IMPACT OF WINTER GRAZING ON FORAGE BIOMASS-TOPOGRAPHY-SOIL STRENGTH SPATIAL RELATIONSHIPS.

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ABSTRACT

Spatial relationships between soil properties, forage productivity, and landscape attributes can be used to manage site-specific grazing. Soil penetration resistance and forage biomass were collected for three years in a winter grazing experiment. The 4.8 ha experimental area was divided into six paddocks, hay was cut twice per year in the months of May and July, and forage stockpiled after the second cutting. Animals were admitted to paddocks at the end of November, at a stocking rate of 3.2 steers/ha. On half of the total area, animals were removed in January and in April from the remaining area. Three elevation zones were defined in the study area. Soil properties (bulk density, penetration resistance, moisture content, rock fragments, texture, and organic matter) were determined in each elevation zone. Bulk density was significantly higher, and rock fragments significantly lower, at higher elevations. Organic matter was not different among elevation zones. Soil penetration resistance rarely exceeded 2500 kPa, implying that soil strength rarely inhibited biomass production. Soil penetration resistance decreased as elevation increased, and its variability was greatest in the topsoil (0-16 cm). Near-surface (0-4 cm) soil penetration resistance was greater after winter grazing ended. Soil moisture retention was generally greater at the higher elevations, which is likely related to the greater biomass found there. During the study period, biomass accumulation at lower landscape positions was more subject to weather extremes. A strong relationship between moisture content and soil penetration (soil strength) resistance was observed only at the lowest elevation; soil strength at 0 to 2 cm was related to biomass production in the high and medium, but not low, elevation zones. Temporal stability in biomass production was related to elevation. In this study, soil strength changes due to grazing did not limit biomass accumulation.

Keywords: Forage biomass production, elevation, penetration resistance, winter grazing

INTRODUCTION

In the context of West Virginia's rather complex landscapes, little is known about variation in relationships between crop growth and the land/soil resource (Boyer et al., 1996), either at the scale of the individual field or that of the farm. In the hill lands of West Virginia, the small beef cow/calf farm is the most common agricultural enterprise. There is generally little mechanization in these operations. Pasture, animal, and soil management improvements can be used to increase herbage production and utilization, increasing farm sustainability.

Characterization of soil physical properties in the landscape (a spatial context) is the first step to studying the physical processes that occur in the soil system (Thompson et al., 2006; Pena-Yewtukhiw and Grove, 2004). Soil physical properties are related to the "quality" of the system, and soil quality is related to crop, production and enterprise sustainability. Degradation of soil physical characteristics (e.g. compaction) has an "impact" on the system. Study and characterization of the actual state of the soil/landscape ecosystem, of the effect of management or "use" on the system, and of the degradative mechanisms and processes will help to prevent and/or allow management of adverse impacts (Pena-Yewtukhiw et al., 2003), guiding the design of best management techniques. Physical degradation effects include loss of soil productivity, increased erosion and greenhouse gas production, and an increased probability of pollution due to associated effects on soil surface hydrology (Dexter, 2004; Hamza and Anderson, 2005; Schoenholtz et al., 2000). Soil compaction has different causes, but its effects on processes such as soil water and temperature regimes (Gifford and Hawkins 1978) will directly impact the productivity and sustainability of grazing and the hay management of grasslands. An increase in soil strength may be caused by intensive grazing or overgrazing. Increased compaction often reduces site productivity (Douglas, 1994), increases runoff and raises site erosion potential. Compaction severity will depend upon climate, land use, soil type, and soil moisture characteristics. Soil compaction is known to initially decrease macroporosity, which has been related to a decrease in pasture productivity (Drewry et al., 2004).

Spatial relationships between soil properties, forage productivity, and landscape attributes can be used to manage site-specific grazing. Our study objectives were to segment the landscape into homogeneous areas based on topography (elevation); to determine relationships between landscape/topographic elevation and soil properties (bulk density, penetration resistance, organic matter); and to determine the relationship between soil strength, landscape/topographic elevation, and herbage production in a winter grazed field in the Appalachian region of West Virginia.

MATERIALS AND METHODS

Our study was conducted in a five-year winter grazing experiment at the West Virginia University Reedsville Experiment Farm located in Preston Co., West Virginia (515 m above sea level, 79°47W and 39°30N).

