Chariton Valley Biomass Project
Task 5.10.0

Site-specific Management for Biomass Production

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BACKGROUND

Concern over the finite supply and environmental impacts of fossil fuels has increased interest in renewable energy sources. In Iowa, one potential source of renewable energy is perennial grasses. Warm-season (C4) grasses possess a number of attributes making them well-suited as bioenergy crops. Switchgrass (*Panicum virgatum* L.), a native, warm-season grass, has been identified as an ideal biomass energy crop because it yields well on marginal soils with moderate inputs and has favorable fuel characteristics in terms of energy content, ash content, and chemistry. Switchgrass and other C4 grasses also contain low amounts of silica, the major component of ash. In addition to the environmental benefits of using switchgrass as a renewable source of energy, it also provides other valuable ecosystem services. Its dense root system filters pesticides and herbicides protecting groundwater (CVRCD, 2000). Furthermore, the dense, fibrous root system also traps nitrogen and nutrients that escape other plant root systems.

Much of the interest in utilizing switchgrass as a biofuel in Iowa centers on the four counties encompassed by the Chariton Valley Resource Conservation and Development (CVRCD) organization. The four counties (Appanoose, Lucas, Monroe, and Wayne) are situated on the Southern Iowa Drift Plain (Prior, 1991). Southern Iowa landscapes are extremely diverse in terms of elevation, slope, and soil characteristics. Although the topography varies, much of the area included in the CVRCD is well-suited for biomass production. Southern Iowa landscapes include highly erodible land, wetlands that have been converted to agricultural uses, and marginal agricultural land – all areas that are recommended for perennial biomass energy crop production (Paine, 1996).

A better understanding of edaphic factors that affect switchgrass yield would enable producers to better manage biomass crops by applying management practices that optimize site productivity. Inputs such as lime and fertilizer can be applied to areas that have greater yield potential and withheld from less productive zones. As a result, crops at more productive sites would have adequate nutrients while plants in other areas limited by factors such as soil type, landscape position, and moisture would not have excess nutrient supplies. However, before such management practices can be developed, mechanisms that impact switchgrass biomass yield must be characterized and understood.

RATIONALE

Southern Iowa landscapes are extremely diverse in terms of soil characteristics and topography. Previous research has demonstrated a significant impact of landscape position on species adaptation and productivity suggesting a potential benefit could be derived from site-specific management of switchgrass grown for biomass (Harmoney et al., 1998; Guretzky et al., 2004). By studying the relationships between soil and terrain properties and switchgrass productivity it should be possible to develop strategies for optimum biomass production from available land resources.

Researchers working on spatial variability in productivity across landscapes have had limited success in identifying underlying soil characteristics that are consistently related to yield (Boyer et al., 1996; Miller et al., 1988). However, landscape characteristics have been shown to be good indicators of site productivity. In our work we have been able to identify sites based upon landscape position and slope class (Harmoney et al., 1998). On landscapes in the Southern Iowa Drift Plain, side slopes are typically the least productive sites, but tend to have higher species diversity because competition from grasses is lower. A greater number of ecological niches exist in these positions. Conversely, upland and bottomland sites are inherently more productive than side slopes and are generally dominated by one or a few grass species.

Site-specific management technologies have shown great potential for improving the efficiency of crop production (Schepers and Francis, 1998) and may be useful for developing and optimizing biomass production systems. Nowalk (1998) argued that true site-specific management systems "should allow the producer to respond to ecological variation in a rational and pro-active manner." This is especially relevant to ecosystems in Southern Iowa, which are generally located on marginal landscapes with inherently diverse edaphic characteristics. However, in order to develop site-specific management strategies for biomass production it is first necessary to be able to characterize landscapes according to their production potential.

Digital elevation model (DEM) technologies coupled with global positioning system (GPS) data and geographic information system (GIS) mapping and analytical tools can be used to develop accurate digital terrain maps (Wilson et al., 1998). These maps could potentially be an excellent tool for developing and optimizing site-specific management systems. Slope can be derived by spatial analysis of digital elevation maps. Using this information, management units or zones could be identified based on landscape position. Kaspar et al. (2003) concluded that terrain attributes could be used to identify spatial patterns in corn (*Zea mays* L.) yield.

Soil electroconductivity (EC) measurements have been used to characterize spatial variability in soils (Doolittle et al., 1994). Soil properties that have been correlated with EC include texture, organic matter, cation exchange capacity, and topsoil depth. All of these soil characteristics are highly related to potential biomass yield and it is reasonable to assume that EC measurements could be used as an indirect method of biomass potential. Electromagnetic induction (EMI) measures soil EC by emitting electromagnetic energy into the soil and measuring the electromagnetic field that it generates. The field strength is proportional to EC. Data collected with EMI sensors can be coupled with GPS data to produce soil EC maps using GIS. Mathematical relationships between yield and EC can then be derived using spatial statistics. Shanahan et al. (2004) observed strong associations between yield variation and assessments of landscape attributes including elevation and apparent soil electroconductivity (soil ECa).

Multispectral radiometry involves the collection of visible and near infrared reflectance data from plant canopies. Using multivariate calibration techniques, it is possible to develop relationships between spectral properties and plant community characteristics such as biomass (Olson and Cochran, 1998), nitrogen status, disease infestation (Green, 1998), and plant stress (Trenholm et al., 1999). Spectral data could be collected simultaneously with elevation data and used to further develop and refine selection of management units. Once management units are established, biomass data collected via spectral radiometry could be layered with other data to estimate seasonal growth rates. This information could in turn be used for making harvesting and other management decisions.

OBJECTIVES

The overall objective of this research was to assess technologies for characterizing potential biomass productivity of diverse landscapes and determine the potential for use of site-specific management technologies for production of biomass crops. Specific objectives were to: 1) characterize productivity of switchgrass using digital elevation mapping, soil electrical conductivity mapping, and multispectral radiometry (vis/nir); and 2) develop models for characterizing potential productivity of switchgrass using this information.

APPROACH

Six switchgrass swards in the Chariton Valley Biomass Project area were selected as 'random' fields. The six sites were designated as A, B, C, D, E, and F. Their locations are shown in the map presented in Fig. 1. Establishment methods, liming additions, and fertilizer inputs varied among sites and represented the diversity of management practices encountered in the Chariton Valley Biomass Project area.

Sampling

In 2002, elevation data were collected using a survey-grade GPS system. The data were incorporated into a GIS, and a digital elevation map (DEM) was created for each site using ArcGIS 9 Spatial Analyst (ESRI, Redlands, CA). The kriging method in ArcGIS was used to develop each elevation map, and parameters were method = ordinary, semivariogram model = spherical, search radius type = variable, number of points = 12, and output cell size = 3 m^2. Slope was derived from the DEM using the Spatial Analyst extension in ArcGIS.

Soil EC_a was measured and georeferenced on May 15, 2003, using an EM-38 (Geonics Limited, Mississauga, ON, Canada) EMI meter. Kriging was used to interpolate EC_a to a raster for each site. Parameters were method = ordinary, semivariogram model = spherical, search radius type = variable, number of points = 12, and output cell size = 3 m^2.

Yield data were georeferenced on August 8 and August 9, 2002 (referred to as 'summer' harvest), and again from December 3 to December 5, 2002 (referred to as 'fall' harvest). The sampling grid consisted of 75-ft centers with occasional random subsampling at shorter distances. During the summer harvest, yield was measured using a 10.8-ft^2 sampling frame. All biomass within the quadrat was clipped to one-inch above the ground and put into cloth bags for drying to estimate biomass yield at each plot. Samples were dried for 48 h or until dry in a forced-air dryer at 140° F to determine biomass yield on a dry weight basis.

Canopy reflectance data was collected concurrently with yield data during the summer harvest. The data were collected using a MSR87 multispectral radiometer (CROPSCAN, Inc., Rochester, MN) by measuring reflectance over the center of each 1-m^2 plot. Reflectance was measured at the center of the following eight wavebands: 460 nm, 510 nm, 560 nm, 610 nm, 660 nm, 710 nm, 760 nm, and 810 nm. Normalized difference vegetation indices (NDVI) were calculated for each plot as [(NIR – red) / NIR + red)] where NIR was reflectance measured at 760 nm and red was reflectance measured at either 610 nm ($NDVI_1$) or 660 nm ($NDVI_2$). Ratios of NIR (760 nm) to red were also calculated using either 610 nm (NIR/R_1) or 660 nm (NIR/R_2).

During the fall, after a killing frost, each of the fields was mowed with a 14-ft self-propelled mower conditioner cutting a 13.5-ft effective swath. To calculate yield, 3.3-ft sections of the windrow were weighed in the field and then subsampled. Subsamples were put into cloth bags and later were dried for 48 h or until dry in a forced-air dryer at 60° C to determine percent dry matter. The yield of each plot was calculated based on the percent dry matter of subsamples.

Chemical Analyses

Samples from both harvests were initially ground to pass through a 6-mm mesh screen using a Model 4 Wiley Laboratory Mill and then ground again using a 1-mm screen in a UDY cyclone mill (UDY Manufacturing, Fort Collins, CO) in preparation for fuel characteristics assessment. Fuel characteristics evaluated were percent ash and gross energy. Percent ash was determined by first placing a 1.5 g forage sample into a preweighed porcelain crucible. The sample was then placed in a muffle furnace at 1100° F overnight. The following morning, the crucibles were transferred to a desiccator and cooled to room temperature. They were then weighed, and the percent ash was calculated on a dry matter basis (Chemical and Biological Methods for Grain and Forage Sorghum, Department of Agronomy, Purdue). Gross energy was determined by calculating the calorific values (BTU/lb) of each sample (Hazen Analytical Laboratories, Golden, CO). Gross energy content values were not sulfur corrected.

Statistical Analysis

Elevation, slope, and soil EC_a measurements were joined to each yield sample point using ArcGIS. Sample points within each site were then evaluated using Management Zone Analyst© (MZA) (University of Missouri-Columbia and Agricultural Research Service, 2000). Yield sample points were grouped into similar zones based on elevation, slope, and soil EC_a by a clustering procedure (Chang et al., 2004). Variation in yield was evaluated by zone with the GLM analysis of variance procedure (SAS, Cary, NC) using a nested model with zones nested within site. Both the fuzziness performance index (FPI) and normalized classification entropy index (NCE) calculated by MZA along with the yield comparison by zone in SAS were used to determine the optimum number of management zones for each field for both summer and fall harvests. Within each zone, the mean, standard deviation, and range were determined for the elevation, slope, soil EC_a, yield, percent ash, and gross energy variables using the UNIVIARIATE procedure (SAS, Cary, NC). Variances associated with yield and fuel characteristics were determined for comparison among and within sites using the VARCOMP procedure (SAS, Cary, NC).

The relationship between biomass yield and spectral reflectance was evaluated using multivariate analyses. Biomass yield was regressed on reflectance at the eight wavelengths using the REG procedure (SAS, Cary, NC). A stepwise selection algorithm was used to develop the best fitting regression model for predicting yield based on spectral reflectance. Principle components were calculated using the PRINCOMP procedure (SAS, Cary, NC) and scores for each observation were computed. Biomass yield was regressed on principle component scores using the REG procedure (SAS, Cary, NC).

RESULTS

Yield

Biomass yield, ash content, and energy content varied considerably within and among sites (Fig. 2). Average biomass yield across all sites was 2.97 T/A in the summer and 2.12 T/A in the fall. Mean yields across sites ranged from 1.00 T/A at site B to 3.94 T/A at site D in the summer and from 0.51 T/A at site B to 3.69 T/A at site F in the fall. For both summer and fall harvests, a majority of the variation in yield was described by differences among sites (Table 1). During the summer harvest, variation among sites accounted for 57.3% of the total variation in biomass yield. Variation among sites accounted for 70.7% of total observed variation in biomass yield for the fall harvest. Within-site variation in biomass yield accounted for only 27.4% and 17.1% of total variation in biomass yield for the summer and fall harvests, respectively.

Composition

Ash content ranged from 3.3% to 11.4% and averaged 6.0% over the six sites for the summer harvest (Fig. 2). For the fall harvest, ash content ranged from 2.6% to 9.1% and averaged 4.3% over all sites. There was considerable variation in ash content among sites. However, in contrast to biomass yield, variation in ash content within sites accounted for a greater percentage of the total variation than variation among sites (Table 1). Less than half of the total variation in ash content was accounted for by variation among sites. For the summer and fall harvests, 44.5% and 27.9% of total variation was due to variation among sites, respectively. However, within-site variation accounted for 55.5% and 47% of total variation for the summer and fall harvests, respectively.

