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The Impact of White Pine (*Pinus strobus*) on a Mollisol After Seven Decades of Soil Development

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Selected chemical, physical, and macro and micromorphological properties in two pedons of a Clarion soil (Fine-loamy, mixed, superactive, mesic Typic Hapludolls) formed in till parent material, one planted to white pines (*Pinus strobus*) for the past 75 years and the other to grass, were compared. The most obvious difference between the two was the increased biological activity under pines; the variety and quantity of excrements suggested the activity of soil microfauna and variability of species resulted in finer and better aggregation of biological origin (crumbs and granules), numerous excrements in voids, and higher total porosity under pines. The matrix was lighter colored in the upper horizons under pines. The soil under pines seemed to be drier and to have more expressed water oscillations in the middle part of profile. There was some evidence of higher groundmass activity in the soil under pines and the groundmass b-fabric was slightly better expressed. The soil under the pines exhibited evidence of stronger weathering (weathered biotite at a shallower depth, more iron-rich fine fraction, common amorphous iron impregnation and frequent amorphous iron coatings related to grains or pores together with abundant iron nodules) than the soil under grass. Analytical and micromorphology methods showed only slight changes in the Clarion soil under pines. That means 75 years, at least under the prevailing climate, is too short a period for the formation of pronounced morphological and physico-chemical differences.

INDEX DESCRIPTORS: Mollisol, micromorphology, pedogenic processes.

Most of the Great Plains region of the United States was covered with native prairie vegetation prior to intensive agricultural use of the region, with limited areas covered by natural deciduous trees. As the central U.S. was settled, many acres were planted into shelterbelts containing both conifers and deciduous trees for protection against wind erosion. Some existing shelterbelts have been in place for 70–100 years. Conifers raised as Christmas trees have also become a popular alternative crop for some Iowa farmers.

Changes in the morphological and chemical properties of forest and adjacent prairie soils have been discussed by numerous authors (Ugolini and Edmonds 1983, Graham and Wood 1991, Dahlgren et al. 1991, Moffet et al. 1994, Ulery et al. 1995, Tice et al. 1996, Quideau et al. 1996, Dahlgren et al. 1997, Scott 1998). The degree of the changes shown in any given soil depended on the duration of the trees impact and the tree species. Differences noted between grass and tree sites were associated with organic carbon content and properties associated with organic carbon (Barrett and Schaetzl 1998), lowering of soil solution pH, removal of base cations, and changes in cycling of Ca, Mg, K, and Cl, (Dahlgren et al. 1991). In the case of oak trees soils under the trees were characterized by such positive changes as lower bulk density, higher pH, and greater concentrations of organic C, nitrogen, total and available P, and exchangeable Ca, Mg, and K (Dahlgren et al. 1997). Other studies have shown that plant species and vegetation type can alter soil aggregate distribution and organic matter concentration, but these alterations are minor (Scott 1998). Changes that have been found between soils formed under differing vegetation include different aggregate stability, C and N content, C/N ratio, exchangeable base cations, acidity, and weathering rates (Graham et al. 1995, Ulery et al. 1995, Quideau et al. 1996 and 1998). Comparing the changes under oak, pine, chamise and ceanothus, the greatest changes in soil carbon, nitrogen and exchangeable cations have been found between oak and pine (Ulery et al. 1995).

It has also been noted that changes in a soil profile take increasing time as depth increases. Changes in soil properties to a depth of 20 cm plus have been documented over time periods of less than 50 years when soil formation factors have been changed (Buol et al. 1997, Davis et al. 2003), but at a depth of 1 m it takes over 1000 years to effect significant change in 2.5 cm of soil in the American Midwest (Troeh et al. 1999).

The objective of this research was to examine pedogenic changes due to white pine (*Pinus strobus*) impact using soil micro- and macromorphological, physical, and chemical attributes. Exact information about the year of the pines' planting allows an estimation of the intensity and velocity of soil processes under the new pedoenvironment.

METHODS

This research was conducted in Story County, Iowa, within the southern part of the Des Moines Lobe of the late Wisconsin glaciation (Fig. 1). Mollisols (Clarion series, Fine-loamy, mixed, superactive, mesic Typic Hapludolls) under grass and pine were investigated 4.8 km south of Ames, IA. White pines were planted in 1923 (Phil Cafferty, verbal communication, May 1998) in an area about 50 m wide and 175 m long with total area of about 0.88 ha. These trees were allowed to grow "wild" for about 75 years between planting

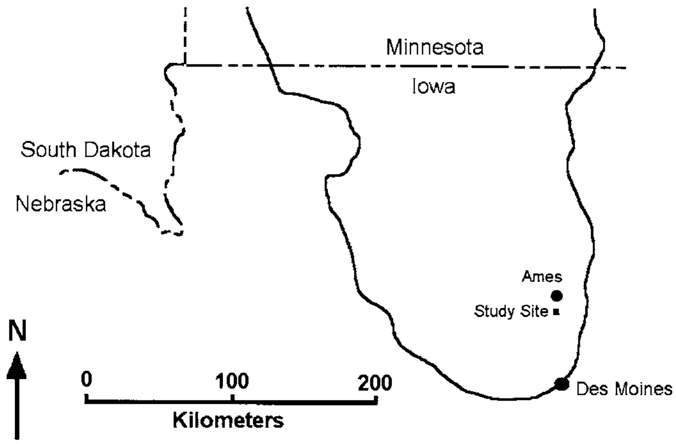

Fig. 1. Location of the study site and its position within the Des Moines lobe.

and soil sampling in 1998. A reference site was established under grass about 10 m from the site where pine-influenced soil was sampled. The reference site was row cropped until about 1986 but has never been under trees. Parent material is a carbonate-rich till with good natural drainage. These soils formed under a midcontinental climate with a present mean annual temperature of about 9° C and a mean annual precipitation of about 790 mm.

