Cultivated and Adjacent Virgin Soils in Northcentral South Dakota: I. Chemical and Physical Comparisons

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Cultivated and Adjacent Virgin Soils in Northcentral South Dakota: I. Chemical and Physical Comparisons

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ABSTRACT

Evaluation of the effects of cultivation on soil properties in Ustic Mollisols has generally been limited to surface horizons. To examine the effects of cultivation on both surface and subsurface horizons, six paired virgin and cultivated pedons of Williams soil (fine-loamy, mixed Typic Argiboroll) or variants of Williams from northcentral South Dakota were compared for differences in various chemical and physical properties. When similar horizons were compared, chemical differences between cultivated and virgin pedons averaged as follows: (i) organic C content was 26% less in Ap horizons; (ii) water-soluble Si was 49, 46, and 21% greater in A, Bt, and Btk horizons of cultivated pedons, respectively; (iii) water-soluble Mg, Na, and K were 42, 32, and 18% lower in C horizons of cultivated pedons, respectively; (iv) oxalate-extractable Fe was 28 and 56% higher in Ap and Bt horizons of cultivated pedons, respectively. When similar horizons were compared, physical differences between cultivated and virgin pedons averaged as follows: (i) bulk density was 18% greater in Ap horizons; (ii) Ap horizons contained 38% more very fine sand and 10% less silt; (iii) A and Btk horizons of virgin pedons possessed greater wet aggregate stability; and (iv) A horizons of virgin pedons average 30% more water retained at 0 MPa tension.

HUMAN IMPACT on the soil environment can only be assessed and placed in perspective by careful long-term monitoring. The most common method of assessing the effects of cultivation on the soil system is by comparison of a cultivated soil with its uncultivated counterpart, herein termed virgin soil.

Several marked or gross changes occur when virgin soil is cultivated. Organic matter content rapidly decreases (Newton et al., 1945; Campbell and Souster, 1982) and eventually reaches an equilibrium depending on cropping, tillage, and climatic regime (Coote and Ramsey, 1983). Edwards and Lofty (1975) determined that intensive cultivation suppressed invertebrates, especially earthworm populations (*Lumbricus* sp.). Cultivation causes deleterious changes in soil physical properties. The pedality and wet-aggregate stability of surface horizons decrease, thereby increasing the risk of soil erosion (Laws and Evans, 1949; Greenland et al., 1962; Bouma and Hole, 1971). Bulk density of surface horizons increases (Bauer and Black, 1981; Coote and Ramsey, 1983) and large pores, created by soil aggregation, are destroyed (Laws and Evans, 1949; Bouma and Hole, 1971; Bauer and Black, 1981).

Other changes in the soil system as a consequence of cultivation are more subtle: they are variable among soil types or difficult to prove statistically. Although crop-fallow management systems allow significantly greater water movement through the soil profile compared with native sod (Ferguson et al., 1972), information is lacking on whether significant differences in leaching occur between a continuously cropped soil and native sod soil. Bouma et al. (1974), however, suggested that greater leaching occurred through a continuously cropped soil in Wisconsin. Martel and Paul (1974) found a similar distribution of C and N among organic fractions in cultivated and virgin Black and Brown Chernozems, but, in similar soils, Dormaar (1979) reported up to a 38% decrease in the humic acid to fulvic acid ratio as a direct result of cultivation of similar soils.

Much of the research dealing with the effect of cultivation on the soil system has concentrated on surface soil horizons. Moreover, inherent soil spatial variability has made it difficult to provide statistical validity to potential subtle changes in the soil caused by cultivation. Therefore, the study was undertaken to: (i) ascertain the effects of cultivation, if any, on lower horizons; and (ii) employ an experimental design that could provide statistical validity to some subtle effects of cultivation.