The 4.8 hectare experimental area was divided into six paddocks (Fig. 1). The entire experimental area is planted to orchardgrass (*Dactilis glomerata* L.). Hay was cut twice per year, in the months of May and July, and forage stockpiled after the second cutting. Nitrogen fertilizer was applied before each cutting and stockpiling, at a rate of 84 kg N/ha. Animals were admitted to paddocks at the end of November at a stocking rate of 4 steers/ha. In January, the animals were removed from three paddocks (Trt1=Grazed), and in April from the remaining area (Trt2=Grazed&fed). The soils described in the experimental area are Rayne silt loam-3 to 8 percent slopes (RaB), Latham silt loam-3 to 8 percent slopes (LaB), and Gilpin silt loam-8 to 15 percent slopes (GnC). The RaB and GnC soils are found in summit and upper backslope positions, with the LaB in lower backslopes.

Fig. 1. Soil series in the delineated experimental area.

Topography of the study area is relatively uniform, with broad level ridges and side-slopes ranging between 3 and 25%. Two landscape positions were observed in the study area, but for our analysis the area was divided into three elevation zones. The lower elevation corresponded to the lower backslope (500-505 masl), the medium elevation to the middle backslope (504-510 masl), and the higher elevation to the summit (510-515 masl) (Fig. 2). The total elevation difference between the lowest and highest points is around 15 meters.

Soil penetration resistance (Rimik penetrologger) and forage biomass were determined for each of three years in the winter grazing experiment. A total of 300 soil penetration resistance locations (yellow dots, Fig. 2) were sampled every year; two times at 2 cm intervals to a depth of 50 cm. Penetration resistance was measured when soil moisture was at field capacity (two days after a soaking rain), and as close as possible to the scheduled biomass measurements. Herbage height (proxy variable for biomass) was measured using the rising plate meter (Rayburn and Rayburn, 1998) for successive growth stages at each of the 300 sampling points used for the penetration resistance sampling pattern (yellow dots, Fig. 2). For the height versus biomass calibration, 20% of sampling points were randomly selected. Total hay production, per paddock, was determined with the hay harvest in May and July of each year.

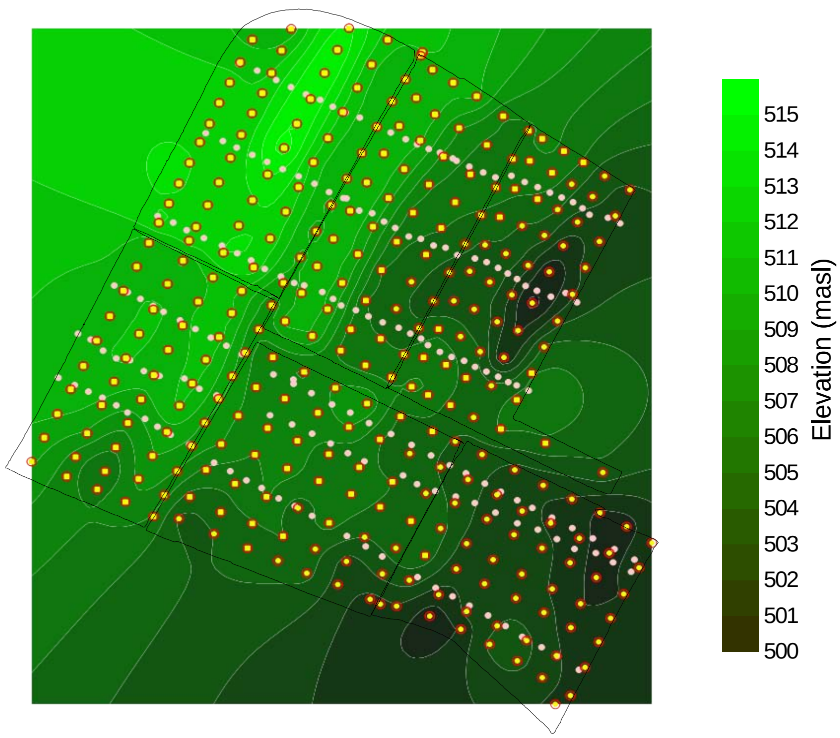

Fig. 2. Study area elevation map and sampling locations

In 2007, we measured soil bulk density (Uhland sampler), rock fragments (gravimetric), soil texture (pipette method), organic matter content (dry combustion), pH (water), and bioavailable Ca, K, and P (Mehlich III extraction) at 180 additional sampling points distributed across the paddocks and elevation zones in the experimental area (pink dots, Fig. 2).

