Topsoil removal effects on soil chemical and physical properties

B. W. Greb and D. E. Smika

In the Central Great Plains of the United States wind erosion is the major cause of soil loss. Eroding topsoil carries with it plant nutrients and organic matter (*7*). Researchers also have documented soil texture changes resulting from wind erosion (*5*, *6*). These losses and changes suggest reduced soil productivity, but they do not provide factual information to document the severity of the soil loss effects on crop production.

Finnell (9) found that the loss of a few centimeters of topsoil reduced productivity by 40 percent on better soils and 60 percent on poorer soils. Stallings (*19*) reported that wheat yields declined 267 kg/ha during a 30-year period as a result of wind erosion. Massee (*15*) found that after removal of 30 cm of topsoil winter wheat yields decreased 70 percent, but 67 kg/ha of N fertilizer brought the yields up to the level obtained where no topsoil had been removed. Lyles (*13*, *14*) proposed a method to estimate crop yield losses from calculated soil losses.

Our study documented the soil physical and chemical changes and related yield reductions and fertilizer responses that occurred when topsoil was removed. We also documented the changes that occurred in the new surface soil with time after the virgin soil was exposed.

Research procedures

The study site near Akron, Colorado, was a field newly broken from native sod. Climate in the area is continental semiarid with an average annual precipitation of 41.3 cm. Average yearly temperature is 9.2°C;

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average frost-free period is about 145 days. Wide variations in precipitation and temperature are common.

The native vegetation is predominately blue grama [*Bouteloua gracilis*, (HBK)] and buffalograss [*Buchloe dactyloides*, (Nutt.)]. Dryland crop production is primarily winter wheat [*Triticum aestivum* (Li)] grown after fallow.

The native grass site was on a Weld silt loam, shallow phase, a fine, montmorillonitic, mesic Aridic Paleustoll. This benchmark soil is typical of loessial soils found extensively in the western portion of the semiarid Central Great Plains (*10*). The combined A and B horizons extend to 23 cm with the parent loessial soil material extending to depths of 24 to 60 m.

Soil layers from 0 to 38.1 cm were exposed gradually by excavation over a horizontal distance of 45.7 m in an area with an initial slope of 0.84 percent. We exposed soil on two adjacent blocks of land to provide for an alternate winter wheat and fallow cropping system. After excavation, each block was level in all directions. We established treatments on five soil-exposure depths: 0 to 7.6 cm, 0 to 15.2 cm, 0 to 22.8 cm, 0 to 30.4 cm, and 0 to 38.1 cm. Main plot size was 9.14 by 18.29 m. Sites were diked to prevent runoff. In order from the shallowest to the deepest removal, the five soil removal treatments were denoted as R_1, R_2, R_3, R_4, and R_5. We randomized three fertility subplots, 6.1 x 9.14 m (no fertilizer, N alone, and N plus P), within each main plot soil-removal treatment; plots were replicated four times in each block. We applied N, as NH_4NO_3, annually at a rate of 40 kg/ha just prior to seeding from 1956-1962 and at a rate of 45 kg/ha from 1965-1967. We applied P, as concentrated superphosphate, at a rate of 50 kg/ha at the beginning of the study and again 5 years later, in 1961, at a rate of 100 kg P/ha; P was disked into the soil prior to seeding.

We obtained soil samples from the 0- to 5-cm depth of each exposure level 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, lime by acidulation (*17*), bulk density of clods by paraffin coating, erodible soil fraction by dry-sieve analysis (*3*) using 2-kg samples collected in the fall of 1959 following a late summer drought, and aggregate stability by wet-sieve and vacuum techniques (*12*).

We took soil samples for analysis of chemical properties at the 0- to 5-cm depth. Organic matter was analyzed by the wet combustion method (*18*), total N by Kjeldahl procedures, and soil NO_3-N by the phenoldisulfonic acid method of analysis on samples collected at the beginning of the experiment, which were incubated at 35°C for 30 days, and on samples collected in the field at end of fallow (early September) in depths of 0 to 30.4 cm and 30.4 to 91.2 cm. Total P analysis involved soil digestion with perchloric acid (*1*); labile P by the sodium bicarbonate extraction process (*16*), with color development by Dickman and Bray method (*8*). We calculated the C/N ratio on the basis that organic matter contained 58 percent carbon.

