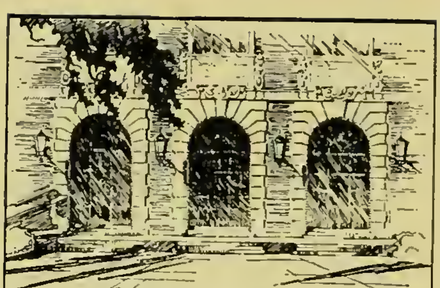

SELECTED MINERALS IN SOILS, PLANTS, AND PHEASANTS:

AN ECOSYSTEM APPROACH TO UNDERSTANDING PHEASANT DISTRIBUTION IN ILLINOIS

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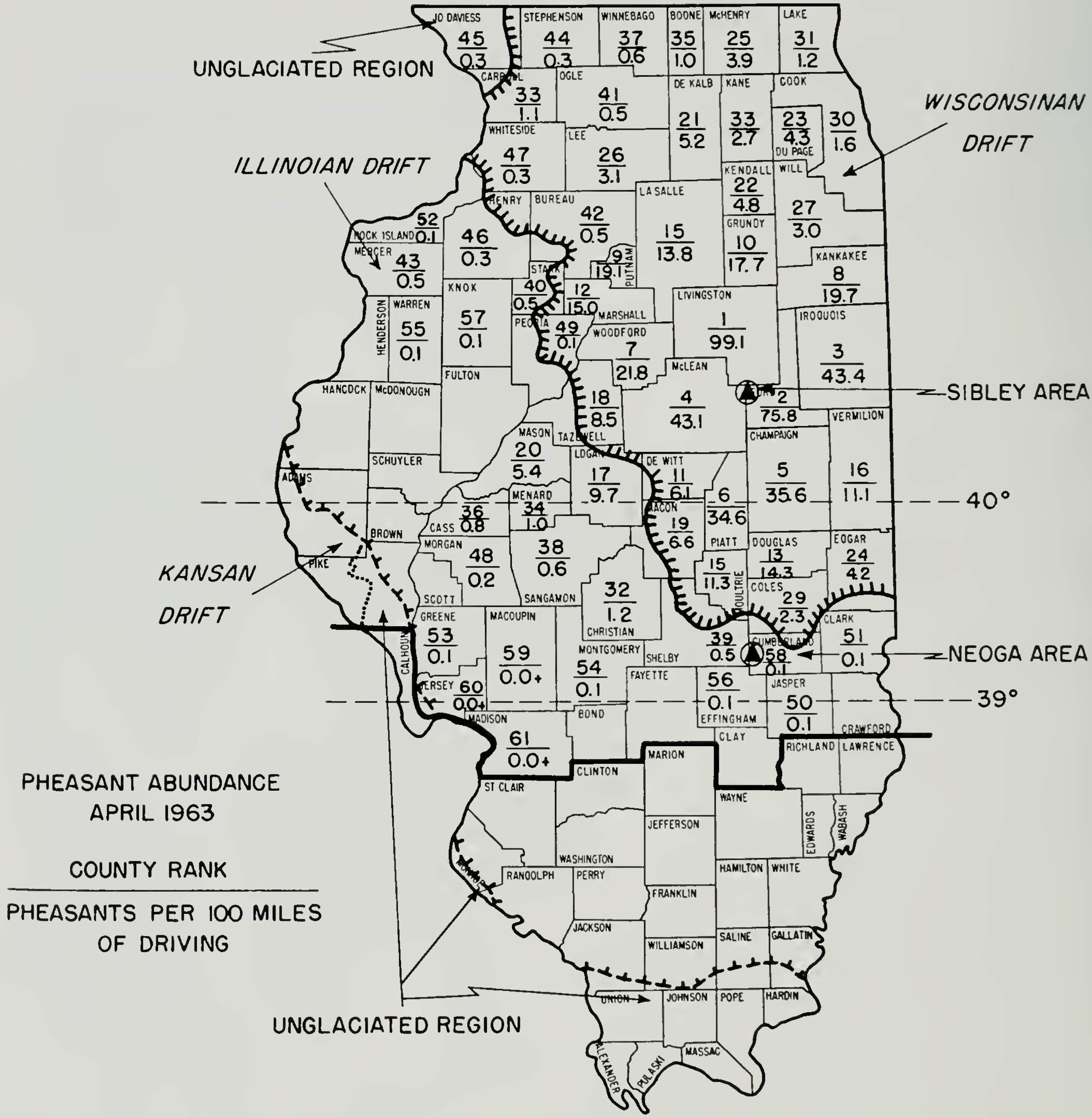

