Wildlife Session

Relationships Between Deer and Soil Nutrients in Mississippi

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Abstract: Soil P, Ca, Mg, K, pH, and organic matter levels were compared to mean deer (*Odocoileus virginianus*) body weights and antler measures from 23 areas of Mississippi. All soil measures were significantly ($P < 0.05$) correlated with deer body weights in all sex and age classes. Antler measurements for yearling, but not older, bucks correlated significantly with all soil measures except pH. In stepwise multiple regression analysis, P weighted most heavily in predicting deer body weights in all age and sex classes except female fawns; both P and K gave identical prediction equations for this age-sex class. This study suggests that soil P is a useful predictor of potential physiologic condition of deer. Management implications are that soil P levels in conjuncion with deer body weight information can be used as decision criteria to increase or decrease antlerless harvest levels or to implement habitat improvements.

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Many authors have suggested relationships between soil fertility and productivity and body size of wildlife species (Allen 1943, Steen 1955, Crawford 1950, Williams and Caskey 1965). Studies on white-tailed deer have indicated that, in general, largest deer are found on the most fertile soils (Sweet and Wright 1953, Steen 1955, Wesley et al. 1969, Short 1969, Moore 1976, Thorsland 1966, Harlow and Jones 1965). However, most studies have been limited to subjective ranking of soils or qualitative assessment of soil fertility. Jacobson et al. (1977) reported that high soil phosphate levels were associated with high body weights. This association led to the conjecture that there is a direct relationship between soil phosphate levels and deer body weights.

The prime objective of this study was to determine if deer body weights are directly correlated with soil nutrient levels. A second objective was to determine if there is correlation between antler characteristics (beam circumference and beam length) and levels of soil nutrients.

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Methods

Twenty-three study areas representing all soil resource regions in Mississippi (Cross et al. 1974) were selected for sampling. Soil samples were collected from 9 areas in summer 1977 (Jacobson et al. 1977). The other soil samples were collected in summer and fall 1981. Weights and antler measurements from deer were collected during the 1977–1981 hunting seasons. With the exception of the 9 study areas selected in 1977, all study areas were selected based on the recommendation by MDWC biologists. Criteria for selection included broad geographic and physiographic representation, a subjective evaluation by MDWC biologists that the area chosen was not an overpopulated deer range, and the availability of reliable hunter check station data which included a minimum sample of 20 adult male deer.

Soil sampling was conducted as described by Jacobson et al. (1977), i.e., 100-m, north-south or east-west transects were run from existing road systems at 1.6-km intervals. Samples were taken from the top 15 cm of soil at these locations. Agricultural fields or other areas known to have been subjected to fertilizer treatments were excluded from the areas to be sampled.

Deer body weights were recorded as dressed weights to the nearest 0.45 kg at hunter check stations. Deer were placed in 3 age classes (fawn, 1½ years, and ≥2½ years) by tooth wear and eruption. All deer aged ≥2½ were placed in a single age class for analysis because of potential error in aging older animals (Hackett et al. 1979) and to insure an adequate sample size. Soil samples were analyzed for organic matter, pH, calcium (Ca), magnesium (Mg), phosphorus (P), and potassium (K) by the Soil Testing Laboratory, MSU. The Statistical Package for Social Sciences (Nie et al. 1975) was used for regression and correlation analyses.

Although soil samples and deer body and antler measurements were collected individually from each area, population means were used for regression analysis. Because individual deer would have access to most soils within an area and could not be specifically related to individual soils within a management area, a regression model using mean soil measures as fixed effects and mean deer body measures as independent variables was used. Soil nutrient levels remain relatively fixed for a given area; however, mean deer body measures can be expected to vary on the basis of herd nutritional condition, weather, and density. Because of these assumptions, a Model I regression, for tests of significance as a special case of a Model II regression (Sokal and Rohlf 1969), was considered appropriate.

