MINERAL CONTENT OF LOUISIANA WHITE-TAILED DEER

Authors: Schultz, S. R., Johnson, M. K., Feagley, S. E., Southern, L. L., and Ward, T. L.

Source: Journal of Wildlife Diseases, 30(1) : 77-85

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-30.1.77

Journal of Wildlife Diseases, 30(1), 1994, pp. 77–85

MINERAL CONTENT OF LOUISIANA WHITE-TAILED DEER

S. R. Schultz,[1,4] M. K. Johnson,[1] S. E. Feagley,[2] L. L. Southern,[3] and T. L. Ward[3]

[1] School of Forestry, Wildlife, and Fisheries, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70803, USA

[2] Department of Agronomy, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70803, USA

[3] Department of Animal Science, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70803, USA

[4] Present address: 1004 Peninsula Avenue, Tarpon Springs, Florida 34689, USA

ABSTRACT: Water, lipid, and mineral composition were determined for metacarpals, phalanges, livers, and antlers from 219 free-ranging white-tailed deer (*Odocoileus virginianus*) collected on six properties in East Feliciana Parish, Louisiana (USA) to provide baseline data and to identify sources of composition variation. Metacarpal and phalangeal composition varied primarily with deer age; liver composition varied with deer sex.

Key words: Liver, metacarpal, minerals, nutrition, *Odocoileus virginianus*, phalange, white-tailed deer.

INTRODUCTION

Analysis of body composition provides valuable information on animal condition that may be used to identify dietary deficiencies. Indices of fat in white-tailed deer (*Odocoileus virginianus*) have been used to evaluate condition (Verme and Ullrey, 1984), and blood assays have been employed to assess deer nutritional status (Seal et al., 1972; Kirkpatrick et al., 1975; Kie et al., 1983; DelGiudice et al., 1987, 1990). Additionally, Ullrey (1982) reported on white-tailed deer rib strength, and calcium (Ca) and phosphorus (P) concentration in relation to diet, and found associations between dietary deficiencies of Ca and P with low antler specific gravity and percent antler ash.

There is a paucity of information regarding the mineral requirements of deer (Robbins, 1983; Jones and Hanson, 1985), and data on tissue mineral concentrations needed to diagnose dietary mineral deficiencies are substantially lacking. Robbins et al. (1974), Wiener et al. (1975), and DelGiudice et al. (1990) reported white-tailed deer whole-body composition. McCullough and Ullrey (1983) analyzed the tissue, organ, and whole-body composition of six captive white-tailed deer in Michigan (USA). Woolf et al. (1982) and Sileo and Beyer (1985) examined metals in tissues of white-tailed deer from Illinois (USA) and Pennsylvania (USA), respectively. However, there are no reports of tissue mineral concentrations from a large sample of free-ranging white-tailed deer in the southeastern United States. Our objective was to provide baseline data and identify potential sources of variation in free-ranging white-tailed deer mineral composition to provide a foundation for future research on levels of these minerals in deer.

MATERIALS AND METHODS

We used six properties in East Feliciana Parish, Louisiana (USA), as study sites. Their locations (latitude, longitude) were 30°45′N, 90°58′W; 30°48′N, 90°58′W; 30°52′N, 90°56′W; 30°54′N, 91°07′W; 30°44′N, 90°59′W; and 30°55′N, 91°04′W, respectively. They ranged from 337 ha to 980 ha in size and were typical of upland pine-hardwood habitats of Louisiana. Area and botanical descriptions were provided by Schultz (1990). This study was a portion of a larger project that examined the consumption of, and effects from broad-spectrum supplemental minerals provided *ad libitum* to free-ranging white-tailed deer (Schultz, 1990). Supplemental minerals were provided for deer on three of the sites used in this study. The remaining three sites received no mineral supplementation. Results presented herein represent those from all sites combined because there were no effects from mineral supplementation on deer body mass, antler development, or on any tissue variable (Schultz, 1990; Schultz and Johnson, 1992a). We assumed deer diets in these areas contained adequate minerals because of the lack of response referenced above despite the consumption of relatively large quantities of sup-

plemental mineral product by deer on sites where it was provided (Schultz and Johnson, 1992b).