Two synoptic soil moisture sampling events were conducted in 2009. Soil volumetric moisture content was measured using a POGO soil moisture sensor (Stevens, 2005). The sampling was done at the same 300 points where penetration resistance was measured. The first soil moisture sampling event (30 June) occurred 24 hrs after a soaking rain brought the area to field capacity. The second sampling (16 July) occurred at the end of a continuous dry period two–weeks in length. Each sampling event was completed in one three-hour period.

Statistical analysis of our data was performed using SAS software (SAS Institute, 2005). Data were analyzed using one-way ANOVA when comparing soil properties among elevation zones or grazing treatments; Pearson correlation analysis was performed between variables (e.g. penetration resistance and biomass); and Spearman rank correlation was performed between certain temporally measured variables (between penetration resistance events, and between volumetric moisture content sampling events). Variography and kriging were used to prepare visual representations (maps) of the measured variables (Pebesma and Wesseling, 1998).

RESULTS AND DISCUSSION

Impact of topography (elevation zones)

Descriptive statistics for soil bulk density, by elevation zone, are shown in Table 1. Bulk density was increased as elevation rose (Fig.). Rock fragments were lower at high elevations (Table 2). Organic matter was not different among elevation zones (Table 2).

Table 1. Bulk density (July 2007) characterization by elevation zone.

Properties	**Bulk Density**		
	Mean (g/cm^3)	Standard deviation	Coefficient of variation (%)
High elevation	1.20a[1]	0.10	8.54
Medium elevation	1.17ab	0.11	9.51
Low elevation	1.15b	0.10	8.39

[1]Values followed by different letters are significantly different at the 90% level of confidence (α= 0.10).

Soil penetration resistance rarely exceeded 2500 kPa, implying that soil strength rarely inhibited biomass production, and explaining the weak negative relationship between biomass production and penetration resistance ($r<0.10$). Soil penetration resistance increased with soil depth, which is consistent with the increase in clay content with depth in these soil profiles, but there were no significant differences in penetration resistance at deeper depths due to grazing treatments or elevation zones. Independent of the time of the year when soil penetration resistance was measured, it generally decreased as elevation increased, and its variability was greatest at the soil surface (0-16 cm).

Table 2. Comparison of soil properties (July 2007) among elevation zones.

Properties	Elevation Zone		
	High	Medium	Low
Penetration resistance (kPa)	1834 b	1970 ab	2068 a
Organic matter (%)	5.8 a	5.9 a	5.9 a
Moisture, July 2007 (cm^3/cm^3)	26 a	23 b	20 c
Rock fragments (%)	2.04 b	1.99 b	2.46 a
Clay at 0-6 cm depth (%)	26.1 a	26.7 a	23.8 b

[1]Values within a row followed by different letters are significantly different at the 90% level of confidence (α= 0.10).

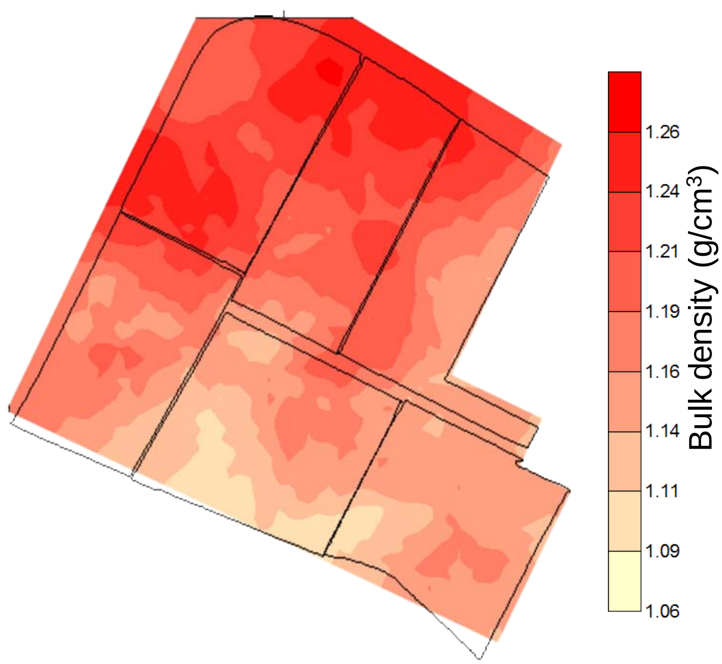

Fig. 3. Bulk density over the study area (July 2007).

