yield was only 0.1 tons per acre with corn (SM) producing an average of 3.8 tons per acre compared with 3.7 tons per acre from corn (R). Generally, in years when rainfall during the growing season was above average, the yield from corn (SM) was lower than that from corn (R). However, this yield differential was compensated for by higher yields from corn (SM) during years when growing season rainfall was below average. Corn yield was higher from corn (SM) in 9 location-years, 6 of which were dry years.

The yield relationship is expressed by the equation

$$Y = 3.75 - 1.51X,$$

where X is departure from the average growing season rainfall and Y is yield difference in bushels per acre of corn (SM) as compared to corn (R). The coefficient of correlation, using 15 years of data, was 0.69 which is significant at the 1% level.

The presence of the mulch had no apparent effect on corn height or color at any time during the growing season over the 9-year period of study. This is in contrast to the data of Larson et al. (4), who found that mulches generally decreased the early growth of corn in northern United States and attributed this decrease to the lower soil temperatures under the mulch.

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# Distribution Patterns of the Weld-Rago Soil Association in Relation to Research Planning and Interpretation[1]

Claude L. Fly and Dale S. Romine[2]


## ABSTRACT

**This study is concerned with criteria for predicting applicability to other soils of research results obtained from key or benchmark soils. Soil-water-plant growth relations which affect yields under different levels of management were evaluated at Akron, Colo. Under 46 years of uniform management, wheat production levels varied from 73 to 120 among eight soil types identified in a 25-acre test field formerly mapped as one soil type. Soil differences induced wider variations under uniform treatment than did different treatments on a single soil type. When the detail of delineation and characterization of soils is comparable to the detail of the research plot layout, existing research fields and plot data may be used to associate soil qualities with response to treatment. The reliability of application of research findings to other areas will depend on adequate characterization and evaluation of the soil in each plot.**


Following reorganization of the Soil Conservation Service and the Agricultural Research Service in 1954, impetus has been given to the interpretation of soil surveys for use in various endeavors such as conservation, engineering, and urban and rural planning. Mapping and characterization of soils on state and federal experimental fields was speeded up to improve interpretations of soil surveys and to facilitate more exact application of research data to soil management.

Guidelines are needed in interpolating or extrapolating the results obtained by research processes from one soil to other soil and soil-climate situations (1). The applicability of research findings or conservation experience to other soils and climates is, at present, largely a matter of opinion.

This study was made to determine, first, if existing research data could be used to help interpret benchmark soils on which research had been performed; and second, whether reliable criteria for prediction of applicability of results could be effectively developed.

## PROCEDURES

Priority was given to research fields having *(a)* long records of reasonably uniform management and *(b)* contrasting soil types. A plot area for study was selected on the USDA Central Great Plains Field Station, Akron, Colo. which included 56 dryland rotations and tillage treatments on 152 plots, 8 by 2 rods in dimensions. Research on most of the field dated from 1908 through 1954,[3] but additional plots were added in 1924, 1928, and 1930 (2). The 25-acre field appears relatively uniform on the surface, and as late as May 1944 (2) published reports described it as being of one soil type.

Plots were selected to represent the production of winter wheat by *(a)* continuous cropping, *(b)* fallow and wheat, and *(c)* wheat following corn in a 4-year rotation. A very detailed study of the distribution of soil types and phases within the 25-acre field was made using a power probe. Soils were sampled at intervals of 100 feet on a uniform grid. Color, thickness, texture, and structure of horizons, depths to zones of carbonate accumulation, and the presence or absence of buried soils were recorded.

Paired profiles of Weld[4] loam and Rago loam were excavated to a depth of 5 feet and samples were taken by horizons for

[1]Joint contribution from the Soil and Water Conservation Research Division, ARS, USDA, and the Department of Agronomy, Colorado Agr. Exp. Sta. (Project 141). Presented before Div. VI, Soil Sci. Soc. Am., Ithaca, N. Y., Aug., 1962. Received Apr. 10, 1963. Approved Aug. 26, 1963.

[2]Soil Scientist, USDA, Fort Collins, Colo., and Associate Professor of Soils, Colorado State University, Fort Collins, respectively.

[3]Unpublished data examined included:
USDA Climatological Records of the Akron Dryland Field Station, Akron, Colo. 1908-62.
USDA Cooperative Cereal Grains Investigations, Ann. Rep., Akron Field Sta., Akron, Colo. 1910-54.
USDA Cooperative Dryland Crop Rotations Studies, Ann. Rep., Akron Dryland Field Sta., Akron, Colo. 1908-54.

[4]Series names based on final field correlation memorandum, SCS Soil Survey, 1961.

laboratory analyses. Analyses included particle size distribution, organic matter, $NaHCO_3$-soluble P, calcium carbonate, pH, cation-exchange capacity and exchangeable cation concentrations, moisture content at saturation and at ⅓- and 15-atm. tension, bulk density, and organic N.

In addition to surface examinations and laboratory data, the soil-boring grid map, the detailed soil map, and a topographic map (vertical interval = 0.2 feet) were used as overlays on a plot map of exactly the same scale in order to establish the composition of each plot. In this manner the specific composition of each plot with respect to percentage distribution of soil types and phases, the mean depth to the $CaCO_3$ horizons, and the dominant slopes were determined. Only the major soil types and depth groupings were used for final comparisons.

Crop yield and management records and climatic data were obtained from the daily records of the experiment station[3] and from the U. S. Weather Bureau (7, 8).