Study area soils were primarily of the Providence-Oliver and Providence-Lexington associations. Providence-Oliver soils are acid, gently sloping, and poorly to moderately well-drained upland soils of low fertility. Providence-Lexington soils are acid, gently to strongly sloping, and moderately well-drained to well-drained soils of low fertility (U.S. Soil Conservation Service, 1971). Soil samples ($n \geq 10$) were collected on each study site to a depth of 152 mm and analyzed using the inductively coupled plasma (ICP) spectrometer (Applied Research Laboratories, Model 34100 ICP-AES, Dearborn, Michigan) of the Soil Testing Laboratory of the Agronomy Department, Louisiana State University Agricultural Center, Baton Rouge, Louisiana. Methodology for soil collections was described by Schultz and Johnson (1992a). These samples had average values of 19.9 ppm P, 19.2 ppm sodium (Na), 57.3 ppm potassium (K), 295 ppm Ca, 130 ppm magnesium (Mg), 103 ppm salts, and a pH of 4.9.

Hunters used hanging scales to measure whole body mass of killed deer, to the nearest 0.45 kg. Hunters also recorded sex of deer and collected lower jaws, right forelegs below the carpals (the metacarpal and foot section of the leg), and antlers from deer shot during 1988–89 and 1989–90 hunting seasons. Liver samples were collected during the 1989–90 hunting season. We selected tissues for collection and analyses based primarily on recommendations in the literature, and secondarily on the ability of hunters to recognize and easily collect samples.

Jaws, legs samples, and liver samples were frozen ≤1 hr after collection and analyzed after each hunting season. We used tooth eruption and wear to estimate deer age-class (Severinghaus, 1949). Leg sections were stripped of skin, tendons, and the majority of muscle tissue using a stainless-steel knife, and the right phalanges were removed. The most distal 5 cm of the metacarpal was removed. We steam-heated all metacarpals and right phalanges using deionized water for 10 min at 121 C and 1.1 kg/cm^2 pressure to loosen remaining tissues, which then were removed.

Antlers were allowed to air-dry for ≥14 days and weighed to the nearest 0.01 g. The number of antler points ≥25 mm was recorded for each antler set. The most distal 5 cm of the right antler was removed. We determined the specific gravity of each antler tip using the air-dried mass divided by the mass of displaced deionized water (Nichols, 1894; Miller, 1903).

The mass of metacarpals, phalanges, and antler tips was determined to the nearest 0.1 mg; they then were freeze-dried for 144 hr using a Virtis Consol 24 Freeze-drier (Gardiner, New York, USA) to remove all water. Freeze-drying time was determined by weighing 53 randomly selected samples after 72 hr of freeze-drying and at 24-hr intervals thereafter until no loss of mass occurred between successive weighings. After freeze-drying, samples were placed in a desiccator and allowed to reach room temperature (24 to 27 C), and then reweighed to the nearest 0.1 mg. Water content of samples was expressed as a percentage of initial mass.

Moisture-free metacarpals, phalanges, and antler tips were extracted for 72 hr in ethanol followed by 72 hr in diethyl ether to remove lipids. Extracted samples were dried at 65 C in a convection oven (Fisher, Model 230F, Chicago, Illinois) for 24 hr then reweighed to the nearest 0.1 mg after reaching room temperature (24 to 27 C) in a desiccator. Ether extract was expressed as a percentage of dry mass. Extracted samples then were ground through 2-mm screen using a Standard Wiley Mill (Model 3, Philadelphia, Pennsylvania, USA).

Liver sections were weighed to the nearest 0.01 g, dried at 70 C for 24 hr in a Precision Scientific Convection Oven (Model 18, Chicago, Illinois) (Woolf et al., 1982), and reweighed to determine water content. Each liver section was ground through 1-mm screen using a Thomas Scientific Wiley Mill (Model S61000, Philadelphia, Pennsylvania, USA).

Tissue samples were dried, ground, and weighed (approximately 0.5000 g; actual weight was recorded and used in calculations) in duplicate for elemental analyses. The samples were placed into glass ignition tubes, digested in 5 ml concentrated (approximately 70%) nitric acid, and diluted to 50 ml with deionized water. Nitric acid digestion consisted of allowing samples to digest at 24 to 27 C for ≥12 hr followed by heating in a heating block at 120 C for ≥2 hr, until replicates were totally digested. Digested replicates were cooled overnight (≥12 hr) then filtered through Whatman No. 42 ashless 12.5-cm filter paper into 50-ml glass flasks. Filtered replicates were brought to 50 ml volume with deionized water, and thoroughly mixed.