Soil volumetric moisture contents were greater at higher elevations, for both measuring events. This soil moisture behavior likely explains the greater biomass found in the higher landscape position.

Soil penetration resistance in the winter grazing treatments (Trt1 and Trt2), increased near-surface (0-10 cm), but was not significantly different at deeper depths. Our measurements exhibited a statistically significant (α=0.10) increase in penetration resistance between November and March/April, indicating the impact of winter grazing on soil compaction (data not shown). The effect of 'grazing compaction' was not evident at deeper depths.

During the study period (2007-2009), herbage biomass production at lower landscape positions was more susceptible to extreme weather conditions (excess rain or drought) than higher and middle elevation areas; the herbage biomass coefficient of variation for the lower position was the highest among all the landscape positions, being almost twice as high as that for the other two zones (Fig. 4). The great variation in soil moisture observed in the lower areas of our study site, being highest in after a rainy period and lowest during a droughty period, appears to be related to the great variability in herbage height/biomass production observed in this zone. A lower value for the Spearman rank correlation coefficient between herbage heights measured at different dates for the lower elevation zones was observed and supports this conclusion.

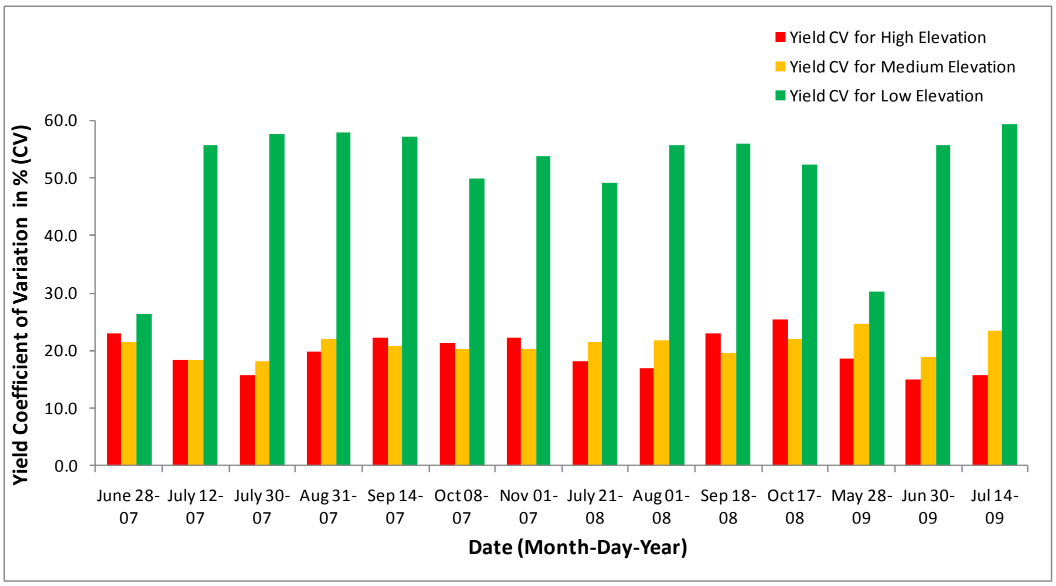

Fig. 4. Coefficient of variation (%) for herbage biomass, by elevation zone.

Variation in paddock penetration resistance and other soil properties caused some of the herbage biomass production variation that is manifest in the site-specific soil-herbage biomass relationship illustrated in Figure 5. Figure 5 shows the high variability in herbage re-growth (expressed in height) thirty (30) after days the second hay cut in 2007.

A strong relationship between soil moisture and soil penetration resistance was observed for lower elevation zones (higher moisture content resulted in lower penetration resistance), but not for more elevated positions. Soil penetration resistance for the 0 to 2 cm depth increment was slightly related to biomass production at high and medium, but not low, elevation (Fig 6).