The fallow period for the winter wheat-fallow rotation at Akron, Colorado, is about 14 months, from harvest (July 1-10) to planting (September 1-10) the next year. For our study, we left the crop stubble undisturbed from harvest until the following spring (May 1). Thereafter, we used an average of five subsurface tillage operations as needed for weed control.

Winter wheat was seeded in September of 1957 through 1961. Sudangrass [*Sorghum sudanese* (Piper) Staff.] was planted in four replications, succeeding fallow in 1961 and succeeding itself in 1962.

In the spring of 1963 we seeded the entire experimental area in 30-cm rows, half to switchgrass [*Panicum virgatum* Hort.] and half to Russian wildrye [*Psathyrostachus juncea* (Fish.) Nevski]. A successful stand of Russian wildrye was achieved by 1965 on two replications in each block.

Attempts to establish switchgrass on the remaining half of the experimental area failed. However, crested wheatgrass [*Agropyron cristatum* (L.) Geartn] seeded in 30-cm rows in 1968 was successful.

Sudangrass, Russian wildrye, and crested wheatgrass yields were determined from 1 m^2 sample areas (two per plot in 4 replications) on an oven dry basis. N content was determined by the Kjeldahl method. Protein content was obtained by multiplying the N percent by 5.7 for grain and 6.25 for forage.

Results of the research

Soil texture, aggregate stability, and relative erodibility. Table 1 shows the physical properties of the surface soil (0 to 5 cm) for each soil removal treatment. 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 that 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 erusting 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 (*4*) showed that erodible fractions high in clay content are susceptible to wind movement.

Initial soil chemical constituents. Organic matter, total N, soil NO_3-N, C/N ratio, and labile P all decreased with increasing depth of soil removal

Table 1. Soil physical constituents in the 0- to 5-cm soil depth following five levels of soil removal on a Weld silt loam.

Soil Removal	*Genetic Horizon*	*Lime (%)*	*Soil Texture**	*Clay Content (%)*	*Clod Bulk Density (g/cm^2)*	*Erodible Fraction† (%)*	*Aggregate Stability‡ (%)*
R_1	Ap	.3a§	L	18a	1.52c	45b	57a
R_2	Ap, A12	.4a	SiL	19a	1.40b	44b	60ab
R_3	B21	.5a	ClL	33bc	1.27a	41ab	62b
R_4	$B3_c2$	2.5b	SiL	27b	1.41b	37a	60ab
R_5	$B3_c2$	5.6c	SiL	23ab	1.42b	34a	55a

*L = loam, Si = silt, and Cl = clay.
†Soil particles less than 0.84 mm by rotary sieve analysis.
‡By the vacuum method.
§Values within each column accompanied by different letters are significantly different at the 95% level of probability.

Table 2. Soil chemical constituents in the 0- to 5-cm soil depth following five levels of soil removal in a Weld silt loam.

Soil Removal	*Organic Matter (%)*	*Total N (%)*	*Soil NO_3-N**	*Total P*	*Labile P*	*C/N Ratio*
			kg/ha			
R_1	2.1b†	.109c	63b	562a	27c	11.2b
R_2	1.7b	.097b	62b	543a	20b	10.2b
R_3	1.5ab	.094ab	59cb	643b	11ab	9.3ab
R_4	1.3a	.087a	54cb	770bc	8a	8.6a
R_5	1.2a	.084a	48a	810c	6a	8.3a

*NO_3-N = nitrate nitrogen accumulated by incubation at 35°C for 30 days.
†Values within each column accompanied by different letters are significantly different at the 95% level of probability.

(Table 2). These results could be expected when considering the shallow A horizon (less than 15.2 cm) of a Weld silt loam in its native state. However, total P tended to increase with depth of soil removal to reveal a substantial reserve of total P for biological transformation to labile P.

