Productivity of a Soil Biosequence of the Fescue Prairie-Aspen Transition

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Highlight

Grassland soils have some quality that enables plants to respond to P fertilizer. This quality deteriorates when poplar trees advance on rangelands; it is completely destroyed when coniferous trees become the dominant vegetation. Clearing of trees and seeding of grass returns some grassland character to soil. If soil organic P is considered an index, NP fertilizers along with the grass are expected to hasten the return of the grassland character.

Morphological and chemical differences between soil profiles, ranging from Black through Dark Gray and Eluviated Dark Gray Chernozemic and a Degraded Brown Wooded, were described previously (Dormaar and Lutwick, 1966). These soils respectively occur under vegetation ranging from fescue prairie (*Festuca scabrella* association) to poplar (*Populus* spp.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (A. Johnston, unpublished data). The Black Chernozem was considered as a parent material for the development of different soils under the invading trees. The biotic changes that produced the chemical and physical differences between the soils of the sequence occurred in a relatively short time. Thus, the ages of the resident trees, *P. tremuloides* Michx. (aspen poplar), *P. balsamifera* L. (black poplar), and the *Pseudotsuga menziesii* (Douglas-fir), were about 45, 80, and 150 years, respectively (Dormaar and Lutwick, 1966).

It seemed probable that the encroachment of trees upon the prairies would alter the fertility of the soil. Accordingly, the objective of this study was to assess by chemical analysis and a greenhouse test the changes in fertility of Black Chernozemic soil brought about by the advance of trees. To represent the transition that would occur were the trees removed and grass established, two samples of a Bisequa Gray Wooded soil, one from under trees (*Picea-Pinus* spp.) and the other from under an 11-year-old stand of cultivated grass, were included in the study.

Materials and Methods

Bulk soil samples were taken from the upper mineral (Ah, Ahe, or Ae) horizons of each profile type, air-dried, and screened (< 4 mm) to remove stones and roots. The biosequence of soils was sampled in the Porcupine Hills of southern Alberta (50° 07′N, 114° 04′W). The Bisequa Gray Wooded soils, of the Caroline series, were sampled near Chedderville, Alberta (52° 10′N, 114° 51′W). After screening, subsamples were crushed with a rubber pestle and passed through a 2-mm sieve for laboratory analysis. Samples were also taken from the pots after cropping to determine changes in soil organic phosphorus content.

For the greenhouse test, equal volumes of each soil were put into half-gallon glazed pots. Four fertilizer treatments were applied: check, N, P, and NP, with N as ammonium nitrate at 300 lb N/acre and P as treble superphosphate at 177 lb P/acre. Three replications were used for the four representatives of the biosequence; two replications were used for the two Bisequa Gray Wooded soils. Eagle oats were planted at 15 seeds/pot and harvested as

Table 1. Some chemical properties of a biosequence of soils of the fescue prairie-aspen transition and of a cleared and an uncleared Bisequa Gray Wooded soil.

Soil and dominant plant species	pH	Total N %	Total P µg/g	Organic P* µg/g	Org. P / Total P %	$NaHCO_3$-soluble P µg/g
Black Chernozem (*Festuca scabrella*) (Ah horizon)	5.9	0.92	1490	817	55	2.66
Dark Gray Chernozem (*Populus tremuloides*) (Ah horizon)	5.7	0.46	846	478	57	1.38
Eluviated Dark Gray Chernozem (*P. balsamifera*) (Ahe horizon)	5.6	0.39	820	419	51	1.34
Degraded Brown Wooded (*Pseudotsuga menziesii*) (Ae horizon)	5.4	0.14	447	131	29	1.77
Bisequa Gray Wooded (In grass 11 years) (Ap horizon)	5.2	0.11	569	98	17	2.17
Bisequa Gray Wooded (*Picea-Pinus* spp.) (Ae horizon)	5.2	0.08	800	187	23	5.85

* Differences of 20 µg organic P/g of soil required for significance.

hay after heading. After the hay had been dried at 70 C, yields were recorded as dry matter per pot.