Soils were described and sampled in soil pits in 1998. Bulk samples from each soil horizon were collected for selected physical and chemical analyses. Total carbon, total nitrogen, C/N, pH, available P and K, and particle size distribution were measured according to the Soil Survey Laboratory Methods Manual (Soil Survey Staff 1996). Undisturbed representative clods from each horizon were taken from the pit and saran-coated for preservation of natural microfabric against drying. One thin section was made for each horizon according to the Soil Survey Laboratory Methods Manual (Soil Survey Staff 1996) and described using the guidelines in Bullock et al. (1985).

RESULTS AND DISCUSSION

Field Morphology

Both pedons had similar morphologies, but some differences were described (Table 1). A thick layer of pine litter covered the soil surface under the trees. Soil under the pines was softer, more friable, and slightly wetter in the topsoil. The middle part of the pedon (25–50 cm) was strongly mottled due to bioturbations (earthworm channels filled with dark humus-rich casts and excrements). The soil under grass had finer aggregation with granular peds in the uppermost horizons, while the soil under the pines trended toward platy aggregates in the A2 horizon. The BA horizon was thinner in the pedon under grass. Evidence of clay translocation included "clean" sand grains at ped surfaces in the 0–50 cm layer and faint to prominent clay-humus cutans at a depth of 43–76 cm under the pines. Such mottling and clay translocation were less expressed in the soil under the grass. Both soils had free carbonates at the bottom of the pedon, but strong effervescence started at a shallower depth in the soil under pines and carbonates were more abundant and more variable in morphology under the pines. Redoximorphic features were common in the bottom of both pedons, but fine soft Fe-Mn masses were present starting at a shallower depth in the pedon under the pines.

Analytical Results

Analytical methods showed weak variation in measured physical and chemical attributes due to vegetation change. There was slightly higher carbon and lower N and pH in the pedon under pines (Figs. 2–4). The upper 30 cm were more sandy and less silty under trees. The clay contents were similar with slightly higher clay content in the pedon under grass, but the whole curve appearance suggested more clay redistribution under trees. Look particularly at the curve from ~25–65 cm (Fig. 5). In the upper 50 cm the soil under pines contained two to three times more available P (up to 56 ppm), but had less K (Figs. 6, 7). The C/N ratio was slightly wider in the soil under trees. This difference was consistent with other data that showed a narrowing of the C/N ratio when soils were cultivated (Fenton et al. 1998).

Differences in selected physical and chemical properties suggest that 75 years, at least under the prevailing climate, was too short a period for the formation of pronounced morphological and physicochemical differences in these soils as a result of the introduction of white pine. In such a case micromorphology was expected to be the best tool for indication of pedogenic changes in their early stages.

Micromorphology

The brief comparative description below summarizes the differences in microfabric attributes of both pedons. The course/fine limit used in the micromorphology analysis was 10 microns.

Microstructure

Degree of aggregation. The general trend was a decrease of aggregation with depth in both profiles ranging from strongly developed in shallow horizons to moderately and weakly developed with the appearance of apedal zones in deep horizons. Aggregation was more strongly developed in the soil profile under pine, especially in the upper horizons (Figs. 8 a,b).

Types of aggregation. The trend in both profiles was a decrease of crumb and granular structure types with depth and increasing numbers of subangular blocky peds. The soil under pines had more crumbs in the upper horizons and better expression of subangular blocky peds in the solum compared with crumb-granular microstructure with spongy aspect in the profile under grass. The dominant sizes were from ultrafine to fine (see Bullock et al. 1985 for ranges of size classes).

Porosity. Total porosity (close to 20–30%) increased in the middle part of both profiles up to 30–35 cm. Micro-zones with total porosity up to 40–50% were noticed in several horizons, mainly in the soil under pines. Both pedons had a compact subsurface horizon. Total porosity of the three upper horizons under grass was close to 15–20% (i.e., these horizons were the most compact). Dominant types of pores in both pedons were compound and complex packing pores with an increase of channels in the middle part of both pedons. Planes were more developed in the soils under grass, especially the fine intrapedal planes (Fig. 9). This indicates wetting and drying of clay has been more important than biological activity in creating pores under grass.

Groundmass

The groundmass had predominantly single space porphyric with minor enaulic, gefuric, and chitonic related distribution patterns in both profiles. Chitonic and a higher percentage of enaulic microzones (in the upper 0–13 cm) were more typical of the profile under pines.

Table 1. Description of soil profiles.