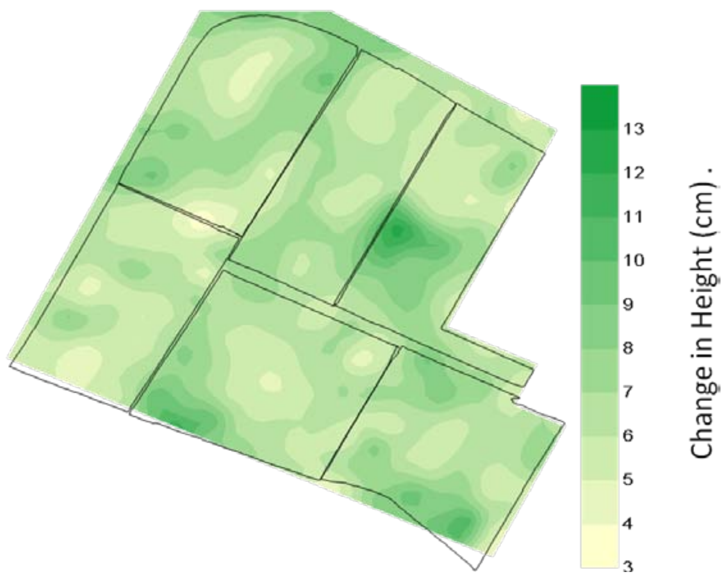

Fig. 5. Change in herbage height 30 days after the second hay cutting in 2007.

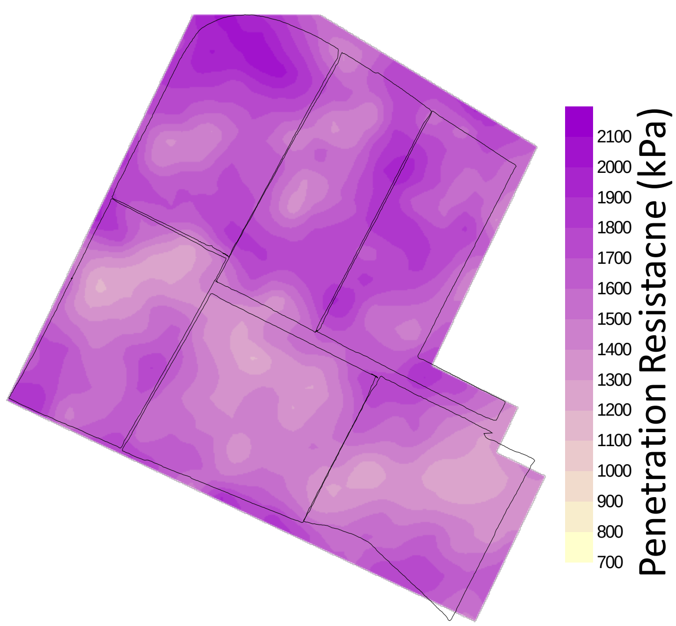

Fig. 6. Soil surface penetration resistance (0-6 cm) in the study area (July 2007).

Temporal stability in the herbage biomass production measured in the two cuttings of forage for hay and assessed through Spearman rank correlation, was not strongly related to elevation (Table 3). This means that biomass production was temporally variable; that temporal consistency was not high. We observed that the Spearman correlation coefficient was 0.76 when hay yields for the high elevation zone were compared to those for the medium zone, 0.60 when comparing the medium elevation zone to the low elevation zone, and 0.45 when comparing the high elevation zone to the low elevation zone.

Table 3. Hay dry matter yield, by cutting, for each elevation zone (2007-2009).

Date	Low Elevation	Medium Elevation	High Elevation
	kg/ha		
May 07	6480	5250	5240
July 07	4640	5950	5640
May 08	5220	5150	3870
July 08	3490	4520	4180
May 09	4980	4950	4360
July 09	3560	3950	4020

Impact of grazing treatments

Bulk density (Table 4) was significantly higher for Trt 2 (Grazed and Fed), but organic matter and penetration resistance (0-6 cm) were consistently lower than in Trt 1 (Grazed). Neither bulk density or penetration resistance reached values considered limiting for herbage production.

Table 4. Comparison of 2007 surface soil properties (0-6 cm) among grazing treatments.

Soil Property	**Treatments**	
	Grazed (Trt 1)	**Grazed and Fed (Trt 2)**
Bulk density (g/cm^3)	1.14 b	1.21 a
Penetration Resistance (kPa)	1978 a	1937 b
Organic matter (%)	6.02 a	5.74 b
Moisture (cm^3/cm^3)	25.1 a	21.3 b
Rock fragments (%)	2.25 a	2.08 a
Clay (%)	24.2 b	26.8 a

[1]Values within a row followed by different letters are significantly different at the 90% level of confidence (α= 0.10).