Results

Data were collected from 425 soil samples and 9,838 deer. The minimum number of soil samples analyzed from any area was 8 and the minimum number of deer examined from any area was 31 (Table 1).

There were significant ($P < 0.05$) correlations between all soil measurements and deer body weights in all sex and age classes. For wildlife management areas that had more than 1 year of data collected on deer body weights, correlations also were run using only the heaviest annual mean weights. These

Table 1. Study areas, sample sizes, and mean soil measurements.

			Mean soil measurements					
			Organic matter		P	K	Ca	Mg
Area	*N* soil samples	*N* deer	%	pH	(ppm)			
Leaf River WMA[a]	36	244	1.5	5.2	0.9	10.5	116	49
Meridian Naval Air Station	10	177	0.6	5.4	1.4	12.9	220	34
Tallahala WMA	36	607	1.6	5.3	1.1	16.0	742	182
Sandy Creek WMA	18	688	1.1	5.2	3.0	20.7	445	167
Choctaw WMA	34	405	1.1	5.5	1.6	23.3	259	135
Noxubee NWR[b]	18	1,675	1.6	5.4	2.4	22.5	752	176
Chickasaw WMA	36	867	1.0	5.3	1.8	21.4	311	92
Issaqueena WMA	8	131	1.8	6.8	16.2	50.4	213	563
Benoit HC[c]	12	480	4.2	6.4	15.6	74.4	5,050	1,496
Davis Island HC	29	1,164	2.9	6.8	16.0	71.6	2,880	637
Kings Point HC	23	797	2.8	7.1	19.1	68.6	3,438	726
Malmaison WMA	11	528	3.0	5.6	8.9	26.1	67	4
Bigbee Valley HC	8	369	2.3	6.0	11.9	25.3	2,369	86
Caney Creek WMA	21	76	3.4	5.5	1.1	20.2	1,941	308
Marion County WMA	15	306	2.4	5.3	0.7	10.9	166	39
Woodlawn HC	12	302	2.0	5.8	5.3	23.0	924	254
Yazoo NWR	10	179	3.2	6.0	15.1	74.8	3,138	597
Copiah WMA	15	94	2.4	5.4	1.0	23.5	425	204
Pearl River HC	18	102	1.9	4.9	5.7	11.1	377	86
Calhoun WMA	14	365	1.4	5.3	2.4	18.3	470	99
Longleaf Plantation HC	16	211	2.4	5.2	0.4	6.7	206	45
James Creek HC	15	40	0.9	5.4	0.9	11.9	264	58
Big "O" HC	10	31	1.1	5.3	1.0	16.3	213	51

[a] WMA—Wildlife Management Area.
[b] NWR—National Wildlife Refuge.
[c] HC—Hunting Club.

also gave significant ($P < 0.05$) correlations between all soil measurements and deer body weights in all age and sex classes.

Of the antler measurements recorded, only antler beam circumference and beam length of 1½-year-old bucks had significant ($P < 0.05$) correlations with any soil measurements and these had relatively small correlation coefficients when compared to those obtained by body weight and soil measure associations (Table 2). Whereas almost all correlations between soil measurements and body weight were highly significant ($P < 0.01$), only P, Ca, and K had highly significant correlations with antler measurements. Antler correlations were weaker than body weight correlations and were inconsistent between age classes and between spike-antlered and fork-antlered yearlings.

Because there were significant correlations between all soil measurements and deer body weights, stepwise multiple regressions for maximum R^2 were conducted to determine which soil measures would serve as the best predictors of deer body measures. Phosphorus was the first variable to enter for all weight

Table 2. Pearson correlation coefficients between mean dressed body weights and antler characteristics of white-tailed deer and selected soil measurements from 23 management areas in Mississippi.