THE STUDY AREA

Geography and Physiography

The study area is in northcentral South Dakota, in McPherson County (Fig. 1). Physiographically, the study area lies within the James River lowland of the central lowland province and is bounded to the west by the Missouri Coteau and to the east by the Lake Dakota plain (Hunt, 1974). The study area has a gently undulating to undulating topography marked by short drainages terminating in shallow depressions.

Geology

The study area is covered by glacial deposits generally agreed to be late Wisconsin in age (Flint, 1955; Lemke et al., 1965; Christensen, 1977). The Wisconsin till has inherited the mineralogy of a host of rock types, but is dominated texturally and mineralogically by incorporation of material from the underlying late Cretaceous Pierre shale formation.

Climate

The study area has a continental climate. The mean annual air temperature is 5.8 °C. The July mean is 22 °C and the January mean is −12.9 °C. The mean annual precipitation is 500 mm, of which 340 mm falls in May, June, and July. The mean annual snowfall is 880 mm.

Vegetation

The study area is centered in the midgrass prairie region (Weaver, 1954). Dominant native prairie species include western wheatgrass (*Agropyron smithii* Rydb.), needle-and-thread (*Stipa comata* Trin. & Rupr.), green needlegrass (*Stipa spartea* Trin.), prairie junegrass [*Koeleria cristata* (L.) Pers.], blue grama [*Bouteloua gracilis* (Willd. ex Kunth) La-

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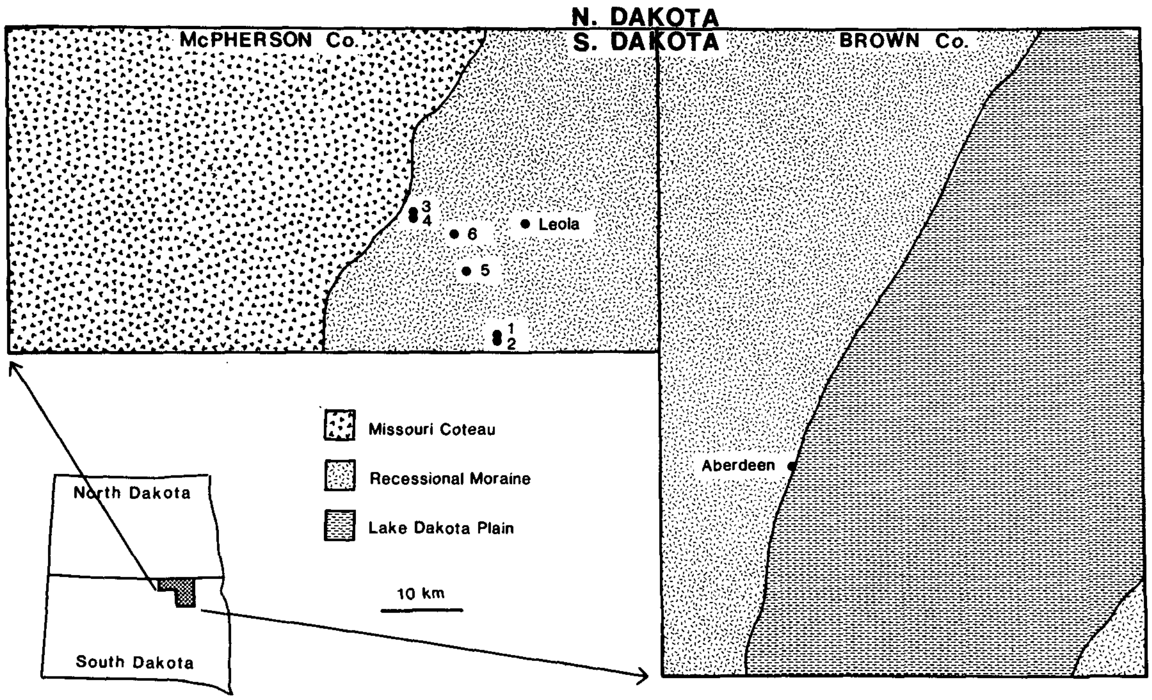

Fig. 1. Map of study area with location of sample sites.

gasca ex Griffiths]. Principal cultivated crops include spring wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), and flax (*Linum usitatissimum* L.). Major pasture plants include alfalfa (*Medicago sativa* L.), bromegrass (*Bromus inermis* Leysser), and crested wheatgrass [*Agropyron cristatum* (L.) Gaertner].

