Fertilizer Requirements for Native Perennial Plants Harvested for Biomass
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Craig Sheaffer and John Lamb
Department of Agronomy and Plant Genetics &
Department of Soil, Waters, and Climate
University of Minnesota, St. Paul

Abstract

Field research evaluated the effect of N, P_2O_5 or K_2O fertilizer on native prairie biomass yield, energy yield, and nutrient content. At the initiation of the trial, unfertilized biomass yields were 2.7, 1.8, and 3.0 ton/acre at Austin, Lamberton, and Rosemount, respectively, and were increased 45, 27, and 43% respectively by N fertilization. Ethanol yield per ton averaged 108 gallons/ton and decreased slightly with nitrogen fertilization. Ethanol yield/acre ranged from 211 to 323 ton/acre and was increased with nitrogen fertilization. Response to K_2O and P_2O_5 application was less consistent and dramatic compared to N fertilizer. Concentration and content of N, P, K, and S in biomass harvested in the fall were low. Short-term harvest should not deplete soil nutrients. Producers will be able to use nitrogen fertilizer as a management tool to optimize biomass and ethanol yield.

Introduction

Native perennial, warm season prairie plants have been designated by the Department of Energy as a source of biomass for energy production. They have potential for conversion to ethanol, gasification, or direct combustion. Perennial prairie species can generate significant biomass and provide many ecological services like nutrient recycling, soil erosion control, and wildlife habitat. Switchgrass, a native perennial grass, is a primary candidate for production of cellulosic fuels. In addition to pure stands of switchgrass, mixtures of native grasses (e.g., switchgrass, big bluestem) with forbs (e.g., sunflowers) and legumes (e.g., Canada milkvetch) have been recommended to provide greater long-term stress tolerance and yield stability compared to grass monocultures. Economically and environmentally sound fertilizer nutrient recommendations are lacking for native grasses and native plant mixtures proposed for biomass crop removal systems. Our objectives were to determine the N, P, and K fertilizer requirements for native perennial prairie plants used for biofuel production.

Methods

Research was conducted in established stands of native perennial plants at Austin, Lamberton, and Rosemount in 2008 and 2009. Initial soil characteristics are described in Table 1. Research that was initiated in 2008 at New Ulm was terminated due to extreme soil irregularities and due to damage to the plots from ATV traffic.

The experimental design was a randomized complete block with 4 replications per location. Plots were 10 by 10 ft. All plots received variable rates of nitrogen (N) fertilizer: 0, 50, 100, 150, and 200 lb/acre that were combined in a factorial arrangement with variable levels of P_2O_5 or K_2O fertilizer depending on the soil type. For the low P soils, we applied P_2O_5 rates of 0, 30, 60, 90 and 120 lb/acre and for low K soils, K_2O was applied at 0, 40, 80, 120, and 160 lb/acre. Based on soil test results (Table 1) variable P_2O_5 rates were applied at Austin and Lamberton. At Rosemount, variable K_2O rates were applied. Fertilizers were broadcast in mid-May of each year.

Biomass yield was determined by harvesting a 3 by 3 ft area to a 3 inch height within each plot in early November each year following freezing and drying of the biomass. A 2 lb subsample was collected to a 3 inch height and oven dried. The subsample was dried and yield expressed on a dry matter basis. The subsample was then ground and was analyzed for cell wall sugars using a combination of wet chemistry (Theander et al., 1995) and Near Infrared Reflectance Spectroscopy. Equations for NIRS were developed using the software program Calibrate (NIRS 3 version 4.0, Infrasoft International, Port Matilda, PA) with modified partial least squares regression option (Shenk, 1991). Random subsets of 10 samples were chosen and subjected to conventional chemical analysis and for mineral content using wet chemistry at a commercial laboratory(Agvise Laboratories, Benson, MN). Ethanol production was determined using the Department of Energy ethanol yield calculator that is based on 5- and 6-carbon sugar content: http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html.

Soil was sampled from a 0-6 inch depth in spring 2008 from each replicate and combined for analysis for pH, P, and K. Soil was also sampled in fall of 2009 from each plot and analyzed for pH, P, and K. Soils were also sampled for soil N from 0-6 inches and 6-12 inches. All soil analysis was conducted using standard analysis techniques (Agvise Laboratories, Benson, MN).