Energy content of switchgrass biomass ranged from 7035 to 7892 and averaged 7566 BTU/lb over the six sites for the summer harvest (Fig. 2). For the fall harvest, energy content ranged from 7175 to 7953 and averaged 7655, respectively. Most of the total variation in energy content was accounted for by within-site variation (Table 1). Variation within sites accounted for 80.3% of total variation in the summer, and 54.6% in fall. Variation among sites accounted for only 19.7% of the total variation in the summer and 22.6% of the total variation in the fall.

Management Zone Analysis

Based on the FPI and NCE index in the MZA output as well as the significance ($P = 0.1$) of the yield comparisons among zones during the summer, site B was divided into one zone, site E into two zones, sites A and C into four zones, and sites D and F into 5 zones. For analysis of fall biomass yields, site E was divided into four zones, sites C, D, and F divided into five zones, and sites A and B into six zones. The mean, standard deviation, and range for elevation, slope, soil EC_a, yield, ash, and energy content are summarized for each zone within each site in Tables 2 through 7. Maps displaying variation in slope, soil EC_a, summer and fall yield, summer and fall ash content, summer and fall energy content, and management zones are presented in Figures 3 through 8.

Management zones accounted for relatively little of total variation in biomass yield, ash content, and energy content. Within sites, biomass yields varied little among zones (Tables 2-7). Variation among plots within zones was greater than variation among the potential management zones (Table 1). Management zones accounted for only 15.3% of total variation in biomass yield for the summer harvest, and 12.1% for the fall harvest.

Spectral Reflectance

Normalized difference vegetation indices and NIR/Red ratios were significantly but not highly correlated with biomass yield (Table 8). Partial correlations ranged from -0.18 for $NDVI_1$ to -0.31 for NIR/R_2. Regression of biomass yield against reflectance measured for each of the eight wavelengths resulted in a substantially better relationship for describing biomass yield than any of the standard indices or ratios (Table 9). Using a stepwise selection algorithm, all eight wavelengths were included in the regression model. The model described about 62% of the total variation in biomass yield. Principal component regression resulted in a model that described a comparable amount of variation in biomass yield as multiple linear regression (Fig. 9).

DISCUSSION

Considerable variability in biomass yield, ash content, and energy content was observed among and within sites (Table 1). We expected a significant proportion of the variability would be related to site characteristics such as elevation and slope. However, when elevation, slope, and soil EC_a were used to delineate management zones using MZA, the resulting zones did not explain the variation in yield that was observed for the summer and fall harvests.

Biomass yield was more strongly influenced by field site than any measured land or soil characteristics within sites. Certain sites were more productive than others and these differences were apparently related to factors not measured in this study. Sites were selected to represent a ‘random’ sample of switchgrass biomass production fields in the CVRCD. It is likely that a large proportion of the yield differences among sites were related to management factors including establishment practices, fertilizer application, and weed control. There was substantial variability in biomass yield within sites that was not well explained by management zones based on slope, elevation, and apparent EC. However, mapping biomass yield using GPS and GIS technologies readily identified areas of fields where future management inputs and efforts should be focused. Yield data was the most labor intensive and expensive dataset to collect and consequently was collected the most sparsely. Increasing the density of yield data would improve the precision of yield mapping and provide more reliable information for making management decisions. Development of yield monitors for biomass harvesting equipment that can be interfaced with a GPS unit for georeferencing the data would greatly enhance the feasibility of using yield mapping to enhance management efforts.

Standard vegetation indices based on spectral reflectance at specific wavelengths were not highly correlated with biomass yield. However, regression models based on all eight measured wavelengths, or principal components derived from them, explained about 62% of the observed variation in biomass yield. That the selection algorithm selected all eight wavelengths for the regression equation suggests that further improvements in predicting biomass yield might be made by measuring reflectance for a larger array of wavelengths. Collection of spectral reflectance using a hyperspectral radiometer and calibration using advanced chemometric procedures should greatly improve prediction performance. Further refinement of remote sensing techniques for predicting biomass yield offers great potential for improving management on both site-specific and regional scales.

Although energy value and ash content varied among and within sites, the values observed in this study were within normal ranges reported for herbaceous biomass. Lower energy values were generally related to higher ash contents within the range of observed values. Although not specifically measured in this study, samples with higher ash content were likely contaminated with broadleaf weeds that accumulate higher mineral concentrations than grasses.

Variability in ash content and, therefore, energy value of biomass would likely be reduced through selective control of broadleaf weeds at those sites for which higher ash contents were observed. Effective weed control should decrease average ash content and increase yield of biomass at these sites.

CONCLUSIONS

Although no strong relationships between elevation, slope, and soil EC_a were measured with respect to biomass yield and composition, a high degree of yield variability exists in the Chariton Valley Biomass Project area. The variability present demonstrates the need for future research focused on site-specific management of switchgrass as a biomass crop. By identifying areas within fields that show greater productivity, potential management practices can be targeted to maximize profitability. Yield mapping through the use of yield monitors and remote sensing represent potentially viable technologies for characterizing and managing variation in switchgrass biomass productivity. Because yield and fuel quality traits were not well correlated with measured land and soil characteristics, it was not possible to develop an acceptable model for predicting them based on elevation, slope, and soil EC_a. However, it is possible that these tools could be potentially useful for refining management practices in well established switchgrass stands grown under intensive management.

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Table 1. Variation in biomass yield and fuel characteristics among warm-season switchgrass sampling sites, zones, and plots.

Component	Total Variance	Site Variance	Site % Total	Zone Variance	Zone % Total	Plot Variance	Plot % Total
Summer							
Yield (ton/ac)	2.340	1.341	57.3	0.359	15.3	0.641	27.4
Ash (% DM)	2.731	1.217	44.5	0	0.0	1.515	55.5
Energy (BTU/lb)	16696	3291	19.7	0	0.0	13405	80.3
Fall							
Yield (ton/ac)	1.541	1.090	70.7	0.187	12.1	0.264	17.1
Ash (% DM)	1.419	0.396	27.9	0.355	25.1	0.667	47.0
Energy (BTU/lb)	16778	3800	22.6	3822	22.8	9156	54.6

Table 2. Mean, standard deviation (SD), and range of elevation values by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	306.20	1.48	4.00	A	1	308.42	1.57	5.00
	2	304.33	1.37	4.00		2	306.43	1.90	6.00
	3	307.26	1.63	6.00		3	310.88	1.25	3.00
	4	310.59	1.00	4.00		4	301.00	1.00	2.00
						5	303.80	1.79	4.00
						6	304.14	1.35	4.00
B	1	342.58	1.60	7.00	B	1	341.60	0.89	2.00
						2	340.25	0.50	1.00
						3	342.75	1.16	3.00
						4	344.25	0.93	3.00
						5	341.27	0.79	2.00
						6	343.33	0.87	2.00
C	1	308.33	1.15	2.00	C	1	307.06	0.25	1.00
	2	306.88	0.35	1.00		2	307.33	0.58	1.00
	3	308.00	0.00	0.00		3	308.20	0.45	1.00
	4	307.00	0.00	0.00		4	306.60	0.55	1.00
						5	307.00	0.00	0.00
D	1	329.00	0.00	0.00	D	1	329.00	0.00	0.00
	2	328.00	0.00	0.00		2	328.00	0.00	0.00
	3	328.00	0.00	0.00		3	328.00	0.00	0.00
	4	327.00	0.00	0.00		4	328.00	0.00	0.00
	5	328.00	0.00	0.00		5	327.00	0.00	0.00
E	1	325.00	1.87	4.00	E	1	323.33	0.71	2.00
	2	323.50	1.00	2.00		2	325.83	0.75	2.00
						3	326.00	0.00	0.00
						4	324.43	0.53	1.00
F	1	324.71	1.11	3.00	F	1	321.67	0.58	1.00
	2	323.33	0.58	1.00		2	321.67	1.53	3.00
	3	327.00	1.15	2.00		3	324.00	0.00	0.00
	4	326.50	0.71	1.00		4	325.00	1.21	3.00
	5	321.67	0.52	1.00		5	327.25	0.50	1.00

Table 3. Mean, standard deviation (SD), and range of slope values by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	10.60	1.67	4.00	A	1	8.05	1.39	5.00
	2	6.00	2.41	9.00		2	5.86	1.57	5.00
	3	7.42	1.57	7.00		3	3.75	0.89	2.00
	4	5.18	1.70	6.00		4	9.20	1.30	3.00
						5	6.00	1.22	3.00
						6	10.86	1.77	5.00
B	1	6.67	3.39	16.00	B	1	3.00	2.00	5.00
						2	10.00	2.94	6.00
						3	11.00	2.20	6.00
						4	5.81	2.17	8.00
						5	5.73	2.05	7.00
						6	4.22	1.20	3.00
C	1	6.67	1.15	2.00	C	1	1.56	0.73	2.00
	2	0.88	0.99	3.00		2	5.33	1.53	3.00
	3	2.13	1.64	4.00		3	1.80	1.92	5.00
	4	0.41	0.72	3.00		4	1.20	1.30	3.00
						5	0.32	0.48	1.00
D	1	0.71	0.49	1.00	D	1	0.89	0.33	1.00
	2	4.67	1.15	2.00		2	2.00	1.00	2.00
	3	2.33	1.15	2.00		3	4.00	1.41	3.00
	4	2.33	0.58	1.00		4	1.07	0.47	2.00
	5	2.00	0.67	2.00		5	1.67	1.53	3.00
E	1	8.60	1.34	3.00	E	1	7.33	1.00	3.00
	2	8.50	1.00	2.00		2	7.67	1.21	3.00
						3	4.50	0.71	1.00
						4	9.71	1.25	4.00
F	1	10.71	1.11	3.00	F	1	6.33	1.53	3.00
	2	11.33	1.53	3.00		2	6.67	0.58	1.00
	3	7.25	0.50	1.00		3	10.50	0.71	1.00
	4	11.50	0.71	1.00		4	10.92	1.00	4.00
	5	7.67	1.37	3.00		5	5.50	1.29	3.00

Table 4. Mean, standard deviation (SD), and range of soil EC_a values by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	22.40	7.73	20.00	A	1	7.05	3.10	10.00
	2	23.25	4.97	16.00		2	19.29	4.68	15.00
	3	8.00	3.79	11.00		3	8.25	2.82	9.00
	4	6.35	3.64	12.00		4	20.60	3.51	9.00
						5	16.20	4.44	11.00
						6	26.86	5.46	17.00
B	1	23.38	8.73	34.00	B	1	31.20	2.86	7.00
						2	36.25	3.10	7.00
						3	18.75	4.30	13.00
						4	20.25	4.51	17.00
						5	23.45	3.39	10.00
						6	10.78	3.83	10.00
C	1	23.00	7.21	14.00	C	1	4.19	2.97	11.00
	2	15.63	3.96	12.00		2	19.00	9.64	18.00
	3	23.50	8.38	23.00		3	24.00	3.54	9.00
	4	5.26	2.67	10.00		4	21.00	9.90	20.00
						5	5.77	2.88	10.00
D	1	3.43	2.23	6.00	D	1	2.67	1.80	5.00
	2	3.00	3.61	7.00		2	17.00	4.00	8.00
	3	14.00	1.73	3.00		3	1.60	0.89	2.00
	4	6.00	2.00	4.00		4	2.86	1.61	5.00
	5	3.20	1.62	5.00		5	5.67	4.62	8.00
E	1	18.00	6.82	17.00	E	1	21.11	5.18	16.00
	2	15.75	5.50	10.00		2	20.00	3.90	10.00
						3	7.00	1.41	2.00
						4	15.71	5.25	15.00
F	1	22.86	3.67	10.00	F	1	4.00	3.46	6.00
	2	15.33	1.53	3.00		2	18.00	6.08	11.00
	3	4.00	0.00	0.00		3	28.00	0.00	0.00
	4	14.00	7.07	10.00		4	15.17	4.30	14.00
	5	16.33	4.46	14.00		5	5.25	3.30	7.00