From long-time records of uniform normal treatment on plots composed of single soil types, it was possible to establish base productivity levels for thin, medium, and deep soils, respectively, and by statistical methods, to assign normal plot productivity values to the heterogeneous plots. Comparisons of actual yields of several treatments with computed plot yields under normal treatment (check plots) permitted differentiation of yield variations caused by soils and those caused by treatment.

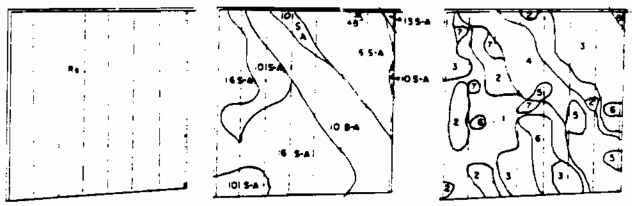
## RESULTS

### Soil Distribution Patterns

From the initiation of the dryland experimental field in 1908 until 1938, there was no specific designation of the soil type or types on which the experiments were being conducted. The Akron Area soil survey, made in 1938 and published in 1947, designated this field as Rago silt loam (5). The 1950 detailed survey divided this 25-acre block into four types and one phase. The 1960 field correlation not only made major revisions in boundary lines, but changed textural classes for all types and changed names of two series. The 1961 detailed examination recognized four of these types and phases, but identified a total of 5 soil types and 3 phases occurring in a rather intricate pattern. Figure 1 indicates the chronological changes in soil boundary designation and soil identification, omitting the 1950 survey. Rago silt loam, shown as 100% of the 25-acre area up to 1950, did not occur on the 1960 or 1961 map. Of the three major types that were shown on the 1950 map, only one appeared on the maps made in 1960 and 1961. Soil variability was found significant in data interpretations, however.

### Soil Descriptions

The soils studied are all derived from relatively recent aeolian deposits, chiefly of fine sands and silts, and are developing on relatively uniform topography under a shortgrass-midgrass complex in the semiarid climate of the Central Great Plains. Therefore, there is no great difference in origin. The primary differences are *(a)* stage of development; *(b)* microrelief, which, because of better water distribution, may have resulted in higher organic matter and deeper development in some soils than in others; *(c)* differential wind erosion with redeposition of the aeolian materials and surface soils; and *(d)* depth of deposition of $CaCO_3$. Major properties of Weld and Rago loams and the other soil types delineated in the detailed examination of plots are described briefly in table 1.



A B C

**Figure 1—A study in progressive soil mapping of the dryland rotation plots, Akron Field Station, Akron, Colo.**
**A. Akron area soil survey (5), 1947: Rs=Rago silt loam.**
**B. Detail soil survey, 1960: 4B=Colby loam; 10S-A=Weld loam, thick solum phase; 10B-A=Rago loam; 13-A=Sligo loam; 16S-A=Weld loam.**
**C. Detail survey, 100 foot Grid, 1961: 1=Weld loam; 2=Weld loam, thick solum phase; 3=Weld loam, thin solum phase; 4=Rago loam; 5=Kuma loam; 6=Norka loam; 7=Norka loam, thick solum phase; 8=Sligo loam.**

**Table 1—Summary of major characteristics of soils in experimental field.**

| Series* names | Surface soil | Upper subsoil | Lower subsoil | Origin and position | Slope and aspect‡ | Zone of calcium carbonate: Depth | Zone of calcium carbonate: Concentration |
|---|---|---|---|---|---|---|---|
| | | | | | | in. | |
| *1 Weld loam | Loam-6-8 in., 10YR 4/2-3/2† mod. med. granular, abrupt boundary. | Clay or silty clay loam-4-8 in., 10YR 4/3-3/3, strong prismatic, density 1.55-1.60. | Clay loam to loam-10-15 in., calcareous, weak to mod. coarse prismatic, hard to firm. | Calcareous, loamy aeolian deposition: upland divides of smooth or convex slopes | 0.1-1.6%, 0.4% dominant. | 15-18 | 12-15% at 20-30 in. |
| *2 Weld loam Thick Solum Phase | Same, less abrupt boundary. | 6-10 in. thick, less dense. | Similar but several inches deeper. | Same on slightly concave slopes | 0.1-1.0%, 0.3% dominant. | 20-24 | less than above |
| *3 Weld loam Thin Solum Phase | Loam-3-6 in., 10YR 4/3-3/2, weak med. granular, smooth boundary. | Clay loam-3-5 in., 10YR 4/3-3/3, mod. prismatic, may be calcareous. | Loam-10-20 in., weak coarse subangular blocky, highly calcareous, soft, friable. | Same but on steeper or strongly convex slopes. | 0.23-3.0%, 2.0% dominant | 6-10 | 10-15% at 12-20 in. |
| *4 Rago loam | Loam-8-10 in., 10YR 4/2-3/3, mod. med. granular, smooth boundary. | Clay loam-4-6 in., 10YR 4/3-3/3, med. prismatic, density 1.45-1.50. | Silty clay loam-12-20 in., 10YR 4/1-2/1 and 4/2-3/2 (buried soil). Non-calcareous, subangular blocky, firm to friable. | Reworked, loamy aeolian materials: smooth divides, slightly concave slopes. | 0.0-0.9%, 0.15% dominant. | 25-30 | 2-4% at 28-40 in. |
| *5 Kuma loam | Loam-8-9 in., 10YR 4/2-3/2, mod. med. granular, gradual boundary. | Loam or light clay loam-10-12 in., 10YR 4/2-3/2, weak prismatic to subangular blocky. | Similar to buried soil of Rago, less dense and lower in clay content. | Similar to Rago. | 0.15-0.8%, 0.2% dominant | 25-30 | 2-4% at 29-40 in. |
| *6 Norka loam | Loam-6-8 in., 10YR 4/3-3/2 weak to mod. med. granular, smooth boundary. | Loam to light clay loam-3-5 in., 10YR 4/3-3/2, weak med. prismatic to subangular blocky. | Loam to vfsl., calcareous weak coarse prismatic to subangular blocky. | Same but thin on smooth to convex slopes; some fine gravel on surface. | 0.18-2.0%, 0.45% dominant | 8-13 | less than in Weld soils |
| *7 Norka loam Thick Solum Phase | Loam-8-9 in., 10YR 4/3-3/2, weak to mod. med. granular, smooth boundary. | Loam to light clay loam-6-10 in., 10YR 4/3-4/2, weak med. prismatic to subangular blocky. | Loam to vfsl., 10YR 4/3-3/3, calcareous below 20 in., firm to friable. | Same on smooth flats or gentle slopes. | 0.10-0.5%, 0.3% dominant. | 20-24 | less than in Weld soils |
| *8 Sligo loam | Loam-8-10 in., 10YR 4/2-2/1, mod. med. granular, gradual boundary. | Loam to light silty clay loam 10YR 4/1-2/1, weak med. subangular blocky. | Dark, loamy and friable to considerable depth. | Well-drained swales in upland; gently concave slopes concentrate runoff water. | 0.1-1.0%, 0.35% dominant. | Variable, low concentration, may be calcareous at surface or at 2-3 feet. | |

