... Society of America Proceedings
Vol. 32, no. 1, January-February 1968
677 South Segoe Road, Madison, Wisconsin 53711 USA

Soil Reflectance, Temperature, and Fallow Water Storage on Exposed Subsoils of a Brown Soil[1]

A. L. BLACK AND B. W. GREB[2]

ABSTRACT

The topsoil of a Weld soil on an 0.84% slope was removed, giving an increasing depth of subsoil exposure ranging from 0 to 38.1 cm over a horizontal distance of 45.7 m. Five subranges of subsoil exposure—0 to 7.6, 7.6 to 15.2, 15.2 to 22.8, 22.8 to 30.4, and 30.4 to 38.1 cm—were formed with each subrange corresponding to a horizontal distance of 9.14 m. The exposed surface 5 cm of these soil removal treatments differed in texture, structure, reflectance, clod bulk density, aggregate stability, and wind-erodible soil fraction.

Over a 5-year period, mean fallow efficiency for all five soil removal treatments ranged from 25.6 to 38.5%. Reflectance of the exposed surface 5 cm of soil of each soil removal treatment varied considerably among treatments. Mean soil temperatures in fallow were negatively correlated with visual efficiency ($P = .05$) which was used as an indirect value of soil reflectance. Average soil water gained in fallow was negatively correlated ($P = .05$) with the mean fallow soil temperature measured at a depth of 7.6 cm. The negative correlation between soil water gained and mean soil temperature was significant ($P = .01$) in a dry year (1960) and nonsignificant ($P = .05$) in a year of above-average precipitation (1957). A positive correlation was obtained between soil water gained during fallow and visual efficiency ($P = .10$).

Soil water storage in fallow and depth to seedbed water were influenced by soil texture and aggregation in some years. No significant relationship was found between soil water storage at the end of fallow and subsequent crop production because of interactions involving soil temperatures and fertility levels.

Additional Key Words for Indexing: soil water storage, Weld soil, aggregation.

PRECIPITATION is extremely variable and often inadequate for maintenance of crop and residue cover in the semiarid Great Plains. Loss of surface soil by wind and water erosion is a natural and often serious problem. In addition to natural erosion, land-modifying practices are becoming important for more efficient water control on nonirrigated soils of the Great Plains. Terraces and level conservation benches are frequently used to conserve precipitation and control runoff. These land-modifying practices, as well as natural erosion, expose subsoils of unknown chemical and physical characteristics.

Most previous research on subsoils has been concerned with nutrient deficiencies, principally N, P, and K, as the primary limiting factors in crop production (1, 5, 10, 12). Zinc deficiency in subsoil has also been reported (6). In most instances, the productivity of subsoils was restored if the deficient element, or combination of elements, was replaced in proper balance. Furthermore, most of these studies were conducted under irrigation, in humid and subhumid climates, or in greenhouses or growth chambers. However, in semiarid climates, crop production on exposed subsoils may be limited by soil water and temperature as well as nutrient deficiencies. Exposed subsoils differ in texture, color, structure, and organic matter.

This manuscript examines the effect of subsoil exposure on some physical characteristics of a Weld soil. Determinations were made of the influence of soil reflectance, soil temperature, soil texture, and aggregation on water storage during fallow and subsequent crop production.

MATERIALS AND METHODS

Climate, Vegetation, and Soil

The climate at Akron, Colorado, is classified as continental semiarid with annual precipitation averaging 42.3 cm over a 56-year period. Precipitation during this study was above average in 1957 and 1958, below average in 1960, and near average in 1959 and 1961. The yearly mean temperature is 9.2C with an average frost-free period of about 145 days. Wide variations in precipitation and temperature are common.

The native vegetation is blue grama, *Bouteloua gracilis,* (HBK), and buffalograss, *Buchloe dactyloides,* (Nutt.). Dryland crop production is primarily winter wheat, *Triticum aestivium,* (Li.), 'Wichita,' grown on fallow.

The native grass site selected for study was on a Weld silt loam, shallow phase. This soil is typical of loessial soil types found extensively in the western portion of the semiarid central Great Plains. The combined A and B horizons extend to a depth of about 23 cm, with the parent loessial soil material extending beyond a depth of 183 cm.