Labile phosphorus. Analysis of the R_1 through R_5 soils every two years from 1956 to 1964 showed a progressive increase in labile P with time and approached a new equilibrium by 1964 (Table 3). Increases in labile P were the greatest in the R_3, R_4, and R_5 removal levels. We believe the increase in labile P was the result of mineralization of organic P and biological mobilization of inorganic P forms, which is thought to be chemically bound to calcium (*11*). These data indicate that the P status on newly leveled land or on other earth moving projects where subsoils are exposed should be frequently monitored.

Labile P in plots fertilized with 50 kg P/ha as a function of time of subsoil exposure decreased an average of 39 percent from 1956 to 1960. The greatest reversion to nonlabile forms of P occurred at the R_1 level of soil removal. A loss of labile P in fertilizer to insoluble P as tied up in calcium compounds is normal.

Soluble P levels were monitored during several months of 1968 on R_1 and R_2 plots with the four replications of O, N, and N + P fertility treatments. The levels of labile P varied somewhat during the year with each fertility treatment showing some increase between April and June (Figure 1). There was a general leveling off from August to December. Labile P in the O fertility plot ran consistently 3 to 7 kg/ha higher than in the N fertility plots.

Comparing the effect of cropping twice with winter wheat to cropping twice with sudangrass showed that on the nonfertilized plots sudangrass had an average of 5 kg/ha more labile P than wheat. The greatest differences occurred in the R_1 and R_2 soil removal treatments. A comparison of labile P in wheat and sudangrass plots fertilized with 100 kg P/ha in 1960 showed no difference. However, in 1964 there was an average 136 kg P/ha for sudangrass and only an average of 76 kg/ha for the wheat plots. Sudangrass residue has more sugar and less lignin than winter wheat, suggesting that the sugar supply hastens decomposition and thereby releases P sooner.

Table 3. Changes in $NaHCO_3$ labile P in nonfertilized plots as a function of time of subsoil exposed.*

Soil Removal	*Labile P*					*Gain*
	1956	*1958*	*1960*	*1962*	*1964*	*1956 to 1964*
	kg/ha					
R_1	27b†	28b	30bc	36b	36bc	9
R_2	20b	27b	27ab	30ab	32b	12
R_3	11ab	22ab	26a	26a	30b	19
R_4	8a	17a	24a	26a	25a	17
R_5	6a	13a	25a	23a	24a	18
Average	15x	21xy	26y	28y	30y	15

*Land use included three seasons of fallow, three years of winter wheat, two crops of sudangrass, and one season of a Russian wildrye grass planting.

†Values within each column accompanied by different letters are significantly different at the 95% level of probability. Average values accompanied by different letters are significantly different at the 95% level of probability.

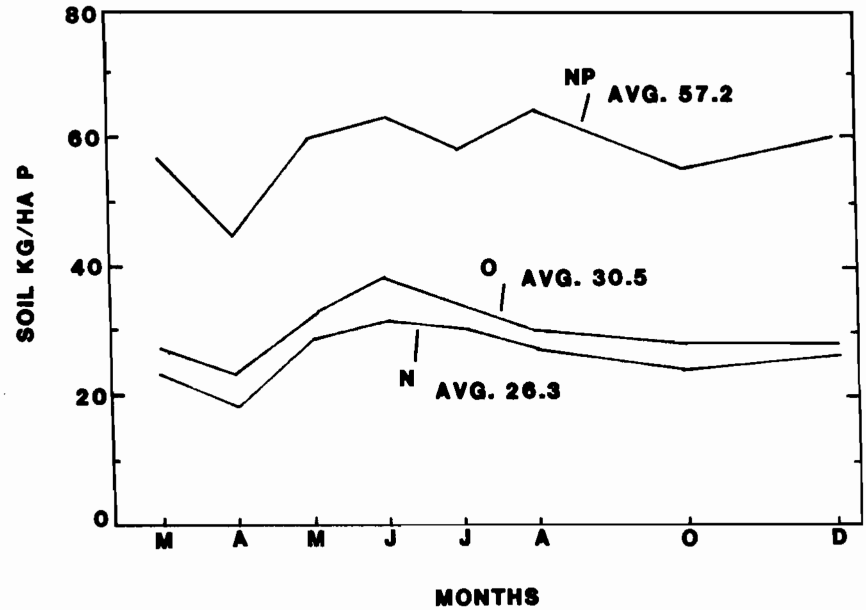

Figure 1. Quantity of $NaHCO_3$ soluble P in surface soil during March to December 1968. Average of five levels of soil removal on a Weld silt loam. The plots containing P fertilizer received 50 and 100 kg/ha P in 1956 and 1960, respectively. Nitrogen was applied at 40 kg/ha 1956-1962 and at 45 kg/ha during 1965-1967.