Table 5. Mean, standard deviation (SD), and range of biomass yield by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	3.00	1.20	2.84	A	1	1.75	0.36	1.17
	2	3.51	0.54	2.16		2	1.71	0.37	1.00
	3	2.81	0.97	3.09		3	1.47	0.48	1.57
	4	3.32	0.82	2.55		4	1.19	0.55	1.36
						5	1.89	0.61	1.70
						6	1.79	0.46	1.38
B	1	0.99	0.38	1.63	B	1	0.70	0.21	0.53
						2	0.93	0.27	0.63
						3	0.61	0.42	1.09
						4	0.32	0.30	0.95
						5	0.70	0.57	2.04
						6	0.29	0.17	0.53
C	1	2.69	0.31	0.61	C	1	1.51	0.24	1.10
	2	3.37	1.02	2.73		2	1.61	0.53	1.01
	3	3.18	1.02	3.39		3	1.73	0.51	1.33
	4	2.60	1.05	4.91		4	2.13	0.95	2.23
						5	1.85	0.53	1.95
D	1	3.85	1.16	3.69	D	1	3.18	0.68	1.93
	2	2.82	0.29	0.53		2	2.64	0.28	0.53
	3	4.70	0.52	1.03		3	2.13	1.15	3.12
	4	4.12	1.10	2.07		4	2.75	0.70	2.60
	5	3.97	1.38	4.28		5	3.48	1.32	2.62
E	1	2.52	0.77	1.78	E	1	2.51	0.95	3.17
	2	3.79	1.71	3.45		2	1.83	0.81	1.67
						3	1.35	0.68	0.97
						4	2.72	0.48	1.22
F	1	4.02	1.50	4.26	F	1	3.56	1.03	2.05
	2	2.99	0.96	1.71		2	4.14	1.42	2.60
	3	3.69	1.30	2.61		3	3.75	0.83	1.17
	4	4.76	1.64	2.32		4	3.87	1.00	3.66
	5	4.18	1.44	3.70		5	2.89	1.44	3.43

Table 6. Mean, standard deviation (SD), and range of ash content by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	5.27	0.60	1.46	A	1	3.67	0.27	1.04
	2	4.78	0.59	1.99		2	3.78	0.60	1.80
	3	5.02	0.62	2.29		3	3.93	0.33	0.94
	4	4.99	0.35	1.51		4	3.70	0.25	0.62
						5	3.54	0.24	0.60
						6	3.40	0.34	1.11
B	1	7.19	1.72	6.36	B	1	3.74	0.82	1.83
						2	3.63	0.32	0.70
						3	4.52	1.07	3.67
						4	4.79	0.85	3.01
						5	4.21	0.58	1.79
						6	5.08	0.63	1.97
C	1	5.82	0.04	0.08	C	1	4.92	0.44	1.67
	2	5.74	0.78	2.17		2	4.73	0.46	0.92
	3	5.60	0.60	1.73		3	4.58	0.18	0.47
	4	6.13	0.90	5.55		4	4.30	0.43	1.14
						5	4.64	0.45	2.04
D	1	4.82	0.48	1.11	D	1	3.45	0.44	1.33
	2	4.28	0.29	0.58		2	3.49	0.26	0.45
	3	4.74	0.23	0.46		3	3.73	0.31	0.74
	4	4.55	0.63	1.26		4	3.50	0.33	1.46
	5	4.94	0.62	1.84		5	3.70	0.27	0.47
E	1	5.69	2.32	5.78	E	1	5.18	2.39	6.29
	2	4.70	1.44	3.04		2	6.98	1.55	4.40
						3	7.21	2.10	2.97
						4	4.20	0.45	1.21
F	1	5.07	0.72	2.14	F	1	4.44	1.26	2.44
	2	4.87	0.34	0.66		2	5.41	3.18	5.85
	3	4.44	0.36	0.79		3	4.23	0.95	1.34
	4	5.43	0.87	1.24		4	3.86	1.99	5.73
	5	5.13	0.35	0.95		5	4.06	1.01	2.18

Table 7. Mean, standard deviation (SD), and range of energy content by zone for each site during summer and fall harvests.

Summer					Fall				
Field	Zone	Mean	SD	Range	Field	Zone	Mean	SD	Range
A	1	7554.00	161.23	384.00	A	1	7726.95	65.48	232.00
	2	7555.00	76.40	235.00		2	7713.29	76.66	214.00
	3	7606.84	80.35	259.00		3	7724.13	81.19	241.00
	4	7605.94	82.19	303.00		4	7676.20	35.35	93.00
						5	7747.20	49.64	133.00
						6	7706.00	53.66	129.00
B	1	7503.05	143.77	624.00	B	1	7708.20	86.94	225.00
						2	7803.00	114.66	260.00
						3	7635.75	74.01	183.00
						4	7671.13	100.75	411.00
						5	7658.91	87.38	309.00
						6	7642.56	96.16	331.00
C	1	7525.33	65.74	127.00	C	1	7518.81	127.63	500.00
	2	7549.75	88.50	274.00		2	7579.00	97.55	192.00
	3	7576.75	71.72	206.00		3	7661.00	102.40	231.00
	4	7572.41	108.11	681.00		4	7607.40	59.91	143.00
						5	7611.55	57.43	240.00
D	1	7584.29	106.75	298.00	D	1	7739.67	65.62	214.00
	2	7656.33	59.53	112.00		2	7693.33	124.13	216.00
	3	7650.67	20.43	38.00		3	7726.00	157.81	423.00
	4	7611.67	182.94	364.00		4	7628.00	108.76	375.00
	5	7630.70	73.93	266.00		5	7767.67	52.20	100.00
E	1	7603.80	113.47	284.00	E	1	7553.33	150.11	463.00
	2	7693.50	182.80	378.00		2	7433.50	172.87	489.00
						3	7401.00	172.53	244.00
						4	7672.86	67.81	164.00
F	1	7660.86	59.47	184.00	F	1	7684.67	117.93	235.00
	2	7622.33	30.92	55.00		2	7528.00	188.22	369.00
	3	7764.75	86.14	184.00		3	7621.50	84.15	119.00
	4	7554.00	59.40	84.00		4	7743.33	195.18	591.00
	5	7647.17	142.38	385.00		5	7700.25	126.01	272.00

Table 8. Mean, standard deviation, and range of biomass yield, reflectance at eight wavelengths, and four vegetation indices over summer harvest samples.

Variable	Mean	Standard Deviation	Minimum	Maximum	Correlation With Yield	P > |r|
Biomass Yield (lb/acre)	5055	2895	571	12764	-	-
Wavelength						
460	2.55	0.47	1.63	5.33	0.14	0.0212
510	3.24	0.51	2.18	5.79	0.08	0.1773
560	6.72	0.93	4.11	9.89	-0.11	0.0687
610	5.53	0.73	3.84	8.21	0.29	<.0001
660	4.74	0.87	2.44	7.65	0.37	<.0001
710	11.16	1.30	7.17	15.75	0.23	0.0002
760	30.14	6.30	15.51	45.18	-0.07	0.2695
810	33.52	6.69	17.54	49.50	-0.01	0.9069
Index						
$NDVI_1$	0.68	0.06	0.52	0.84	-0.18	0.0033
$NDVI_2$	0.72	0.08	0.52	0.90	-0.21	0.0005
NIR/R_1	5.54	1.43	3.20	11.77	-0.25	<.0001
NIR/R_2	6.72	2.54	3.17	18.55	-0.31	<.0001

Table 9. Parameter estimates and statistics from stepwise regression of biomass yield (lb/acre) on reflectance measurements at eight wavelengths.

Variable	Parameter Estimate	Standard Error	Order Entered	Partial R^2	Model R^2	C(p)	F Value	Pr > F
Intercept	912.44	1081.007						
460	8778.87	1954.397	3	0.147	0.318	202.30	58.24	<.0001
510	-8330.16	2342.688	2	0.034	0.170	301.31	11.04	0.0010
560	-3762.87	837.229	6	0.074	0.576	30.91	46.77	<.0001
610	7161.90	1446.618	4	0.162	0.480	93.20	83.67	<.0001
660	-4690.72	1038.631	1	0.137	0.137	322.51	43.01	<.0001
710	1197.72	333.318	8	0.019	0.616	7.48	12.91	0.0004
760	-2129.72	408.534	7	0.021	0.597	18.32	14.05	0.0002
810	2015.25	330.070	5	0.022	0.502	79.87	12.02	0.0006

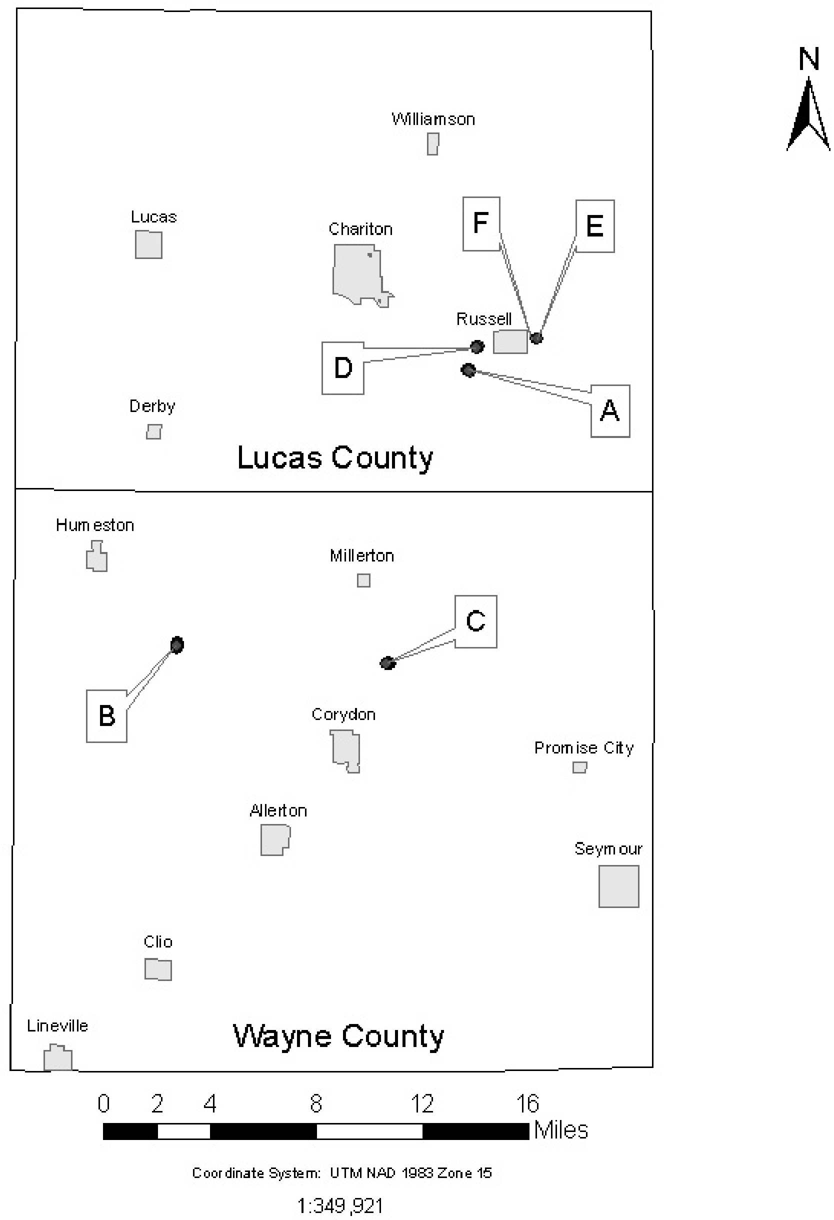

Figure 1. Map locations of six field sites sampled in study.