Under our study conditions soil penetration resistance was not limiting to herbage production, although changes in this property due to winter grazing were observed. Using the information provided from our spatial (landscape/elevation) and temporal analysis, we could recommend a better grazing management system. We would recommend increasing the number of animals or the length of grazing time in areas that were consistently producing more herbage biomass during the year and/or where lower penetration resistance was observed.

CONCLUSIONS

During the study period, herbage at lower landscape positions was more susceptible to extreme weather conditions (excess rain or drought) than that growing in higher and middle elevation zones. We would recommend managing these areas with less animals and/or a shorter winter grazing time.

Temporal stability in herbage height was found to be related to elevation. Medium elevation position showed the highest stability measured with Spearman rank correlation index, followed by the higher and the lower landscape positions.

Variation in paddock penetration resistance and other soil properties caused some of the herbage biomass production variation that is manifest in the site-specific soil-herbage biomass relationship. Soil penetration resistance for the 0 to 2 cm depth interval was slightly related to biomass production in high and medium, but not low, elevation zones. Further study of the characteristics of these pasture areas would improve management decisions.

Under our study conditions, soil penetration resistance was not a limiting factor to herbage production, although changes in this property due to winter grazing were observed.

Sustainable livestock production in West Virginia can be achieved by maintaining pasture productivity, which depends on maintaining soil quality. We conclude that the site-specific response of soil and biomass production to grazing management, and knowledge of soil properties and the weather, indicates that we should have different animal densities-time periods at each landscape/elevation position. The differences in the temporal stability of the biomass response are site-specific, and in our study area this indicates that we should decrease the number of animals in the lower landscape position and increase animal numbers in the upper landscape position.

REFERENCES

Boyer, D. G., Wright, R. J., Feldhake, C. M., and Bligh, D. P. 1996. Soil Spatial Variability Relationships in a Steeply Sloping Acid Soil Environment. Soil Science, 161: 278-287.

Betteridge, K., A. D. Mackay, T. G. Shepherd, D. J. Barker, P. J. Budding, B. P. Devantier, and D. A. Costall. 1999. Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. Aust. J. Soil Res. 37:743-760.

Drewry, J.J., R.O. Littlejohn, R.J. Paton, P.L. Singleton, R.M. Monaghan, and L.C. Smith. 2004. Dairy pasture responses to soil physical properties. Australian Journal of Soil Research. 42: 99-105.

Dexter, A.R. 2004. Soil physical quality Part I. Theory, effects of soil texture, density and organic matter, and effects on root growth. Geoderma 120:201-214.

Douglas, J.T. 1994. Responses of perennial forage crops to soil compaction. Development in Agricultural Engineering. 11: 343-364.

Gifford G.F., and R.H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resources Research 14, 305–313.

Hamza, M.A., and W.K. Anderson. 2005. Soil compaction in cropping systems; A review of the nature, causes and possible solutions. Soil Tillage Res. 82:121-145.

Pebesma E.J., and C. G. Wesseling. 1998. GSTAT: a program for geostatistical modelling, prediction and simulation. Computers Geosciences 24: 17-31.

Pena-Yewtukhiw, E.M., and J.H. Grove. 2004. Spatial/temporal probabilistic distribution of soil moisture in a well-drained Paleudalf as influenced by landscape. Proc. 8th Int. Conf. Precision Agriculture. Minneapolis, Minnesota. (CD-ROM), July 25-28.

Pena-Yewtukhiw, E.M., J.H. Grove, and J.A. Thompson. 2003. Role of topography in the probability of response of no-till corn yield response to in-row fertilization. p. 51-58, Proc. Southern Plant Nutrient Management Conf. (CD-ROM), Olive Branch, Mississippi. Oct. 7-8.

Rayburn, E.B., and S.B. Rayburn. 1998. A standardized plate meter for estimating pasture mass in on-farm research trials. Agronomy Journal 90: 241

Schoenholtz, S.H., H. Van Miegroet, and J.A. Burger. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. Forest Ecology and Management. 138:335-356.

SAS Institute. 2005. SAS user's guide. Cary, NC.

Stevens, Water Monitoring System. 2005. POGO Manual. Stevens Water Monitoring System Inc. Portland, Oregon.

Thompson J.A., E.M. Pena-Yewtukhiw, and J.H. Grove. 2006. Soil-landscape modeling across a physiographic region: topographic patterns and model transportability. Geoderma 133:57-70.