Land Use

Most operators in the study area practice diversified farming and ranching. Native grasslands are used for grazing and occasional haying. An 8-yr rotation commonly used on cultivated land is 2 yr in small grain, 1 yr in corn (*Zea mays* L.), and 5 yr in pasture.

MATERIALS AND METHODS

Experimental Design and Field

Landowners were interviewed to locate virgin pedons immediately adjacent to pedons cultivated for at least 50 yr. At present, landowners do not inorganically fertilize cultivated fields, but apply manure occasionally. Paired sites were used to minimize the effects of soil spatial variability. Special care was taken to locate all sites on similar positions on the landscape (level ridgetops). Six pairs of virgin and cultivated pedons of Williams or Williams variant soil, with similar horizonation, were located, described and sampled (Soil Survey Staff, 1951 and 1975). The distance between paired pedons was as close as possible: on opposite sides of a fence-line, a road, or a section-line boundary. Pedons were at least 20 m from the boundary. Horizons were sampled uniformly throughout; however, thin transitional zones between horizons were not sampled. The C horizons were sampled to a depth of 152 cm or less if another horizon was encountered. Subsamples for bulk-density determination, for immiscible-displacement analysis, and for thin-section preparation were also obtained at each sampling site.

Laboratory

Preliminary Preparation. Soil samples were oven dried at 39 °C and then made to pass a 2-mm sieve. The A horizons were lightly crushed; all other horizons were mechanically ground. The <2-mm fraction was reserved for chemical and physical analyses.

Chemical Methods. Soil pH and electrical conductivity (EC) were determined on a saturated soil paste extract (U.S. Salinity Laboratory Staff, 1954). A modified Walkley-Black method (Walkley, 1935; Peech et al., 1947) was used to quantify organic carbon. A modified immiscible displacement technique was used to extract soluble ions and soluble Si (Mubarak and Olsen, 1976). The procedure was as follows: (i) duplicate 20-g samples of undisturbed soil were hand broken to fit 50-mL polypropylene centrifuge tubes; (ii) the samples were saturated with deionized water and then placed in a constant-temperature incubator at 27 °C with thymol added to retard microbial growth; (iii) after an incubation period of 10 d, water in the samples was immiscibly displaced with CCl_4 for 1 h at 1500 × *g*; and (iv) the displaced water was passed through a 1.50-μm filter, and then immediately analyzed for Si, Ca, Mg, Na, and K. Silica was quantified by molybdenum blue colorimetry (American Public Health Association, 1960). Calcium and Mg were quantified by atomic absorption spectroscopy. Sodium and K were quantified by atomic emission spectroscopy. Aluminum, Fe, and Mn were extracted in duplicate, using two methods: the ammonium oxalate procedure (Al_o, Fe_o, and Mn_o) of McKeague and Day (1966) and the buffered citrate-dithionite procedure (Al_d, Fe_d, and Mn_d) of Mehra and Jackson (1960). Extracted Fe, Al, and Mn were quantified by atomic absorption spectroscopy.

Physical Methods. Bulk density (D_b) was determined in triplicate on special field-collected soil clods by the Saran method (Brasher et al., 1966). Centrifugation and dry sieving were used to measure particle-size distribution (Jackson, 1956; Kilmer and Alexander, 1949). To remove organic matter, 10-g samples of soil were treated and retreated with 300 g kg^{-1} H_2O_2 until completely bleached or until no further reaction took place. Samples then were washed with acidified CH_3OH followed by 950 g kg^{-1} C_2H_5OH to remove soluble ions. Next, the samples were suspended in a solution of 50 g kg^{-1} $(NaPO_3)_6$ and sonified to disperse soil particles.