Fig. 1.—Distribution and abundance of pheasants in Illinois in relation to the most recent (Wisconsinan) and older glacial drifts. The solid and broken lines with projections designate the terminal boundaries of the Wisconsinan and Illinoian ice sheets. A small region of the exposed Kansan drift is located in southwest-central Illinois. The pheasant abundance statistics were derived from a 1963 rural mail carrier census (after Labisky & Anderson 1965:129–130); rank was assigned only to the 61 counties from which pheasants were reported. The 28 southernmost counties, below the heavy black line, are classed as nonpheasant range (Greeley *et al.* 1962:14).

Selected Minerals in Soils, Plants, and Pheasants: An Ecosystem Approach to Understanding Pheasant Distribution in Illinois

Robert L. Jones, Ronald F. Labisky, and William L. Anderson

In the eastern half of the United States the exotic pheasant (*Phasianus colchicus*) occupies a band of contiguous range, except along the Mississippi River, from Iowa and southern Minnesota across southeastern Wisconsin, northeastern and east-central Illinois, northern Indiana, southern Michigan, and into Ohio and Pennsylvania. Yet, despite repeated introductions following its initial establishment in the eastern United States during the early 1900's, the pheasant has never established self-maintaining populations south of the 39th parallel. Factors potentially responsible for limiting the southward expansion of pheasant range in Illinois (Fig. 1) and elsewhere in the eastern United States, such as land use, climate, and a calcium deficiency, have been the subject of considerable research —and of conflicting findings (Labisky *et al.* 1964).

A deficiency of soil minerals, and particularly of calcium, has long been considered one of the major factors affecting pheasant distribution. Leopold (1931:125) pointed out that pheasants were confined mainly to range within the boundary of the most recent, or Wisconsinan, glaciation. He suggested that some plant or substance, such as lime (calcium carbonate) or gravel, present in geologically young soils was necessary for the establishment and maintenance of pheasant populations.

Years later Dale (1954:320) revived interest in the "calcium hypothesis" by reporting that pheasant abundance in the eastern half of the United States was apparently correlated with the availability of calcium in soils. Dale (1955), Dale and DeWitt (1958), and Greeley (1962) then studied the calcium requirements of pen-reared pheasants to establish minimum amounts of calcium necessary to maintain physiological balance, particularly during the reproductive period when demands for calcium are high.

At this point it was apparent that the organic items eaten by wild pheasants did not supply sufficient calcium to meet their physiological needs, particularly for reproduction. The logical supplementary source of calcium was calcium-bearing grit. McCann (1961: 189–190) reported that wild pheasants in Minnesota were most abundant on soils that contained grit that was relatively rich in calcium and poor in magnesium. Subsequent reports by Harper (1963, 1964) and Korschgen (1964) described the intake of calcium from grit and foods by wild pheasants in the midwestern United States. The finding that the wild pheasant hen apparently has the ability to select calcium-rich grit in preference to calcium-poor or noncalcareous grit constituted an important contribution toward understanding how the pheasant fulfills its requirements for this mineral (Sadler 1961; Harper 1964; Harper & Labisky 1964; Korschgen 1964; Kopischke & Nelson 1966; and Kopischke 1966).

In Illinois Harper and Labisky (1964) investigated the possibility that a deficiency of calcium was a factor limiting the southward spread of pheasants. They compared the availability of calcium and its ingestion and physiological use by wild pheasants on two areas, Neoga and Sibley, located on the geographically older Illinoian-age drift and on the comparatively younger Wisconsinan-age drift, respectively (Fig. 1). Harper and Labisky (1964:729–730) concluded that both the availability of calcium on the older drift and its ingestion by pheasants were adequate to establish self-maintaining pheasant populations. However, as Labisky *et al.* (1964:12) later pointed out, this conclusion does not contradict the possibility that a deficiency of some other mineral or of some vitamin might prevent the establishment of self-maintaining populations of pheasants on pre-Wisconsinan drift.