Experimental Design and Procedure

Subsoil layers from 0 to 38.1 cm were exposed gradually by excavation over a horizontal distance of 45.7 m. This was done on two adjacent blocks of land, each having a slope of 0.84%. Treatments were then established by selecting five levels of soil removal with soil exposure depths for each treatment ranging from 0 to 7.6, 7.6 to 15.2, 15.2 to 22.8, 22.8 to 30.4, and 30.4 to 38.1 cm, with each plot length corresponding to a 9.14-m horizontal distance. In this order, the five soil removal treatments are denoted by R_1, R_2, R_3, R_4, and R_5. Three fertility subplots (no fertilizer, N alone, and N plus P) were randomized within each soil-removal treatment. Alternate crop and fallow subblocks were provided each year in four replications. Nitrogen, as NH_4NO_3, was applied annually at a rate of

[1] Contribution from the Northern Plains Branch, Soil and Water Conserv. Res. Div., ARS, USDA, in cooperation with Colorado Agr. Exp. Sta., Journal Series no. 1196. Received June 7, 1967. Approved Sept. 11, 1967.

[2] Soil Scientists, USDA, Sidney, Mont., and Akron, Colo., respectively.

34 kg/ha of N just prior to seeding. Phosphorus, as concentrated superphosphate, was applied at a rate of 49 kg/ha of P at the beginning of the study and again in 1961 at a rate of 98 kg/ha of P and disked into the soil prior to seeding.

Soil excavation was completed in November 1955, and the soil was chiseled to control wind erosion over the winter. Alternate crop-fallow treatments were initiated in the spring of 1956. Small dykes were constructed and maintained between soil removal plots to prevent water from crossing between plots or replications.

Physical Soil Properties

Soil samples were obtained from the 0- to 5-cm soil depth of each exposure at the beginning of the study. Samples were air dried, screened to pass a 9-mm sieve, and stored in a cool, dry atmosphere. Textural class was determined by the hydrometer method. Bulk density of clods was determined by paraffin coating. The erodible soil fraction was obtained by dry-sieve analysis (2) using 2-kg samples collected in the fall of 1959 following late summer drought conditions. Wet sieve and vacuum techniques were used for aggregate stability (8).

Soil color characteristics were determined from reflectance curves based on the ten select ordinate method (7). Calculations were based on illumination A, using a tungsten incandescent bulb. Reflectance measurements were made on dry soil samples with a spectrophotometer equipped with reflectance attachments using an MgO standard.

Soil Temperature and Soil Water

From 1960 to 1962, two standard mercury thermometers were placed at 7.6-cm soil depths in each soil removal plot. The thermometers were encased in amber rubber tubing above the mercury bulb to minimize the influence of radiation. Thermometers in fallow were read daily to obtain biweekly averages on clear days between 1300 and 1500 hours during selected spring, summer, and fall periods.

Soil water measurements were obtained gravimetrically at 30.4-cm increments to a depth of 183.0 cm, and soil water storage during each fallow year was determined. Eight samplings were taken for each soil removal treatment per sampling date.

Summer Fallow

The fallow period at Akron, Colorado, is about 14 months, from harvest (July 1–10) to planting (September 1–10) the next year. Crop stubble was left undisturbed from harvest until the following spring (May 1). Thereafter, subsurface tillage implements were used as needed for weed control and seedbed preparation. Three subsurface tillage operations with sweeps (76-cm V-blades) and two rodweeder operations were usually sufficient per fallow season.

RESULTS AND DISCUSSION

Soil Texture, Aggregate Stability, and Relative Erodibility

Physical properties of the surface soil (0 to 5 cm) of each soil removal treatment are shown in Table 1. Clay content was highest in the R_3 surface soil which corresponded to the initial B21 horizon. This layer was composed of hard aggregates about 10 mm in diameter which fragmented to granules of 2 to 3 mm in diameter when exposed and subjected to cultivation and weathering. Laboratory analysis confirmed that the R_3 soil had the greatest aggregate stability by either wet dunking or vacuum analysis. The erodible soil fraction decreased as the increments of soil removal increased from the R_1 to the R_5 soil. However, in the winter seasons of 1959 and 1960, soil movement occurred only in the R_3 soil during periods of high wind velocities. The lack of surface crusting and low bulk density due to high clay content of the R_3 soil appeared to be related to wind movement of these soil particles. Chepil (3) has shown that erodible fractions high in clay content are highly susceptible to wind movement.