* Soil series names are those used in field correlation and are subject to approval in final correlation of area.
† Color symbols by Munsell System. ‡ All soils on southeast and east exposures.

### Soils Analyses

Comparative analyses of Rago loam and Weld loam are given in figure 2. No strongly unfavorable reactions were observed in any of the soils. Conductivity of saturation extracts of Rago and Weld loams was less than 1.0 millimho per cm., except in the C horizons which ranged from 0.9 to 1.7 millimhos per cm. The paste pH was 6.5 for all surface soils, 6.5 to 7.8 for progressively deeper subsoil horizons, and 7.6 to 8.1 in the C horizons. The 1:5 dilution pH rose slightly above 9.0 in the C horizon only. The two soils differ markedly in certain respects, however. The Rago soil has a buried profile, being underlain by a darker soil at relatively shallow depths. This "two-story" soil accounts for deeper accumulation of organic matter. Concentrations of $CaCO_3$ are only 2 to 4% at depths of 28 to 34 inches in the Rago loam whereas Weld loam has as high as 15% lime within the 20- to 30-inch layer. Total N to a depth of 5 feet computed from one sample of Rago loam was 11,500 pounds per acre as compared to 9,800 pounds computed from analysis of a sample of Weld loam; 1,400 pounds more N was found in the first 3 feet of the Rago loam. Bicarbonate-soluble P in the 5-foot profile of a sample of Rago loam was 218 pounds (500 pounds $P_2O_5$) and in the Weld loam was 120 pounds (275 pounds $P_2O_5$). The Weld loam has an abrupt change in texture and compaction between the plow layer and the B horizon, with a 10 to 15% increase in bulk density. The available moisture capacity above the zone of highest concentration of $CaCO_3$ is 3 inches greater in the Rago loam than in the Weld loam.

### Relative Soil Productivity

The procedure for determining the characteristics of individual plots and of evaluating relative differences in response to treatments and crop sequences has been explained. Because of the difficulties involved in segregating an adequate number of plots of each soil type for the entire period, it was necessary to compare some types under similar levels of management for shorter periods and make adjustments in relative yields by comparison with soil types having the longer records.