Body weight or antler characteristic	Soil measurement[a]					
	P	K	Ca	Mg	pH	Organic matter
Weight (All years pooled)						
0.5 Males	0.86***	0.73***	0.57**	0.55**	0.73***	0.52**
0.5 Females	0.81***	0.81***	0.66***	0.55**	0.70***	0.53***
1.5 Males	0.77***	0.71***	0.64***	0.60**	0.69***	0.59**
1.5 Females	0.83***	0.71***	0.60**	0.49**	0.73***	0.55**
2.5 Males	0.63**	0.59**	0.40*	0.41*	0.55**	0.47*
2.5 Females	0.73***	0.65***	0.57**	0.47*	0.60***	0.60**
1.5 Spike-antlered	0.81***	0.76***	0.69***	0.62**	0.74**	0.60**
1.5 Fork-antlered	0.85***	0.80***	0.67***	0.61**	0.77***	0.63**
Weight (Best annual mean)						
0.5 Males	0.81***	0.73*	0.54**	0.49*	0.66**	0.52**
0.5 Females	0.78***	0.77***	0.63**	0.51**	0.65**	0.59**
1.5 Males	0.85***	0.82***	0.67***	0.67***	0.75***	0.63**
1.5 Females	0.79***	0.69***	0.62**	0.45*	0.69***	0.60**
2.5 Males	0.74***	0.64***	0.38*	0.41*	0.63**	0.50**
2.5 Females	0.79***	0.73***	0.65***	0.54**	0.63**	0.73***
Antlers (All years pooled)						
1.5 Beam circumference	0.56**	0.56**	0.46*	0.37*	0.33	0.35
2.5 Beam circumference	0.06	0.02	−0.17	−0.19	−0.05	−0.27
1.5 Beam length	0.31	0.40*	0.32	0.27	0.18	0.42*
2.5 Beam length	−0.03	0.14	0.02	−0.06	0.09	−0.10
1.5 Spike-antlered circumference	0.51**	0.54**	0.50**	0.43*	0.29	0.40*
1.5 Fork-antlered circumference	0.33	0.17	0.07	0.09	−0.01	0.05
1.5 Spike-antlered beam length	0.29	0.45*	0.59**	0.43*	0.30	0.40*
1.5 Fork-antlered circumference	0.33	0.14	0.07	0.09	0.09	0.18

[a] * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

equations except fawn females. For female fawns, both P and K gave identical coefficients of determination. Little R^2 improvement for body weight predictions resulted from multiple regressions over prediction equations from P alone, and there was no apparent consistency in variable entry into the equations for sex and age classes, except for P (Table 3). Multiple regression analysis failed to provide any 1 variable as a consistent predictor of antler measures. Log transformation did not improve R^2. Soil P and body weight regression associations are shown in figure 1.

To examine means of further clarifying regression associations, some data manipulation was conducted. For wildlife management areas that had more than 1 year of data collected on deer body weights, regressions were run using only the heaviest annual mean weights. Prediction equations when the highest annual mean body weights were used resulted in intercept values of about 1 to 2 kg higher than prediction equations from the combined years of data (Fig. 1).

It is known that spike-antlered yearling bucks result from nutritional deficiencies (Severinghaus et al. 1950, French et al. 1956, Ullrey 1981) and/or genetic influence (Harmel 1983). Spike-antlered yearling deer have lower body weights than fork-antlered yearlings on the same diets (Williams et al. 1983). Because of this, separate analyses were conducted on spike-antlered and fork-antlered yearling deer. Although R^2 values and slopes were similar,

Table 3. Comparisons of R^2 values resulting from maximum R^2 multiple regression models to a single variable P model for deer body weight and antler measures prediction equations.