Clays were decanted after centrifugal settling of silt and sand, dried at 65 °C, and weighed. Silts were isolated from sands by washing through a 50-μm sieve, then dried at 65 °C and weighed. Subsamples of silt-sized material were fractionated into 15 size classes by electronic means (Pennington and Lewis, 1979). The USDA sand fractions were separated by sieving and then weighed. Water retention was determined in duplicate on the <2-mm material, using a ceramic plate and pressure membrane apparatus (U.S. Salinity Laboratory Staff, 1954). The index of aggregation (IA), defined by the following equation, was determined using the method of Harris (1971): IA = 100 × [1 − (natural clay/total clay)]. Total clay is the percent clay as determined above. Natural clay was determined by pipette sampling after soaking 10 g of soil for 8 h in deionized water, followed by exactly 5 min of mechanical stirring with a malt mixer.

Statistical Methods. The experimental design was a randomized complete block with two treatments (Ott, 1977). The paired T-test was used for all comparative tests. In addition, the Statistical Analysis System (Barr et al., 1979) was used to determine correlations by horizon among measured values (reported values are significant at the $P < 0.01$ level).

RESULTS AND DISCUSSION

Comparison of Cultivated and Virgin Pedon Descriptions

Morphological differences between cultivated and virgin pedons are most expressed in A horizons (Table 1). The A horizons of virgin pedons have lower color values and chroma (a chroma of 1 places virgin pedons in the Udic subgroup), have more pronounced pedality, and have softer dry consistencies compared with Ap horizons. Morphological differences between similar horizons of cultivated and virgin pedons are muted in lower horizons; however, when all pedons are considered, several trends are indicated. Roots are more plentiful and a greater proportion of roots are found inside prismatic structural units in the Bt and Btk horizons of virgin pedons compared with similar horizons of cultivated pedons. In addition, Bt horizons of virgin pedons contain more and darker-colored tongues than do Bt horizons of cultivated pedons. Interestingly, nests of gypsum were noted in the C horizons of all six virgin pedons, but were only identified in the C horizon of one cultivated pedon.

General Chemical and Physical Comparisons

The significant decrease in OC in Ap horizons compared with A horizons of virgin pedons (Table 2) supports what has been extensively reported in the literature (Newton et al., 1945; Doughty et al., 1954). The Ap and Btk horizons of cultivated pedons have significantly greater D_b than their virgin counterparts (Table 3). In A horizons, D_b correlates with OC ($r = -0.71$). Organic matter is thought to be a principal binding agent in models of aggregate formation (Har-

Table 1. Pedon descriptions of paired cultivated and virgin soils at Sample Site 1.†

Horizon	Depth, cm‡	Matrix color		Structure		Consistence		Root abundance
		dry	moist	primary	secondary	dry	moist	
		Cultivated Williams soil, nonargillic variant, fine-loamy, mixed, Typic Haploboroll						
Ap	0–18 (0–18)	10YR 4/2	10YR 2/2	m & 1,c,sbk	1,vf,gr	dsh	mfr	many
Bt	18–33 (18–48)	10YR 5/3	10YR 4/2	2,m&c,pr	2,m,sbk	dsh	mfr	common
Btk	33–46 (33–66)	2.5Y 6/2	2.5Y 4/3	2,m,pr	2,c,sbk	dh	mfi	few
Bk	46–99 (46–119)	2.5Y 6/2	2.5Y 5/3	m	m	dsh	mfr	few
C	99–150 (86–152+)	2.5Y 6/4	2.5Y 5/3	m	m	dh	mfi	none
		Virgin Williams soil, dark surface variant, fine-loamy, mixed, Udic Argiboroll						
A	0–15 (0–25)	10YR 4/1	10YR 2/1	1,m,sbk	2,f&m,gr	dso	mfr	many
Bt	15–33 (15–51)	10YR 5/3	10YR 4/2	2,m,pr	2,m,sbk	dsh	mfr	common
Btk	33–48 (33–71)	2.5Y 6/2	10YR 4/2	1,m,pr	2,c,sbk	dsh	mfr	common
Bk	48–81 (48–119)	2.5Y 6/2	2.5Y 4/2	m	m	dsh	mfr	common
C	81–127 (74–152+)	2.5Y 6/2	2.5Y 4/2	m	m	dh	mfi	few