Total phosphorus and nitrogen contents of the plants and pH, total nitrogen, $NaHCO_3$-soluble phosphorus, and total phosphorus of the soils were determined by standard procedures (Ward and Johnston, 1960, and Atkinson et al., 1958).

A 2-g sample of soil (60 mesh) was heated at 550 C for 1 hr. This sample and a separate unheated sample were extracted with 2N H_2SO_4 (Anderson, 1960). The inorganic P in the two extracts was determined by a molybdophosphoric acid method (Mehta et al., 1954). The difference in inorganic P between the two extracts was taken as the organic P content of the soil. With this method a difference between samples of 20 µg organic P/gram of soil is required for significance (Kaila and Virtanen, 1955).

Results

In the biosequence of soils, pH, total nitrogen, total phosphorus, and organic phosphorus decrease as trees advance upon the grassland (Table 1). Also, as the species of trees change from poplar to Douglas-fir, the losses of these constituents become more pronounced and organic phosphorus becomes a less major part of the total phosphorus.

In the Bisequa Gray Wooded soil cleared of trees and seeded to grass, nitrogen was slightly higher but all forms of phosphorus were lower than in the uncleared soil (Table 1). The grass was harvested every year but no fertilizer was applied.

For the check and P treatments on the soils of the biosequence, oat yields were highest on the Black Chernozem, lowest on the Degraded Brown Wooded, and intermediate on the Dark Gray and Eluviated Dark Gray Chernozems (Table 2). For the N treatment, oat yields were highest on the Black Chernozem and similar for the other three soils. The yields on the NP treatments were essentially the same for all soils—the differences were not significant.

There was a yield response to P alone on the Chernozemic soils of the biosequence but none on the Degraded Brown Wooded soil. Similarly, on the Bisequa Gray Wooded soil, there was a yield response to P alone on the soil seeded to grass but not on that still under coniferous trees.

With the exception of the Eluviated Dark Gray Chernozem, the organic P content of all unfertilized soils was less than that of the original soil (Tables 1 and 2). The decrease in organic P was least for the Black Chernozem and the Bisequa Gray Wooded from under grass.

When the treatment with P alone was compared with the check, the organic P decreased in the uncleared Bisequa Gray Wooded soil only; in all other soils the decrease was not significant (Table 2). With N alone, the changes in organic P were not significant for any soil except the Black Chernozem, where it just barely reached significance. With NP fertilizer, the organic P content of all soils was greater than that of the check treatments but only in the Black Chernozem was it significantly greater than the original soil.

Table 2. Effects of N and P fertilizers on growth of oats and on the soil organic phosphorus content of a biosequence of soils of the fescue prairie-aspen transition and of a cleared and an uncleared Bisequa Gray Wooded soil.

			Oats					Soil		
Soil and dominant plant species	Reps	Fert. treatment	Dry matter yield g/pot	N content %	P content %	Uptake of N mg	Uptake of P mg	Total P μg/g	Org. P* μg/g	Org. P / Total P %
Black Chernozem	3	O	10.6	1.63	0.26	172.8	27.6	1443	801	56
(*Festuca scabrella*)		P	13.0	1.47	0.42	191.6	54.6	1563	803	51
(Ah horizon)		N	15.5	2.53	0.22	392.2	34.1	1472	781	53
		NP	16.5	2.85	0.58	470.3	95.7	1736	884	51
Dark Gray Chernozem	3	O	8.1	1.11	0.24	89.9	19.4	819	312	38
(*Populus tremuloides*)		P	10.1	1.17	0.52	118.2	52.5	924	296	32
(Ah horizon)		N	12.1	2.24	0.15	271.0	18.2	834	316	38
		NP	15.2	2.23	0.45	339.0	68.4	954	386	40
Eluviated Dark Gray Chernozem	3	O	8.1	1.08	0.24	87.5	19.4	808	456	56
(*P. balsamifera*)		P	10.7	1.01	0.51	108.1	54.6	928	445	48
(Ahe horizon)		N	12.5	2.15	0.14	268.8	17.5	868	458	53
		NP	15.9	2.13	0.47	338.7	74.7	967	470	49
Degraded Brown Wooded	3	O	5.2	0.88	0.34	45.8	17.7	422	70	17
(*Pseudotsuga menziesii*)		P	6.2	0.84	0.66	52.1	40.9	501	65	13
(Ae horizon)		N	13.1	1.87	0.14	245.0	18.3	435	85	20
		NP	15.9	1.75	0.47	278.3	74.7	482	109	23
SE for biosequence			0.84							
Bisequa Gray Wooded	2	O	6.9	1.77	0.37	122.1	25.5	559	81	14
(In grass 11 years)		P	10.1	1.26	0.34	127.3	34.3	644	82	13
(Ap horizon)		N	12.2	2.59	0.28	316.0	34.2	575	99	17
		NP	14.8	2.61	0.26	386.3	38.5	657	108	16
Bisequa Gray Wooded	2	O	6.2	1.18	0.54	73.2	33.5	787	47	6
(*Picea-Pinus* spp.)		P	7.9	1.01	0.55	79.8	43.5	864	13	2
(Ae horizon)		N	16.1	2.10	0.26	338.1	41.9	808	48	6
		NP	16.5	1.97	0.31	325.1	51.2	890	99	11
SE for Bisequa soils			0.63							