Horizon	Depth (cm)	Color (moist)	Texture	Structure	Consistence	Wetness	Other Features
Grass							
A1	0–9	10YR 2/2	Sandy loam	f to cr gr, f abk	fr	ds	upper 2.5 cm—very dense roots
A2	9–18	10YR 2/1	Sandy loam	f sbk	vf	ds	
Bw1	18–35	10YR 2/2, few 3/3	Sandy loam	f & m pr; m abk	vf	ms	
Bw2	35–48	10YR 4/3 and 3/3	Sandy loam	m pr; cr & m abk	f	ms	
Bw3	48–64	10YR 4/4 and 4/3, 3/3	Sandy loam	m pr; cr & m abk	f	ms	
Bw4	64–81	10YR 4/4	Sandy loam	m pr; m abk	fr	ms	weak FeMn cutans in some pores
BC	81–94	10YR 5/4	Sandy loam	m pr; f abk	fr	ms	weak redoximorphic mottles
Ck	94–115	2.5YR 4//4 few 10YR 4/4	Sandy loam	m&cr pr & abk	fr	mm	str. efferv., few medium carbonate nodules, many fine FeMn soft masses
Pine							
A1	0–8	10YR 2/2	Sandy loam	f sbk	v fr	ms	
A2	8–18	10YR 2/2 and 3/2	Sandy loam	f sbk, vw pl	fr	ms	
A3	18–25	10YR 4/3 and 3/3	Sandy loam	m pr; f & m gr & abk	f	ms	
AB	25–36	10YR 4/3, and 4/4, 3/3	Sandy loam	m pr; m abk & gr	vf	ms	strongly mottled due to bioturbations
AB	36–43	10YR 4/4 and 4/3	Sandy loam	cr pr, m abk & gr	fr	ms	strongly mottled due to bioturbations
Bw1	43–51	10YR 5/4	Sandy loam	cr pr; m abk & gr	fr	ms	prominent clay films
Bw2	51–61	10YR 5/4	Sandy loam	m pr & abk	fr	ms	moderately few prominent clay films
Bw3	61–76	10YR 5/4	Sandy loam	m pr & abk	fr	ms	few faint clay films
Bw4	76–86	10YR 5/4	Sandy loam	m pr & abk	fr	ms	few faint clay films; few medium nodules
BCk	86–102	10YR 5/4	Sandy loam	m pr & abk	fr	ms	str. efferv.; faint clay films; many fine carbonate veins
Ck	102–114	10YR 5/4 and 5/6	Sandy loam	m & cr pr & abk	fr	mm	str. efferv.; few medium to coarse nodules, many soft masses and veins, many fine FeMn soft masses

Abbreviations: Wetness: ds = slightly dry, ms = slightly moist, mm = moderately moist. Structure: vf = very fine, f = fine, m = medium, cr = coarse, gr = granular, abk = angular blocky, sbk = subangular blocky, pr = prismatic, pl = platy. Consistence: vfr = very friable, fr = friable, f = firm, vf = very firm. Other features: str. efferv. = strong effervescence.

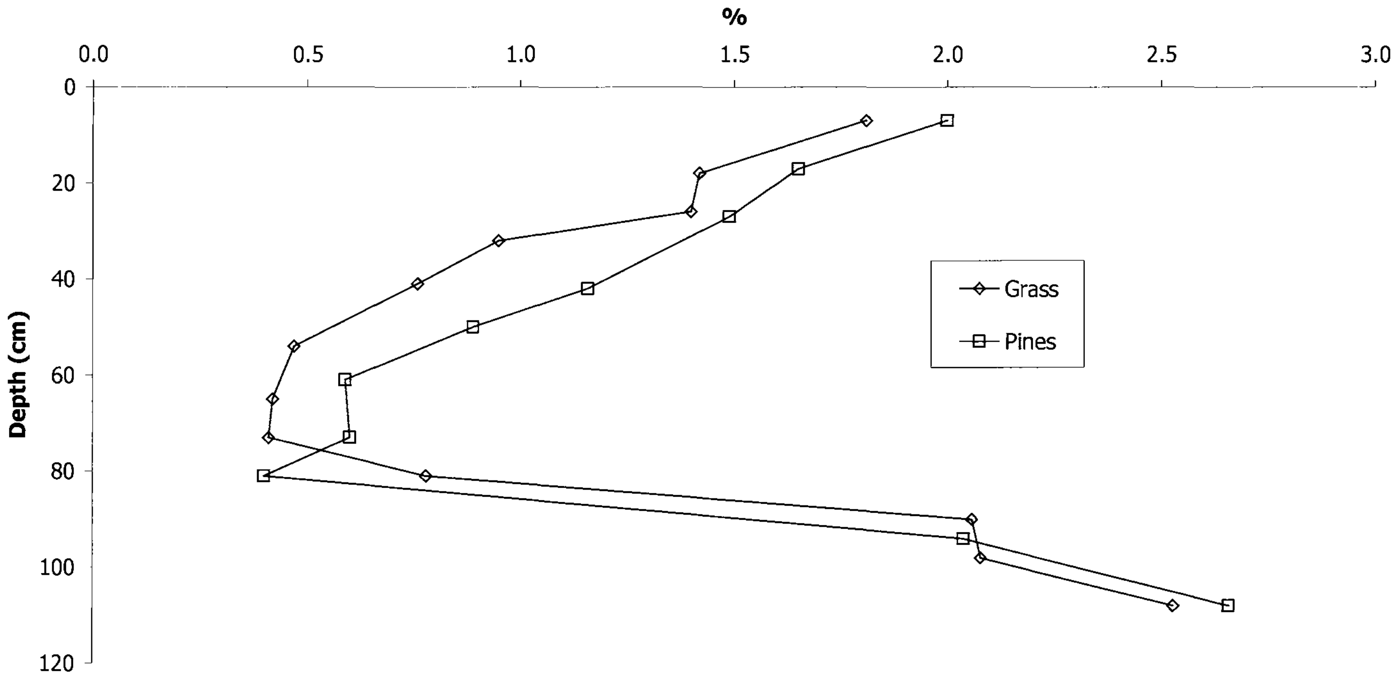

Fig. 2. Comparison of total carbon with depth in the sampled soils. The upper part of the soils are leached of carbonate minerals; the increase in total carbon in the lower parts of the soil is due to the presence of carbonate minerals.