Dependent variable	P model	Two variable model[a]	Three variable model[a]
Weight			
0.5 Males	0.74	0.75 (P, Mg)	0.75 (P, Mg, Om[b])
0.5 Females	0.66	0.74 (K, Mg)	0.77 (K, Mg, Ca)
1.5 Males	0.59	0.61 (P, Om)	0.62 (P, Om, Mg)
1.5 Females	0.69	0.72 (P, Mg)	0.75 (P, Mg, Om)
2.5 Males	0.40	0.40 (P, Om)	0.45 (P, Om, Ca)
2.5 Females	0.53	0.58 (P, Om)	0.68 (P, Om, Ca)
1.5 Spike-antlered	0.66	0.68 (P, Om)	0.68 (P, Om, Ca)
1.5 Fork-antlered	0.72	0.75 (P, Om)	0.76 (P, Om, Mg)
Antlers			
1.5 Beam circumference	0.31	0.50 (P, pH)	0.57 (P, pH, K)
2.5 Beam circumference	0.00	0.14 (Om, P)	0.22 (Om, P, pH)
1.5 Beam length	0.10	0.21 (Om, K)	0.31 (Om, K, pH)
2.5 Beam length	0.00	0.17 (K, P)	0.38 (K, P, Mg)
1.5 Spike-antlered circumference	0.26	0.38 (K, pH)	0.47 (K, pH, P)
1.5 Fork-antlered circumference	0.11	0.62 (P, pH)	0.68 (P, pH, Om)
1.5 Spike-antlered beam length	0.08	0.42 (Ca, P)	0.47 (Ca, P, K)
1.5 Fork-antlered beam length	0.11	0.07 (Om, Ca)	0.13 (Om, Ca, P)

[a] Parenthesis indicate first variables to enter the model.
[b] Om = Organic matter.