Table 4. Soil nitrate-N for 183-cm profile at the end of fallow as affected by depth of soil removal, nonfertilized plots.

Soil Removal	Soil $NO_3 - N$ 1959	1960	1961	1962	1963	Five Year Average
	kg/ha					
R_1	140c*	104b	83c	130c	111c	113
R_2	103ab	94ab	69b	113b	149d	105
R_3	120b	102b	66ab	90b	84b	92
R_4	93a	77a	60a	49a	81b	72
R_5	93a	72a	56a	56a	60a	67
Average	110	90	67	87	97	90

*Values within each column accompanied by different letters are significantly different at the 95% level of probability.

Soil nitrate nitrogen, fallow. We obtained soil nitrate N accumulations at the end of the 1959 through 1963 fallow seasons for all five soil removal levels where no fertilizer had been applied (Table 4). Quantities of nitrate N varied considerably between years, as could be expected in the semiarid locale. Average levels ranged from 110 down to 67 kg/ha as experienced in 1959 versus 1961. In general, soil nitrate N gradually decreased with depth of soil removal when averaged over a 5-year period. Using 113 kg/ha for the R_1 level of soil removal as 100 percent, quantities averaged 93, 81, 64, and 59 percent for the R_2, R_3, R_4, and R_5 levels, respectively.

Table 5. Yield of wheat grown on fallow as influenced by depth of soil removal and fertilization, average of 1958, 1960, and 1962 (from 2).

Soil Removal	*Fertilizer Treatment**	*Yield Grain*	*Yield Straw*	*Total Dry Matter*	*Grain Protein (%)*
		kg/ha			
	O	1,530a†	2,830a	4,360a	16.1a
R_1	N	1,460a	2,880a	4,340a	17.3b
	N+P	1,450a	2,930a	4,380a	17.0b
Average		1,480xy	2,880xy	4,360y	16.8z
	O	1,530a	2,870a	4,400a	15.3a
R_2	N	1,510a	2,930a	4,440a	16.8c
	N+P	1,590a	3,230b	4,820b	15.9b
Average		1,540xy	3,010y	4,550y	16.0y
	O	1,490a	2,820a	4,310a	13.9a
R_3	N	1,490a	2,930a	4,420a	15.7b
	N+P	1,440a	3,050a	4,490a	15.5b
Average		1,470xy	2,930xy	4,400y	15.0y
	O	1,460a	2,830a	4,290a	12.1a
R_4	N	1,460a	3,020a	4,480a	14.1b
	N+P	1,750b	3,390b	5,140b	14.2b
Average		1,560y	3,080y	4,640y	13.5x
	O	1,220a	2,460a	3,680a	11.7a
R_5	N	1,260a	2,690ab	3,950ab	14.7b
	N+P	1,550b	3,050b	4,600b	15.0b
Average		1,340x	2,730x	4,070y	13.8x
	O	1,440a	2,770a	4,210a	13.8a
All depths	N	1,440a	2,900a	4,340a	15.7b
	N+P	1,550b	3,140b	4,690a	15.6b

*Applied 40 kg N/ha per crop and 50 kg P/ha applied in 1956 and 100 kg P/ha applied in late 1960.

†Values within columns within each soil removal depth accompanied by different letters are significantly different at the 95% level of probability. Soil removal average values within columns accompanied by different letters are significantly different at the 95% level of probability.

Table 6. Dry matter yield of sudangrass as influenced by depth of soil removal and fertilization.