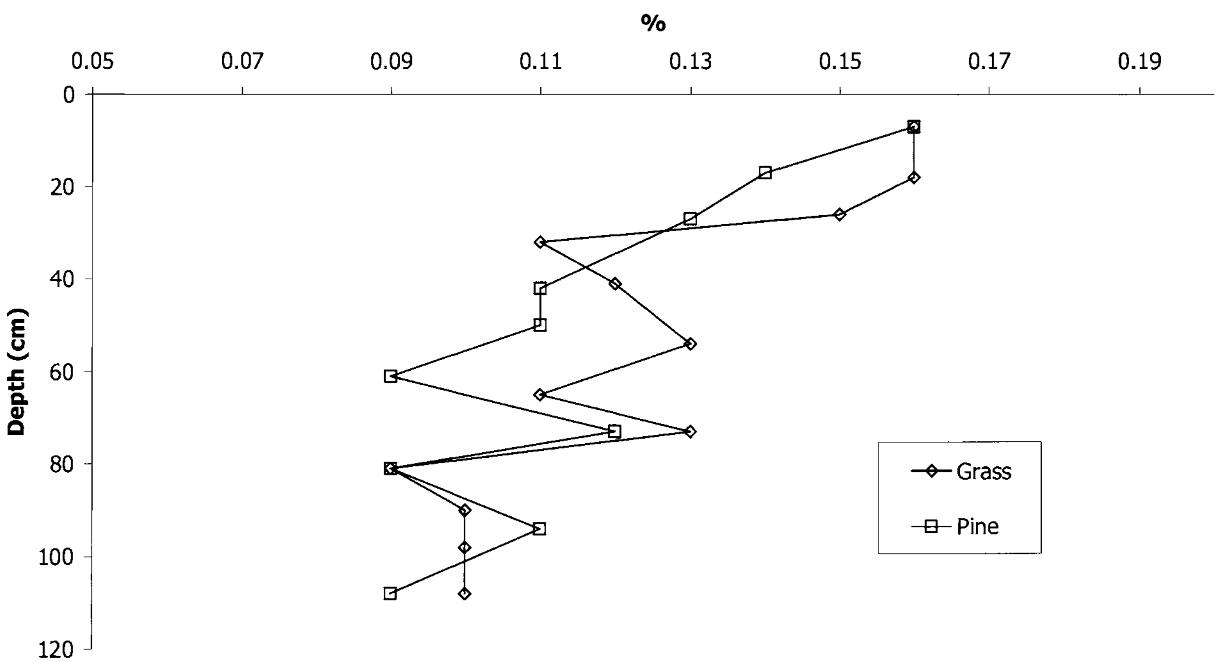

Fig. 3. Percent total nitrogen with depth in the sampled soils.

b-fabric

The general trend through both profiles was a change from undifferentiated b-fabric through speckled to the stipple-speckled with elements of reticulate-striated and striated in the deepest horizons. Granostriated and porostriated b-fabric was also characteristic of most of the subsoil in both profiles. The thickness of horizons with isotropic micromass with undifferentiated b-fabric appeared thicker in the profile under grass (0–13 cm) than in the soil under pines (0–8 cm). Stipple-speckled and reticulate-striated b-fabric appeared closer to the surface in the profile under pines. Crystallitic b-fabric was described in the Bw4 horizon in the soil under pines. The deepest horizon under grass (94–114 cm) had mosaic-speckled b-fabric without any character of crystallitic b-fabric.

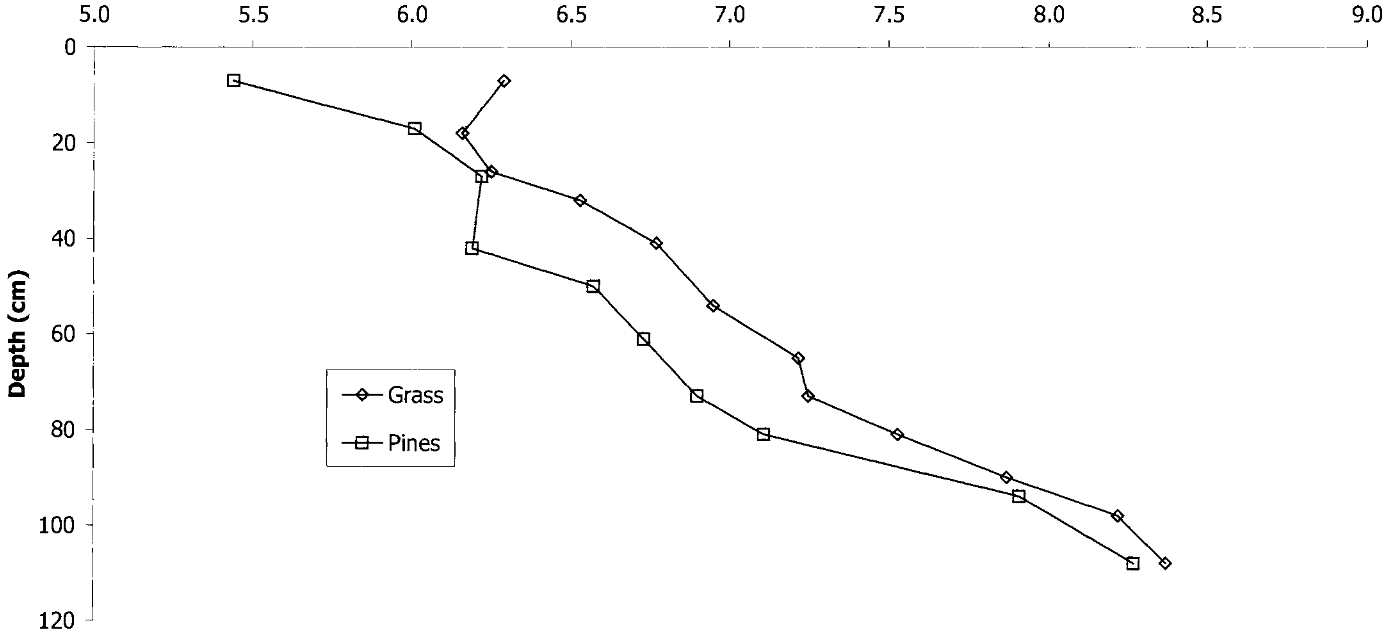

Fig. 4. Distribution of pH with depth in the sampled soils. Note the much more acidic value at the surface of the soil under pines.