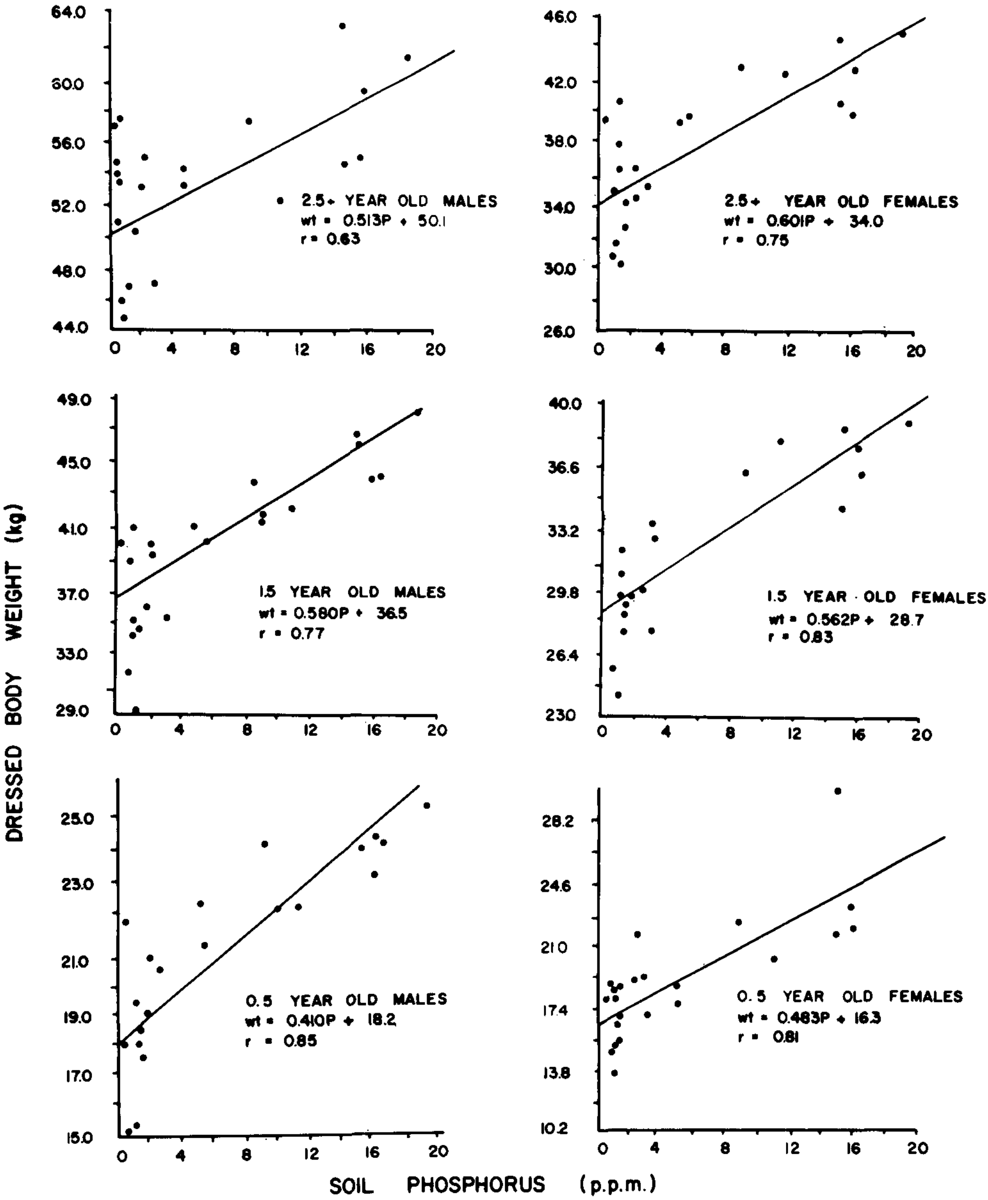

Figure 1. Relationships between soil phosphorus and mean dressed body weights of hunter-killed deer from 23 management areas in Mississippi.

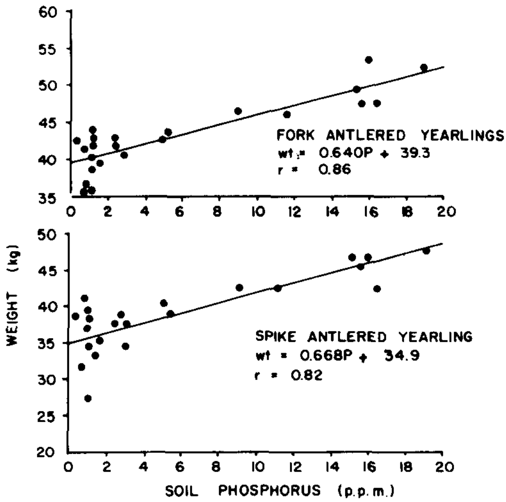

Figure 2. Relationships between soil phosphorus and mean dressed body weights of hunter-killed spike-antlered and fork-antlered yearling deer from 23 management areas in Mississippi.

regression predictions for fork-antlered yearlings were about 4.4 kg heavier than those of spike-antlered yearlings from areas with the same phosphorus levels (Fig. 2).

Discussion

Criticism could be made of the exclusion of agricultural fields from soil sampling, since some deer would have access to these areas. However, agricultural areas made up a small proportion of the habitat on most areas sampled. Plantings of winter wheat or rye grass wildlife food plots were present on most areas. Additionally, soybean fields were adjacent to all management areas. Fertilizer history on agricultural fields was not known and soil samples from these areas would not be considered representative of the general habitat sampled. However, exclusion of these areas would increase the likelihood of accepting a null hypothesis of no relationship between soil nutrients and deer body or antler characteristics. Fertilizer used on poor soils would be expected to have a proportionally greater impact on plant quality and nutrient availability than those areas of high soil fertility. Thus, it is believed exclusion of agricultural areas from the sampling base strengthens the significance of the results.

The results of this study suggest that use of soil phosphorus levels has management application for determining relative levels of herd health for deer in Mississippi. Body weights have been shown to be sensitive indicators of deer population health in Mississippi. Average annual weight improvements or weight losses as great as 14 kg within sex and age classes have been documented on specific management areas in response to known population reduction or increase. Maximum-recorded changes in weights have been much greater in high P, fertile delta soils, than in low P, coastal plain soils (MDWC, unpubl. data).

