾-inch diameter hole in untilled soil). Depth of plowing was controlled at 6 inches. Postplant tillage treatments were 3 shovel-type cultivations and no cultivation. In both treatments, weed control was achieved through herbicides and hand pulling.

Data for the listing and ridging treatments also reported here were obtained from selected plots of a complementary study located on Grundy silt loam near Beaconsfield, Iowa.

Porosity prior to tillage was determined from 3 Uhland-type undisturbed core samples (10) of the 0- to 6- inch layer taken at random in each plot. Changes in average surface elevation were observed with a point-quadrant instrument, more simply called a "microrelief meter." The soil surface elevations were measured to the nearest 0.1 inch on a 2- by 2-inch grid for a 40- by 40-inch area (figure 1). The measurements were taken between 2 center corn rows of the 6-row plot, over which there was no wheel traffic for the postplant tillage operations. Two steel rods, 18 inches long, placed to a depth of 12 inches in each of the 2 corn rows, served as support pins for the microrelief meter. Reference points were established in border areas, and ordinary surveying procedures were employed for the proper alignment and elevation setting of the support pins.

The microrelief meter was placed on the support pins, with the scale board in the starting position, and the measuring pins were gently lowered until all pins were resting on the soil surface. The height measurements were read from the scale board at the top of the measuring pins. The measuring pins were then raised to clear the soil surface, the measuring pins and scale board advanced 2 inches, lowered, and again height measurements were made. This procedure was repeated until 400 point stations were measured and recorded. The readings were systematically recorded for orientation of readings with respect to direction of tillage.

Microrelief measurements were made before tillage. The support pins were removed from the plots for tillage and planting operations and then were restored to their previous positions and remained throughout the season without elevation realignment to the elevation of the reference point. Measurements were made after preplant tillage, after each cultivation, and at other times.

The total porosity of the plow layer for an arbitrary date was obtained by summing the equivalent inches of porosity in the initial 0- to 6-inch layer prior to tillage and the change in average surface elevation obtained as the difference between the average surface elevation prior to tillage and that at the arbitrary date. Thus, total porosity for a given date is the "inches of porosity per initial 0- to 6-inch layer."

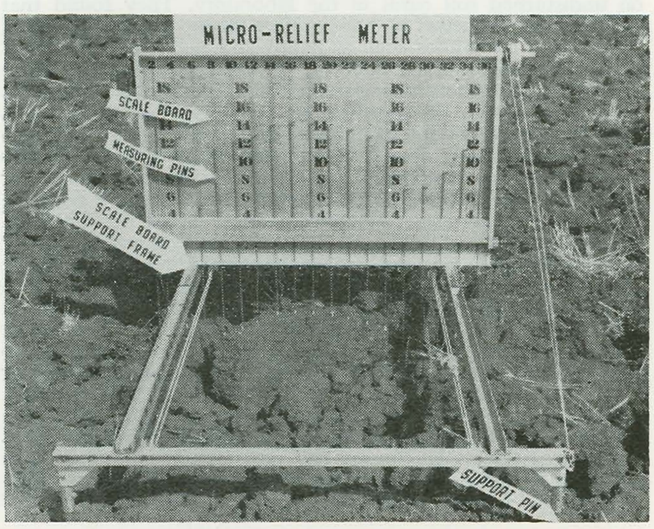

Figure 1—Microrelief meter used in the field to determine total porosity and microrelief characteristics of plowed soils.

RESULTS AND DISCUSSION

The average total porosity of the 0- to 6-inch soil layer before tillage as computed from 54 undisturbed core samples was 3.20 inches, with a standard error of 0.01 inch. The coefficient of variability for determination of the porosity in a single plot was 1.4%. These data indicate that the soil condition before tillage was sufficiently uniform for accurate measurement of the initial porosity, which is the absolute base for the estimates of total porosity.

Comparisons among treatments at an arbitrary date reveal measurable and real differences in total porosity due to tillage (table 1). The difference of 0.7 inch between the total porosity due to wheel-track and to conventional preplant tillage can be attributed to the consolidating effects of discing and harrowing. Effects of postplant cultivation on total porosity were relatively minor except when 3 cultivations in the wheel-track planting tillage reduced the total porosity by 0.8 inch.