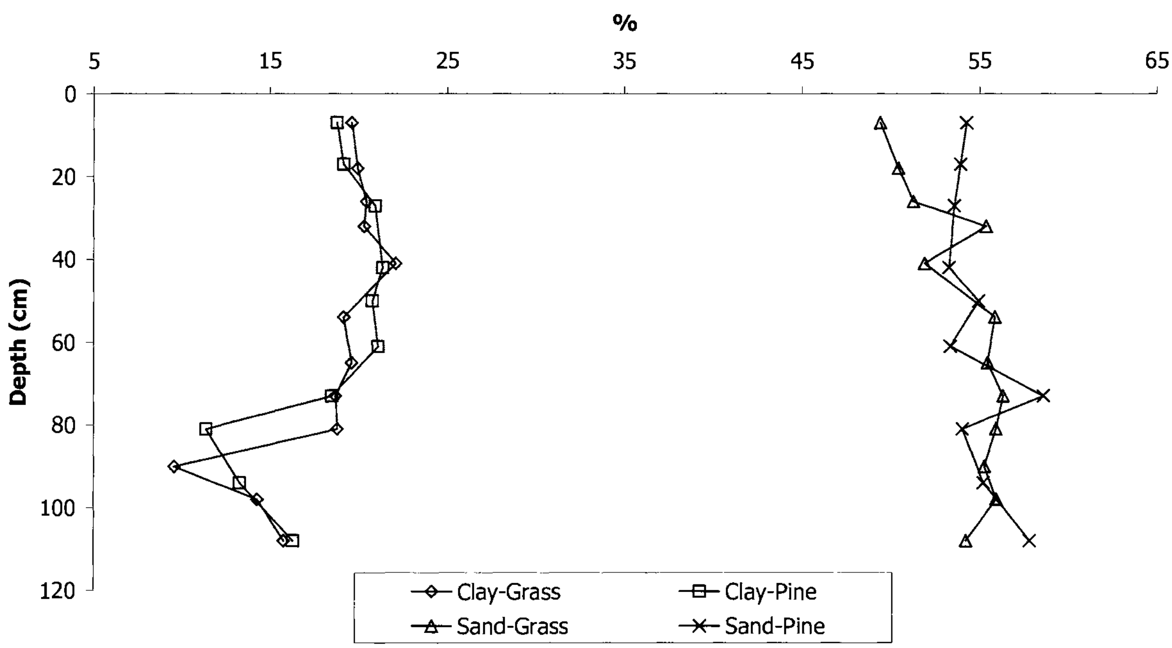

Fig. 5. Particle size distribution in the soils.

Micromass color and composition

The composition of micromass changed from iron-clayey-humic in the upper horizons to humic-iron-clayey in the middle part. At a depth of about 60 cm groundmass became humic-clayey. The two deepest horizons in the pedon under pines had carbonate-clayey groundmass. Soil color was dark brown under pines and very dark brown under grasses in the upper horizons. In the middle part of the profiles (18–76 cm under pines and 34–81 cm under grass) colors were brown or light brown, and changed completely to light brown starting at a depth of 76 cm under pines and 81 cm under grass.

Coarse fraction

The coarse fraction consisted of single mineral grains (very fine to medium coarse sand) and rock fragments up to 6 mm. The coarse fraction was unsorted, angular to rounded, and smooth and undulating, characteristics common to till deposits. The coarse fraction

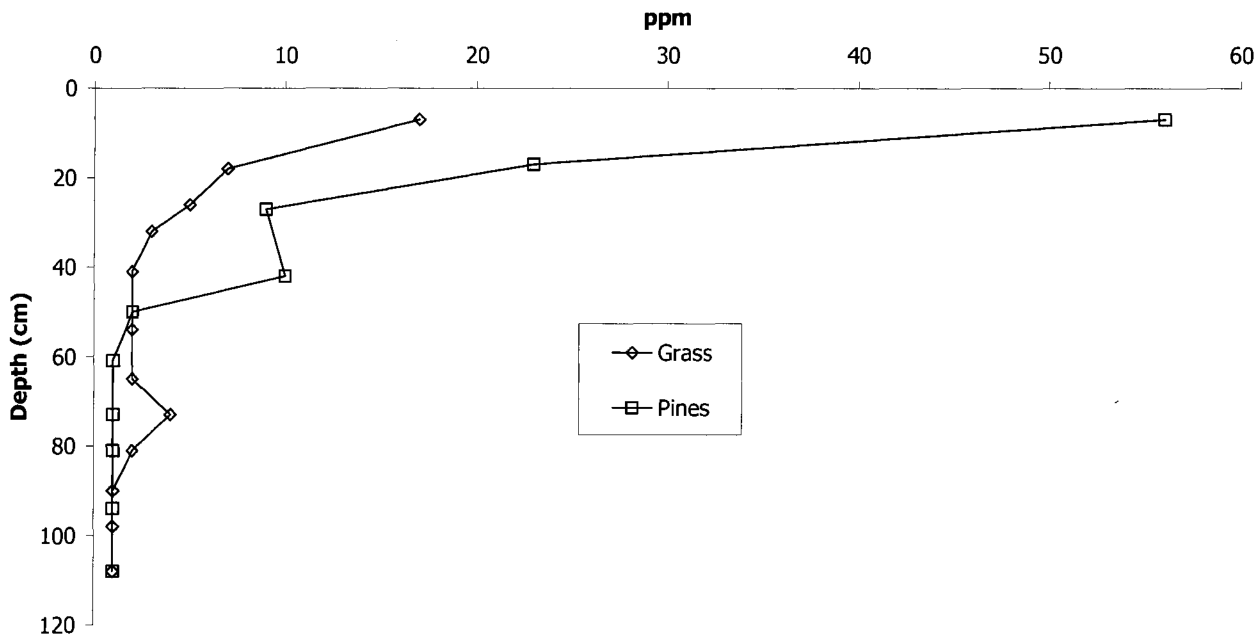

Fig. 6. Available phosphorus in the sampled soils. Note the significantly increased values of available phosphorus beneath the pines.