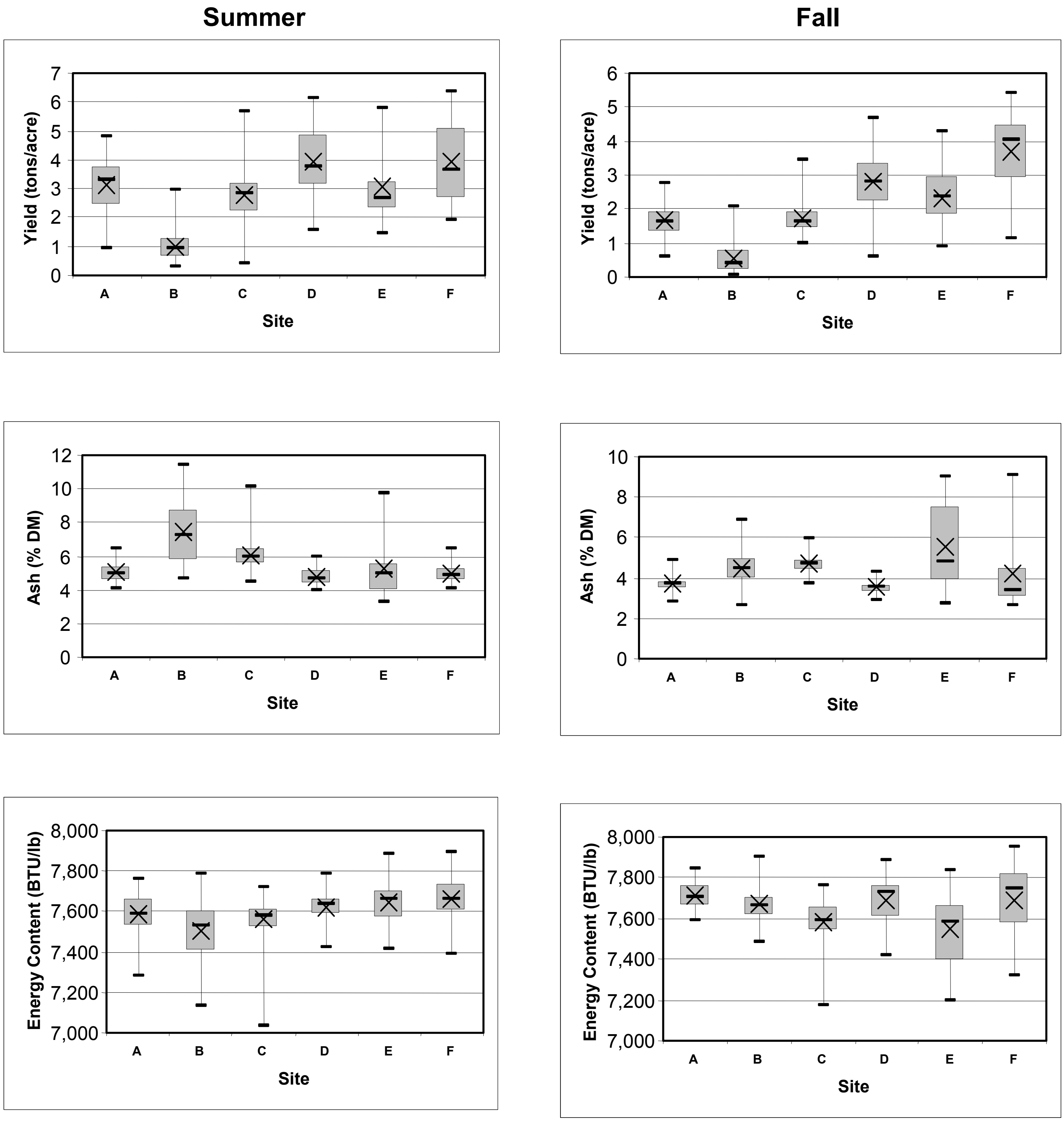

Figure 2. Box plots of biomass yield, ash content, and energy content for summer and fall harvests at each site. ‘X’ = mean or average, ‘–’ = median, shaded box = inner quartile range (25th - 75th percentiles), tails = highest and lowest values observed at each site.

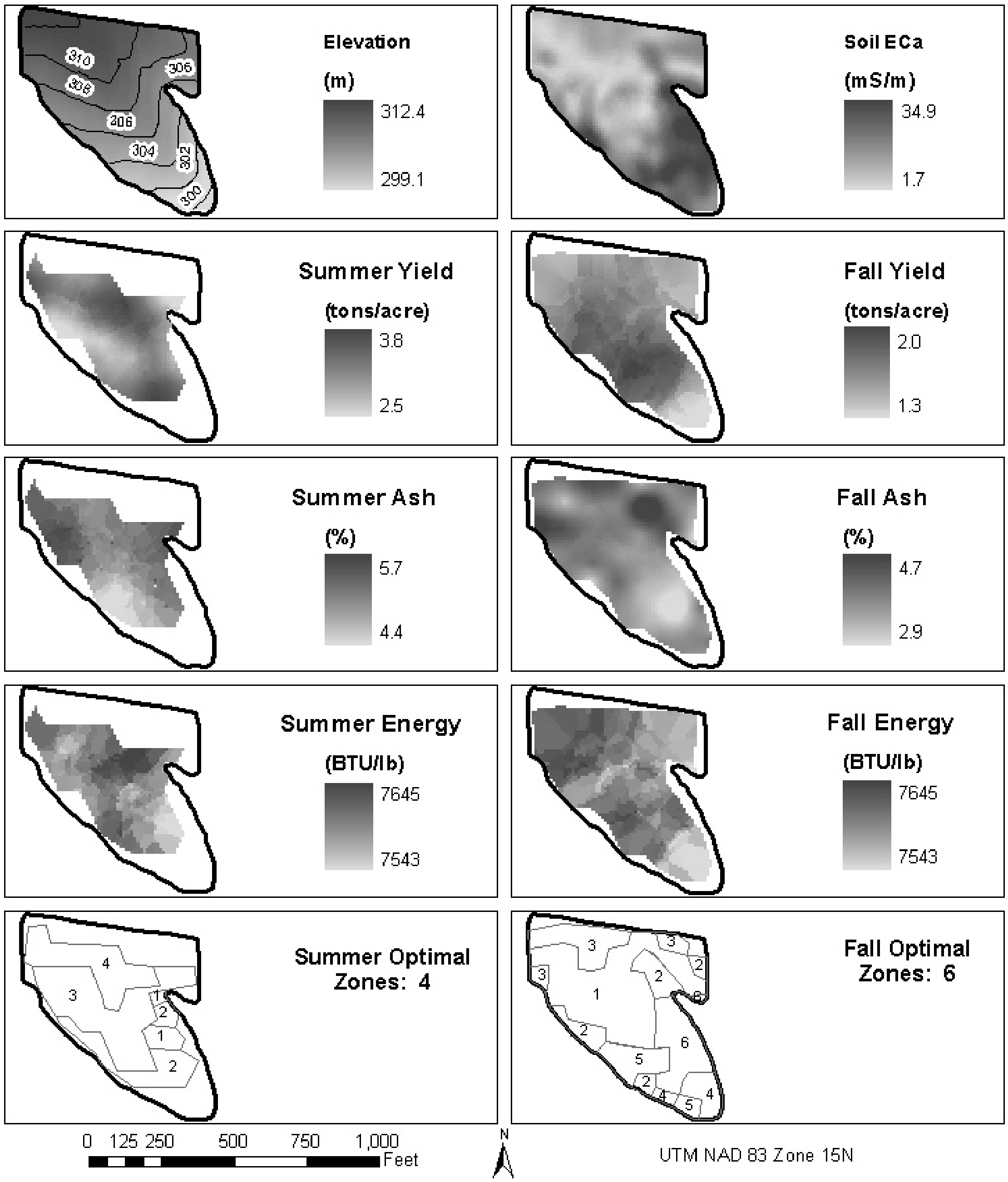

Figure 3. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site A.

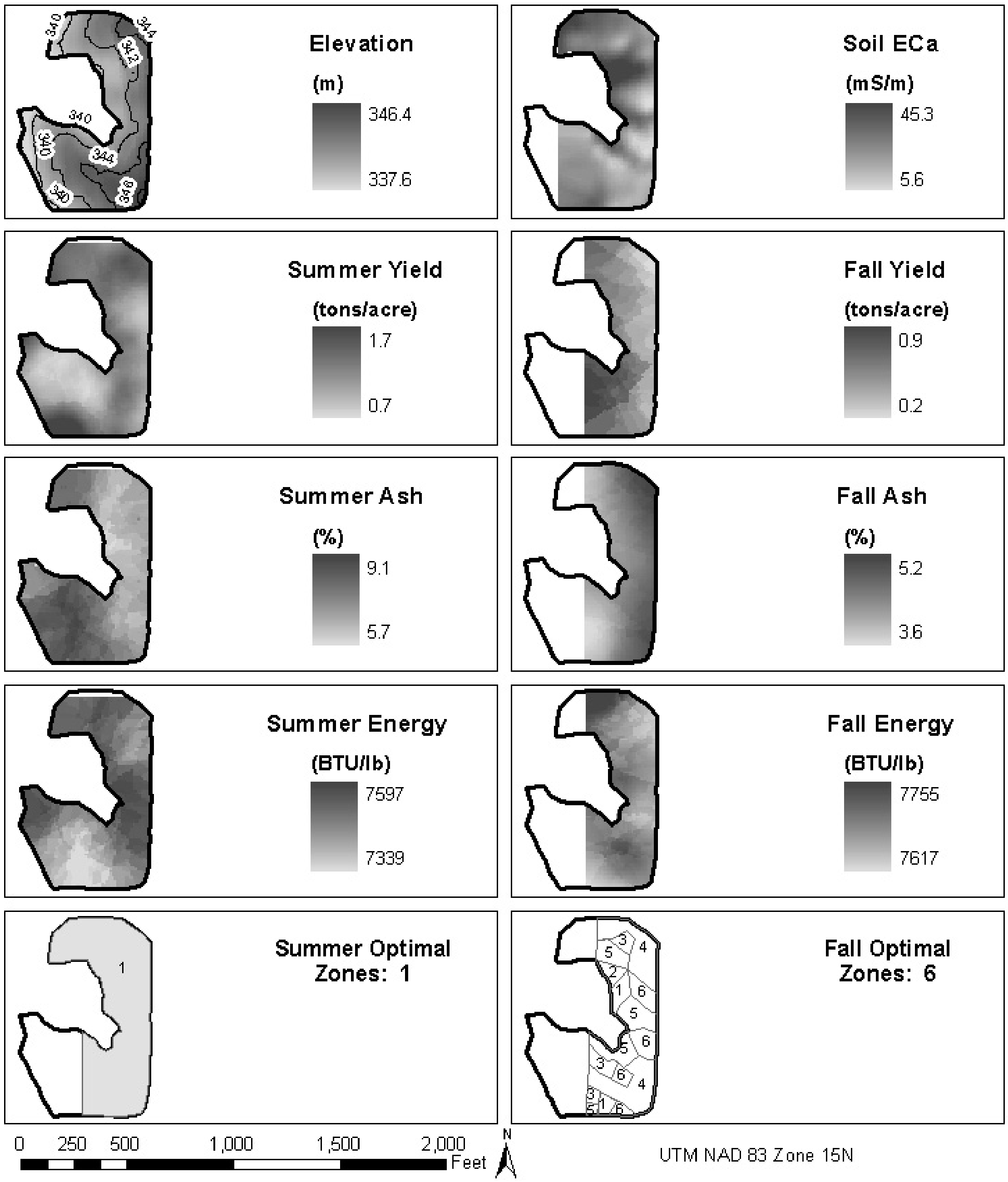

Figure 4. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site B.