* Differences of 20 μg organic P/g of soil required for significance.

Discussion

The advance of trees upon grassland causes, with time, a progressive loss of organic P and N, as well as other constituents, and loss of fertility. The clearing of coniferous trees from soils that lost, or never had, Chernozemic character, and the establishment of grass does increase the N content of the soil somewhat but does not increase organic P content. Apparently, the establishment of grass and harvesting the crop without application of fertilizer causes a more rapid loss of soil P than does the natural advance of trees on grassland. These changes in N and P are probably related to the sources of the nutrients. For example, soil N is withdrawn from the air by free living bacteria or by bacteria associated with plant roots. Phosphorus, on the other hand, is derived from primary and secondary minerals of the soil; crop removal from the soil would, therefore, reduce the soil phosphorus content.

Grass contributes some undefined quality to soil that enables plants to respond to P fertilizer. Thus, the oats responded to P fertilizer on all soils that had been under native or cultivated grass or under poplar trees where the soil still retained Chernozemic character. The oats on the soils from under coniferous trees, the Degraded Brown Wooded and the Bisequa Gray Wooded, did not exhibit a yield response to applied P.

The unique quality that grass contributes to soil deteriorates as trees advance upon the grassland. This deterioration is evident in the soils from under poplar trees but most strikingly in the soils from under coniferous trees. Fertilizers may be used to increase rangeland productivity, either for existing native species or for introduced species. The most efficient use of fertilizer, on the basis of this study, will be realized where trees have not advanced upon the grassland. Also, restraining the advance of trees will restrain the deterioration of the native soil fertility contributed to the soil by the grass. However, in areas completely covered by trees, removing the trees and seeding grass will restore the unique but undefined quality to the soil.

Morphologically, there are four kinds of soil within the biosequence. On the basis of organic P and N contents, these soils may be separated into three groups, namely: 1) Black Chernozemic, 2) Dark Gray and Eluviated Dark Gray Chernozemic, and 3) Degraded Brown Wooded. These relationships have already been established (Dormaar and Lutwick, 1966). In this study the fertility status of these soils, especially in terms of plant response to fertilizer P, also reflects the three groups of soils.

Generally, the NP treatment increased yields more than did N alone or P alone. Also, NP fertilizer increased the organic P of the Black Chernozem, tended to increase organic P, though not significantly, on the Bisequa Gray Wooded soil from under grass, and on the other soils significantly curtailed but did not prevent the loss of organic P with cropping. Incubation studies have shown that fertilizer P increases the mineralization of soil organic P (Enwezor, 1966). Our study would indicate that the organic P content of soils can be increased by using grass or grasslike vegetation, oats for example, and applying P fertilizer especially along with N fertilizer.

This study does not prove that soil organic P is directly associated with soil fertility. The changes in content of organic P and in fertility may simply be concurrent with changes in vegetation. However, in biological systems, such as plants and animals, organic P compounds are important in energy transfer reactions. Since soil is a biological system, soil organic P may be expected to play an important role in soil fertility. This role is not yet understood.

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