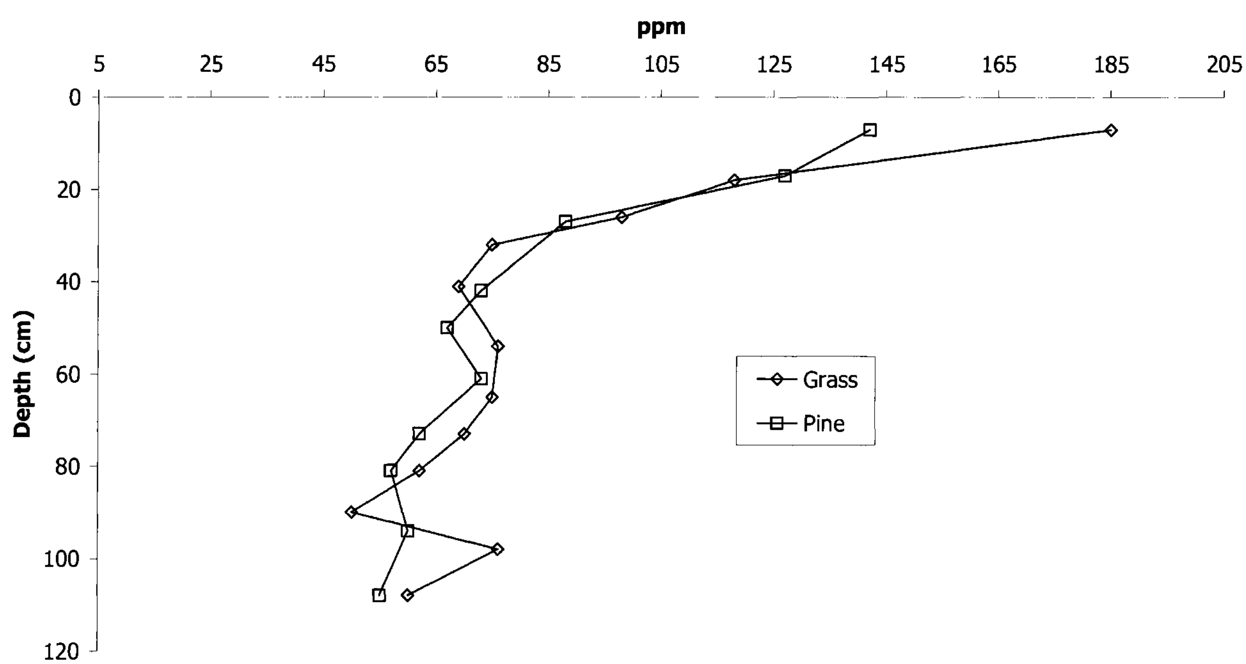

Fig. 7. Available potassium in the sampled soils, showing less potassium in the upper part of the soil under pines.

composition included quartz and plagioclase, which dominated the mineral types. Other minerals and rock fragments included orthoclase, hornblende, biotite, calcite (in the deepest horizons under pine), sericite, glauconite, schist, gneiss, limestone, sandstone, and basalt. The coarse fraction fragments showed various degrees of alteration. Biotite seemed to be more weathered starting at a depth about 76 cm in the soil under pines compared with similar depths in the soil under grass.

Pedofeatures

Excremental. The amount and morphological variety were different in the two profiles. There were few to very few excrements in the soil under grass to a depth of 63 cm, and they occurred mainly in pores and plant debris. The total quantity and the variety of excremental forms and size were much higher in the soil under pines. They were distributed through the whole profile from top to bottom. At least four morphological types were found (Fig. 10).

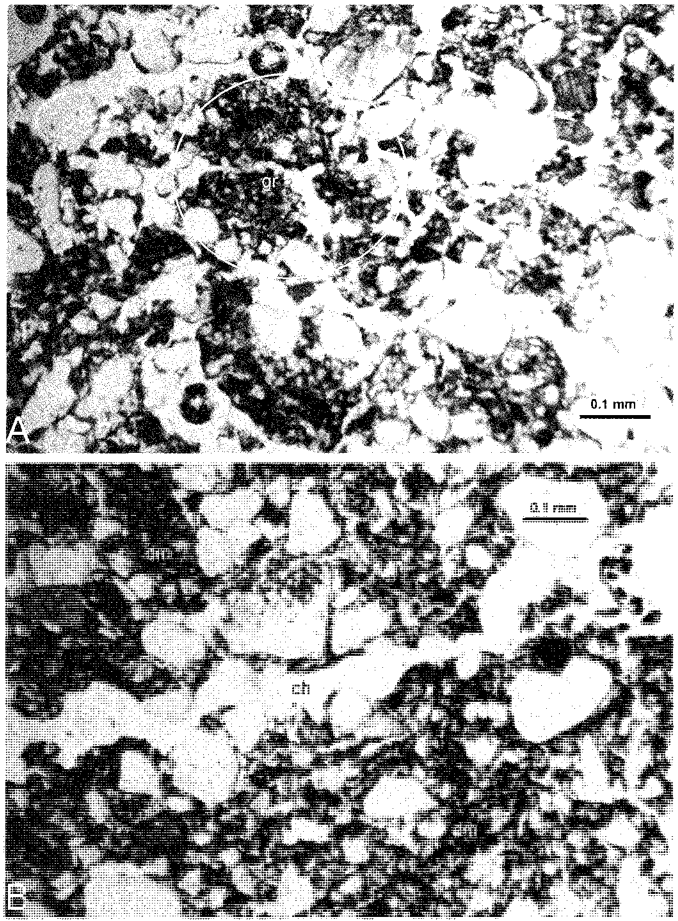

Fig. 8. 8A (0–7.5 cm under pines)—Loosely packed granular aggregates (gr) (presumably biogenic, formed by earthworms) in the middle of the photo. Strongly developed pedality, granular microstructure, and high porosity (compound packing voids and planes). 8B (0–9 cm under grass)—Weakly aggregated dense matrix (dm) with few voids (large channel (ch) across the photo), subangular blocky microstructure. Bar scale shows 0.1 mm on the photos. Parallel planer light, 30× magnification.