Table 1—Physical properties of the surface 0 to 5 cm of soil of each soil removal increment of a Weld soil

Soil	Genetic horizon	Soil texture*	Clay content	Clod bulk density	Erodible fraction†	Aggregate stability wet sieve	Aggregate stability vacuum
			%	g/cm²		%	
R_1	Ap	L	18	1.52	45	23	57
R_2	Ap, A12	SiL	19	1.40	44	30	60
R_3	B21	ClL	33	1.27	41	34	62
R_4	B3ca	SiL	27	1.41	37	30	60
R_5	B3ca	SiL	23	1.42	34	26	55

* L = Loam, Si = Silt, and Cl = Clay. † Soil particles less than 0.84 mm by rotary sieve analysis.

Soil Color and Reflectance

Soil removal caused a marked change in dry soil color, progressing from R_1 brown (10 YR 5/2), to R_2 and R_3 gray-brown (10 YR 5/2.5), to R_4 light gray (10 YR 7/2), to R_5 gray-white (10 YR 8/2). The sharpest change in visual soil color occurred between the R_1, R_2, and R_3 soils and the R_4 and R_5 soils. Reflectance curves for each soil over wave-lengths ranging from 380 to 1,000 mμ also revealed that a sharp difference in reflectance occurred between these same soils (Fig. 1). The R_3 soil had a slightly higher reflectance than either the R_1 or R_2 soil. About 70% of the solar energy reaching the earth's surface arrives in the spectral range used in Fig. 1.

From the reflectance curves of each soil, visual soil color characteristics were calculated and reported in Table 2. The color of each soil is described by the visual efficiency (soil color brightness), dominant wavelength, and percent purity. The latter two characteristics were similar for all five soils. The visual efficiency values calculated represent the average eye response to a very limited range of wavelengths (approximately 450 to 650 mμ), and they are not necessarily

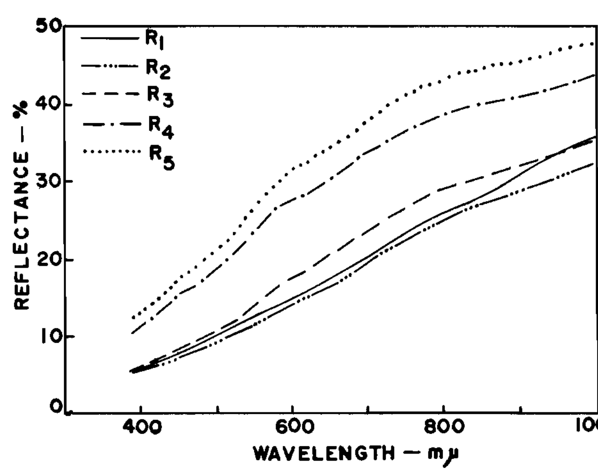

Fig. 1—Reflectance percentage for the surface soil (0 to 5.0 cm) of each soil removal increment over a wavelength range of 380 to 1,000 mμ.

Table 2—Mean soil temperature in fallow at 7.6-cm depth and reflectance measurements of soil color of each soil removal increment

Soil	Mean soil temperature*	Calculated energy absorbed†	Characteristics of soil color: Visual efficiency	Purity	Dominant wavelength
	C	Cal cm^{-2} min^{-1}	%		mμ
R_1	25.3	.37	13.9	36.9	589.3
R_2	24.6	.37	12.8	37.4	590.2
R_3	24.3	.36	15.8	43.0	590.4
R_4	23.8	.32	25.3	35.5	588.8
R_5	23.5	.30	28.4	35.9	588.6

* Mean of 116 recordings per soil removal treatment taken periodically from May to September in 1960, 1961, and 1962. Calculated from a typical solar spectrum curve at sea level minus the reflected energy calculated from Fig. 1 for wavelengths between 380 and 1,000 mμ

Table 3—Soil water accumulation during fallow as influenced by soil removal increments of a Weld soil