If the total porosity of the plowed soil layer can be considered as an index of the amount of water that can be temporarily stored in that layer of soil, the differences in total porosity observed above have a real significance with respect to water management of the area between crop rows. In the Corn Belt and the Northern Plains States the greatest erosive rainfall predicted for a given year occurs during the first 2 months following seedbed preparation for corn and soybeans (11). At the end of the cultivation season (6 weeks following seedbed preparation) there were 1.4 inches (table 1) more total porosity in the wheel-track system without cultivation than in the conventional system with 3 cultivations. Hence, this porosity difference could influence the potential erosion during the early part of the growing season.

In the wheel-track and conventional tillage systems with no cultivation, the total porosity at the end of the 1961 growing season and at the beginning of the 1962 growing season was at least 0.7 inch greater than that observed at the beginning of the 1961 season (figure 2). During the same period, the unplowed treatment remained at nearly the same total porosity observed at the beginning of the 1961 growing season. Hence, the differences in total porosity noted in 1962 (figure 2) are deemed to be real effects. These effects are of special interest with respect to rainfall because 11.4 inches of rain occurred from April 9 to June 18, 1962. Several factors inherent in the measurement process could have caused inaccuracy of these measurements, especially if they did not affect all treatments alike. Swelling and shrinkage of the 12- to 72-inch soil layer (delineated by the base of the support pins and the reference pin, respectively) caused elevation changes that were within the random error of the survey-

Table 1—Effect of preplant and postplant tillage on total porosity per initial 0- to 6-inch layer of a Barnes loam.*

Tillage treatment: Preplant	Tillage treatment: Postplant	Before tillage	After preplant tillage 6/8/61	After first cultivation 6/22/61	After second cultivation 7/5/61	After third cultivation 7/17/61
				Total porosity, inches‡		
Conventional	Cultivated	3.20†	4.39 b	4.36 b	3.62 ab	3.66 ab
	Noncultivated			4.29 b	3.94 bc	4.04 b
Wheel-track	Cultivated		5.06 c	5.13 c	4.56 cd	4.26 b
	Noncultivated			5.03 c	4.99 d	5.03 c
Unplowed	Cultivated		3.20 a	3.66 a	3.63 ab	3.23 a
	Noncultivated			3.27 a	3.24 a	3.30 a

* Preplant tillage indicates type of seedbed preparation, and postplant tillage indicates cultivation normally performed for weed control.

† Porosity averaged from 54 Uhland core samples, and the standard error of this average is 0.011 inches.

‡ Porosity computed as indicated above. Within a column values not followed by the same letter are significantly ($p = 0.05$) different as evaluated by the Duncan Multiple Range Test.

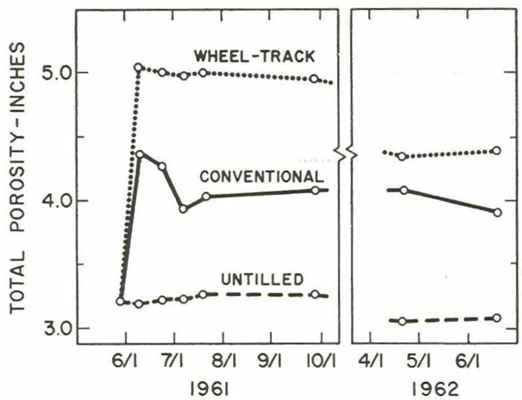

Figure 2—Effect of preplant tillage on total porosity per initial 0- to 6-inch layer of a Barnes loam (plowing performed June 2, 1961).

ing procedures. Therefore, height readings were not corrected for changes in elevation of the support pins with respect to the reference pin. If swelling and shrinkage of the 6- to 12-inch soil layer (delineated by the plowing depth and the base of the support pins, respectively) occurred, it is confounded with total porosity estimates for the initial 0- to 6-inch layer. Frost action could also have raised the support pins relative to the soil surface as illustrated by Decker and Ronningen (1). Thus, the total porosity estimates for 1962 in figure 2 could be negatively biased. These factors are being evaluated relative to porosity estimates for as long a period as illustrated in figure 2.

In addition to temporary storage of water in the total void space of tilled soil layers, temporary storage of water may be provided in soil surface depressions created by tillage operations. The magnitude of such surface storage depends on the type of surface roughness or configuration. Macro surface depressional-volumes created by tillage tool marks may be great. Examples of this type of surface roughness would be furrows formed between plow slices, and furrows made by cultivator shovels, and by listing and ridging implements. These surface configurations are especially relevant to water management.