† Terminology and abbreviations follow Soil Survey Staff (1951); the other collected virgin and cultivated pedons are morphologically similar to the ones presented in this table.
‡ Depths in parentheses encompass the range of all six sample sites.

Table 2. General chemical comparisons between cultivated and virgin pedons.‡

Horizon	Treatment	pH	Immiscibly displaced					Organic C	Electrical conductivity
			H_4SiO_4	Ca	Mg	Na	K		
			mg L^{-1}	mmol L^{-1}				g kg^{-1}	dS m^{-1}
A	Cultivated	6.4	55	2.2	2.6	0.5	0.8	26	0.9
	Virgin	6.2	37*	2.6	2.4	1.1	0.4	35*	0.5
Bt	Cultivated	6.6	35	1.8	1.6	1.6	0.3	11	0.4
	Virgin	6.8†	24†	2.1	1.9	0.5*	0.5†	10	0.5
Btk	Cultivated	7.7	35	1.9	2.2	2.8	0.5	6	0.5
	Virgin	7.7	29†	2.7	3.6	1.5**	0.6	7	0.7
Bk	Cultivated	8.1	41	1.0	2.2	8.7	0.5	4	0.8
	Virgin	8.0	43	2.4	9.1†	13.3	0.7	4	3.9†
C	Cultivated	8.1	48	3.3	13.2	26.0	0.9	3	4.5
	Virgin	8.0	45	4.1	22.9**	38.3**	1.1†	3	9.9*

†, *, and ** denote significant differences between means at the 0.10, 0.05, and 0.01 levels, respectively.
‡ Data are an average of all six sample sites.

ris et al., 1965; Emerson, 1959) and its loss would contribute to aggregate destabilization and an increase in D_b. Loss of organic binding agents and compaction caused by implement traffic destroys most pores larger than 30 μm (Laws and Evans, 1949). Three mechanisms can explain significantly higher D_b in the Btk horizons of cultivated pedons. First, heavy implement traffic may cause soil compaction at depth (Söhne, 1958). Moreover, the Btk horizons of cultivated pedons contain noticeably fewer roots in ped interiors than Btk horizons of virgin pedons. Decreased root volume, which both creates and stabilizes channel voids, would lead to increased D_b. Finally, there is a general decrease in faunal populations with cultivation (Edwards and Lofty, 1975), which would be expected to reduce void-space volume, and thus increase D_b.

The Ap horizons have significantly lower wet aggregate stability (IA) than A horizons of virgin pedons (Table 3). Index of aggregation values are correlated with OC (r = 0.86), oxalate-extractable Fe (Fe_o) (r = -0.61), and dithionite-extractable Fe (Fe_d) (r = -0.62). The positive correlation with OC is consistent with some models of aggregate formation and stabilization (Harris et al., 1965) and suggests that loss of OC as a result of cultivation reduces interparticle bonding. The negative correlation with Fe_o and Fe_d is not consistent with other models of soil-aggregate formation and stabilization (Giovannini and Sequi, 1976). One would expect higher levels of amorphous and poorly crystalline Fe-oxyhydroxy compounds to increase aggregate stability.