Amorphous. The presence of iron and iron-manganese nodules was characteristic of both profiles and they were present through the whole profile. Their numbers increased from the middle part to the bottom. Nucleic and typic nodules (50–300 μm up to 600 μm) were the most common. The soil under pines had a higher abundance of nodules and a larger variety of morphological forms. Concentric nodules were present in the middle part of the pedon (15–86 cm). Impregnations and aggregated nodules were more abundant than in the soil under grass and present through the whole profile. Fe-coatings related to grains and pores were noted in the soil under pines.

Textural. Silty-clay, mainly thin and fragmented coatings (films) related to mineral grains were described in both profiles, especially in the middle part, where they became thicker and more continuous than in other parts of the profiles. They appeared at a shallower depth and were more expressed in the soil under pines.

Crystalline. Calcite appeared at a depth of about 86 cm in the soil under pines. No calcite was found in the thin section from the soil under grass at similar depth. Calcite pedofeatures were very abundant in the soil under pines and were found as crystallitic b-fabric in the matrix, dense incomplete micrite infillings (Fig. 11), compound micrite/microsparite/mineral grains, incomplete infillings, micrite hypocoatings, micrite/microsparite and micrite coatings related to voids, common typic micrite and microsparite nodules, and a few compound sparite nodules. Some additional morphological forms appeared in the deepest horizons, such as compound micrite nucleic/geodic nodules, typic sparite nodules and coatings related to rootlets.

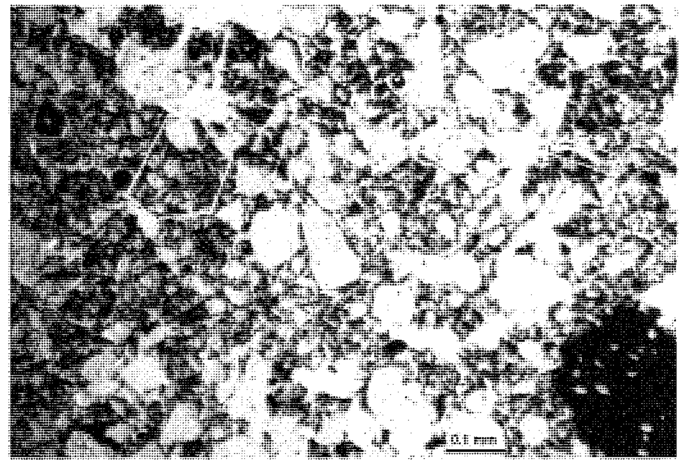

Fig. 9. (9–18 cm under grass) Weakly developed pedality with weakly developed granules (example at gr), granular to spongy microstructure. Very fine short intra-aggregate microplanes (example at mp) are typical to this horizon. Bar scale shows 0.1 mm on the photo. Parallel planer light, 30× magnification.

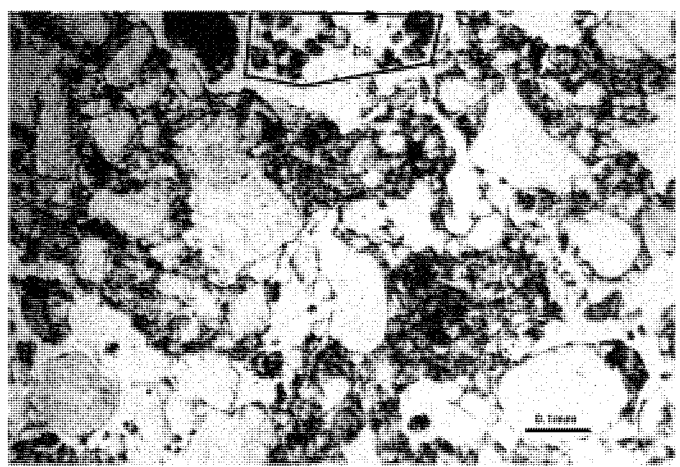

Fig. 10. (43–51 cm under pines) Example of biogenic excrements (be) in soil voids. See also Figure 8 A and B. Bar scale shows 0.1 mm on the photo. Parallel planar light, 30× magnification.

Organic components

Organic components were represented by coarse and fine organ and tissue residues, fine amorphous organic components, and charcoals, with a predominance of organic pigments. Organic compounds occurred to a depth of 86 cm in the soil under pines and 94 cm under grass. Their depth distribution was similar in both pedons. The upper horizons in the pedon under grass were darker, i.e. had more organic pigments. Microzonality of organic pigments was characteristic of the middle part of both pedons.

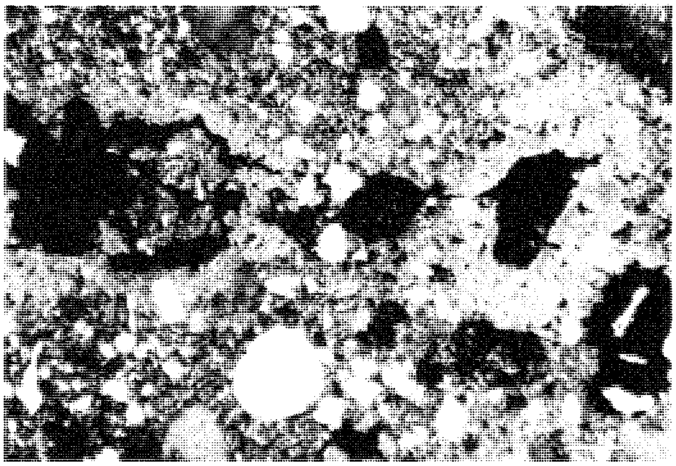

Fig. 11. (86–102 cm under pines) Spongy to massive microstructure, crystallitic b-fabric, calcite coatings, and infillings in the voids. Bar scale shows 0.1 mm on the photo. Cross polarized light, 30× magnification.