Differences among treatments were determined using ANOVA. Because the interaction between treatments and location was significant ($P < 0.05$), we analyzed each location separately. Least significance differences (LSD) were used to separate means when F tests were statistically significant ($P < 0.05$). For some variables, if statistically significant response to N, P, or K was indicated by ANOVA, regression analysis was conducted (SAS Institute, 2003). Data were analyzed at $\alpha = 0.05$ using the MIXED procedure of SAS (SAS Institute, 2003).

Results

The contrasting soil types, vegetation, and climate for each location resulted in a statistically significant ($P<0.05$) location by treatment by year interaction. Therefore, results are presented separately for each location and year.

Biomass and ethanol yield

Biomass and ethanol yield results are shown in Tables 2-10. Unfertilized yields in 2008 ranged from 1.5 ton/acre at Lamberton to 3.1 ton/acre at Rosemount. Possibility due to combined effect of consecutive years of harvest and moisture deficits yields of unfertilized treatments declined in 2009 at all locations and ranged from 1.0 ton/acre at Rosemount to 1.6 tons per acre at Austin.

Biomass and ethanol yields were increased by N applications at all locations and yield responses to N fertilization were similar at all rates of P_2O_5 and K_2O fertilization (i.e., no significant ($P<0.05$) N rate by P_2O_5 and K_2O rate interactions. Biomass yield only responded to P_2O_5 at Austin in 2008. Biomass yield did not respond to K_2O fertilization at Rosemount. At Austin in 2009 and Rosemount in both years, a quadratic response to nitrogen fertilizer occurred indicating that we had reached a nitrogen fertilizer rate that maximized yield. At Lamberton in both years and Austin in 2008, the response was linear indicating that the optimum rate had not been reached, but the yield increased only 11.6 lb of biomass dry matter for each pound of N fertilizer applied at Austin in 2008 and an average of 5.4 lb of biomass dry matter for each pound of N fertilizer applied at Lamberton. The biomass and ethanol responses to N are illustrated in Figures 1-6.

Ethanol yield (in gallon/ton) was calculated based on biomass sugar content and was similar over the three locations (average of 106 gal/ton). Within locations, the response to increased N rates was small with the greatest yield in gallon/ton often for the unfertilized treatment. Ethanol yield (gal/ton) declined linearly at all location except at Lamberton in 2008 when no response to N fertilization occurred. The effects of P_2O_5 and K_2O fertility treatments on yields were limited except in 2008 at Austin where increasing P_2O_5 rates increased ethanol yield (Figure 1).

Ethanol yield (gallon/acre) averaged 323, 211 and 317 gal/acre at Austin, Lamberton, and Rosemount, respectively, but considerable year-year variability occurred at Austin and Rosemount. Ethanol yield per acre response to N fertilization was similar to that observed for biomass yield. The response to increasing N rate was quadratic for both years at Rosemount and linear at Lamberton. The response was linear and quadratic in 2008 and 2009, respectively, at Austin.

Mineral concentration of the biomass.

Nitrogen, P, K, and S concentration of the biomass was low and averaged 0.63, 0.08, 0.31, and 0.05%, respectively, over the three locations and years (Tables 11-23). These levels in the mature biomass harvested in fall were low relative to herbage harvested during the growing season because of nutrient translocation to belowground portions of the plant. It is likely that nutrient leaching also occurred. The response of biomass nutrient concentration to N fertilization varied with location and nutrient. Biomass N concentration increased linearly with increased N rates at all locations and years. Biomass P, K, and S concentrations were increased by N fertilization at Austin and Rosemount each year. This response was mostly linear (data not shown). At Austin and Lamberton, where P_2O_5 fertilizer rates were applied, P_2O_5 application increased P concentration of the biomass. At both locations, this response was linear in 2008 and quadratic in 2009. The linear increase in biomass K concentration due to K_2O fertilization at Rosemount was significant but small. Biomass S concentration response to N fertilization was linear at Austin and Rosemount and quadratic at Lamberton.