Both deer body weights and soil phosphorus levels within areas were found to have relatively low levels of sample variability. Comparisons of coefficients of variation for weights of yearling bucks and soil phosphorus levels are shown in Table 4. Areas with the highest coefficients of variation for soil phosphorus were generally found on areas with mean phosphorus levels less than 4 ppm; mean deer body weights from such areas also show the poorest fit to regression equations (Fig. 1).

It is not known how close the prediction equations for body weights from soil phosphorus levels are to those which would be obtained from deer herds in optimum condition. Undoubtedly, predicted weights would be somewhat higher than those obtained. In this regard, the regression equation which considers only fork-antlered yearling bucks may be the closest approximation to expected weights on areas where deer herds are in optimum physiologic condition. Although an attempt was made to only sample areas which were thought

Table 4. Comparisons of sample variability for dressed body weight of yearling bucks and soil phosphorus levels between 23 areas in Mississippi as indicated by coefficients of variation (C.V.).

Area	1½-year-old-bucks			Soil phosphorus		
	N samples	Mean ± SE body wt. (kg)	CV %	*N* samples	Mean ± SE soil P p.p.m.	CV %
Leaf River WMA[a]	85	29.4 ± 0.2	21	36	0.9 ± 0.1	27
Meridian Naval Air Station	41	34.4 ± 0.3	18	10	1.4 ± 0.3	25
Tallahala WMA	279	35.1 ± 0.1	15	36	1.1 ± 0.2	43
Sandy Creek WMA	147	35.7 ± 0.1	19	18	3.0 ± 0.5	81
Choctaw WMA	111	34.6 ± 0.1	17	34	1.6 ± 0.3	120
Noxubee NWR[b]	555	39.6 ± 0.1	15	18	2.4 ± 0.6	106
Chickasaw WMA	300	36.6 ± 0.1	15	36	1.8 ± 0.3	89
Issaqueena WMA	65	44.3 ± 0.2	15	8	16.2 ± 0.5	5
Benoit HC[c]	199	46.1 ± 0.1	12	12	15.6 ± 0.7	16
Davis Island HC	515	43.8 ± 0.1	17	29	16.0 ± 0.4	23
Kings Point HC	411	48.4 ± 0.1	14	23	19.1 ± 0.5	24
Malmaison WMA	169	44.0 ± 0.1	18	11	8.9 ± 0.5	32
Bigbee Valley HC	147	42.6 ± 0.1	15	8	11.9 ± 0.7	32
Caney Creek WMA	44	41.0 ± 0.2	10	21	1.1 ± 0.2	56
Marion County WMA	93	31.8 ± 0.1	16	15	0.7 ± 0.1	34
Woodlawn HC	73	41.4 ± 0.2	12	12	5.3 ± 0.6	66
Yazoo NWR	50	46.9 ± 0.2	11	10	15.1 ± 0.8	37
Copiah WMA	36	39.2 ± 0.3	16	15	1.0 ± 0.2	59
Pearl River HC	55	40.3 ± 0.2	17	18	5.7 ± 0.5	65
Calhoun WMA	177	40.2 ± 0.1	14	14	2.4 ± 0.2	49
Longleaf Plantation HC	84	41.6 ± 0.2	13	16	0.4 ± 0.1	86
James Creek HC	20	41.2 ± 0.3	10	15	0.9 ± 0.2	45
Big "O" HC	14	41.4 ± 0.4	13	10	1.0 ± 0.2	25

[a] WMA—Wildlife Management Area.
[b] NWR—National Wildlife Refuge.
[c] HC—Hunting Club.

not to have overpopulated deer herds, spike-antlered bucks comprised more than 50% of the yearling age class on 21 of the 23 areas sampled.