Soil Removal	Fertilizer Treatment*	Yield† 1961	Yield† 1962	Protein Content‡ (%)
		kg/ha		
	O	2,310a§	2,090a	12.3a
R_1	N	2,240a	2,120a	12.9a
	N + P	2,280a	2,060a	14.0b
Average		2,270x	2,090x	13.1y
	O	2,510a	1,840a	12.3a
R_2	N	2,310a	1,880a	13.4b
	N + P	2,590a	2,250b	14.2b
Average		2,460xy	1,950x	13.3y
	O	2,890b	2,530a	12.4a
R_3	N	2,690a	2,630ab	12.5a
	N + P	2,550a	2,770b	14.2b
Average		2,710y	2,640y	13.0y
	O	2,550a	2,120a	11.8a
R_4	N	2,430a	2,880b	13.4b
	N + P	2,700b	3,260c	13.6b
Average		2,560xy	2,760y	12.9y
	O	2,300a	1,940a	10.5a
R_5	N	2,340a	3,070b	13.1b
	N + P	2,650b	3,470c	12.5b
Average		2,430x	2,820y	12.0y
	O	2,520a	2,100a	11.9a
Average all depths	N	2,400a	2,510b	13.1b
	N + P	2,590a	2,760c	13.7b

*Applied 40 kg N/ha per crop and 100 kg P/ha added in fall of 1960.

†The 1961 sudangrass was grown succeeding fallow and the 1962 sudangrass followed the 1961 crop.

‡Average of 1961 and 1962.

§Values within columns within each soil removal depth accompanied by different letters are significantly different at the 95% level of probability. Soil removal average values within columns accompanied by different letters are significantly different at the 95% level of probability.

Winter wheat production. Crop failures of winter wheat occurred in 1959 because of hail damage and in the R_1, R_2, and R_3 soils in 1961 because of low seedbed water for seed germination the previous fall at planting. Grain and straw yields were obtained in 1958, 1960, and 1962 (Table 5). No significant relationship existed between grain, straw, or total dry matter and soil water storage at seeding time with or without N and P fertilization. Fertilization with N + 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 (2), wheat production did not increase proportionally. During early growth stages there were soil temperature differences associated with soil color differences resulting from the soil removal (2) which may have influenced nutrient uptake and other plant growth factors. Plant maturity was delayed 3 to 5 days on the R_4 and R_5 soils with N + P fertilizer and by 5 to 7 days when not fertilized.

Table 7. Yield and protein content of Russian wildrye as influenced by soil removal and annual and residual fertilization.

Soil Removal	*Fertilizer Treatment**	*Grass Yield†*		*Protein Content*	
		Annual	*Residual*	*Annual*	*Residual*
		kg/ha		%	
	O	730a‡	660a	12.6a	10.4
R_1	N	1,090b	1,310b	16.9b	11.0
	N + P	1,190b	1,360b	16.5b	11.2
Average		1,000x	1,110z	15.3z	10.9
	O	590a	560a	11.7a	11.2
R_2	N	1,240b	1,200b	15.7b	10.1
	N + P	1,210b	1,240b	14.5b	9.8
Average		1,010x	930y	14.0y	10.4
	O	590a	440a	10.8a	10.6
R_3	N	1,260b	1,000b	13.9b	9.9
	N + P	1,290b	1,050b	13.6b	9.8
Average		1.050x	830y	12.8xy	10.1
	O	480a	380a	10.4a	11.0
R_4	N	1,110b	570b	12.8b	10.8
	N + P	1,270b	630b	12.0b	10.7
Average		950x	530x	11.7x	10.8
	O	440a	290a	10.8a	11.0
R_5	N	1,090b	490b	12.4b	10.7
	N + P	1,100b	570b	12.0b	10.8
Average		880x	450x	11.7x	10.8
	O	560a	470a	11.3a	10.9
Average all depths	N	1,160b	910b	14.3b	10.5
	N + P	1,210b	950b	13.7b	10.5

*Applied 40 kg N/ha during late winter of 1965, 1966, and 1977. Applied 50 and 100 kg P/ha in 1955 and late 1960.