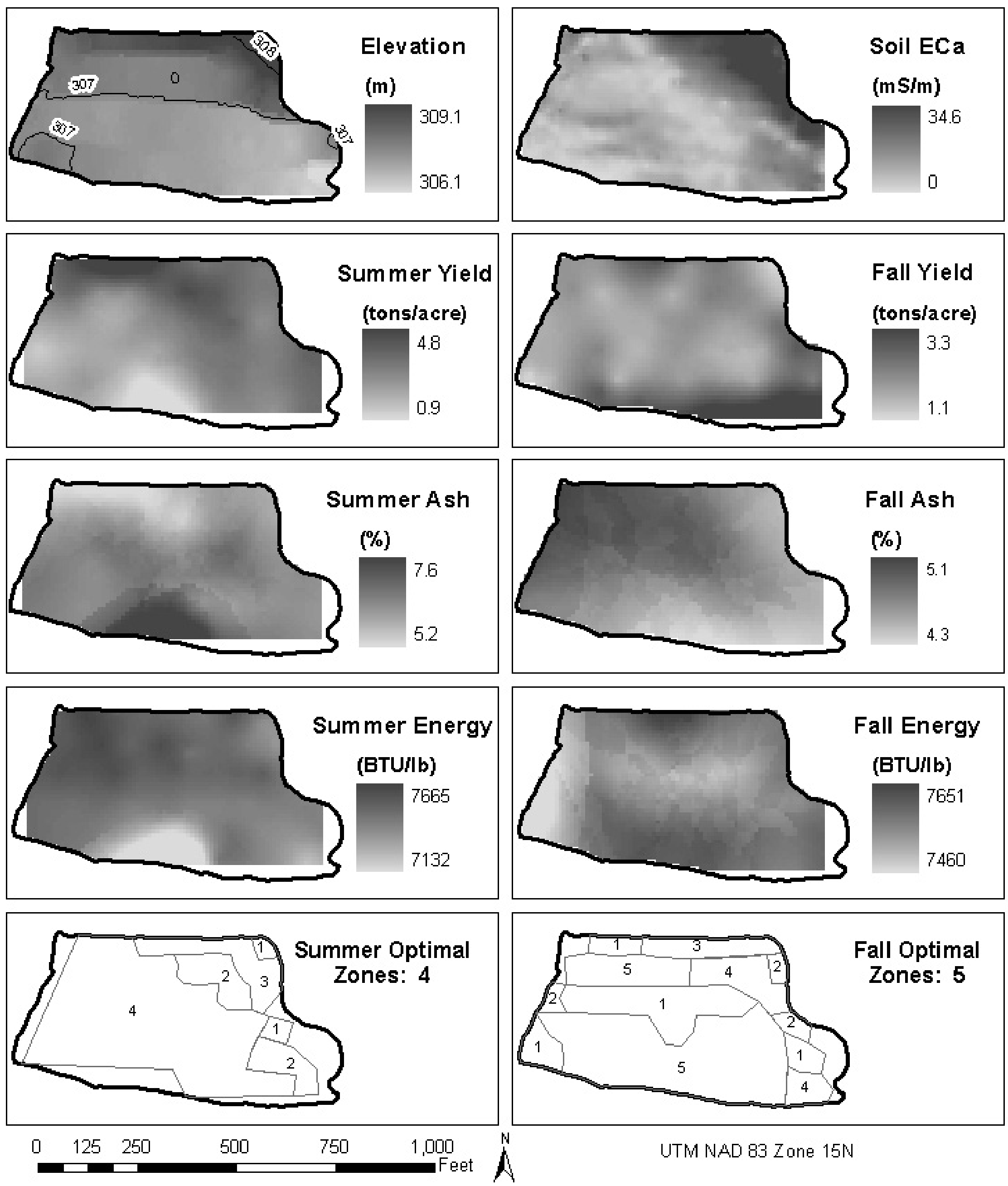

Figure 5. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site C.

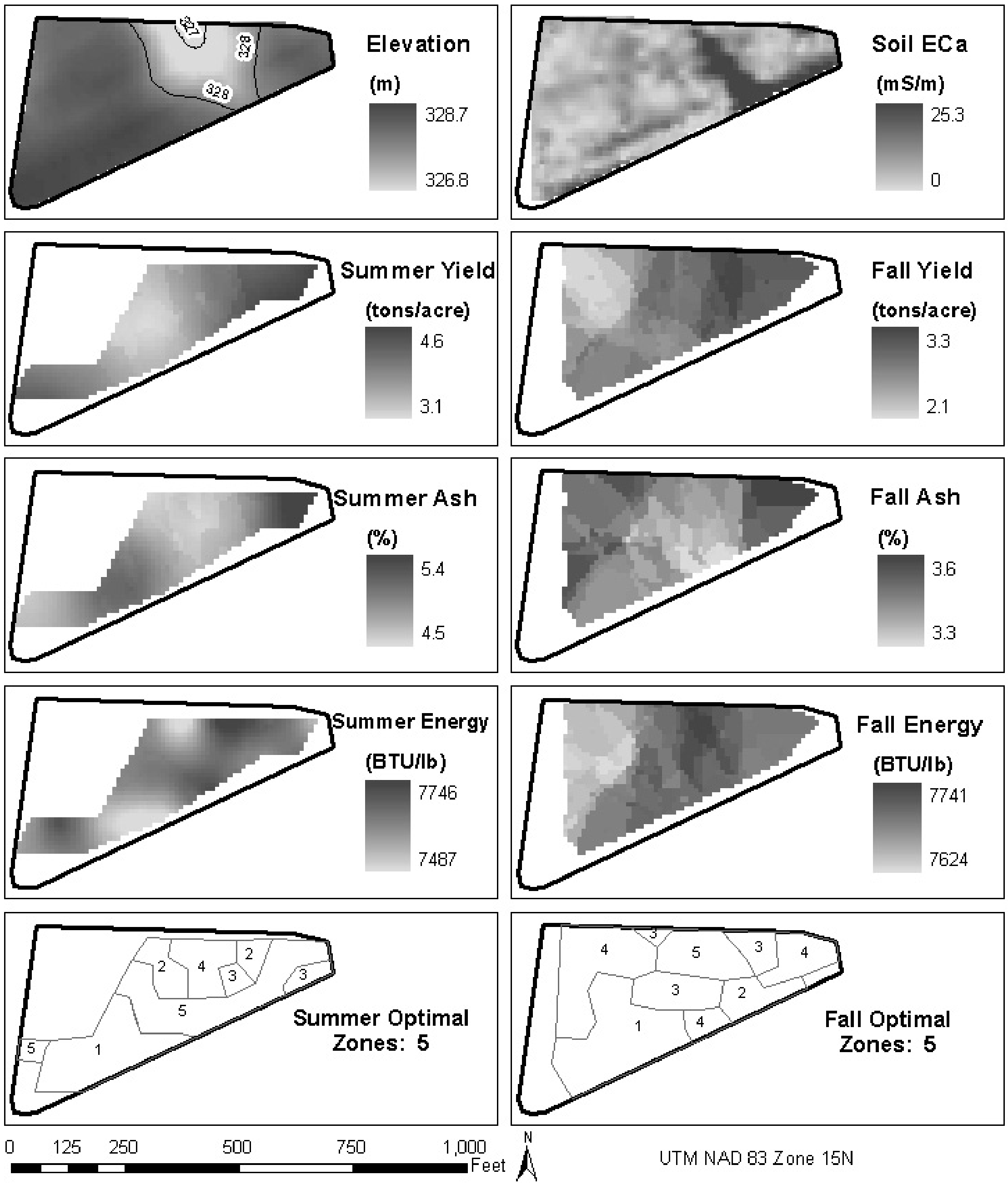

Figure 6. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site D.

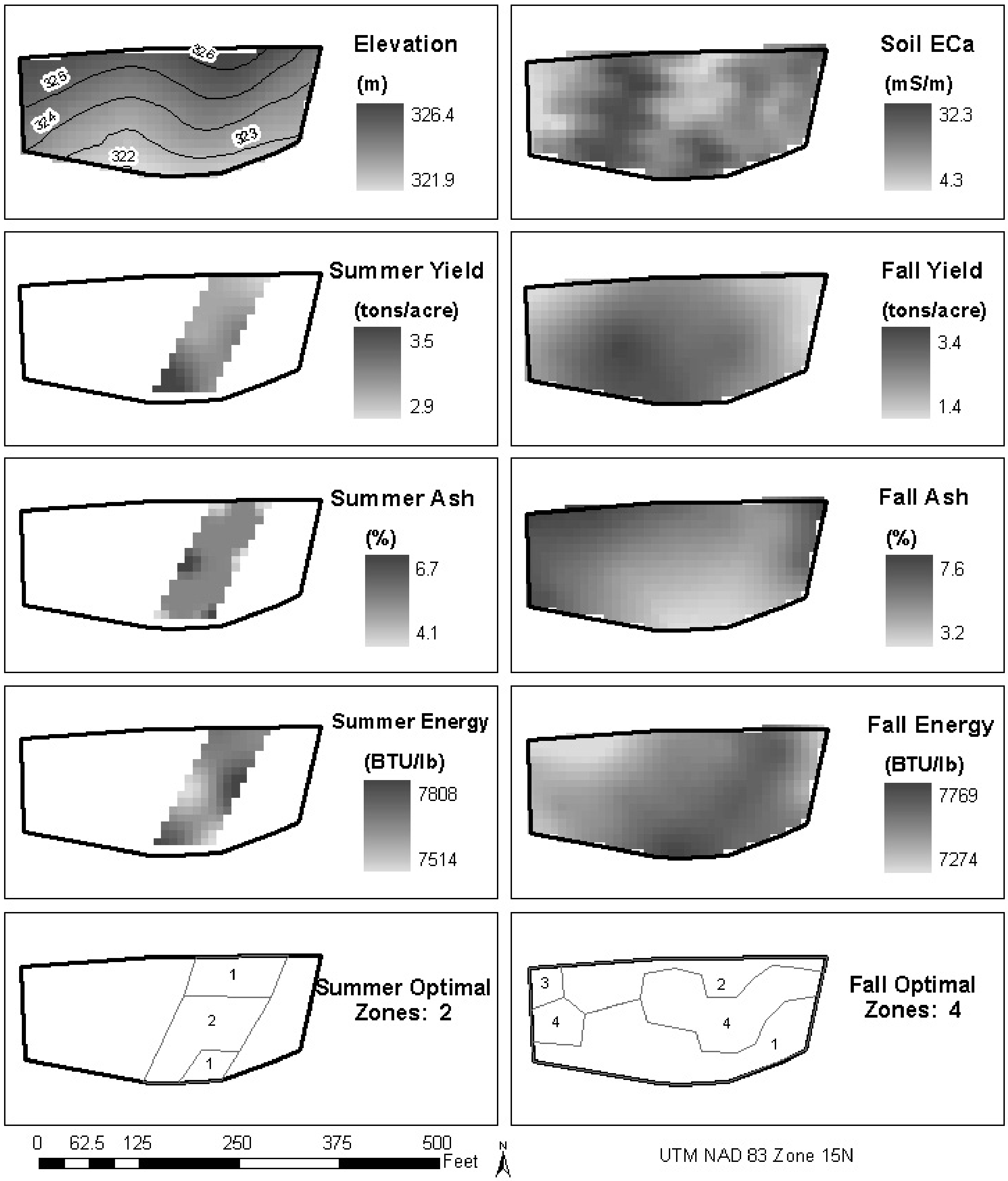

Figure 7. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site E.