Temporary storage capacities of these depressions are influenced by their orientation with respect to slope direction. Depressional volumes that occur at random on the soil surface may also be considered as having temporary water storage capacities. This random roughness is likely to be more relevant to water management problems in the conventional and reduced tillage systems than in tillage systems such as contour listing and contour ridge tillage.

Estimation of random roughness requires some knowledge of the distribution of height measurements made by the microrelief meter. Although no exact test for distribution of height measurements can be made, three points of evidence are presented to demonstrate that the logarithm of the heights is normally distributed. The 400 height measurements for each setting of the microrelief meter were taken on a grid extending in 2 directions on the soil surface. When tillage tool impressions were present they were oriented parallel to one direction of the grid extension. Then there was greater variation among marginal height averages each obtained by summing parallel to the direction of tillage than among the marginal height averages each obtained by summing perpendicular to the direction of tillage. This observation was made for all tillage systems, including the conventional, wheel-track, listing and ridging systems. Plots of the marginal averages, obtained by summing in the direction of tillage, versus the dispersion among heights associated with the marginal average revealed a linear relation between mean and

Table 2—Random roughness revealed by height readings taken after different tillage operations.

Tillage prior to height measurements	Estimates of the standard error among logarithm of heights
None	0.0162
Plow, conventional preplant tillage	0.0166, 0.0185
Plow, wheel-track plant	0.0305, 0.0326, 0.0390
Plow, wheel-track plant, 1 cultivation	0.0340

variance. The estimate of random roughness is a variance estimate. When a linear relation exists between mean and variance, homogeneity of variance can be obtained by transforming to the logarithm of the heights. This is the first evidence for considering a normal distribution of logarithm of the heights.

The second and third evidences for log-normally distributed heights were obtained from description of the distribution of the random component of height measurements. The random component of the height measurement was obtained by mathematically removing the variation due to tillage tool orientation. In the following model representing the components of a height measurement, Y_{ij}:

$$\bar{Y}_{..} + A_i + e_{ij} = Y_{ij} - (\bar{Y}_{.j} - \bar{Y}_{..}),$$

the left hand side of the identity describes the components of variation and the right hand side describes the operation performed on the height measurement. In the model $\bar{Y}_{..}$ is the average of 400 height observations (retained to avoid negative numbers), A_i and e_{ij} are both random components of variation, and $\bar{Y}_{.j}$ is the average of 20 readings ($i = 1, 2, \ldots, 20$) in the direction of tillage for the j^{th} tillage tool mark. Thus, an "adjusted" height contains a fixed component common to all 400 height observations, and 2 random components, A_i and e_{ij}. The magnitude of e_{ij} depends on the i^{th} position along a path parallel to the row and on the j^{th} tillage tool mark or position along a path perpendicular to the row, and the magnitude of A_i depends only on the i^{th} position along a path parallel to the row.

For the second evidence, the moments of the distribution of adjusted heights were compared with the moments of the theoretical normal distribution. The method is illustrated by Snedecor (9). In 5 out of 7 sets of 400 observations the moments of the distribution of heights departed significantly from those of the theoretical normal distribution. These departures were randomly distributed among sets having different tillage prior to measurement, and the departures were in the direction expected if the logarithm of the heights were normally distributed. The third evidence demonstrating that the logarithm of heights is normally distributed was based on a test of the linearity of the relation between percent undersize and adjusted height (and adjusted logarithm of height), plotted on a probability scale. Six comparisons each consisting of 400 observations were made: one each of ridge, listing, and wheel-track tillage systems immediately after tillage; 2 of conventional system after tillage; and one after 3 cultivations on a wheel-track tillage system. Except in the ridge system, the linearity was better when the adjusted logarithm of the height was considered than when the adjusted height was considered.

Estimates of the standard error among logarithm of the heights were used as an index of random roughness. Standard errors of the logarithm of heights from the conventional and wheel-track tillage systems are given in table 2. These data show homogeneity among standard errors estimated from different plots of the same tillage treatment and a real difference between the random roughness of a freshly plowed surface and that of a surface conventionally row-crop tilled or untilled for several years. This index of random roughness is being considered in relation to water management problems.

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