Replicates were analyzed for concentrations of Ca, P, sulfur (S), Mg, Na, Cu, K, zinc (Zn), Co, aluminum (Al), Mn, and Fe with an ICP spectrometer (Applied Research Laboratories Model 34100 ICP-AES, Dearborn, Michigan). A blank of 5 ml digested nitric acid (containing no sample material) diluted to 50 ml with deionized water was included every 45th analytic replicate to standardize elemental concentrations. Instruments were standardized daily using certified stock calibration standards (Spex Industries, Inc., Eorson, New Jersey) for all elements except Ca and P. Calcium and P stan-

dards were made from reagent grade $CaCl_2$ and KH_2PO_4, respectively, so that standards >1,000 ppm could be used to calibrate the spectrometer. The root mean squares (RMS) of percent errors for all elemental curves of standards were computed to provide an indication of goodness of fit. A RMS of <3% was considered to be an acceptable fit (Dahlquist et al., 1981). Sample mineral concentrations were means of duplicate values.

We deleted the recorded concentration of any sample mineral if either duplicate value for that mineral varied more than 10% from the sample mean. All elemental values were recorded as concentrations. Some values were converted to percentages for comparison to other studies or to conserve space. Unless otherwise specified, concentrations of minerals in metacarpals, phalanges, and antler tips are on a moisture-free and lipid-free basis, and concentrations of minerals in livers are on a moisture-free basis.

We converted mineral concentrations in livers to wet-mass concentrations using percent water values for comparison to other studies. Seven metacarpals, 13 phalanges, and two antler tips were converted to ash and the percent ash content was calculated. Means ±SE percent ash of these samples was 62.67 ± 0.40%, and did not differ among sample types ($P = 0.63$). This value was used to convert average mineral concentrations in metacarpals, phalanges, and antler tips to estimates on a dry-ash basis for comparison to other studies.

The General Linear Models and Analysis of Variance procedures of SAS (Ray, 1982) and the Backward Elimination Technique (Ray, 1982) were used to determine the effects of study area, sex of deer, and age-class of deer on body mass, antler mass, number of antler points, and tissue compositions. Individual tissues and composition variables were analyzed separately except that compositions of metacarpals and phalanges were also compared. The *t*-test procedure (Triola, 1983) was employed when comparing data between two classes, such as between sexes of deer, when no other variables were statistically significant. All data reported are means ± SE.

RESULTS

Of 219 deer killed on all study areas during both hunting seasons, 197 leg, 64 antler, and 62 liver samples were collected. The mean age of 82 female deer (2.4 yr ± 0.2) was greater ($P < 0.01$) than that of 125 male deer (1.7 yr ± 0.1). The body mass of the deer was related to the interaction of age-class and sex ($P < 0.01$), but did not differ among study areas ($P = 0.99$). The RMS of percent errors for all elemental curves of standards was 1.48 ± 0.16% ($n = 72$). Concentrations of Fe in metacarpals, phalanges, and antler tips varied widely between sample replicates and are not reported because of suspected contamination during grinding.

Metacarpal water content and concentrations of S, Mg, K, and Mn decreased while lipid content, and Ca and Cu concentrations increased as deer aged (Table 1). There also was a trend ($P = 0.07$) of higher metacarpal Na concentration with increased age. Concentration of Co was higher ($P = 0.04$) in metacarpals from females (3.0 ± 0.1 ppm) than from males (2.8 ± 0.1 ppm). Age-class was not related to metacarpal P (10.4 ± <0.1 %), Co (2.9 ± 0.1 ppm), or Al (21.3 ± 0.7 ppm) concentrations. Concentration of Zn in metacarpals varied with sex ($P < 0.01$) and age-class ($P < 0.01$) of deer, although the interaction of these variables was not significant ($P = 0.31$). Study area did not account for significant variation ($P > 0.05$) in any metacarpal constituent measured.

Phalangeal water content and concentrations of S, Mg, and K decreased while concentrations of Ca, P, and Na increased as deer grew older (Table 1). Phalangeal concentrations of Al and Mn differed among age-classes, but no distinct age-related trends were apparent. Zinc concentration was lower ($P < 0.01$) in phalanges from male deer (73.9 ± 0.9 ppm) than from females (80.1 ± 1.4 ppm). Concentration of Mn in phalanges varied with age-class ($P < 0.01$) and study area ($P < 0.01$). Phalangeal lipid content (7.6 ± 0.2 %), and concentrations of Co (2.9 ± 0.1 ppm) and Cu (6.7 ± 0.1 ppm) did not vary with age-class.