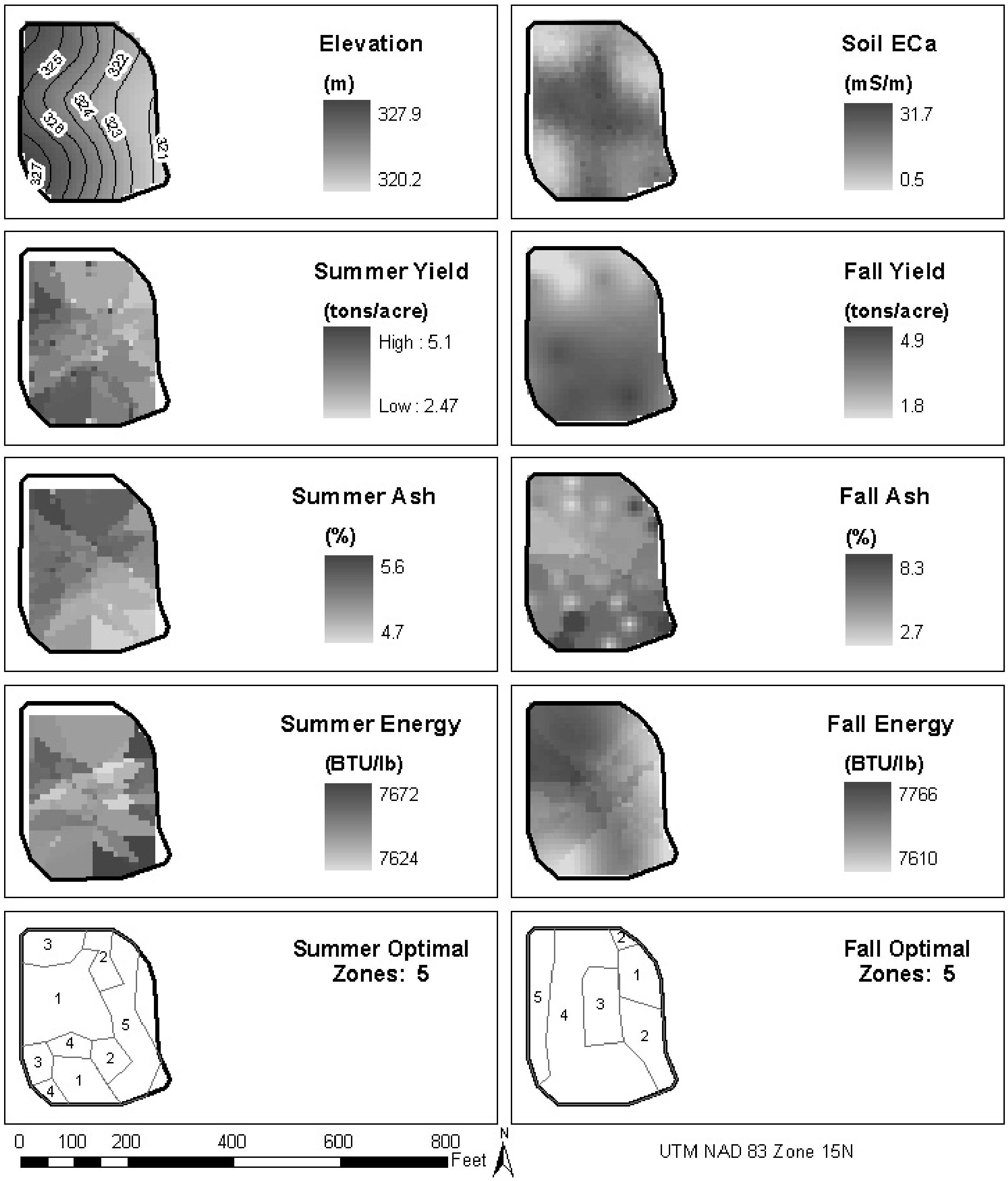

Figure 8. Maps of interpolated elevation, soil EC, biomass yield, ash content, and energy content, and management zones for site F.

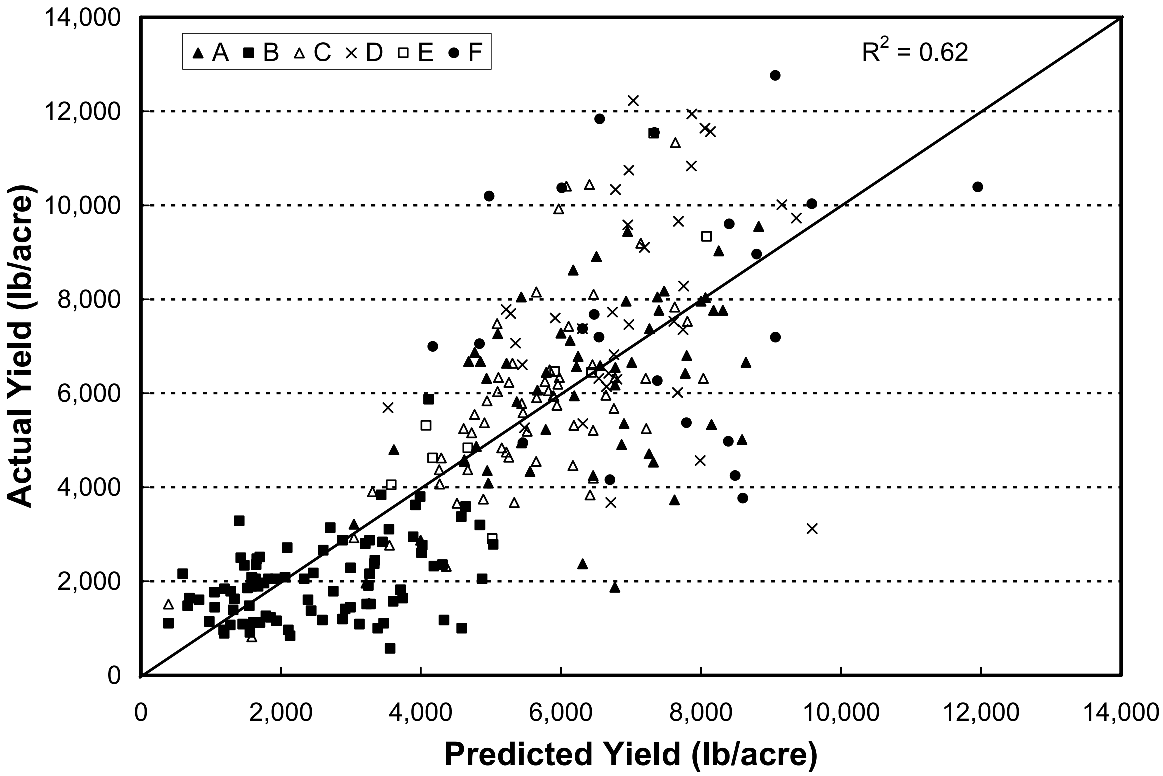

Figure 9. Relationship between actual biomass yield and biomass yield predicted using principal component regression based on reflectance at eight wavelengths.

APPENDIX

Data Observations

Summer

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
A	480547	4534903	312	4	3	5.12	7642	5355.39
A	480626	4534880	311	6	9	4.93	7617	6444.32
A	480603	4534881	311	2	11	4.62	7460	6426.46
A	480603	4534876	311	3	9	5.05	7489	4337.86
A	480581	4534881	311	5	4	5.02	7595	6069.44
A	480581	4534879	311	6	4	5.01	7502	5337.54
A	480558	4534879	311	7	4	5.11	7508	9032.75
A	480558	4534881	311	7	3	4.75	7569	4534.23
A	480536	4534881	311	7	7	5.01	7678	7765.31
A	480536	4534876	310	8	8	5.22	7625	8622.17
A	480547	4534858	309	7	5	5.90	7652	7961.67
A	480547	4534898	312	5	2	4.82	7691	4552.08
A	480569	4534858	310	8	4	4.88	7672	6569.27
A	480569	4534818	307	6	12	5.87	7557	1874.39
A	480592	4534858	310	8	3	4.72	7692	7961.67
A	480592	4534818	308	9	13	5.79	7663	4909.10
A	480615	4534858	311	5	3	4.92	7672	7372.58
A	480637	4534858	310	3	3	4.76	7763	6801.34
A	480660	4534858	308	5	14	6.04	7665	5944.48
A	480682	4534858	307	8	7	5.29	7555	2874.06
A	480682	4534770	305	4	25	5.56	7584	8175.89
A	480705	4534858	307	8	4	5.52	7554	3730.92
A	480693	4534835	305	6	23	4.45	7648	6176.55
A	480671	4534835	307	11	27	5.06	7621	8050.93
A	480648	4534836	308	10	6	5.15	7663	6658.53
A	480626	4534836	309	6	11	5.33	7625	8907.79
A	480603	4534836	309	7	3	5.48	7529	7765.31
A	480558	4534836	308	6	9	6.44	7478	4248.61
A	480569	4534813	307	5	13	4.97	7482	6783.49
A	480592	4534813	307	8	14	4.54	7663	4873.40
A	480614	4534813	308	10	8	4.60	7538	4355.71
A	480614	4534808	307	9	6	5.39	7479	4087.95
A	480637	4534813	308	6	5	4.30	7731	7283.33
A	480660	4534813	307	3	7	5.03	7608	8050.93
A	480682	4534813	305	0	24	6.04	7477	5230.43
A	480693	4534790	304	13	33	5.40	7544	2374.22
A	480671	4534791	306	9	20	4.33	7663	8033.08
A	480648	4534791	306	7	11	4.63	7572	3213.23
A	480648	4534751	303	9	27	4.14	7622	6676.38
A	480626	4534791	306	8	8	4.37	7532	5016.21
A	480626	4534841	310	6	9	4.53	7645	5819.52
A	480603	4534791	306	6	16	4.34	7579	7765.31
A	480614	4534768	304	6	18	4.05	7584	7122.66
A	480637	4534768	304	7	13	4.15	7663	6319.36
A	480637	4534853	310	3	4	4.61	7555	9443.33
A	480659	4534773	305	8	14	4.54	7655	6658.53
A	480659	4534768	305	7	13	4.59	7737	7265.47

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
A	480682	4534768	305	5	26	4.98	7435	6676.38
A	480704	4534768	303	8	27	5.09	7535	6551.42
A	480693	4534746	303	7	24	4.72	7462	6872.75
A	480671	4534796	306	11	19	5.76	7279	6640.68
A	480671	4534746	303	8	29	4.73	7582	9550.44
A	480648	4534746	303	8	27	4.32	7670	6587.13
B	462890	4518233	340	12	39	8.74	7514	2356.37
B	462913	4518233	342	8	33	8.14	7458	2499.18
B	462935	4518232	343	3	30	6.36	7662	2052.90
B	462940	4518232	343	2	29	7.62	7416	1106.78
B	462958	4518232	344	6	27	8.66	7507	1374.55
B	462992	4518210	344	11	18	6.46	7451	2177.86
B	462969	4518210	344	5	20	5.00	7586	3838.03
B	462946	4518210	343	3	24	5.08	7613	2874.06
B	462924	4518210	342	5	28	6.01	7551	2338.52
B	462901	4518210	341	7	31	8.43	7536	2052.90
B	462884	4518210	340	10	32	10.01	7453	1856.53
B	462879	4518210	340	6	34	8.92	7420	2481.33
B	462867	4518188	339	11	36	7.26	7569	2874.06
B	462890	4518188	341	6	25	9.21	7631	2052.90
B	462912	4518188	342	6	25	8.69	7540	1517.36
B	462935	4518187	342	8	24	5.25	7760	2374.22
B	462957	4518187	341	16	21	5.06	7759	1196.04
B	462975	4518187	343	5	27	6.82	7361	1624.47
B	462980	4518187	343	5	24	5.17	7495	3141.83
B	463003	4518187	344	4	17	8.53	7363	2659.84
B	462991	4518165	342	13	31	11.37	7136	1106.78
B	462969	4518165	342	9	38	5.12	7540	2284.96
B	462946	4518165	340	1	41	7.67	7172	3284.64
B	462926	4518165	340	7	39	5.72	7621	2784.80
B	462924	4518165	340	7	39	7.79	7441	1570.91
B	462957	4518142	341	4	38	6.34	7548	999.67
B	462980	4518142	342	4	30	5.33	7605	1910.09
B	462975	4518142	342	9	31	5.77	7711	1820.83
B	463002	4518142	344	6	19	8.00	7357	1178.19
B	462991	4518120	343	6	9	6.17	7496	1642.32
B	462989	4518120	343	3	9	6.00	7493	1178.19
B	462968	4518120	341	9	18	5.09	7507	1088.93
B	462946	4518120	341	2	29	5.05	7634	2802.65
B	462957	4518098	341	2	37	5.13	7682	2945.46
B	462980	4518097	342	8	21	5.07	7707	3195.38
B	463002	4518097	343	5	17	8.05	7602	1160.33
B	462991	4518075	342	11	22	8.96	7424	2052.90
B	462968	4518075	341	8	22	8.99	7568	1642.32
B	462912	4518053	342	9	18	8.10	7697	839.01
B	462917	4518053	342	10	21	10.07	7243	1767.28
B	462934	4518053	341	9	30	6.67	7559	2766.95
B	462957	4518053	342	6	25	5.63	7665	2160.01