Lightly crushed samples of A horizons from the virgin pedons retain significantly more water at 0 MPa tension than do similarly treated Ap horizons (Table 3). Water retained at 0 MPa tension is highly correlated with OC (r = 0.89). High levels of organic matter and the continual presence of roots in the A horizons of virgin pedons promote the conditions necessary for microbial and invertebrate reworking of soil material that creates and stabilizes soil aggregates. The secondary packing porosity created and the nature of humified organic material act to increase the water-retentive properties of A horizons of virgin pedons. The C horizons of cultivated pedons retain significantly more water at tensions 0, 0.02, and 0.03 MPa than do similar horizons of virgin pedons (Table 3). The fact that the samples were mechanically crushed, which would likely destroy natural pores >50 μm, instead of using intact samples may invalidate these results.

The Ap, Bt, and Btk horizons of cultivated pedons contain significantly more water-soluble Si than similar horizons of virgin pedons (Table 2). Beckwith and Reeve (1964) reported that mineral surfaces, especially sesquioxide surfaces, have site-specific surface sorptive sites for Si. Loss of organic matter as a consequence of cultivation may expose more mineral surfaces that are then able to contribute Si to the soil solution. Higher levels of water-soluble Si in cultivated soils hint at the potential for greater Si mobility in these soils. Unfortunately, no chemical extractions were performed to quantify a horizon of Si accumulation but one would predict higher Si levels in the Btk or Bk horizons because they are near the wetting front.

Two processes may help explain the water-soluble cation data (Table 2). The first process, greater water movement through the cultivated soils, is suggested by (i) significantly lower EC, and lower levels of water-soluble Mg, Na, and K in the C horizons of cultivated pedons compared with the similar horizons in virgin pedons; and (ii) the absence of gypsum accumulations in all but one C horizon of the cultivated pedons, whereas all C horizons of the virgin pedons contained gypsum accumulations. Cultivated crops do not utilize available moisture as completely as native vegetation. The excess water moving through the soil, as Ferguson et al. (1972) have reported in the crop-fallow soils of Montana, is able to leach soluble salts from cultivated pedons. The second process, upward moisture movement in the cultivated soils, is suggested by significantly higher water-soluble Na within the Bt and Btk horizons of these soils compared with similar horizons in the virgin pedons. During the fall, winter, and early spring, moisture accumulates at depth in cultivated soils because either vegetation has been removed or the plants are dormant. On virgin sites, however, some native plant species will transpire during the cold fall and spring periods (Weaver, 1954).

Table 3. Physical comparisons between cultivated and virgin pedons.‡

Horizon	Treatment	Bulk density	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	IA§	Water-retained tension (MPa) 0	0.02	0.03	0.15	1.5
		Mg m^{-3}	g kg^{-1}								g kg^{-1}				
A	Cultivated	1.57	12	36	60	121	153	370	248	86	540	350	280	210	180
	Virgin	1.33**	14†	41*	55	125	111*	410*	244	93**	700**	350	290	210	190
Bt	Cultivated	1.67	21	48	66	163	117	320	265	87	540	300	250	180	160
	Virgin	1.59	15	43	60	119*	142†	350	271	84†	540	310	250	190	170
Btk	Cultivated	1.64	16	35	47	108	130	397	267	77	520	320	260	190	170
	Virgin	1.54*	12	33	47	119	110	427†	252	81*	490†	300	250	180	160
Bk¶	Cultivated	1.59	17	33	45	143	121	423	218	63	490	340	270	200	160
	Virgin	1.60	12	40	61	149	132	421	185	74	490	320	260	180	160
C¶	Cultivated	1.67	17	38	45	87	118	408	287	63	540	370	300	220	190
	Virgin	1.67	12	44	56	131	118	442	197	79	470*	330*	270†	200	170

†, *, and ** denote significant differences between means at the 0.10, 0.05, and 0.01 levels, respectively.
‡ Unless otherwise noted, data are an average of all six sample sites.
§ The index of aggregation (IA) is a measure of wet aggregate stability.
¶ Particle size-data and IA values are based only on Sample Site 1.