The objectives of the research reported here were 1) to determine if the concentrations of four essential elements—sodium, potassium, calcium, and magnesium —in the primary feathers of pheasants from a high-density population on Wisconsinan drift differed from those of pheasants from a low-density population on pre-Wisconsinan drift, and 2) to learn if the relative concentrations of minerals in feathers reflected the levels of these elements in the nutrient chain (i.e., from soil to plant to pheasant).

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STUDY AREAS

The two areas from which soils, plant seeds, and pheasants were collected were the two areas—Neoga and Sibley—studied by Harper and Labisky (1964). The Sibley Area (23,200 acres), which supports thriving populations of wild pheasants, is located on Wisconsinan drift (Fig. 1). In contrast, the Neoga Area (10,240 acres), which lies in the southern fringe of the contiguous range of the pheasant in Illinois, is found on the geologically older Illinoian drift. The low-level pheasant population on the Neoga Area originated from releases of various strains of propagated pheasants and of transplanted wild pheasants (Anderson 1964). Both of these areas are intensively farmed; corn and soybeans are the major crops.

These two areas differ markedly in geomorphology, age, and nature of soils. The Sibley Area lies within that region of rolling topography formed by the Normal and Cropsey morainic system; about two-thirds of it lies on a gently undulating morainic ridge and the remainder on a broad, flat outwash apron. The till is calcareous; the Cropsey moraine, in La Salle County, has a mean calcium carbonate content of 23 percent (Jones *et al.* 1966:366). The soils, which reflect the fine-textured nature of the glacial till, are silt loams or silty clay loams. The major soil series found on the Sibley Area are Elliott and Saybrook, both classified as Brunizem or Prairie soils, and Drummer, classified as a Humic-Glei soil. Elliott and Drummer occur on the moraine and Saybrook on the outwash apron. All of these soils are near neutral in pH in their surface horizons and have high natural productivity; most of the soils are tile drained. The age of the soils of the Sibley Area is probably about 16,000 years. However, a small amount of younger loess is incorporated in the surface horizons (Jones & Beavers 1963:439–440).

The Neoga Area lies immediately south of the outwash apron bordering the Shelbyville moraine, the terminal moraine of Wisconsinan glaciation (Fig. 1). Topographic relief is slight at Neoga. The soils of the study area, being of pre-Wisconsinan origin, have had a longer and more complicated history of development than those of the Sibley Area. The till is calcareous only at depths greater than 3.4 meters. Two predominant soil series, Cisne and Ebert, are found at Neoga. Cisne, a Planosol, is characterized by a shallow clay layer that impedes drainage. Ebert, an intergrade soil having properties between a Planosol and Humic-Glei soil, is more poorly drained than Cisne. Both soils are moderately acid; the pH in the surface horizons ranges from 5.3 to 6.0 in Cisne soils and from 5.6 to 6.5 in Ebert soils. These soils developed in 1.2 meters of loess (Fehrenbacher *et al.* 1965:568) overlying Illinoian till that has an ancient soil or paleosol in it. This paleosol is quite impermeable and restricts internal drainage. Thus, these soils, which have low natural productivity, are mostly surface drained. The Neoga soils may be 100,000 or more years old.

TECHNIQUES

Sample Collections

Samples of seeds commonly consumed by pheasants —corn (*Zea mays*) and Chinese foxtail (*Setaria faberii*)—and soil were collected at 10 sites on both the Neoga and Sibley areas during October 1966. The sampling sites, all located in cornfields, were distributed proportionately among the major soil series on each area. At each site, about 15 meters from the edge of the field, a sample of soil from the 0- to 18-cm layer was taken from within 30 cm of the base of what we judged to be a normal corn plant surrounded by clumps of foxtail. Kernels of corn were harvested from the corn plant and seeds were stripped from the associated foxtail plants to complete the sample collection at each site.

Samples of primary feathers were taken from 14 pheasants collected on each area during the autumn of 1966. The feather samples were taken from birds killed by hunters, from birds killed by vehicles on highways, and from birds captured by nightlighting (Labisky 1968:6–8). The collection of pheasants from the Neoga Area included only birds that had been hatched and reared on the area. The depth of the bursa of Fabricius was used to separate juveniles, or young-of-the-year, from adults. The Neoga sample included 12 juvenile males and 2 adult males; the Sibley sample, 11 juvenile males, 1 adult male, and 2 juvenile females.