†Average for 1965, 1966, and 1967 for annual and 1968 and 1970 for residual fertilization.

‡Values within columns within each soil removal depth accompanied by different letters are significantly different at the 95% level of probability. Soil removal average values within columns accompanied by different letters are significantly different at the 95% level of probability.

Table 8. Dry matter production of crested wheatgrass as affected by depth of soil removal and fertilization with nitrogen plus iron. June 1976.

Soil Removal	Fertilizer Treatment*	Yield Grass (kg/ha)	Protein Content Grass (%)
R_1	O	770a†	7.3a
	N	1,150b	7.9b
		960y	7.4x
R_2	O	760a	5.7a
	N	1,100b	7.7b
		930y	6.9x
R_3	O	620a	6.0a
	N	900b	7.4b
		760xy	6.8x
R_4	O	500a	5.4a
	N	710b	7.2b
		610x	6.5x
R_5	O	460a	6.4a
	N	650b	7.2b
		960x	6.8x
Average all depths	O	580a	6.0a
	N	900b	7.5b

*Applied 40 kg N/ha and 40 kg N/ha plus 12 kg Fe/ha as ferrous ammonium sulfate.

†Values within columns within each soil removal depth accompanied by different letters are significantly different at the 95% level of probability. Soil removal average values within columns accompanied by different letters are significantly different at the 95% level of probability.

Protein content of the grain decreased about 3 percent with increasing depth of exposed subsoil. In general, N fertilization tended to increase protein responses as the soil removal depths increased.

Sudangrass production. Sudangrass succeeding fallow in 1961 had no response to N alone and to N + P only on the R_4 and R_5 soils (Table 6). Conversely, with the continuously grown sudangrass there was a significant yield increase to both N and N + P on the R_4 and R_5 soils. For all soil removal depths, the sudangrass yield from the N + P treatment exceeded that from the treatment N alone by an average 250 kg/ha.

Protein content of sudangrass was similar for both years regardless of previous crop and nearly equal from R_1 to R_4 soils, but dropped about 1 percent on the R_5 soil. The protein content increased an average of 1.2

percent and 1.8 percent for N and N + P fertilizer treatments, respectively.

Russian wildrye production. Yields and protein contents in Russian wildrye responded to annual application of N fertilization at all levels of soil removal (Table 7). Yields were doubled with N fertilization; P had little effect. Nonfertilized grass yields progressively decreased with depth of soil removal. Plots fertilized with N did not show this trend. Russian wildrye yields showed a response to the residual N, but at a decreasing rate with increasing depth of soil removal. Nonfertilized Russian wildrye yields also decreased with increased depth of soil removal. There was little evidence of a yield response to P above that with N alone.

Protein content of annually fertilized Russian wildrye increased an average of 3 percent with N fertilizer alone. There was no protein response to residual N and the addition of P did not influence the protein content.

Crested wheatgrass response to fertilization. In 1976 crested wheatgrass was fertilized with N plus Fe. Results show a significant yield response of about 400 kg/ha to the N + Fe fertilizer (Table 8).

The protein content of crested wheatgrass showed no trend with the soil removal depths but there was about a 1.4 percent increase from the use of the N + Fe fertilizer.

In summary

The amount of native topsoil removed resulted in marked differences in physical and chemical properties of the new surface soil. In the 0- to 5-cm depth, clay content increased as much as 15 percent, bulk density decreased as much as 0.25 g/cm^3, and the erodible soil fraction decreased 11 percent. Chemical property changes in the same 5-cm profile segment included an increase in lime content of 5.3 percent, a total N decrease of 0.025 percent, and a labile P decrease of 21 kg/ha.

Although labile P initially was very low in the newly exposed soil, there was a gradual increase during the first 8 years after soil removal. The crop grown also had some influence on labile P, with sudangrass more favorable for P increase than wheat.

Regardless of crop grown, yield decreased with increasing depth of soil removed. The application of N or N and P tended to overcome the yield decrease of cultivated crops and grasses grown (Russian wildrye and crested wheatgrass) during the years fertilizer was applied. However, the residual effects of the fertilizer were short for the grasses.

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