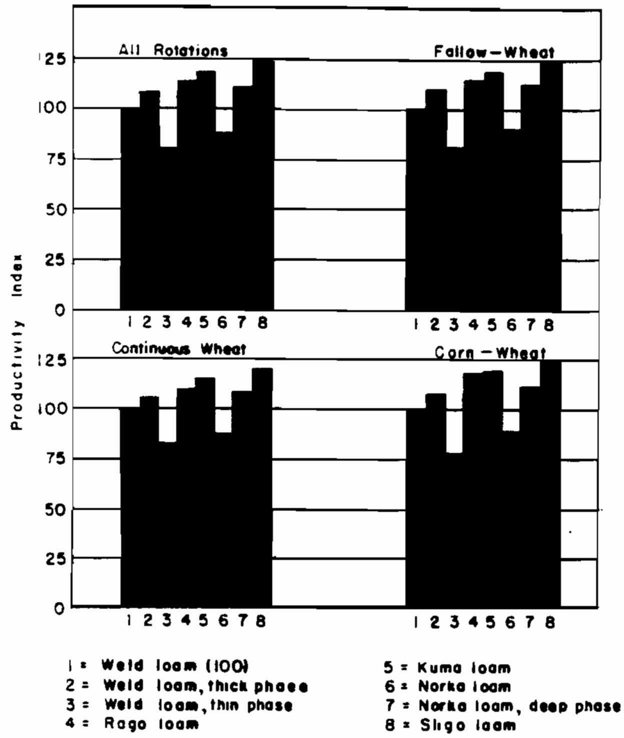



**Figure 3—Productivity of winter wheat, Akron, Colo.**

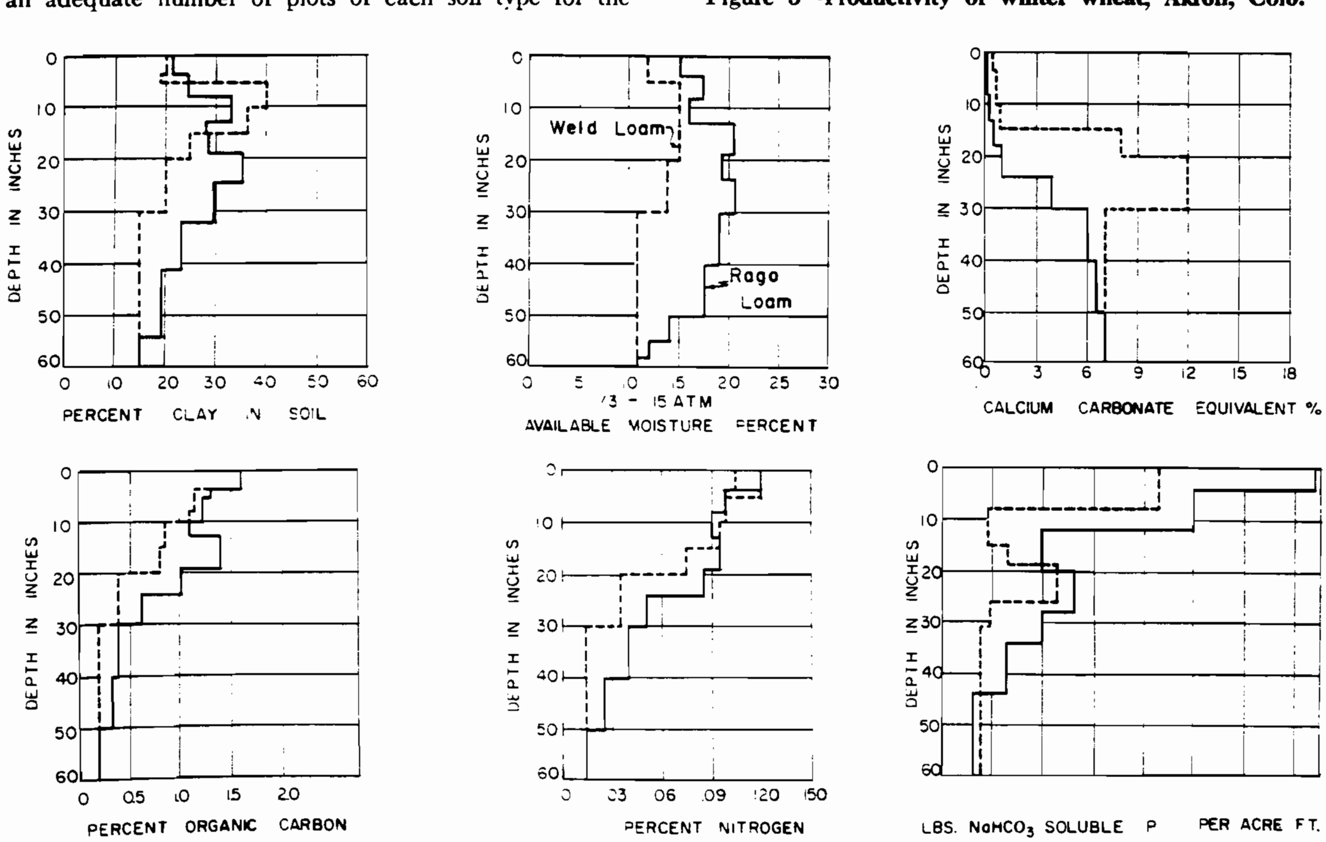



**Figure 2—Comparison of important physical and chemical properties of Rago and Weld loams.**

Figure 3 shows the relative productivity of the eight soil types for winter wheat at Akron, Colorado, using Weld loam as 100. The relative position of each type changes only slightly for different cropping systems, the deeper soils[5] being somewhat more responsive than thinner soils under a fallow-wheat program. "Relative productivity" is used on a percentage basis because quantity ratings in terms of bushels of wheat would be reliable only for a given period (1). During a 30-year period of wheat grown under continuous culture, the deep soils produced 20% more paying crops[6] and 55% more wheat above cost of production than did the thin soils in the same experimental field. During 47 years of record, the deep soils[5] produced 16% more paying crops and 52% more wheat above cost of production from corn-wheat rotations than did the thin soils. Where wheat was grown after fallow over a 29-year period, the deep soils produced 19% more paying crops and 64% more wheat above cost of production. These relationships could not have been determined without the detailed field and laboratory examination of soils in the experimental plots and association of plot response with soil properties and soil distribution patterns.

## The Effect of Soil Type Variations on Interpretations of Dryland Rotation and Tillage Experiments

Where it was possible to segregate a representative number of plots for a single soil type, (Weld loam, thin solum phase) the six treatments used for growing continuous wheat, involving dates and types of tillage and seeding methods, were generally insignificant in their effects on wheat yield. The variation among treatments was no greater than the variation within the treatments. The mean yield of all continuous wheat on Weld loam, thin phase, was 342 pounds for 330 plot years with a mean variation of ±8.4 pounds or 2.5% among treatments.