Analytical Procedures

Soil, including grit, was air dried and ground to pass through a 2-mm mesh screen. A subsample was then taken from each sample and ground until it would pass through a 0.25-mm mesh screen. Calcium and potassium concentrations in the soils were determined by X-ray spectrography; the finely ground soils were compressed into flat discs for analysis. The concentrations of calcium and of potassium were estimated from calibration curves that we derived for each element by analysis of National Bureau of Standards samples and by analysis of standards we prepared by the addition of a salt of the element to soil. Sodium and magnesium concentrations were determined by flame photometry and atomic absorption analysis, respectively, after the soil had been fused with lithium metaborate (Ingamells 1966:1228). A total elemental analysis, rather than plant-available analysis, was performed because we believed it to better represent the minerals to which the pheasant is exposed. Also, a relatively large proportion of the elements in these fine-textured soils occurs in forms available to plants.

The corn and foxtail seeds were oven-dried at 60° C. The corn was finely ground in a Wily mill; the foxtail seeds were left intact (with floret structures attached). Except for calcium in corn, the elemental concentrations in seeds were determined by direct-reading emission spectrography. A rotating-disc solution technique, with a-c spark excitation, was used in the analyses; lithium was the internal standard. The samples were prepared for analysis by ashing 1.5 g of material at 500° C. for 24 hours. The ash was taken up in a solution of 4.5 percent HCl, 1.5 percent HNO_3 (by volume), and 1 percent lithium (as LiCl). The concentration of each element was estimated from calibration curves derived by our analyses of reference plant samples assembled by Kenworthy *et al.* (1956). The calcium content of corn was determined by X-ray fluorescence; the finely ground corn was compressed into disc-shaped pellets for this analysis. The concentrations of calcium in the corn samples were estimated from calibration curves that we derived from analyses of similarly prepared corn samples to which known quantities of calcium had been added.

The feather samples were prepared by clipping the primaries, at the junction of calamus and skin, from the right wing of each pheasant. The clipped feathers were then cut into 4-cm segments. Each sample was then placed in a conical flask, washed several hours in distilled water on a reciprocating shaker (with frequent changes of water), and oven-dried at 60° C. The dried samples, which individually weighed 1.5–2.0 g, were ashed at 500° C. for 36–48 hours. The ash was taken up in hot 6*N* HCl and then filtered. The filtrate was analyzed for sodium and potassium by flame photometry; the concentrations of these minerals were estimated from analyses of standards that we prepared from reagent-grade chemicals to approximate the matrix of the feathers. Atomic absorption analysis was used to determine the amounts of calcium and magnesium in the filtrate; lanthanum chloride was used as the suppressant.

The rationale for using feathers to study the mineral complex in birds was derived from early work on ruffed grouse (*Bonasa umbellus*) in New Hampshire by McCullough and Grant (unpublished[1]) and from the later studies on blue and lesser snow geese (*Anser caerulescens caerulescens*) by Hanson and Jones (1968). In view of the findings of these studies, we considered the concentrations of elements in pheasant feathers to reflect the mineral status of the metabolic pool and interelemental relationships during feather growth.

[1]Studies by Robert A. McCullough and C. L. Grant in 1952 and 1953, involving laboratory analyses of fish and game and their foods, under the auspices of New Hampshire Pittman-Robertson and Dingel-Johnson projects.

FINDINGS

In soils, mean concentrations of potassium, calcium, and magnesium were less, and those of sodium greater, at Neoga than at Sibley. The differences, Neoga versus Sibley, for all four elements were statistically significant (Table 1). These findings illustrate, in a general way, the degree of weathering of the soils on the two areas. Potassium and calcium are among the first elements to respond to weathering processes under Illinois conditions (Jones & Beavers 1966:622). The relatively low concentrations of these alkali and alkaline earth elements in soils at Neoga reflect, in particular, the weathering of calcium-bearing feldspars, magnesium- and potassium-bearing micas, and ferromagnesian minerals. Sodium, which occurs in the sodium-rich feldspar albite that is resistant to weathering, and in rather high levels as an exchangeable cation in planosols, has become relatively concentrated at Neoga.