Water ($P < 0.01$) and lipid ($P < 0.01$) content, and concentrations of Ca ($P < 0.01$), P ($P = 0.02$), Na ($P = 0.04$), Mg ($P < 0.01$), Zn ($P < 0.01$), and Mn ($P < 0.01$) differed between metacarpals and phalanges, but Cu ($P = 0.14$), Co ($P = 0.55$), and Al ($P = 0.93$) did not differ between these

TABLE 1. Water, lipid,[a] and mineral[b] composition of metacarpals and phalanges of white-tailed deer harvested during the 1988–89 and 1989–90 hunting seasons in East Feliciana Parish, Louisiana, USA; and Probability > *F* of a difference among age-classes.[c]

	Age-class					
	0.5	1.5	2.5	3.5	≥4.5	*P* > *F*
			Metacarpals			
Water (%)						
$\bar{x}$	9.1	8.9	7.4	6.8	7.1	<0.01
SE	0.4	0.2	0.3	0.3	0.3	
n	24	102	33	19	17	
Lipid (%)						
$\bar{x}$	9.8	8.4	11.1	10.2	10.9	0.02
SE	0.8	0.4	0.7	0.7	0.8	
n	24	102	33	19	17	
Calcium (%)						
$\bar{x}$	23.5	23.5	23.8	24.0	24.5	<0.01
SE	0.2	0.1	0.2	0.2	0.2	
n	24	104	33	19	17	
Phosphorus (%)						
$\bar{x}$	10.4	10.4	10.4	10.5	10.6	0.88
SE	0.1	0.1	0.1	0.1	0.1	
n	24	104	33	19	17	
Sulfur (ppm)						
$\bar{x}$	2,583	2,394	2,193	2,170	2,157	<0.01
SE	46	19	28	31	24	
n	24	104	33	19	17	
Magnesium (ppm)						
$\bar{x}$	4,623	4,627	4,370	4,190	4,191	<0.01
SE	81	35	67	67	74	
n	24	104	33	19	17	
Sodium (ppm)						
$\bar{x}$	5,079	5,289	5,285	5,280	5,604	0.07
SE	134	64	105	127	141	
n	24	104	33	19	17	
Aluminum (ppm)						
$\bar{x}$	22.7	20.8	20.0	21.6	23.3	0.96
SE	2.5	1.0	1.4	2.5	0.7	
n	15	56	18	15	9	
Copper (ppm)						
$\bar{x}$	6.6	6.8	6.9	7.0	7.1	0.03
SE	0.1	0.1	0.1	0.2	0.2	
n	23	101	30	19	16	
Potassium (ppm)						
$\bar{x}$	811.8	579.6	479.0	373.2	391.1	<0.01
SE	41.8	11.4	13.0	15.8	10.5	
n	24	104	33	19	17	
Manganese (ppm)						
$\bar{x}$	1.9	1.4	1.4	1.4	1.3	<0.01
SE	0.1	<0.1	0.1	0.2	0.1	
n	18	88	26	16	13	

TABLE 1. Continued.

	Age-class					
	0.5	1.5	2.5	3.5	≥4.5	$P > F$
Zinc (males[d]) (ppm)						
$\bar{x}$	85.6	77.6	73.4	70.2	88.1	0.05
SE	3.8	1.4	1.8	2.9		
n	11	81	16	6	1	
Zinc (females) (ppm)						
$\bar{x}$	98.4	82.5	78.7	81.1	75.9	<0.01
SE	3.7	2.6	3.1	2.8	2.3	
n	13	22	15	12	15	
Cobalt (males) (ppm)						
$\bar{x}$	2.6	2.8	2.7	3.2		0.58
SE	0.2	0.1	0.2	0.3		
n	5	48	13	4	0	
Cobalt (females) (ppm)						
$\bar{x}$	2.8	3.1	2.9	3.2	3.1	0.55
SE	0.1	0.2	0.1	0.2	0.2	
n	13	12	10	9	11	
	Phalanges					
Water (%)						
$\bar{x}$	8.4	7.5	6.7	6.2	6.6	<0.01
SE	0.4	0.1	0.2	0.4	0.2	
n	23	102	33	19	17	
Lipid (%)						
$\bar{x}$	8.2	7.2	7.6	7.8	9.2	0.37
SE	0.1	0.3	0.6	0.6	0.5	
n	23	102	33	19	17	
Calcium (%)						
$\bar{x}$	23.3	24.0	24.3	24.7	25.3	<0.01
SE	0.2	0.1	0.2	0.3	0.2	
n	24	102	33	19	17	
Phosphorus (%)						
$\bar{x}$	10.4	10.5	10.6	10.7	10.8	0.04
SE	0.1	0.1	0.1	0.1	0.1	
n	24	102	33	19	17	
Sulfur (ppm)						
$\bar{x}$	2,488	2,224	2,193	2,170	2,157	<0.01
SE	40	17	24	22	26	
n	24	102	33	19	17	
Magnesium (ppm)						
$\bar{x}$	4,382	4,474	4,337	4,259	4,248	<0.01
SE	80	35	62	82	117	
n	24	102	33	19	17	
Sodium (ppm)						
$\bar{x}$	5,249	5,287	5,434	5,618	5,778	0.01
SE	118	58	108	133	152	
n	24	102	33	19	17	