Soil	Soil water gained during fallow year: 1957	1958	1959	1960	1961	Mean	Mean storage efficiency*
	cm						%
R_1	14.5 c†	10.5 d	14.5 b	8.7 d	13.3 b	12.3 c	25.6 c
R_2	19.9 ab	13.4 bc	15.8 b	11.3 c	19.4 a	16.0 b	33.3 b
R_3	17.9 b	14.7 bc	15.1 b	13.5 b	18.3 a	15.9 b	33.1 b
R_4	21.0 a	15.6 b	18.0 a	16.6 a	20.4 a	18.3 a	38.1 a
R_5	20.5 a	17.3 a	18.0 a	17.4 a	19.2 a	18.5 a	38.5 a
Fallow pptn.	64.8	51.5	43.7	37.2	42.6	48.0	

* Storage Efficiency $\% = \frac{\text{Soil water gained during fallow}}{\text{Fallow year precipitation}} \times 100.$

† Means within the group followed by the same letter or letters are not significantly different (P = .05).

indicative of the response of all soils to wavelengths outside this wavelength range.

However, using a total solar energy spectrum curve at sea level the absorbed energy curves for each soil were calculated (solar energy minus percent energy reflected from Fig. 1), and the resulting curves were integrated to estimate absorbed energy. The absorbed energy estimated in this manner (Table 2) was negatively correlated with the visual efficiency values of the soils ($r = 0.95$, $P = .01$). Since the reflectance curves for the soils in this study tended towards linearity over the entire wavelength range used, the visual efficiency values would be expected to be highly correlated with calculated values for either reflected or absorbed energy. Therefore, the visual efficiency values were used as an indirect measure of the influence of soil reflectance on soil temperature and water storage during fallow.

Using the visual efficiency values, a linear regression analysis was made to determine if mean soil temperature in fallow was related to soil reflectance (Fig. 2). Soil temperature was negatively correlated with visual efficiency of the soils ($r = 0.88$, $P = .05$).

A positive correlation was obtained between mean soil water storage during fallow and the calculated values for visual efficiency used as an indirect measure of soil reflectance ($r = 0.80$, $P = .10$). Mean soil water storage during fallow was significantly lower on the R_1 soil than on the R_2 or R_3 soils even though the reflectance curves were quite similar. Soil water storage in the R_1 soil may have been influenced by the large volume of native grass roots which resisted decomposition throughout the study. These grass roots appeared to loosen the soil and to cause the surface 0 to 7.6 cm of soil to dry out rapidly following a rain.

Soil Water Storage During Fallow

Soil water accumulation was recorded for each fallow year from 1957 to 1961 (Table 3). Significant differences in fallow soil water accumulation were obtained each year as a result of soil removal treatment. The 5-year mean soil water gain of the R_1 soil was significantly lower than that of any other soil. No significant difference in mean soil water gained per fallow year was obtained between the R_2 and R_3 soils, or between the R_4 and R_5 soils. However, mean soil water accumulation in the R_4 and R_5 soils was significantly higher than in all other soils. In 1960, when precipitation was below average, soil water storage increased progressively as the soil removal increment increased, with differential significance obtained between each soil removal increment except R_4 and R_5. In years of above-average precipitation, soil water storage tended to be similar in the R_2 and R_3 and also in the R_4 and R_5 soils. Mean fallow efficiency of water storage for the 5-year period ranged from 25.6% on the R_1 soil to 38.5% on the R_5 soil. These values for water storage efficiency in fallow are considerably higher than the 15 to 20% previously reported for the central Great Plains (4, 9, 13).

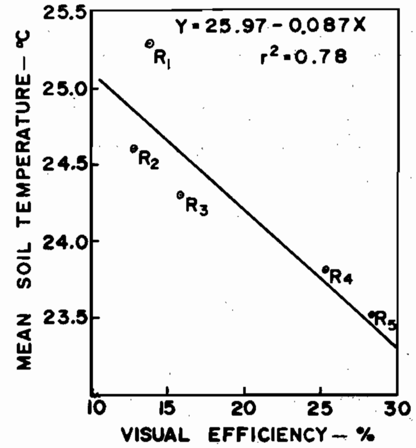

Fig. 2—Regression analysis of the visual efficiency (soil color) of each soil removal increment to mean soil temperature at 7.6-cm soil depth in fallow.