The mechanism responsible for the soil P and deer body weight relationship can only be speculated at this time. Phosphorus intake has been shown to have a demonstrable effect on body weight and skeletal and antler growth of deer (Short 1969, French et al. 1956). Reitz (1981) reported yearling males on diets containing about 0.4% P gained 0.12 kg per day compared to control males on diets of about 0.2% P which gained only 0.08 kg per day. Antlers were also larger for animals on the 0.4% P diet. Thorsland (1966) found soil P levels to be reflected in plant protein and plant P levels for 7 areas of South Carolina. It is likely that plants on soils high in P will have greater growth and higher P and protein than plants on low P soils.

The significant correlations between other soil measures and deer body weights may be explained in part by their correlation to soil P levels. Correlation coefficients for Ca, K, Mg, pH, and organic matter with P were 0.74, 0.90, 0.74, 0.90, and 0.59, respectively. These correlations were significant at the $P < 0.001$ level. Although organic matter (an indicator of soil nitrogen), pH, and other soil nutrients have major effects on plant growth and nutrient uptake, these variables explained little of the variability for the body weight-soil regressions beyond that accounted for by P. These other variables would likely help to obtain greater predictability for deer body weights in other geographic regions where weights are not so highly correlated with P.

The lack of strong correlations between soil measurements and antler measures was unexpected. There are substantial data to indicate the importance of Ca and P to antler growth (Ullrey 1981). Antler growth is a seasonal phenomenon, occurring primarily in April through September in Mississippi (Jacobson and Griffin 1983). This period also is likely to be the time when protein and phosphorus levels in forage are the highest. Seasonal changes in these nutrients in browse species are well documented (Swank 1956, Short 1969, Blair and Halls 1967). It is likely that plant nutrient levels have their greatest effect on the growth rate of deer in their first year of life. Once skeletal size becomes relatively fixed, sufficient plant nutrients may be present during antler growth periods on even poor soils. This may explain why no significant correlations were seen between soil measures and antler measures of 2½-year-or-older bucks. High mineral requirements for skeletal growth of young animals would explain significant correlations for soil measures and antler measures of yearling bucks. Body growth of young deer is continuous through their first 18 months (French et al. 1956). Therefore, it is also reasonable to assume that a much stronger relationship would be seen between soil nutrients and body weight than with antler measures.

The consistent difference in weights of spike-antlered and fork-antlered yearling bucks on all areas is of importance. Two explanations seem feasible for these differences. Genetics could account for this difference, or timing of birth could also be a factor. In Mississippi, fawns are born from late June through mid-October (Jacobson et al. 1979). Antler growth ceases in September (Jacobson and Griffin 1983). Thus, some yearlings have up to 15 months body growth whereas others have as few as 11 months body growth when their first set of antlers is completed. Because of the relationship between age and growth, yearlings with late birth dates would be expected to have lower body weights and poorer antler development than yearlings from the same area but with early birth dates. Regardless of the cause, it is apparent that managers should take these differences into account when conducting comparative herd health evaluations between areas or years.

The management significance of soil P and body weight relationships should be readily apparent. They may provide a practical tool for relating the physiologic condition of deer to optimum population levels based on site potential. In Mississippi, the association between soil P levels and predicted body weights is now being used as a guide for management decisions relating to the need for increased or decreased antlerless harvests. The prediction equations in Figure 1 are used; and on management areas with average deer body weights below that predicted from soil P levels, increased antlerless harvest is generally recommended. Major improvements in body weights have been observed on some areas following initiation of these recommendations. Similarly it might be expected that habitat improvements or plant fertilization could also lead to improved deer body weights, given management areas with low P soils.

How soil site index relationships translate to sustainable harvest yields or deer density remains to be determined. Additionally, whether or not these same relationships hold for other geographic areas and under different meteorologic conditions should be investigated. Further investigations into the mechanism underlying the soil phosphorus-body weight relationship are also needed.

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