In corn samples, sodium, potassium, and magnesium, as well as total ash, were more abundant in samples from Neoga than in those from Sibley (Table 1). However, except for the difference in magnesium, none of these differences was statistically significant. The mean concentrations of calcium in corn were low, being only 38 and 31 ppm in the samples from Sibley and Neoga, respectively. Foxtail seeds contained 25–30 times more calcium than corn did on both areas.

In foxtail, potassium and total ash exhibited higher mean concentrations among samples from Neoga than among those from Sibley; the difference for potassium was significant. The high ash content of foxtail, in contrast to that of corn, was due in part to the fact that the entire foxtail floret was ashed. The structures of the floret, compared with the seed, are rich in minerals, particularly silicon. Concentrations of sodium, calcium, and magnesium in foxtail did not differ appreciably between areas.

In pheasant feathers, mean concentrations of all four elements and of total ash were higher for samples from Neoga than for those from Sibley (Table 1). The differences exhibited by sodium, potassium, and magnesium were significant. Sodium was almost five times and potassium about two and one-half times more abundant in feathers from pheasants at Neoga than in those from Sibley pheasants.

The ratio of sodium to potassium was notably greater in soils, foxtail seeds, and pheasant feathers from Neoga than in those from Sibley (Table 2). Although the ratio of calcium to magnesium was greater in soils and corn from Neoga than in those from Sibley, it was identical in foxtail seeds and pheasant feathers from the two areas.

The flow of minerals in the ecosystem—from soil to plants (seeds) to pheasants (feathers)—did not generally reflect a direct relationship (Table 1). The one exception was sodium; it was more abundant in soil

Table 1.—Concentrations of elements in soils, plant seeds (corn and foxtail), and pheasant feathers from an area of high-density pheasant populations (Sibley) and from an area of very low-density pheasant populations (Neoga) in Illinois.

Sample Type and Element	*Neoga Area*					*Sibley Area*					*Test of Means*°	
	Number of Samples	Mean	Standard Error of the Mean	Range	Coefficient of Variability	Number of Samples	Mean	Standard Error of the Mean	Range	Coefficient of Variability	Degrees of Freedom	*t* Value
Soil												
ppm Na	10	815	10	740–840	4	10	678	14	590–760	7	18	7.80^{s}
ppm K	10	19,530	420	16,900–20,900	7	10	25,910	640	23,500–29,800	8	18	8.41^{s}
ppm Ca	10	9,350	843	5,000–14,000	29	10	12,550	872	9,300–18,400	22	18	2.64^{s}
ppm Mg	10	860	72	540–1,240	26	10	1,874	139	1,400–2,460	23	9†	6.49^{s}
Corn												
Percent ash	10	2.07	0.27	1.67–2.45	41	10	1.77	0.31	1.23–2.23	56	18	0.73^{ns}
ppm Na	9	71	8	35–120	33	8	60	9	25–93	41	15	0.95^{ns}
ppm K	10	5,150	211	4,200–6,300	13	10	4,540	231	3,700–6,200	16	18	1.94^{ns}
ppm Ca	10	31	3	24–51	25	10	38	2	28–51	19	18	2.00^{ns}
ppm Mg	10	1,640	123	1,100–2,400	24	10	1,170	62	800–1,500	17	18	3.42^{s}
Foxtail												
Percent ash	10	7.20	0.50	4.53–10.04	22	10	6.38	0.10	5.03–8.64	5	18	1.39^{ns}
ppm Na	10	102	25	77–161	78	10	103	5	75–125	17	18	0.15^{ns}
ppm K	10	5,230	268	3,700–6,700	16	10	3,180	216	3,000–5,300	18	18	4.12^{s}
ppm Ca	10	920	36	800–1,200	12	10	910	72	700–1,400	25	18	0.12^{ns}
ppm Mg	10	2,140	54	1,900–2,500	8	10	2,180	144	1,400–3,200	21	18	0.82^{ns}
Feathers												
Percent ash	14	0.37	0.02	0.23–0.54	27	14	0.32	0.03	0.21–0.67	37	26	1.21^{ns}
ppm Na	13	221	6	123–348	10	13	45	8	19–105	17	12†	8.07^{s}
ppm K	14	72	7	10–117	38	14	28	3	17–58	47	13†	5.62^{s}
ppm Ca	14	207	17	118–273	31	14	168	7	114–218	16	13†	2.07^{ns}
ppm Mg	14	111	6	41–126	19	14	83	4	53–114	18	26	4.00^{s}