However, when all records were adjusted to a 46-year period on the basis of comparable years, and adjusted for years of production under different climatic situations, the mean average yield of wheat under continuous culture for the 46 years was Rago loam = 516 pounds; Weld loam = 450 pounds; and Weld loam, thin phase = 372 pounds. The productivity ratings were Rago loam = 114, Weld loam = 100, and Weld loam, thin phase = 83. It appeared from these data that significant differences in wheat yields reported in the past for certain rotations and treatments could be the result of soil differences rather than treatment.

To evaluate the effects of soil type distribution patterns on interpretation of results, the mean weighted productivity level for each plot was determined from the percentage distribution of soil types and the mean productivity levels under normal treatment for the deep, medium, and thin soils, respectively. Normal yield values were assigned to each plot for fallow-wheat, corn-wheat and wheat-wheat sequences. Calculated mean plot productivity values ranged from 77 to 114, and the soil distribution patterns ranged from 100% deep to 100% shallow soils. Comparisons of actual plot yields with yields computed from normal treatment and for the weighted soil productivity of each plot permitted differentiation between variations due to soils and those due to treatment (see procedure).

[5]Deep soils include Kuma, Rago, and Sligo loams, and Weld loam, thick solum phase; medium includes Weld loam, and thin soils include Norka loam and Weld loam, thin solum phase.

[6]Paying crops were considered as 600 pounds (10 bushels) or more from fallow-wheat, and 300 pounds (5.0 bushels) or more from continuous wheat or corn-wheat rotations.

Table 2—A summary of rotations and treatments used in production of winter wheat at Akron, Colo. and interpretation of results with and without benefit of detailed soils evaluation.

| Treatment or practice | Rotation & plot numbers | Actual plot yield avg. | Treatment minus check unadjusted | Potential yield adjusted for soils | Treatment minus check adjusted |
|---|---|---|---|---|---|
| | | pounds/acre | | | |
| **Time & frequency of plowing continuous wheat** | | | | | |
| Check plots: Normal disked & seeded | 571 B, 572 B, 573 B, -C, 568 | 342 | 0 | 342 | 0 |
| Early fall disked | 572-1-B | 498 | +156 | 468 | + 30 |
| Early plowed & strip seeded | 592 | 450 | +108 | 402 | + 48 |
| Early fall listed | MC F | 444 | +102 | 468 | - 24 |
| Early listed & seeded in lister furrow | 572-1-A | 390 | + 48 | 466 | - 78 |
| Subsoiled & plowed | MC E | 378 | + 36 | 450 | - 72 |
| Early fall plowed | MC-B, -B', 572 A, 573 A | 360 | + 18 | 340 | + 20 |
| Late fall plowed | MC A | 348 | + 6 | 366 | - 18 |
| No treatment, seeded in stubble | 591 | 330 | - 12 | 366 | - 66 |
| **Manuring** | | | | | |
| A. On fallow land: | | | | | |
| Check plots: No manure | 267 | 954 | 0 | 954 | 0 |
| Spring topdressed | 269-1 | 1,050 | + 96 | 1,176 | -126 |
| Plowed under in spring | 268 | 942 | - 12 | 918 | + 24 |
| Fall topdressed | 269 | 912 | - 42 | 912 | 0 |
| B. On corn land: | | | | | |
| Check plots: No manure | 252 | 546 | 0 | 546 | 0 |
| Manure plowed under | 251 | 552 | + 6 | 556 | - 4 |
| **Crop rotation & sequence** | | | | | |
| A. Wheat after fallow: | | | | | |
| Check plots: Alternate fallow-wheat | MC-C, -D, 267 | 1,038 | 0 | 1,038 | 0 |
| Corn-oats-fallow-wheat | 28 | 1,092 | + 48 | 1,096 | - 4 |
| Wheat-fallow-wheat | 568 | 552 | -186 | 550 | + 2 |
| B. Wheat after corn (All seeded on disked corn ground) | | | | | |
| Check plots: Corn-wheat | 252 | 552 | 0 | 552 | 0 |
| Fallow-oats-corn-wheat | 81 | 654 | +102 | 630 | + 24 |
| Rye-oats-corn-wheat | 26 | 564 | + 12 | 620 | - 56 |
| Corn-wheat (manured) | 251 | 546 | - 6 | 654 | -108 |
| Peas-oats-corn-wheat | 97 | 540 | - 12 | 498 | + 42 |

The summary of treatment, tillage, and rotation practices is given in table 2, where the effects of correcting yield relations with respect to soil productivity differences among individual plots and rotations are shown. In several cases, the interpretation one would assume from reports of plot treatment averages is reversed when the relative plot productivity potentials are considered. This is clearly illustrated by rotation 269-1 where spring topdressing of wheat with manure appeared to have increased yields by 96 pounds. This particular plot consisted largely of deep, dark soils of much higher potential production than was obtained. After soil productivity correction, it would appear to be that spring topdressing actually depressed yields.

For 11 out of 21 practices and treatments, correcting for soil differences either reversed the original interpretation based on plot averages or made changes of 30 pounds or more in the yield values indicated. After correcting for soil differences, over one-half of the practices and treatments appeared to have negligible effects on yields of winter wheat. It can be seen, therefore, that where plot yields are not corrected for soil differences, rotations and treatments which are wholly or to a large extent on a thin soil may be unfavorably rated in comparison with those on deep soils.