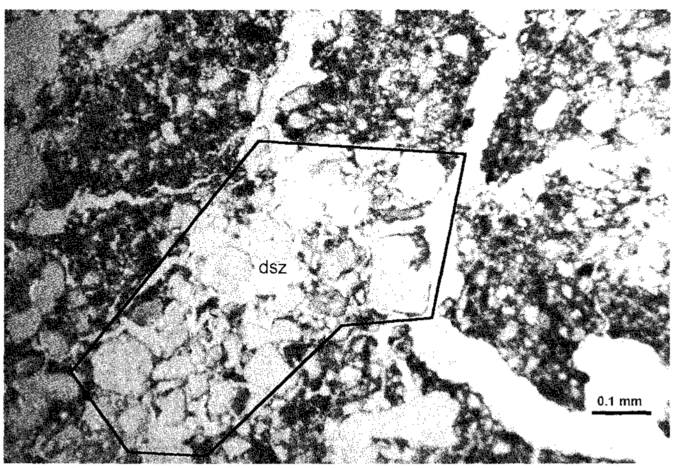

Fig. 12. (7.5–18 cm under pines) Microzonality typical for this horizon: skeletal zone poor (depleted) in fine fraction in the center of the photo (dsz), mineral grains have thin clay coatings or no coatings at all. Bar scale shows 0.1 mm on the photo. Parallel planar light, 30× magnification.

Interpretation and pedogenic processes

Biological activity, both number of organisms and variability of species, was higher under the pines than under grass, as suggested by the large variety of excrement sizes and morphologies. As a result, soil under the pines was characterized by finer and better aggregation of biological origin (crumbs and granules), numerous excrements in voids, and higher total porosity. High biological activity was also probably responsible for the higher organic carbon content of the upper 86 cm of the soil under pines despite the smaller organic matter input of coniferous vegetation. Grasses completely replace their root systems about once every two years, with the discarded roots being incorporated directly into the soil. By contrast, tree root systems have a longer turnover time; major organic matter additions to the soil are through leaf and litter fall. Because grass roots are discarded within the soil as opposed to on top of it, grasses are more efficient at adding organic matter to the soil and soils formed under grass typically have a higher organic matter content than soils formed under trees, all other factors being equal (Troeh and Thompson 1993). However, higher organic matter content under coniferous forests versus adjoining grassy areas, such as was seen at this site, have been reported in the literature when earthworm activity was higher in the forest soils (Skvortsova and Yakimenko 1991, Graham et al. 1995, Ulery et al. 1995).

Some changes in the water regimes of the compared soils were suggested. The soil under pines seemed to be drier and had more variation in the position of the watertable (the watertable rose and fell more) in the middle part of the pedon due to the deep root system. This interpretation was supported by a lack of very fine intrapedal porosity and less dark organic pigments than were found in the soil under grass. These features normally indicate seasonal over moistening. The presence of concentric Fe-nodules in the middle part of the soil under pines indicated pronounced wet and dry periods in the pedoenvironment. The presence of such nodules in the soil under pines and their absence in the pedon under grass also supported the theory of stronger water oscillation in the soil under pines, which could be explained by stronger evapotranspiration by pine trees plus the effect of deeper root penetration. Differences in soil water regimes may also explain observed differences in the depth to carbonates. Either 1) differences in carbonate depth were related to original depth to carbonates in the parent material; or 2) differences were due to the upward movement of pedogenic carbonates with soil solutions because of the water regime under the pines.

The minerals in the soils under the pines appeared to be more strongly weathered. Weathered biotite was found at a shallower depth. Other indicators of stronger alteration under the pines include a more iron-rich fine fraction and common amorphous iron impregnations and frequent amorphous iron coatings related to grains or pores. The abundance of iron nodules was also higher under the pines. This suggested stronger weathering of primary minerals leading to release of iron from crystalline lattices.

Some evidence of higher groundmass activity was found in the soil under pines. The groundmass orientation (groundmass b-fabric) is more pronounced in the soil under pines. Clear evidence of clay migration was not found (true typic or laminated clay coatings are absent, probably because of high biological pedoturbations). Evidence of clay transport from upper horizons in the soil under pines included the presence of microzones (up to 40% of thin section) with chitonic and enaulic related distribution patterns in two of the upper horizons under pine. Such microzones consisted mainly of mineral grains with very little matrix (Fig. 12). Silty-clay coatings related to mineral grains and rock fragments were characteristic of both pedons, but were more strongly expressed in the soil under pines.

The profile under pines had a less dark matrix in the upper horizons compared to the soil under grass. This could be related to some redistribution of organic matter in the soil under pines (microzonality and humic-silty-clay coatings were described). Chemical data also supported a gradual decrease of organic carbon with depth in the soil under pines.

Therefore, morphological, analytical and micromorphological methods revealed some differences in soil attributes and processes in a central Iowa Mollisol due to the change of vegetation 75 years ago. However, significant changes in soil properties were not found. This demonstrates that 75 years, at least under the prevailing climate of central Iowa, was too short a period for strong differentiation of soil processes and the formation of more pronounced morphological, physical and chemical differences. The major changes between the two soils were found in their functioning, including changes in the moisture regime and biological activity.

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