° All tests at 0.05 level of probability; s denotes significance, and ns, the lack of significance.
† Variances dissimilar; test degrees of freedom equal $n-1$ rather than $2(n-1)$.

at Neoga (815 ppm) than at Sibley (678 ppm) and was also more abundant in pheasant feathers from Neoga (221 ppm) than in those from Sibley (45 ppm). Potassium was present in greater concentrations in soils from Sibley (25,910 ppm) than in those from Neoga (19,530 ppm), but was more abundant in foxtail and feathers at Neoga (5,230 and 72 ppm) than at Sibley (3,180 and 28 ppm). Concentrations of calcium were greater in soils from Sibley (12,550 ppm) than in those from Neoga (9,350 ppm), but differed very little in samples of corn, foxtail, and feathers from the two areas. Magnesium was more abundant in soils from Sibley (1,874 ppm) than in soils from Neoga (860 ppm), but was more abundant in corn and feathers from Neoga (1,640 and 111 ppm) than in those from Sibley (1,170 and 83 ppm). Thus, the

Table 2.—Sodium:potassium and calcium:magnesium ratios in soils, plant seeds (corn and foxtail), and pheasant feathers from an area of high-density pheasant populations (Sibley) and from an area of very low-density pheasant populations (Neoga) in Illinois.

Elemental Ratios and Samples	*Neoga Area*				*Sibley Area*				*Test of Means*°	
	Number of Samples	Mean	Standard Error of the Mean	Coefficient of Variability	Number of Samples	Mean	Standard Error of the Mean	Coefficient of Variability	Degrees of Freedom	*t* Value
Na/K Ratios										
Soil	10	0.42	0.010	7	10	0.26	0.010	12	18	3.81^{s}
Corn	9	0.01	0.002	37	8	0.01	0.002	40	15	0.28^{ns}
Foxtail	10	0.02	0.003	42	10	0.03	0.002	20	18	2.25^{s}
Feathers	13	2.90	0.150	19	13	1.58	0.128	13	24	6.75^{s}
Ca/Mg Ratios										
Soil	10	10.98	0.699	21	10	7.00	0.633	29	18	4.23^{s}
Corn	10	0.02	0.002	33	10	0.003	0.0101	30	18	2.75^{s}
Foxtail	10	0.43	0.017	13	10	0.42	0.025	19	18	0.33^{ns}
Feathers	14	2.04	0.088	16	14	2.05	0.102	19	26	0.07^{ns}

° All tests at 0.05 level of probability; s denotes significance, and ns, the lack of significance.

differences in concentrations of elements in soils were not directly proportional to the levels in either plant seeds or pheasant feathers.

DISCUSSION

The amounts and rates of flow of minerals through the ecosystem, i.e., from soils to plants to animals and eventually back to soils, have profound and far-reaching effects on all living organisms. In the present study, sodium, potassium, calcium, and magnesium were not, for the most part, incorporated into plant seeds and pheasant feathers in the same proportions that they occurred in soils. For example, significant differences existed in the amounts of potassium in foxtail seeds and of magnesium in corn between the Sibley and Neoga areas. Yet correlation analyses indicated that a significant inverse relationship existed between the concentrations of potassium in soil and in foxtail seeds ($r = -0.445$, 18 df) and between the concentrations of magnesium in soil and in corn ($r = -0.618$, 18 df). Clearly the flow of elements through the environmental complex was not straightforward. As the uptake and use of elements by plants and animals are influenced by many factors, this finding was understandable. Interactions among elements are particularly effective in altering translocation and storage of minerals in plants and animals (Schütte 1964).

The role of calcium is central to the many considerations of ion uptake by plants (Emmert 1961). Calcium is reported to antagonize the uptake of manganese, potassium, iron, boron, zinc, and magnesium in some plant structures (Schütte 1964:41). Correspondingly, we found the concentrations of magnesium in corn were inversely and significantly correlated with the amounts of calcium in this grain ($r = -0.623$, 18 df). Yet we found no significant correlations between soil calcium and the subsequent uptake of potassium by foxtail seed ($r = 0.041$, 18 df) or of magnesium by corn ($r = 0.306$, 18 df). However, these relationships are tempered by the fact that our determinations were for total soil calcium and not for plant-available calcium.