TABLE 1. Continued.

	Age-class					
	0.5	1.5	2.5	3.5	≥4.5	$P > F$
Aluminum (ppm)						
$\bar{x}$	21.0	20.3	18.3	28.2	23.5	0.02
SE	1.8	1.0	1.9	3.8	3.0	
n	16	52	21	11	12	
Copper (ppm)						
$\bar{x}$	6.9	6.7	6.7	7.0	6.6	0.77
SE	0.1	0.1	0.1	0.2	0.2	
n	24	98	31	18	17	
Potassium (ppm)						
$\bar{x}$	809.3	539.6	503.1	427.9	440.6	<0.01
SE	38.9	10.2	16.0	19.4	13.4	
n	24	102	33	19	17	
Manganese (ppm)[c]						
$\bar{x}$	1.8	1.7	1.5	1.8	1.5	<0.01
SE	0.1	0.1	0.1	0.1	0.2	
n	21	86	27	19	14	
Zinc (males) (ppm)						
$\bar{x}$	80.2	73.5	72.4	74.2	69.4	0.31
SE	2.2	1.2	1.7	3.3		
n	11	81	17	6	1	
Zinc (females) (ppm)						
$\bar{x}$	86.8	77.8	79.2	80.5	78.4	0.30
SE	4.8	2.5	3.1	3.4	2.1	
n	12	20	16	12	16	
Cobalt (ppm)						
$\bar{x}$	2.7	2.9	2.9	3.0	2.7	0.61
SE	0.1	0.1	0.1	0.2	0.1	
n	17	68	20	15	15	

[a] Lipid compositions are on a moisture-free basis.
[b] Mineral compositions are on a moisture- and lipid-free basis.
[c] Analysis of variance with backward elimination (Ray, 1982).
[d] Sexes presented separately when different ($P < 0.05$); analysis of variance with backward elimination (Ray, 1982).
[e] Study area effects were also significant ($P < 0.05$); analysis of variance with backward elimination (Ray, 1982).

bones. Concentrations of K ($P = 0.04$) and S ($P < 0.01$) varied with the interaction of leg bone type (metacarpal or phalange) and age-class. Dry ash equivalents (expressed as 95% confidence intervals) of mineral concentrations in moisture- and lipid-free metacarpals and phalanges were 38.0 to 38.3% Ca, 16.6 to 16.8% P, 3,632 to 3,689 ppm S, 7,042 to 7,165 ppm Mg, 8,389 to 8,587 ppm Na, 10.7 to 11.0 ppm Cu, 32.1 to 35.5 ppm Al, 853.8 to 904.6 ppm K, 2.4 to 2.6 ppm Mn, 122.5 to 126.4 ppm Zn, and 4.5 to 4.7 ppm Co.

Fifty-five antler sets were collected from 1.5-yr-old males and nine from 2.5-yr-old males. Antler mass ($P < 0.01$) and number of antler points ($P < 0.01$) were greater for 2.5-yr-old males (335 ± 84 g and 6.6 ± 0.7 points, respectively) than 1.5-yr-old males (94 ± 8 g and 3.3 ± 0.2 points, respectively). These variables also differed among study areas ($P < 0.01$); also, the antler mass varied with the interaction of age-class and study area ($P < 0.01$), but the number of antler points did not ($P = 0.17$).