## DISCUSSION AND CONCLUSIONS

These studies indicate that, if research results are to be correlated with soil type characteristics, the detail of mapping should be comparable to plot layout and intensity of agronomic or other research performed. Successive changes in the concepts of soil mapping and soil identification and in the detail of soil mapping may also necessitate occasional re-examination of data interpretation.

Determination of the principal physical and chemical

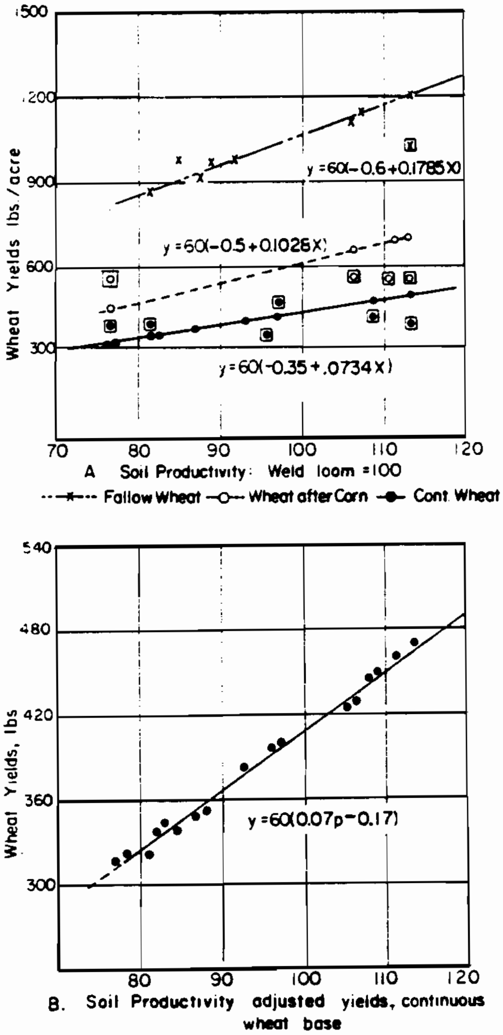



**Figure 4—Plot yields of winter wheat vs. soil productivity. Dryland rotation plots, Akron, Colo. Plots where treatment causes significant (18 lb. ±) difference from soil effect are shown in square, ⊡**

soil properties responsible for plot heterogeneity and correlation of these with mappable soil units would aid interpretation of plot research results and furnish improved criteria for prediction of research applicability to other soil-climate areas. Any new plot layout should be very carefully aligned with soil variations encountered in order to provide for statistical examination of results by soil types. Such a procedure would not eliminate need for replication but would provide a basis for interpretation of results. When plot uniformity tests are being made to evaluate soil heterogeneity, a detail grid-type soil survey should be made and the soil type and phase map used as an overlay to (*a*) guide plot layout, (*b*) to serve as a plot sampling guide, and (*c*) to aid computation of mean plot productivity values.

Interpretation of the applicability of research to other soil areas and climates depends upon a thorough knowledge not only of the soil distribution patterns but also of climatic influences during the important phenological growth periods of the crop. One must first know the micropattern of soil type and phase distribution and microclimatic effects within the research plots. Then one must know the "macro" soil patterns within the broader areas into which research results are to be interpolated.

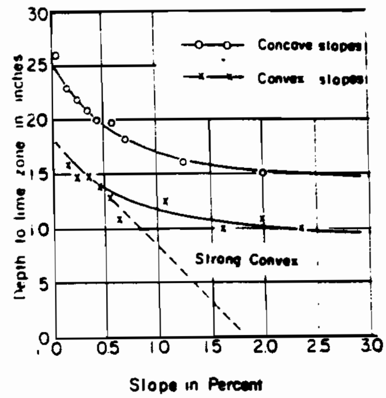



**Figure 5—Depth of calcium carbonate as related to slope.**

This procedure was applied to the Akron area by use of overlays and of planimetric measurement of similar soils and soil associations on three maps, viz., the detail soil survey of the 25-acre research field (scale: 1 inch = 200 feet), the Akron Area soil survey (1 inch = 1 mile), and the Great Plains Soil Association map (1 inch = 40 miles). Research results from the 25-acre block apply specifically and directly to 52% of the county. Based on soil variations from the regional soil association map, the research has specific application to 14% and general application to an additional 14.6% of a surrounding area of 40,000 square miles. It is recognized, however, that certain research findings or interpretations may apply generally over a larger area and to a number of soils under a given land use, while other findings may have direct application to only a few soil types or a local situation.

## Developing Research Applicability Criteria

Mathematical expressions of soil criteria for predicting applicability of research results are not easily developed for a specific soil type or soil association. In this study the yields were adjusted to a common base in a subjective manner. This gives satisfactory results but is impractical or impossible on a large scale. Development of a mathematical model which will allow adjustments to be made by inexperienced personnel using modern statistical equipment would facilitate application of the effects of soil type distribution patterns to interpretation and use with field or field plot results.

Plot yields for dryland wheat production were associated with soil distribution patterns within the plots and regression lines computed for yields of fallow-wheat, corn-wheat, and continuous wheat at different levels of soil productivity (figure 4A). This allows quick evaluation of the relative levels of the three cropping systems and the effect of soil productivity on these levels. Fallow-wheat response to soil productivity is estimated to be 2.4 times that of continuous wheat as shown by the slopes of the regression lines. While moisture is the primary limiting factor in production of continuous wheat, crops respond more readily to increased moisture deposits in the deeper, more productive soils.