Uptake and therefore potential removal of N, K, and P by biomass harvest is shown in Tables 24-36. Nitrogen fertilization resulted in removal of N, K, and P at all locations. These responses were primarily linear for N concentration of the biomass, and a combination of linear and quadratic for P and K concentration of the biomass. As expected, P_2O_5 and K_2O application that increased P concentration of the biomass also increased P and K removal. Overall, nutrient removal was low and most soils should be able to supply adequate levels of P, K, and S for continued biomass production.

Biomass sugar content

Cell wall sugar concentration information is shown in Tables 37-40. Nitrogen fertilization decreased C5 (xylan and arabinan) sugar and C6 (glucan, galactan, and mannan) sugar concentration at Austin in both years, and at Lamberton and Rosemount in 2009. Nitrogen fertilization also decreased C5 sugar content at Lamberton in 2009 and C6 sugar content in 2009. Effects of P and K fertilization were inconsistent over the locations and years. Changes in cell wall sugar content due to fertilization are reflected in the slight decrease in ethanol yield/ton of biomass with increased N fertilization rates (Table 10).

Soil properties

The effect of treatments on soil characteristics is shown in Tables 41-47. Fertilization with N, P, or K had a slight but inconsistent effect on soil pH. Average ending pH at Austin, Lamberton, and Rosemount was 6.2, 6.5, and 6.7, respectively.

At all locations, soil N levels were low reflecting plant uptake of soil N. However, nitrogen fertilization increased 0-6 inch and 6-12 inch soil nitrogen at Lamberton and Rosemount but not at Austin. The greatest effects were observed at the 150-200 lb N rates. Nitrogen fertilization had no effect on soil P or K levels. However, as expected, P and K fertilization did significantly increase soil test P and soil test K values when those treatments were applied (Table 47).

At Austin the soil test P was increased from the intial soil test of 12 ppm to 33 ppm at the end of the study for the zero phosphate rate treatment. The addition of phosphate fertilizer increased the soil test P from 32.9 ppm for the check to 48.6 ppm when 120 lbs phosphate per acre was applied for two years. At Lamberton, the initial soil test P was 8 ppm. The check after two years of this study was similar at 5 ppm. The addition of 120 lbs phosphate per acre each year of the study increased the soil test P to 21 ppm. This indicates that the phosphorous removal by the harvest of the vegetation is minimum and should not be a production problem.

At Rosemount, the initial soil test potassium was 160 ppm. After two years of production the soil test K for the check plots receiving no potash fertilizer was 128 ppm. This reduction is surprising as the potassium removal in the vegetation was small, 10 to 30 lbs per acre. The addition of potash fertilizer increased the soil test K. When 160 lbs of potash per acre was applied each year the soil test increased from 128 ppm for the check to 197 ppm.

Educational activities:

The results of this research were presented at the Third Crop Producer Meetings. February 8, 2010 at Fairmont, MN. The event was promoted by Rural Advantage and University of Minnesota Extension. The presentation was titled: Biomass Fertility and Yield Trials at the University of Minnesota. We plan a presentation at the Southwest Research and Outreach Center this summer and to develop educational publications on this research.

Tables

Table 1. Initial soil characteristics for native plant fertility trials at three locations.

Location	Soil texture	pH	Organic matter	Phosphorus	Potassium
			%	ppm	ppm
Austin	Silty clay loam	5.9	3.0	12	126
Lamberton	Silty clay loam	7.2	3.8	8	172
Rosemount	Silt loam	6.8	4.3	49	160

Table 2. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass yield (tons/acre) as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*			*Rosemount*	
	2008	2009	2008	2009		2008	2009
Ntrt	<.001	<.001	0.02	<.001	Ntrt	<.001	<.001
Ptrt	0.01	0.65	0.42	0.54	Ktrt	0.10	0.82
Ntrt*Ptrt	0.28	0.55	0.94	0.86	Ntrt*Ktrt	0.67	0.24

Table 3. Effect of nitrogen rate on biomass dry matter yield (ton/acre) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	2.72	1.66	1.80	1.54	3.05	1.06
50	3.25	3.30	2.12	2.01	3.94	1.77
100	3.46	3.04	2.20	2.04	4.13	1.93
150	3.66	3.13	2.16	2.12	4.18	1.85
200	3.96	2.78	2.30	2.30	4.39	1.92
mean	3.41	2.78	2.12	2.00	3.94	1.71
LSD @ 0.05	0.28	0.50	0.29	0.22	0.33	0.24