Mean antler tip specific gravity (1.60 ± 0.02) did not vary with age-class ($P = 0.88$) or study area ($P = 0.62$). Antler tips contained no extractable lipids. Concentrations of Na (4,578 ± 79 ppm, $P = 0.04$) and Mn (29.1 ± 3.1 ppm, $P = 0.02$) varied with the interaction of age-class and study area, but concentrations of neither of these minerals varied with either age-class or study area alone ($P > 0.05$). Mean antler tip Ca (23.2 ± 0.2%, $P < 0.01$) and K (975.0 ± 50.6 ppm, $P < 0.01$) concentrations differed among study areas. Mean P (10.5 ± 0.1%), S (2,260 ± 16 ppm), Mg (5,636 ± 51 ppm), Cu (6.4 ± 0.1 ppm), Zn (70.4 ± 1.8 ppm), Co (2.5 ± 0.1 ppm), and Al (32.9 ± 1.6 ppm) concentrations did not differ ($P > 0.05$) among age-classes or study areas. Dry ash equivalents (expressed as 95% confidence intervals) of mineral concentrations in moisture- and lipid-free antler tips were 36.4 to 37.6% Ca, 16.6 to 16.9% P, 3,555 to 3,658 ppm S, 8,831 to 9,153 ppm Mg, 7,075 to 7,553 ppm Na, 10.0 to 10.6 ppm Cu, 46.8 to 57.6 ppm Al, 1,398 to 1,714 ppm K, 35.3 to 54.8 ppm Mn, 107.5 to 118.6 ppm Zn, and 3.8 to 4.2 ppm Co.

Concentrations of Co and Al in livers were at or near zero in all samples. No liver composition variable measured varied ($P > 0.05$) with study area. Livers from 32 male deer contained higher concentrations of P (12,488 ± 189 ppm; $P < 0.01$) and Mg (603.5 ± 7.6 ppm; $P = 0.05$) than livers from 30 females (11,836 ± 133 ppm and 580.5 ± 8.4 ppm, respectively). Mean concentrations of S (8,177 ± 91 ppm) and Mn (16.0 ± 0.6 ppm) in livers from females were higher ($P = 0.01$ and $P < 0.01$, respectively) than in livers from males (7,837 ± 94 ppm and 12.4 ± 0.5 ppm, respectively). Mean liver Cu (236.6 ± 13.8 ppm) and K (12,017 ± 109 ppm) concentrations differed among age-classes ($P \leq 0.05$), but no distinct age-related trends were apparent. Mean water (67.3% ± 0.3) content and concentrations of Ca (124.3 ± 3.0 ppm), Na (3,024 ± 101 ppm), and Zn (118.5 ± 3.8 ppm) did not differ ($P > 0.05$) between sexes or among age-classes. Liver mineral concentrations on a wet-mass basis (expressed as 95% confidence intervals) were 38.7 to 42.5 ppm Ca, 3,867 to 4,087 ppm P, 2,550 to 2,678 ppm S, 188.2 to 199.3 ppm Mg, 925 to 1,024 ppm Na, 68.3 to 85.9 ppm Cu, 3,821 to 4,043 ppm K, 36.3 to 41.2 ppm Zn, 4.3 to 5.0 ppm Mn, and 123.3 to 150.6 ppm Fe.

DISCUSSION

Blood, bone, and liver normally are used to evaluate animal mineral status; bone and liver are particularly useful because they store certain minerals (Underwood, 1981). Bone may be used to detect Ca and P deficiencies (Underwood, 1981), and most animal nutritionists use long bones to measure Ca depletion (Ensminger and Olentine, 1978). Stelter (1980) reported trace element concentrations in metacarpals of mule deer (*O. hemionus*) in Colorado (USA). The liver may be used to assess Co, Cu, Mn, selenium (Se), and iron (Fe) status (Munshower and Neuman, 1979; Underwood, 1981; McDowell et al., 1983). Sileo and Beyer (1985) used livers, kidneys, and brains from white-tailed deer for analyses of heavy metal concentrations. Woolf et al. (1982) analyzed mineral concentrations in livers from deer in Pennsylvania.

The trends for leg bone (metacarpal and phalangeal) water content to decrease, and lipid content to increase as deer grew older have been reported for other species (Lloyd et al., 1978; Robbins, 1983). Deer age-class also influenced metacarpal or phalangeal concentrations of 10 minerals. Puls (1988) and Robbins (1983) reported changes in the composition of bone particularly related to animal age.

Estimated dry-ash concentrations of Ca, P, and Mg were similar to those reported in the bones of other species (Fontenot and Church, 1979; Robbins, 1983). Estimated dry-ash Ca, Mg, Na, and Cu concentrations in leg bones were similar to those reported by McCullough and Ullrey (1983) of bone from six white-tailed deer. Estimated dry-ash concentrations of P, Zn, and

K in leg bones in our study were higher than reported by McCullough and Ullrey (1983). Differences were not surprising, however, considering that we examined two specific bones and McCullough and Ullrey (1983) analyzed white-tailed deer bone in general. The concentrations of eight minerals in our study were influenced by bone type (metacarpal or phalange), and Ullrey (1982) found differences in the Ca and P content of dry-ashed white-tailed deer ribs versus coccygeal vertebrae.