When all plot yields were reduced to the level of continuous wheat, the r value was 0.741 for the regression equation

$$Y \text{ [yield]} = 60\ (.068\ P \text{ [productivity index]} - .202).$$

When the yields were adjusted also to compensate for treatment effects and for micellaneous factors, such as hail, a correlation coefficient of $r^2 = .992$ was obtained (figure 4B) for the regression equation,

$$Y = 60\ (0.07\ P - 0.17).$$

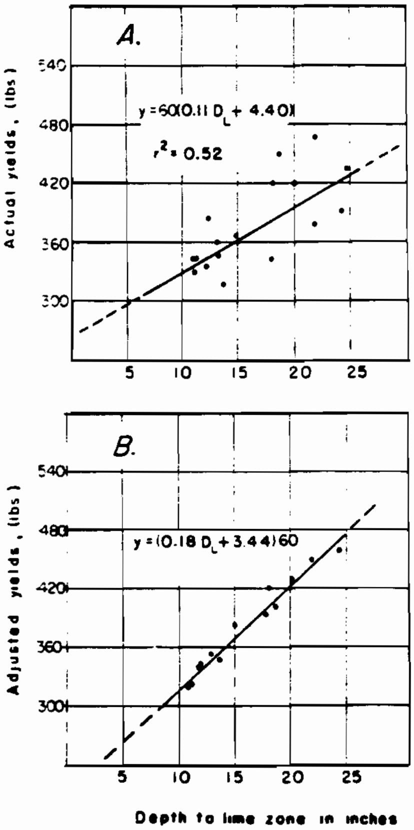



**Figure 6—Depth of calcium carbonate as related to wheat yields.**
**A. Actual yields of continuous wheat vs. lime zone depth.**
**B. Adjusted yields of continuous wheat vs. lime zone depth.**

Thus figures 4A and 4B provide one criterion for extrapolation of research results between soils of different productivity levels and also for comparing treatment effects where soils or more than one productivity level are involved.

Depth to the primary zone of $CaCO_3$ accumulation is often used by soil surveyors in the semiarid regions as a quick clue to soil development of medium- to fine-textured soils. At Akron, concave slopes, which tend to concentrate more than the normal flow of water across an area, generally had soils with lime zones 4 to 6 inches deeper than those soils developing on convex surfaces where greater runoff and surface soil loss was to be expected (figure 5). Microrelief appeared significantly connected, also, with other soil-forming processes such as organic matter accumulation, clay migration, and structural development. A direct comparison of lime zone depth to unadjusted plot yields (figure 6A) shows some scatter, perhaps caused by treatment variation and miscellaneous factors, with an $r^2$ value of 0.521 for the regression equation

Y [yield] = 60 (0.11 $D_L$ [depth to lime] + 4.40).

When yields are adjusted for treatment differences and miscellaneous factors (such as hail or insect damage), the values fit rather closely the regression line

$$Y = 60 (.18 D_L + 3.44)$$

with an $r^2$ value of 0.988 (figure 6B). There is some justification in using a single, easily measured, soil property to quickly assess relative productivity of developed soils which are derived from similar parent materials and are developing under the same general influences of climate and vegetation. Such technique might not apply to recent alluvium or other undeveloped soils or to soils differently irrigated and fertilized.

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# NOTES

## A RECORDING BALANCE FOR MEASURING UNSATURATED MOISTURE FLOW IN SOIL[1]

The transient outflow method for making unsaturated conductivity measurements, described by Kunze and Kirkham,[2] requires accurate measurements of the initial flow rate out of a soil sample. Green[3] found that the method also was applicable for transient flow into a soil sample. Both methods were adequate for most conductivity experiments, but apparently were unsatisfactory for some experiments in the near saturation range. In the investigations cited above, the flow rates were obtained by measuring the movement of an air bubble in a pipette. The air bubble technique has several limitations: *(1)* more force is required to move a column of water containing an air bubble than without it; *(2)* with fast outflow the bubble movement is too rapid to be recorded accurately with the eye; and *(3)* the initial surge effect

[1]Contribution from the Soil and Water Conservation Research Division, ARS, USDA, in cooperation with the Minnesota Agr. Exp. Sta., St. Paul 1, Minn. Minn. Agr. Exp. Sta. No. 5041. Received Apr. 17, 1963. Approved May 27, 1963.

[2]Kunze, R. J. and Kirkham, D. Simplified accounting for membrane impedance in capillary conductivity determinations. Soil Sci. Soc. Am. Proc. 26:421-426. 1962.

[3]Green, R. E. Infiltration of water into soils as influenced by antecedent moisture. Ph.D. Thesis, Iowa State University, Ames. 1962.