Thus, when cultivated crop growth begins in the late spring, the lower horizons often contain appreciably more moisture than similar horizons under native grass (a fact readily observed in the field). As established crops or planted seeds begin to uptake moisture on cultivated sites, initially at a shallow depth, a steep upward moisture gradient will ensue, thereby enriching the Bt and Btk horizon with Na.

Extractable Fe, Al, and Mn Comparisons

Compared with the A horizons of virgin pedons, Ap horizons have significantly greater Fe_o (Table 4), an explanation of which requires one to consider Fe chemistry in soils. Oxalate-extractable Fe is a measure of ferrihydrite (Schwertmann, 1973) and amorphous products of recent weathering (McKeague and Day, 1966). If ferrihydrite only forms by rapid oxidation of solution Fe(II) or by inhibition of Fe-oxide crystallization (Schwertmann, 1985), then higher levels of Fe_o in Ap horizons would seem to imply greater release of Fe to solution, with subsequent precipitation to ferrihydrite, than occurs in the A horizons of virgin soils. Three mechanisms, individually or together, that could lead to enhanced solubility of Fe in Ap horizons include: (i) production of chelating-weathering agents, (ii) lithic fragment breakdown, and (iii) biochemical reactions involving soil organic matter.

Some plant root exudates, cellular components, and extracellular metabolites produced by rhizosphere organisms are known to solubilize Fe in silicate mineral lattices (Robert and Berthelin, 1986). Perhaps rhizospheral differences between cultivated and virgin soils and the effects of yearly root lysing in cultivated soils result in the increased production of chelating-weathering agents in cultivated soils. Increased production of these agents would result in the attack and release to solution of Fe from mineral lattices. Subsequent precipitation, either in a pure Fe-oxyhydroxy phase (ferrihydrite) or as an amorphous Fe-Al-oxyhydroxy phase, would increase the pool of Fe_o. If the solubilization of Fe is greater in Ap horizons due to a chelating-weathering mechanism, then mobile Fe-chelates could accumulate in lower horizons (Atkinson and Wright, 1957). Significantly higher levels of Fe_o in the Bt horizons of cultivated pedons compared with Bt horizons of virgin pedons (Table 4) support such a model.

Table 4. Oxalate- and citrate-dithionite-extractable Al, Fe, and Mn comparisons between cultivated and virgin pedons.†

Horizon	Treatment	Mn_o	Mn_d	Fe_o	Fe_d	Al_o	Al_d
		g kg^{-1}					
A	Cultivated	0.67	0.51	1.28	3.56	0.49	0.55
	Virgin	0.73*	0.56	1.00†	2.86†	0.56	0.56
Bt	Cultivated	0.57	0.45	1.33	3.97	0.43	0.46
	Virgin	0.61	0.46	0.85*	3.96	0.48†	0.46
Btk	Cultivated	0.34	0.48	0.31	3.39	0.10	0.12
	Virgin	0.11	0.38†	0.24	3.69	0.10	0.21*
Bk	Cultivated	0.06	0.42	0.13	3.05	0.03	0.06
	Virgin	0.19	0.44	0.28	3.44	0.04	0.05
C	Cultivated	0.38	0.46	0.35	3.48	0.05	0.04
	Virgin	0.24	0.49	0.42	3.51	0.04	0.04

†, and * denote significant differences between means at the 0.10 and 0.05 levels, respectively.

‡ Data are an average of all six sample sites; Mn_o, Fe_o, and Al_o are oxalate-extractable Mn, Fe, and Al, respectively; Mn_d, Fe_d, and Al_d are citrate-dithionite-extractable Mn, Fe, and Al, respectively.