Antler tip specific gravity was similar to that reported by Ullrey (1982) for captive white-tailed deer fed diets sufficient in Ca and P for optimal antler development. The Ca and P concentrations in antler tips were similar to values reported by Robbins (1983) for cervid antlers, but estimated dry-ash concentrations of these minerals were less than concentrations reported by Ullrey (1982). However, we analyzed only the most distal portion of each antler and Ullrey (1982) reported whole-antler concentrations.

All wet-mass liver mineral concentrations fell within or above cattle and sheep liver mineral concentrations reflecting adequate dietary intake or normal values (Puls, 1988). Liver concentrations of Ca, Zn, Fe, Mg, and Na were similar to those found by McCullough and Ullrey (1983) in livers of six white-tailed deer, but concentrations of Cu and K were higher, and P lower, respectively, in our study. Liver concentrations of Cu, Mg, Mn, and Zn differed from those reported by Woolf et al. (1982) for deer in Illinois. Differences may have been due to differences in diet or to variations in analytical methods. Woolf et al. (1982) also found significant effects on liver mineral concentrations from the sex or age of deer. Puls (1988) did not report liver S concentration, and McCullough and Ullrey (1983) did not report liver S or Mg levels.

We provide baseline data on the mineral composition of four analytical substrates from free-ranging deer and provide evidence that the mineral content of white-tailed deer may be influenced by the tissue being analyzed, the age or sex of the animals, or the area from which animals are collected. Researchers utilizing tissue mineral concentrations to investigate deer mineral nutrition or condition should consider variation from these sources during study design and data analyses.

ACKNOWLEDGMENTS

This project was funded by the Louisiana Agricultural Experiment Station under McIntire-Stennis project LAB02154. Additional support was provided by Safari Club International, Dow Chemical Company, and Mr. J. S. McIlhenney. We thank G. Berger, T. Jones, B. Jones, F. Jones, and L. Hawes for use of their lands, and the many individuals who collected samples and data from the deer. J. Banta provided invaluable assistance during all phases of laboratory analyses. Approved for publication by the Director, Louisiana Agricultural Experiment Station as manuscript number 91-22-5224.

LITERATURE CITED

DAHLQUIST, R. L., C. F. HAYES, AND S. M. HOOPER (editors). 1981. 34000 ICP system user's manual. Applied Research Laboratories, Inc., Dearborn, Michigan, 363 pp.

DELGIUDICE, G. D., L. D. MECH, U. S. SEAL, AND P. D. KARNS. 1987. Effects of winter fasting and refeeding on white-tailed deer blood profiles. The Journal of Wildlife Management 51: 865–873.

———, ———, AND ———. 1990. Effects of winter undernutrition on body composition and physiological profiles of white-tailed deer. The Journal of Wildlife Management 54: 539–550.

ENSMINGER, M. E., AND C. G. OLENTINE, JR. 1978. Feeds and nutrition, complete. The Ensminger Publishing Company, Clouise, California, 1417 pp.

FONTENOT, J. P., AND D. C. CHURCH. 1979. The macro (major) minerals. *In* Digestive physiology and nutrition of ruminants, Vol. II. Nutrition, D. C. Church (ed.). O and B Books, Incorporated, Corvallis, Oregon, pp. 56–99.

JONES, R. L., AND H. C. HANSON. 1985. Mineral licks, geophagy, and biochemistry of North American ungulates. Iowa State University Press, Ames, Iowa, 301 pp.

KIE, J. G., M. WHITE, AND D. L. DRAWE. 1983. Condition parameters of white-tailed deer in Texas. The Journal of Wildlife Management 47: 583–594.

KIRKPATRICK, R. L., D. E. BUCKLAND, W. A. ABLER, P. F. SCANLON, J. B. WHELAN, AND H. E.

BUCKHART. 1975. Energy and protein influences on blood urea nitrogen of white-tailed deer fawns. The Journal of Wildlife Management 39: 692–698.

LLOYD, L. E., B. E. MCDONALD, AND E. W. CRAMPTON. 1978. Fundamentals of nutrition. W. H. Freeman and Company, San Francisco, California, 466 pp.