Soil Temperature

During three summer fallow periods from May to September (1960 to 1962), soil temperatures were recorded periodically at the 7.6-cm soil depth in each soil. The mean soil temperature data are shown in Table 2. Soil temperature gradually decreased with increased soil removal increment. The mean soil temperature difference between the R_1 and R_5 soil was 1.8C.

Mean water storage in fallow for the 5-year period was negatively correlated with the mean soil temperature in fallow ($r = 0.97$, $P = .05$, Fig. 3). The negative correlation between water gained in fallow and mean soil temperature was highly significant ($r = 0.99$, $P = .01$) in 1960 when precipitation was below average, and nonsignificant ($r = 0.86$, $P = .05$) in 1957 when precipitation was above average (Fig. 3).

An additional factor that may have influenced soil water storage during fallow in some years was the high clay content and granular structure of the 0- to 5-cm soil depth of

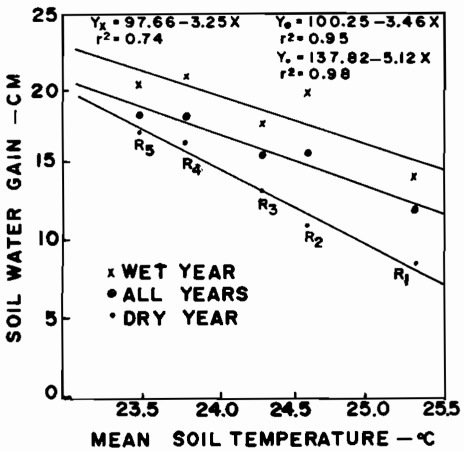

Fig. 3—Regression analysis of soil water gained during fallow to mean soil temperature at the 7.6-cm soil depth in fallow.

the R_3 soil. In 1957, 1959, and 1961, water storage was lower in the R_3 soil than the R_2 soil. During relatively short periods following a rain, the 0- to 7.6-cm soil depth of the R_3 soil would hold more soil water nearer the surface than the other soil removal increments, making soil water more available for evaporation (11). The quantity of soil water lost in this manner would depend on the frequency and quantity of each rain received during fallow.

Seedbed Soil Water

In dry years, the R_1, R_2, and R_3 soils dried out to deeper soil depths than the R_4 and R_5 soils. In September 1960, following an extended drought period, the average depth to seedbed moisture was 17.8, 20.3, 17.8, 10.2, and 7.6 cm for the R_1, R_2, R_3, R_4, and R_5 soils, respectively. Seedbed water was never a limiting factor at fall planting time in seed germination on the R_4 and R_5 soils. Winter wheat failed to germinate on the R_1, R_2, and R_3 soils in the fall of 1956 and 1960 even though a deep furrow drill and a seeding depth of 10 to 12 cm were used.

Differences in soil reflectance and soil temperature significantly influenced soil water storage during fallow. In addition, soil texture and structure (aggregation) influenced soil water storage in fallow and depth to seedbed water in some years. These factors become extremely important at fall planting time in obtaining satisfactory winter wheat stands.

Plant Growth Relationships

Crop failures of winter wheat occurred in 1959 because of hail and in 1961 because of inadequate seedbed water in the R_1, R_2, and R_3 soils for seed germination the previous fall. Grain and straw yields were obtained in 1958, 1960, and 1962, and the 3-year means are shown in Fig. 4. No significant relationship existed between grain, straw, or grain plus straw production and soil water storage at seeding time with or without N and P fertilization. Fertilization with N plus P significantly influenced winter wheat production only on the R_4 and R_5 soils.

Although the R_4 and R_5 soils consistently had more stored water at seeding time than the other soils, winter wheat production did not increase proportionally. During early growth stages, differential soil temperatures associated with soil color may have influenced nutrient uptake and other plant growth factors. Work by Power et al. (14) has shown total P in barley tops was reduced by soil temperatures above or below 15C.