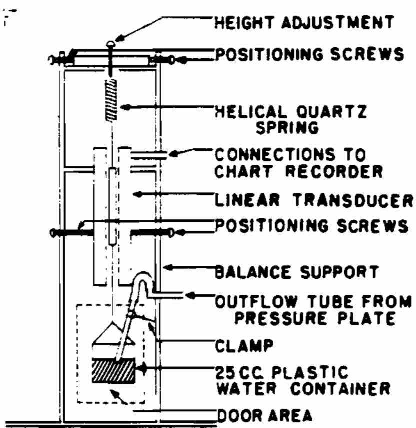


**Figure 1—Balance for measuring moisture desorption or adsorption rates in soil.**

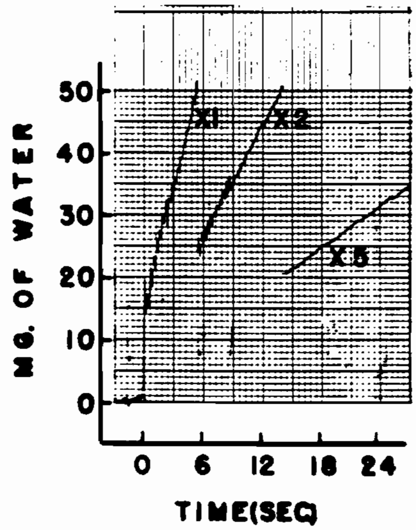


**Figure 2—Early portion of moisture outflow plotted as a function of time.**

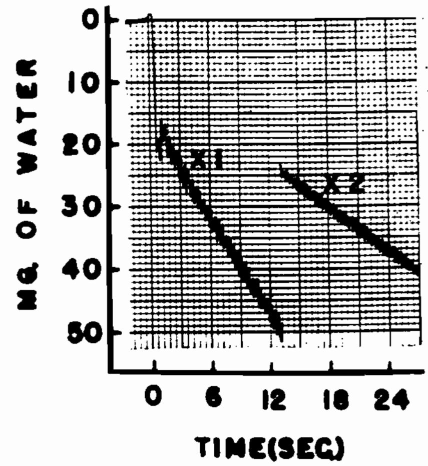


**Figure 3—Early portion of moisture inflow plotted as a function of time.**

(see text below) that is observed the instant the pressure is changed is difficult to correct for.

A recording balance, shown in figure 1, overcame these limitations and gave a continuous and accurate history of the flow sequence. The principal components of the recording balance were a carrier amplifier recorder[1] (model 321, Sanborn Co., Waltham, Mass.), a linear transducer consisting of a soft-iron core, a primary, two secondary coil windings (model 585-DT, Sanborn Co., Waltham, Mass.), a helical quartz spring (60-g. capacity, Worden Laboratory, Houston, Texas) and a 25 cc. plastic water container, arranged as shown in figure 1. When the amount of water changed in the container, because of a change of air pressure in the pressure plate assembly, the quartz spring either contracted or expanded, changing the position of a soft-iron core in the transducer. The movement of the soft-iron core induced more voltage in one secondary winding than in the other. This gave a voltage output which represented the core displacement and its direction. The instrument was calibrated for measuring the loss or gain of water by attaching a 50-mg. weight to the water container and then setting the amplifier for the desired gain. Sensitivity was almost unlimited, but, only at a sacrifice of balance capacity, however. A maximum sensitivity of 1 mg. per division of chart paper with a resulting capacity of 10 g. was adequate for our work. A complete enclosure for the balance, as shown in figure 1, was necessary to minimize evaporation.

To maintain zero head difference, when flow occurred, between the plate and the water level in the 25-cc. plastic container, the correct diameter for the container had to be chosen. With a container of the correct diameter, the elevation change of the water surface was exactly equal and opposite in effect to the deformation characteristics of the spring. Thus, the water level in the container, relative to the plate, remained constant.

In figure 2, the three segments X1, X2, and X5 are plots of outflow vs. time for a soil sample for the first 24 seconds after a pressure change was initiated. The ordinates for segment X2 and X5 are to be multiplied by 2 and 5, respectively. When this is done two immediate observations can be made: *(1)* the rate of flow was nearly constant for the 24-second period, and *(2)* there was a surge effect the instant the pressure was changed. Similar remarks are valid for figure 3 which was for inflow.

The magnitude of this surge effect aparently was dependent on the deformation properties of the plate assembly and on the changes of the air-water interfaces in the plate pores. This effect can be demonstrated, independent of any soil, by applying small increments of pressure or suction on a pressure plate assembly. Generally the surge effect was proportionate to the size of the pressure increment but larger at low pressures. When computing the volume of flow associated with soil, it was necessary to subtract the volume of water connected with the initial surge effect from all volumes measured at any later time; otherwise the experimental data were found to deviate substantially from the theory at the early stages of the outflow. This correction is best carried out by extrapolating the flow curve back to zero time and subtracting the extrapolated value from any later volume measurements. Without a continuous record of the initial flow sequence, this correction would be difficult to make. Figures 2 and 3 indicate that after one corrects for the surge effect, routine flow measurements can be made 0.6 of a second after a pressure change is initiated.

The saw-tooth effect observed in the flow plots of figures 2 and 3 is the recording of minute vertical oscillations arising from the initial extension or contraction of the helical quartz spring. Although these oscillations will generally damp-out with time, the damping-out time can be shortened by raising the outflow tube, prior to beginning a run, slightly above the water surface and thereby utilize the surface-tension phenomenon to damp out the oscillatory motion.

The more accurate information of the early portion of transient flow data obtained by this method as compared to the bubble method nearly doubled the useful portion of the transient flow data when plotted and fitted to the theoretical plot given by Kunze and Kirkham. Only minor recorder adjustments are required when a change is made in the type of flow that is to be measured.—R. J. KUNZE, *Soil Scientist, ARS, USDA, Morris and St. Paul, Minn., and* D. B. PETERS, *Soil Scientist, ARS, USDA, Urbana, Ill.*

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[1]Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U. S. Department of Agriculture.