MCCULLOUGH, D. R., AND D. E. ULLREY. 1983. Proximate mineral and gross energy composition of white-tailed deer. The Journal of Wildlife Management 47: 430–441.

MCDOWELL, L. R., J. H. CONRAD, G. L. ELLIS, AND J. K. LOOSLI. 1983. Minerals for grazing ruminants in tropical regions. Department of Animal Science, Center for Tropical Agriculture, University of Florida, Gainesville, Florida, and the U.S. Agency for International Development, Washington, D.C., 86 pp.

MILLER, D. C. 1903. Laboratory physics. Ginn and Company, Boston, Massachusetts, 403 pp.

MUNSHOWER, F. F., AND D. R. NEUMAN. 1979. Metals in soft tissue of mule deer and antelope. Bulletin of Environmental Contamination and Toxicology 22: 827–832.

NICHOLS, E. L. (editor). 1894. A laboratory manual of physics and applied electricity. The MacMillan Company, London, England, 294 pp.

PULS, R. 1988. Mineral levels in animal health. Sherpa International, Clearbrook, British Columbia, Canada, 240 pp.

RAY, A. A. (editor). 1982. SAS user's guide: Statistics. SAS Institute, Cary, North Carolina, 548 pp.

ROBBINS, C. T. 1983. Wildlife feeding and nutrition. Academic Press, New York, New York, 343 pp.

———, A. N. MOEN, AND J. T. REID. 1974. Body composition of white-tailed deer. Journal of Animal Science 38: 871–876.

SCHULTZ, S. R. 1990. Effects of artificial mineral licks on white-tailed deer. Ph.D. Dissertation. Louisiana State University, Baton Rouge, Louisiana, 128 pp.

———, AND M. K. JOHNSON. 1992a. Effects of supplemental mineral licks on white-tailed deer. Wildlife Society Bulletin 20: 303–308.

———, AND ———. 1992b. Use of artificial mineral licks by white-tailed deer in Louisiana. Journal of Range Management 45: 546–548.

SEAL, U. S., L. J. VERME, J. J. OZOGA, AND A. W. ERICKSON. 1972. Nutritional effects on thyroid activity and blood of white-tailed deer. The Journal of Wildlife Management 36: 1041–1052.

SEVERINGHAUS, C. W. 1949. Tooth development and wear as criteria of age in white-tailed deer. The Journal of Wildlife Management 13: 195–216.

SILEO, L., AND W. N. BEYER. 1985. Heavy metals in white-tailed deer living near a zinc smelter in Pennsylvania. Journal of Wildlife Diseases 21: 289–296.

STELTER, L. H. 1980. Baseline levels of selected trace elements in Colorado oil shale region animals. Journal of Wildlife Diseases 16: 175–182.

TRIOLA, M. F. 1983. Elementary statistics. The Benjamin/Cummings Publishing Company, Menlo Park, California, 496 pp.

ULLREY, D. E. 1982. Nutrition and antler development in white-tailed deer. *In* Antler development in Cervidae, R. D. Brown (ed.). Caeser Kleberg Wildlife Research Institute, Kingsville, Texas, pp. 49–59.

UNDERWOOD, E. J. 1981. The mineral nutrition of livestock. Commonwealth Agricultural Bureau, Farnham Royal, England, 180 pp.

U.S. SOIL CONSERVATION SERVICE. 1971. General soil map—East Feliciana Parish, Louisiana. U.S. Department of Agriculture and Louisiana Agricultural Experiment Station, Baton Rouge, Louisiana, 2 pp.

VERME, L. J., AND D. E. ULLREY. 1984. Physiology and nutrition. *In* White-tailed deer, ecology and management, L. K. Halls (ed.). Stackpole Books, Harrisburg, Pennsylvania, pp. 91–118.

WIENER, J. G., I. L. BRISBIN, JR., AND M. H. SMITH. 1975. Chemical composition of white-tailed deer: Whole-body concentrations of macro- and micronutrients. *In* Symposium on mineral cycling in southeastern ecosystems, F. G. Howell, J. B. Gentry, and M. H. Smith (ed.). Technical Information Center, Office of Public Affairs, U.S. Energy Research and Development Administration, Washington, D.C., pp. 536–541.

WOOLF, A., J. R. SMITH, AND L. SMALL. 1982. Metals in livers of white-tailed deer in Illinois. Bulletin of Environmental Contamination and Toxicology 28: 189–194.

Received for publication 22 October 1992.