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
B	462979	4518053	343	3	9	5.76	7579	1785.13
B	463002	4518052	344	4	7	6.63	7575	1088.93
B	462991	4518030	344	4	10	6.04	7528	2356.37
B	462968	4518030	343	6	21	6.32	7448	3106.12
B	462950	4518030	342	17	17	6.16	7661	1517.36
B	462945	4518030	342	13	13	5.78	7577	571.24
B	462923	4518030	344	8	14	7.12	7468	1231.74
B	462912	4518008	344	4	21	10.50	7209	1392.40
B	462934	4518008	344	4	18	10.64	7199	1142.48
B	462957	4518008	344	6	13	5.69	7643	3588.11
B	462979	4518008	345	7	15	5.05	7608	2606.29
B	463002	4518007	345	5	14	9.31	7403	892.56
B	462990	4517985	346	7	14	6.45	7563	1410.25
B	462988	4517985	346	6	14	6.29	7576	999.67
B	462968	4517985	345	3	17	6.14	7571	1892.24
B	462945	4517985	345	7	19	6.73	7368	1481.66
B	462923	4517985	344	3	26	9.18	7359	1606.62
B	462911	4517963	342	6	30	10.26	7232	2052.90
B	462929	4517963	343	8	25	8.58	7354	1785.13
B	462934	4517963	343	5	22	8.80	7377	2088.60
B	462956	4517963	344	12	13	6.38	7493	3373.89
B	462979	4517963	345	2	16	8.89	7351	1838.68
C	475779	4516949	307	0	4	10.15	7035	1517.36
C	475801	4516949	307	0	2	6.21	7588	4373.57
C	475801	4516951	307	0	2	6.11	7637	6319.36
C	475824	4516949	307	0	9	6.60	7518	4748.44
C	475824	4516951	307	0	8	6.20	7572	5926.63
C	475846	4516949	307	1	10	6.53	7524	3909.43
C	475869	4516949	306	1	16	5.90	7377	6604.98
C	475835	4516972	307	0	13	5.20	7514	5194.72
C	475813	4516972	307	0	5	5.56	7586	6247.95
C	475790	4516972	307	1	4	4.93	7499	5319.68
C	475790	4516977	307	1	2	4.60	7539	6033.74
C	475745	4516972	307	1	9	5.89	7470	1535.21
C	475723	4516972	307	1	8	6.30	7521	4195.05
C	475700	4516972	307	0	6	5.67	7563	5587.45
C	475655	4516972	307	1	0	6.18	7590	4373.57
C	475666	4516995	307	0	3	6.62	7568	1963.64
C	475689	4516995	307	0	7	6.27	7559	3838.03
C	475711	4516994	307	0	10	5.85	7598	3677.37
C	475711	4516999	307	1	12	5.78	7578	4552.08
C	475734	4516994	307	0	9	6.36	7531	4070.09
C	475734	4516999	307	0	10	6.40	7581	5373.24
C	475756	4516994	307	0	5	6.55	7550	2320.67
C	475756	4516989	307	0	4	5.96	7575	5962.33
C	475779	4516994	307	0	2	7.07	7523	5676.71
C	475802	4516994	307	0	3	6.40	7534	5159.02
C	475824	4516994	307	0	7	7.06	7513	5944.48

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
C	475847	4516994	307	6	15	5.87	7545	5248.28
C	475835	4517017	308	2	27	5.51	7660	3659.51
C	475813	4517017	307	1	15	6.65	7606	9193.41
C	475813	4517022	307	1	18	6.94	7604	4462.82
C	475790	4517017	307	0	9	6.36	7608	6194.40
C	475768	4517017	307	0	3	5.92	7610	5248.28
C	475768	4517022	307	0	7	5.74	7651	5212.58
C	475745	4517017	307	1	3	6.45	7581	5783.82
C	475723	4517017	307	2	4	6.26	7679	3748.77
C	475700	4517017	307	3	4	6.02	7614	4587.78
C	475678	4517017	307	2	4	5.85	7651	4623.48
C	475689	4517039	307	0	7	6.84	7556	7836.72
C	475689	4517037	307	0	7	5.74	7689	5551.75
C	475712	4517039	307	0	4	6.56	7674	2927.61
C	475734	4517039	307	0	3	6.60	7558	2766.95
C	475757	4517039	307	0	4	5.29	7690	6337.21
C	475779	4517039	307	0	15	4.77	7651	9925.32
C	475779	4517034	307	0	12	4.87	7479	6497.87
C	475802	4517039	307	3	24	5.83	7589	7479.69
C	475824	4517039	308	4	32	6.15	7515	5837.37
C	475847	4517039	308	4	23	5.16	7480	6230.10
C	475836	4517056	309	8	29	5.79	7452	4837.70
C	475836	4517061	309	6	25	5.81	7579	6051.59
C	475813	4517062	308	4	32	5.91	7686	6640.68
C	475790	4517062	308	1	25	6.04	7517	4641.34
C	475768	4517062	308	1	27	6.19	7580	5908.78
C	475745	4517062	308	1	13	5.34	7596	10443.00
C	475745	4517057	308	0	9	4.47	7580	7533.24
C	475723	4517062	307	0	4	5.16	7510	11335.57
C	475723	4517060	307	0	4	4.81	7716	10407.30
C	475700	4517062	307	1	6	4.99	7686	8158.04
C	475700	4517060	307	1	3	4.98	7677	8104.49
D	481082	4536151	329	0	2	4.51	7617	11942.51
D	481105	4536151	329	1	7	4.67	7640	7461.84
D	481161	4536174	329	1	1	4.23	7462	6819.19
D	481138	4536174	329	0	4	5.30	7456	7729.61
D	481116	4536174	329	1	4	5.34	7536	9104.16
D	481071	4536174	328	1	3	4.24	7592	6140.84
D	481088	4536174	329	1	1	4.39	7754	6301.50
D	481127	4536196	329	1	5	5.31	7625	4569.93
D	481150	4536196	328	2	2	5.15	7632	3677.37
D	481172	4536196	328	2	6	4.47	7679	7069.11
D	481195	4536196	328	3	3	4.89	7654	10835.73
D	481193	4536196	328	3	1	4.53	7784	6015.88
D	481251	4536218	328	1	13	4.98	7674	10335.90
D	481229	4536218	328	2	5	5.08	7598	11567.64
D	481206	4536218	328	3	16	4.53	7636	8283.00
D	481184	4536218	327	3	8	3.96	7633	6604.98

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
D	481208	4536218	328	3	13	4.70	7642	9586.14
D	481161	4536219	328	4	7	4.60	7633	5355.39
D	481139	4536219	328	2	4	4.14	7634	7783.16
D	481150	4536241	328	6	0	4.02	7612	6319.36
D	481172	4536241	327	2	4	5.22	7419	7354.73
D	481195	4536241	327	2	6	4.47	7783	10746.48
D	481218	4536241	328	4	2	4.22	7724	5266.13
D	481240	4536241	328	2	4	5.13	7665	6426.46
D	481263	4536241	328	1	3	5.98	7518	7604.65
D	481258	4536241	328	2	1	5.83	7551	12228.13
E	484768	4536712	327	7	6	4.32	7701	6462.17
E	484788	4536712	326	10	20	3.92	7660	2909.76
E	484790	4536712	326	10	20	4.98	7662	6444.32
E	484756	4536690	324	8	11	3.26	7882	9336.22
E	484761	4536690	324	8	11	5.50	7574	4623.48
E	484779	4536690	324	10	20	6.31	7504	4837.70
E	484745	4536667	322	8	21	3.72	7814	11531.93
E	484763	4536667	323	8	23	5.54	7579	5319.68
E	484768	4536667	323	8	21	9.70	7417	4052.24
F	484547	4536709	326	7	4	4.24	7892	10193.09
F	484569	4536709	324	11	15	4.58	7606	6997.71
F	484592	4536709	322	6	9	4.98	7647	10389.45
F	484547	4536704	326	8	4	4.86	7743	8961.35
F	484569	4536704	324	10	22	6.47	7565	4944.81
F	484535	4536687	326	9	19	4.99	7652	4248.61
F	484558	4536687	325	11	21	5.06	7697	10032.42
F	484580	4536687	323	10	14	5.25	7603	3766.62
F	484580	4536682	322	8	17	5.02	7741	11549.78
F	484546	4536664	325	12	25	5.48	7690	7051.26
F	484569	4536664	323	10	29	4.68	7749	12763.67
F	484592	4536664	321	6	23	5.78	7385	10371.60
F	484558	4536647	326	12	19	6.05	7512	7194.07
F	484535	4536644	328	7	4	4.07	7708	4980.51
F	484535	4536642	328	7	4	4.59	7716	5373.24
F	484558	4536642	326	11	19	4.32	7657	7676.05
F	484580	4536642	323	13	17	4.78	7658	7194.07
F	484603	4536642	321	9	17	5.29	7608	6265.80
F	484592	4536626	322	8	16	4.82	7732	7372.58
F	484592	4536621	322	9	16	4.89	7770	4159.35
F	484546	4536619	327	11	9	4.81	7596	11835.40
F	484569	4536619	324	12	25	4.51	7616	9603.99

Fall

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
A	480536	4534899	312	5	3	3.89	7642	3450.45
A	480562	4534903	312	3	7	3.81	7692	2212.85
A	480591	4534902	312	4	12	4.22	7603	2704.84
A	480619	4534901	311	3	11	4.14	7708	2689.12
A	480650	4534899	310	7	7	3.31	7694	3791.58
A	480679	4534894	309	3	8	3.56	7810	4345.48
A	480710	4534871	308	5	14	3.40	7750	3067.31
A	480684	4534873	308	7	12	3.76	7711	3078.74
A	480655	4534875	309	6	18	4.92	7807	2408.11
A	480626	4534876	311	7	8	3.69	7725	2939.66
A	480597	4534878	311	3	10	3.77	7844	3275.12
A	480597	4534874	311	4	8	3.54	7765	3558.94
A	480569	4534879	311	7	3	3.22	7844	2977.91
A	480538	4534879	310	8	7	3.76	7764	3931.92
A	480538	4534855	309	5	7	4.48	7729	1214.90
A	480565	4534854	309	8	4	4.17	7794	4000.90
A	480593	4534853	310	7	5	3.83	7717	4796.88
A	480621	4534851	310	7	3	3.79	7712	5025.66
A	480649	4534851	309	11	5	3.81	7687	3095.85
A	480648	4534846	308	12	5	3.56	7657	2690.97
A	480677	4534849	306	8	18	4.20	7657	2950.46
A	480706	4534846	306	9	13	3.13	7707	3078.50
A	480710	4534832	305	9	25	3.33	7663	3449.55
A	480678	4534821	305	11	23	3.63	7705	2608.14
A	480650	4534821	308	8	3	3.53	7691	4666.32
A	480626	4534820	308	7	7	3.57	7737	3624.44
A	480599	4534821	308	9	9	3.77	7720	2687.09
A	480599	4534815	307	8	10	4.00	7657	2705.14
A	480575	4534820	307	7	5	3.78	7687	3374.59
A	480559	4534820	307	6	17	3.68	7686	3720.79
A	480573	4534796	306	3	20	3.69	7705	4413.12
A	480597	4534797	306	6	19	3.12	7795	4269.09
A	480624	4534796	307	8	7	3.99	7615	3193.33
A	480647	4534796	307	8	10	3.60	7847	3120.49
A	480647	4534792	306	8	11	3.40	7846	3846.53
A	480672	4534798	306	12	18	3.37	7741	5371.72
A	480695	4534798	304	14	35	3.25	7641	3404.10
A	480714	4534770	302	11	29	3.95	7770	3685.51
A	480691	4534768	304	9	28	2.84	7765	3844.09
A	480667	4534771	305	7	16	3.14	7766	3493.58
A	480642	4534772	305	7	11	3.50	7687	5498.67
A	480618	4534774	305	6	13	3.74	7725	3988.30
A	480631	4534746	303	6	19	3.64	7820	3804.46
A	480654	4534745	303	7	29	3.46	7593	3147.16
A	480678	4534744	303	10	30	3.46	7657	2628.14
A	480702	4534742	302	9	23	3.68	7697	4286.44
A	480723	4534741	301	10	24	3.43	7663	1629.06