Significantly greater levels of Fe_d in Ap horizons compared with A horizons of virgin pedons can be explained by a combination of the above model and lithic fragment breakdown as a result of tillage operations. Because Fe_d is a measure of free Fe oxides (Mehra and Jackson, 1960), increased production of weathering agents on cultivated sites would, over time, be expected to release Fe from silicate mineral lattices (these soils have a high hornblende content) and increase the amount of Fe_d through production of secondary Fe minerals (geothite, lepidocrocite). Lithic fragment breakdown could also increase Fe_d. Destruction of lithic fragments (schist, shale, gniess) may expose more Fe-oxide surfaces, thereby contributing to more Fe_d and possibly more Fe_o. The biochemical nature of the organic fraction controls the relative mobility of elements such as Fe and Al in soils; the greater the ratio of fulvic acid to humic acid the greater the mobility of Fe and Al (Duchaufour, 1977). If the ratio of fulvic acid to humic acid increases as a result of cultivation (Dormaar, 1979), then one might expect the mobility of Fe to be increased by these changes.

The Btk horizons of cultivated pedons contain significantly more Mn_d, a trend toward significantly higher levels of Mn_o, and significantly less Al_d than the Btk horizons of virgin pedons (Table 4). Citrate-dithionite-extractable Mn and Mn_o are highly correlated with each other ($r = 0.93$), which suggests they are extracted from the same pool. The Al_d is significantly correlated with water-soluble Si ($r = -0.68$).

Particle Size Comparisons

The Ap horizons contain significantly less silt than A horizons of virgin pedons (Table 3). Size partitioning by electronic means (data not presented here) indicated that relative differences in the proportion of silt between the Ap horizons and the A horizons of virgin pedons occur in the 30 to 50 μm size range. This particular size fraction is moved very efficiently by wind in short-term suspension (Pye, 1987, chapter 3). It thus appears that: (i) periodic bare soil surfaces on cultivated sites allows deflation of silt-sized material, or (ii) the continuous grass cover on virgin sites allows silt-sized eolian-transported material to accumulate, or both. Models of eolian particle entrainment and transport (Bagnold, 1937) and experimental data from medium-textured soils (Chepil, 1945) indicate that coarse silt- through fine sand-sized material should be readily removed from the bare soil surfaces. In other words, Ap horizons should be relatively depleted in coarse silt and fine and very fine sand compared with A horizons of virgin pedons. Yet the Ap horizons contain significantly more very fine sand than the A horizons of virgin pedons (Table 3). Clearly, mechanisms other than eolian transport must be considered to explain the data. One alternative process could be lithic fragment breakdown, as a consequence of tillage operations, to create very fine sand-sized material.

The Bt horizons of cultivated pedons contain significantly more fine sand and significantly less very fine sand than the Bt horizons of virgin pedons (Table 3). When sand-sized particles only mildly treated with surfactants were observed with a microscope, particles from the cultivated soil contained more coatings and bridges of an Fe-rich substance than particles from the virgin soil. This observation, along with the significant correlation of levels of very fine sand with Fe_o ($r = -0.66$), suggest that Fe-oxide coatings of very fine sand-sized particles from the Bt horizons of cultivated pedons may create larger (fine sand-sized) particles.

CONCLUSIONS

It is apparent that, when virgin soil is cultivated, the focus of change occurs in the A or surface horizons. In this regard, our investigations corroborate previous research indicating that cultivation leads to marked loss of OC and destruction of pedality. In addition, we have measured several changes as a consequence of cultivation in both surface and subsurface horizons that, although subtle, may have significant long-term ramifications. Cultivation allows excess water to move through the soil and thereby leach soluble salts from the profile; however, it is unclear if enough excess water moves beyond the rooting zone to create saline seeps lower in the landscape such as occur in the crop-fallow areas of North Dakota and Montana. Cultivation increases levels of Fe_d and Fe_o in Ap horizons and levels of Fe_o in Bt horizons. In cultivated Bt horizons, these poorly crystalline and amorphous Fe-oxyhydroxy compounds bridge and coat particles and may, over time, increase the strength of prismatic structural units relative to that of Bt horizons of virgin pedons. There are significant differences in the particle-size distribution between cultivated and virgin surface horizons that cannot be completely accounted for by eolian entrainment and transportation.

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