The low levels of calcium in corn, the staple diet of the pheasant, are noteworthy. If pheasants are to obtain a sufficient level of calcium—at least the minimum dietary requirement of 1.2 percent as indicated by Dale and DeWitt (1958 *In* Greeley 1962:186) and Scott *et al.* (1958:1421)—they must obtain it from calcareous grit. To illustrate, if a pheasant consumes 35 g of corn (R. F. Labisky & W. L. Anderson unpublished) containing 35 ppm of calcium per day, its dietary intake of calcium is only 0.0035 percent. To attain the 1.2 percent level, the pheasant must then ingest daily, and totally utilize, 1.04 g of limestone containing 40 percent calcium. In this case, the limestone grit constitutes 99 percent of the pheasant's calcium intake.

The differences detected in the concentrations of potassium, calcium, and magnesium in the soils of the Neoga and Sibley areas (Table 1) illustrate, somewhat axiomatically, that older (Illinoian) glacial drift is relatively poor in three, and probably several more, important inorganic nutrients. These findings support the contention that a deficiency of calcium, and perhaps of other minerals, may limit the distribution of pheasants in many areas in the eastern United States. If, however, pheasants on the Neoga area were suffering from insufficient levels of potassium, calcium, or magnesium, the insufficiencies were not expressed in the mineral composition of their feathers (Table 1).

Inasmuch as Burns *et al.* (1953:327) reported that a wide disparity in the ratio of sodium to potassium was toxic to domestic chicks (*Gallus gallus*), the high ratios of sodium to potassium in soils, foxtail, and pheasant feathers from Neoga suggest that a nutritional imbalance may exist on the Illinoian drift (Table 2). In this particular case, the disparity in the sodium: potassium ratio in soils from Neoga and Sibley (0.42 versus 0.26) was similar to that reflected by the feathers from the respective areas (2.90 versus 1.58). Although calcium:magnesium ratios differed significantly for soils and corn from the two areas, no differences were found for the feathers. Little is known of how the relative levels of these elements affect the uptake and metabolism of other minerals by the pheasant.

None of the elemental differences, as such, found in the soils, plant seeds, or pheasant feathers from the pheasant-poor area on Illinoian drift (Neoga) and from the pheasant-rich area in Wisconsinan drift (Sibley) is satisfactory—with our present knowledge of the mineral needs of pheasants—to explain the magnitude of difference in population levels between the two areas. Nevertheless, differences did exist between the areas in concentrations of sodium, potassium, calcium, and magnesium in soils; of magnesium in corn; of potassium in foxtail; and of sodium, potassium, and magnesium in pheasant feathers. These findings, to our knowledge, represent the first documentation of clear-cut elemental differences in both birds and environment between areas of contrasting pheasant abundance.

SUMMARY

Concentrations of four essential elements—sodium, potassium, calcium, and magnesium—were measured in soils, plant seeds (corn and Chinese foxtail), and pheasant feathers from two areas of contrasting pheasant abundance in Illinois. The low-density pheasant population was located on the geologically older Illinoian glacial drift and the high-density population on the younger Wisconsinan drift. Potassium, calcium, and magnesium were less abundant, and sodium was more abundant, in Illinoian drift soils than in Wisconsinan drift soils. Magnesium was more abundant in corn, and potassium was more abundant in foxtail on the Illinoian drift. And higher concentrations of sodium, potassium, and magnesium were found in feath-

ers of pheasants on the Illinoian drift than from those of pheasants on the Wisconsinan drift. Thus, the differences in the concentrations of elements in soils were mirrored neither in plant seeds nor in pheasant feathers. If pheasants were suffering from a deficiency of calcium, potassium, or magnesium on the more weathered Illinoian drift, the defieiency was not reflected by the mineral composition of their feathers. However, high sodium-to-potassium ratios in soils and feathers on the Illinoian drift, in contrast to those on the Wisconsinan drift, may indicate a nutritional imbalance.

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