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
A	480724	4534736	300	11	21	4.05	7723	1570.02
A	480718	4534718	300	8	15	3.52	7668	2182.24
A	480695	4534718	301	4	22	3.70	7738	2101.41
A	480670	4534730	302	8	20	3.81	7630	2240.87
B	462993	4517966	346	7	19	5.26	7,660	348.98
B	462995	4517992	346	8	14	5.40	7,608	91.57
B	462996	4518020	344	6	18	4.86	7,704	1048.36
B	462997	4518047	344	4	7	5.21	7,620	438.58
B	463001	4518047	344	3	7	4.94	7,597	357.63
B	463002	4518073	343	5	13	4.95	7,707	362.61
B	463002	4518116	344	6	7	5.18	7,701	619.06
B	463002	4518144	344	7	20	4.87	7,696	276.21
B	463001	4518175	343	6	21	5.64	7,487	350.32
B	463001	4518203	344	5	20	5.61	7,613	442.16
B	463002	4518237	344	9	14	4.58	7,707	350.03
B	463001	4518265	342	4	7	5.76	7,661	179.91
B	462983	4518265	341	6	22	5.46	7,653	91.64
B	462982	4518248	343	10	17	4.77	7,603	792.94
B	462981	4518223	344	2	21	4.68	7,630	873.63
B	462982	4518191	343	5	25	5.20	7,702	267.31
B	462982	4518131	343	4	17	4.29	7,652	784.82
B	462983	4518097	342	2	20	4.10	7,527	365.58
B	462983	4518063	342	3	13	4.97	7,550	885.84
B	462982	4518024	344	8	20	4.88	7,608	1596.51
B	462980	4517996	345	4	14	5.10	7,844	421.99
B	462979	4517968	345	2	14	4.61	7,672	862.71
B	462953	4517960	344	3	14	6.20	7,482	360.61
B	462954	4517984	345	7	18	4.71	7,775	177.03
B	462955	4518010	344	6	12	4.23	7,813	1240.83
B	462957	4518039	342	7	25	4.94	7,614	1404.12
B	462957	4518060	342	5	20	4.02	7,741	800.63
B	462953	4518061	341	3	22	4.21	7,684	707.70
B	462957	4518115	341	5	25	3.67	7,836	715.69
B	462956	4518135	341	6	33	4.07	7,703	705.40
B	462956	4518207	343	15	17	4.48	7,701	1384.75
B	462956	4518235	344	10	26	5.95	7,600	96.30
B	462957	4518262	341	11	19	6.89	7,524	617.47
B	462960	4518277	340	7	36	4.08	7,831	1587.15
B	462943	4518275	340	12	32	3.65	7,849	1946.03
B	462928	4518273	341	13	39	3.37	7,896	1310.24
B	462927	4518250	342	2	35	3.15	7,843	1635.05
B	462925	4518222	343	7	31	3.46	7,898	1402.10
B	462923	4518194	342	5	23	3.72	7,530	1407.94
B	462921	4518166	340	8	38	3.44	7,636	2565.39
B	462943	4518118	341	1	31	4.45	7,728	1360.87
B	462947	4518117	341	2	29	4.40	7,649	1755.47
B	462933	4518047	342	7	24	3.70	7,690	4162.62
B	462932	4518024	344	9	15	3.93	7,686	2294.81

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
B	462931	4517997	344	5	22	2.94	7,610	1993.65
B	462930	4517970	343	4	28	2.62	7,618	1556.13
B	462905	4517954	341	12	27	4.25	7,531	1589.13
B	462905	4517966	341	6	29	3.69	7,642	2230.76
B	462906	4517986	343	13	23	3.23	7,667	2453.57
B	462908	4518013	344	4	21	3.37	7,631	89.87
B	462909	4518043	343	9	18	4.02	7,667	273.97
B	462911	4518076	340	9	19	4.65	7,655	1266.18
B	462922	4518068	340	8	29	4.16	7,676	2219.34
C	475706	4517066	308	1	3	5.16	7,612	3145.07
C	475727	4517064	307	1	2	5.26	7,576	4198.98
C	475751	4517063	308	0	18	4.54	7,756	4714.57
C	475774	4517063	308	1	26	4.37	7,758	3748.18
C	475801	4517063	308	1	24	4.83	7,676	2889.35
C	475840	4517063	308	2	27	4.69	7,527	3859.29
C	475774	4517059	309	5	25	4.48	7,588	2045.65
C	475687	4517042	308	5	23	4.23	7,665	2045.65
C	475709	4517039	307	3	32	4.25	7,585	2425.04
C	475736	4517038	307	0	18	5.00	7,591	3439.88
C	475763	4517037	307	0	6	5.75	7,608	3827.60
C	475791	4517037	307	0	3	5.14	7,555	2606.50
C	475822	4517038	307	0	4	4.68	7,614	3325.45
C	475846	4517038	307	1	8	4.78	7,551	2524.62
C	475664	4517021	307	4	8	5.15	7,599	3530.81
C	475690	4517017	307	3	5	5.43	7,542	2801.02
C	475754	4517019	307	3	5	4.87	7,470	3142.69
C	475720	4517015	307	2	4	5.03	7,539	2815.88
C	475747	4517014	307	1	2	4.60	7,534	2810.78
C	475775	4517014	307	2	2	4.63	7,457	3366.42
C	475805	4517014	307	2	9	5.52	7,406	3436.81
C	475843	4517015	307	1	31	3.86	7,664	2941.20
C	475652	4517003	307	7	26	4.81	7,473	4074.45
C	475675	4516999	307	0	5	4.81	7,535	4610.26
C	475707	4516996	307	0	1	4.85	7,648	2697.57
C	475831	4516995	307	1	5	4.64	7,634	2812.78
C	475858	4516997	307	0	8	4.85	7,519	3320.87
C	475737	4516995	307	1	11	4.69	7,759	2717.53
C	475765	4516994	307	1	6	4.84	7,636	3717.43
C	475791	4516994	307	1	3	5.93	7,175	2934.34
C	475648	4516984	307	1	3	4.66	7,397	2904.82
C	475662	4516982	307	2	3	4.26	7,428	3113.29
C	475653	4516977	307	0	4	4.08	7,622	3065.97
C	475692	4516976	307	1	8	4.62	7,658	2266.26
C	475667	4516973	307	1	9	4.43	7,686	3436.22
C	475721	4516972	307	0	4	4.68	7,614	2962.14
C	475751	4516971	307	1	4	4.71	7,665	3081.75
C	475869	4516972	307	0	4	4.55	7,613	3705.58
C	475691	4516969	307	0	11	5.06	7,671	2695.42

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
C	475771	4516971	307	2	13	4.82	7,675	3254.45
C	475803	4516970	306	2	12	4.34	7,670	5585.90
C	475825	4516971	306	0	12	4.05	7,527	6891.57
C	475803	4516967	307	1	7	4.24	7,559	6168.76
C	475707	4516964	307	1	9	4.19	7,594	5442.46
C	475737	4516957	307	0	4	3.71	7,643	5306.66
C	475763	4516953	307	0	7	4.21	7,565	4240.82
C	475791	4516949	307	0	4	3.98	7,664	4508.80
C	475877	4516949	307	0	1	5.08	7,554	4653.07
C	475816	4516947	307	0	3	4.79	7,586	3791.58
C	475839	4516944	307	1	2	4.64	7,605	2475.42
C	475855	4516946	307	1	2	4.51	7,586	1994.47
D	481088	4536253	328	1	3	3.61	7,685	5170.61
D	481116	4536253	328	1	3	3.57	7,684	5584.19
D	481146	4536252	328	6	3	3.62	7,889	4733.04
D	481175	4536251	327	0	3	4.01	7,785	9369.69
D	481204	4536251	328	3	2	3.95	7,725	4788.03
D	481235	4536250	328	1	2	3.65	7,603	6513.84
D	481236	4536247	328	1	2	3.58	7,687	6699.74
D	481262	4536240	328	1	3	3.70	7,739	5905.53
D	481090	4536235	328	1	1	4.32	7,551	3876.10
D	481105	4536234	328	1	3	3.36	7,690	8481.60
D	481089	4536231	328	1	1	3.25	7,520	6066.89
D	481134	4536233	328	2	6	2.85	7,694	6171.39
D	481164	4536233	327	3	3	3.55	7,809	4130.65
D	481195	4536233	327	2	11	3.54	7,709	7355.31
D	481223	4536232	328	3	1	4.15	7,466	1214.90
D	481250	4536230	328	1	6	3.67	7,420	3991.80
D	481232	4536221	328	2	3	3.47	7,457	4424.41
D	481237	4536215	328	1	13	3.78	7,550	4644.84
D	481088	4536212	328	1	4	3.23	7,795	3284.70
D	481118	4536211	329	1	3	3.21	7,741	7789.22
D	481147	4536209	328	3	1	3.41	7,793	3138.66
D	481177	4536209	328	5	1	3.54	7,757	7454.51
D	481206	4536208	328	3	17	3.33	7,764	5713.12
D	481210	4536201	328	2	21	3.34	7,766	5470.77
D	481091	4536190	328	0	2	3.55	7,682	6536.60
D	481120	4536190	329	1	1	3.38	7,740	5581.76
D	481151	4536189	329	1	5	3.25	7,571	6535.02
D	481183	4536189	328	1	1	3.22	7,585	4365.95
D	481157	4536177	329	1	1	2.89	7,754	4437.76
D	481089	4536168	329	1	1	3.14	7,785	6851.63
D	481116	4536167	329	0	6	3.54	7,743	8002.78
D	481134	4536166	329	1	2	4.22	7,781	4148.01
D	481089	4536164	329	1	2	4.08	7,776	6681.93
D	481099	4536150	329	1	3	3.37	7,766	7124.56
E	484806	4536712	325	6	25	8.62	7,309	2046.79
E	484777	4536713	327	7	15	4.21	7,688	2155.74

Field	Easting	Northing	Elevation (m)	Slope (%)	Soil EC (ms/m)	Ash (%)	Energy (BTU/lb)	Yield (lb/ac)
E	484747	4536712	326	8	21	7.51	7,529	4921.97
E	484718	4536710	326	7	20	8.12	7,199	2374.27
E	484694	4536709	326	4	8	8.69	7,279	1722.94
E	484695	4536700	326	5	6	5.73	7,523	3659.34
E	484721	4536703	325	9	23	6.84	7,388	5381.40
E	484747	4536706	325	9	15	4.95	7,583	5369.54
E	484768	4536706	326	9	16	6.59	7,488	5103.51
E	484790	4536706	325	12	21	4.07	7,747	4122.40
E	484789	4536702	325	10	20	3.91	7,726	4586.59
E	484798	4536690	324	6	20	8.98	7,372	2201.20
E	484774	4536690	324	10	18	3.79	7,712	6280.69
E	484752	4536689	324	8	12	4.38	7,634	4855.84
E	484729	4536687	323	8	30	3.82	7,638	8539.20
E	484705	4536684	324	9	6	4.56	7,593	6337.08
E	484697	4536676	324	7	16	7.51	7,389	4446.29
E	484701	4536677	324	8	19	8.07	7,403	3661.60
E	484725	4536680	323	6	28	5.03	7,524	6304.26
E	484749	4536683	324	8	19	4.36	7,575	5610.88
E	484771	4536683	324	10	18	3.74	7,715	6570.25
E	484799	4536679	323	7	14	3.11	7,638	3992.54
E	484773	4536671	323	9	22	3.07	7,606	3988.65
E	484749	4536666	322	7	22	2.69	7,835	6506.83
F	484535	4536715	327	4	3	3.90	7,734	2236.14
F	484554	4536713	326	10	7	2.65	7,760	6654.24
F	484583	4536713	323	6	11	3.97	7,691	5015.79
F	484535	4536702	327	6	3	5.52	7,514	5066.45
F	484554	4536700	326	9	9	3.16	7,815	8585.98
F	484572	4536700	324	11	19	2.68	7,827	3526.16
F	484591	4536699	322	8	8	4.09	7,673	5213.00
F	484534	4536698	327	7	10	3.46	7,767	9089.33
F	484550	4536690	325	10	14	3.34	7,828	5011.32
F	484604	4536689	321	5	2	3.39	7,808	6820.06
F	484569	4536689	324	10	28	4.90	7,562	6338.89
F	484600	4536687	322	6	2	5.83	7,573	9317.80
F	484547	4536658	325	13	20	3.86	7,590	8721.43
F	484570	4536657	324	11	28	3.56	7,681	8677.03
F	484593	4536656	322	7	22	3.21	7,571	10225.37
F	484530	4536645	328	5	5	3.34	7,786	6755.69
F	484553	4536646	326	11	16	3.05	7,815	8343.50
F	484580	4536645	323	12	19	3.13	7,818	8809.24
F	484554	4536642	326	11	13	2.87	7,881	8456.87
F	484556	4536634	326	11	16	7.72	7,377	6640.65
F	484587	4536632	323	11	15	2.72	7,953	10842.78
F	484612	4536631	320	7	21	9.05	7,322	9596.51
F	484576	4536620	324	11	21	8.39	7,362	9509.99
F	484548	4536620	326	11	13	2.78	7,894	7713.13