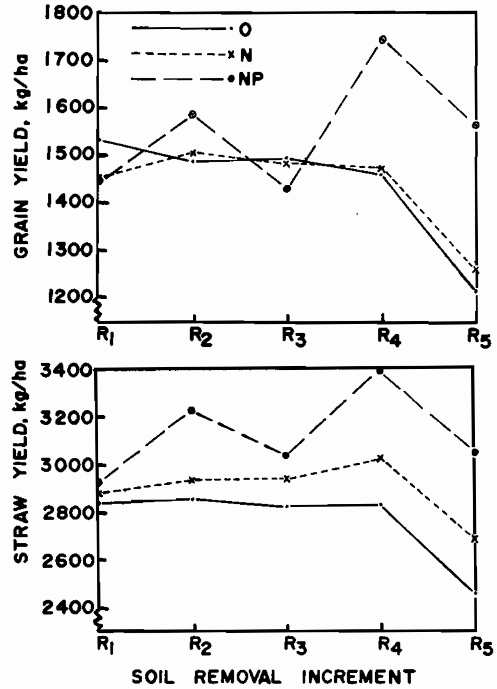

Fig. 4—Grain and straw yields as influenced by N and N-P fertilizer and soil removal treatments (3-year mean).

Lower soil temperatures associated with lighter soil color also delayed plant maturity 3 to 5 days on the R_4 and R_5 soils even with N-P fertilizer. Plant maturity on these two soils was delayed from 5 to 7 days when no fertilizer was applied. Delayed plant maturity extended the ripening period, causing prolonged plant exposure to the hot, dry, southerly winds which normally prevail at ripening time. As available soil water becomes exhausted, delayed plant maturity is often followed by a loss in kernel weight.

LITERATURE CITED

1. Carlson, C. W., D. L. Grunes, J. Alessi, and G. A. Reichman. 1961. Corn growth on Gardena surface and subsoil as affected by applications of fertilizer and manure. Soil Sci. Soc. Amer. Proc. 25:44–47.
2. Chepil, W. S. 1952. Improved rotary sieve for measuring state and stability of dry soil structure. Soil Sci. Soc. Amer. Proc. 16:113–117.
3. ———. 1955. Factors that influence clod structure and erodibility of soil by wind: IV. Sand, silt, clay. Soil Sci. 80:155–162.
4. Cole, J. S., and O. R. Mathews. 1939. Subsoil moisture under semiarid conditions. USDA Tech. Bull. 637.
5. Eck, H. V., V. L. Hauser, and R. H. Ford. 1965. Fertilizer needs for restoring productivity on Pullman silty clay loam after variable degrees of soil removal. Soil Sci. Soc. Amer. Proc. 29:209–213.

6. Grunes, D. L., L. C. Boawn, C. W. Carlson, and F. G. Viets, Jr. 1961. Zinc deficiency of corn and potatoes as related to soil and plant analysis. Agron. J. 53:68–71.
7. Judd, D. A. 1961. Colorimetry. Nat. Bur. Stand. Hdbk. 77. 3:473–528.
8. Kemper, W. D., and E. J. Koch. 1965. Aggregate stability of soils from western United States and Canada. USDA Tech. Bull. No. 1355.
9. Kuska, J. B., and O. R. Mathews. 1956. Dryland crop-rotation and tillage experiments at the Colby (Kans.) Experiment Station. USDA Circ. 979.
10. Latham, E. E. 1940. Relative productivity of the A horizon of the Cecil sandy loam and the B and C horizons exposed by erosion. J. Amer. Soc. Agron. 32:950–954.
11. Lemon, E. R. 1956. The potentialities for decreasing soil moisture evaporation loss. Soil Sci. Soc. Amer. Proc. 20:120–125.
12. Nelson, J. L., and C. L. Crawford. 1960. Fertilizer needs of leveled land of the Columbia Basin. Washington Agr. Exp. Sta. Circ. 368.
13. Mathews, O. R., and T. J. Army. 1960. Moisture storage on fallowed wheatland in the Great Plains. Soil Sci. Soc. Amer. Proc. 24:414–481.
14. Power, J. F., D. L. Grunes, G. A. Reichman, and W. O. Willis. 1964. Soil temperature and phosphorus effects upon nutrient absorption by barley. Agron. J. 56:355–359.