Table 4. Regression equations and statistics showing the relationship between N fertilizer rate and biomass dry matter yield (tons/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		*Lamberton*		*Rosemount*	
	2008	2009	2008	2009	2008	2009
Model	Linear	Quadratic	Linear	Linear	Quadratic	Quadratic
p-value	<.0001	<.0001	0.0015	<.0001	<.0001	<.0001
R^2	0.4291	0.3104	0.0987	0.3130	0.4193	0.3815
Equation: Dry matter =	$2.834 + 0.0058N$	$1.846 + 0.0250N - 0.00010N^2$	$1.909 + 0.0021N$	$1.678 + 0.0033N$	$3.138 + 0.0144N - 0.00004N^2$	$1.128 + 0.0124N - 0.00004N^2$

Table 5. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on ethanol yield (gallon/acre) as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	<.001	0.01	<.001
Ptrt	0.08	0.60	0.32	0.80
Ntrt*Ptrt	0.16	0.95	0.90	0.89

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.09	0.81
Ntrt*Ktrt	0.76	0.28

Table 6. Effect of nitrogen rate on ethanol yield (gallon/acre) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	292	171	175	171	354	120
50	348	347	208	217	454	195
100	361	314	216	216	472	208
150	381	323	216	228	473	197
200	406	279	222	243	490	200
mean	358	287	207	215	449	184
LSD @ 0.05	30	57	28	25	38	26

Table 7. Regression equations and statistics showing the relationship between N fertilizer rate and ethanol yield (gallon/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		*Lamberton*		*Rosemount*	
	2008	2009	2008	2009	2008	2009
Model	Linear	Quadratic	Linear	Linear	Quadratic	Quadratic
p-value	<.0001	<.0001	0.0014	<.0001	<.0001	<.0001
R^2	0.3616	0.2728	0.0998	0.2616	0.3749	0.3323
Equation: Eth (gal/ac) =	$305.418 + 0.5239N$	$193.158 + 2.5971N - 0.0111N^2$	$186.753 + 0.2038N$	$183.529 + 0.3121N$	$364.166 + 1.6257N - 0.0052N^2$	$127.649 + 1.2895N - 0.00483N^2$

Table 8. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on ethanol yield (gallon/ton) as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	0.001	0.40	0.0002
Ptrt	0.00	0.19	0.17	0.25
Ntrt*Ptrt	0.01	0.37	0.03	0.42

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.83	0.27
Ntrt*Ktrt	0.89	0.21

Table 9. Effect of nitrogen rate on ethanol yield (gallon/ton) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	107.4	107.2	97.6	111.0	116.2	113.3
50	107.1	106.9	98.6	108.4	115.3	110.2
100	104.3	102.9	97.8	105.8	114.2	107.8
150	104.3	99.9	99.8	107.5	113.4	106.2
200	102.7	102.8	96.4	105.5	111.8	104.3
mean	105.2	103.9	98.1	107.6	114.2	108.3
LSD @ 0.05	1.9	3.4	NS	2.5	1.2	0.7

Table 10. Regression equations and statistics showing the relationship between N fertilizer rate and ethanol yield (gallon/ton). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		*Lamberton*		*Rosemount*	
	2008	2009	2008	2009	2008	2009
Model	Linear	Linear	NS	Linear	Linear	Linear
p-value	<.0001	<.0001		<.0001	<.0001	<.0001
R^2	0.1596	0.2163		0.1461	0.4196	0.8493
Equation:						
Eth (gal/T) =	107.621 - 0.0246N	107.692 - 0.0383N		110.086 - 0.0243N	116.319 - 0.0215N	112.747 - 0.0440N

Table 11. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass N concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	<.001	0.01	<.001
Ptrt	0.31	0.06	0.39	0.58
Ntrt*Ptrt	0.09	0.91	0.19	0.33

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.56	0.71
Ntrt*Ktrt	0.39	0.89

Table 12. Effect of nitrogen fertilizer rate on biomass N concentration (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	0.55	0.40	0.57	0.45	0.44	0.34
50	0.54	0.43	0.68	0.51	0.49	0.43
100	0.67	0.64	0.66	0.59	0.59	0.65
150	0.78	0.77	0.73	0.67	0.67	0.80
200	0.89	0.83	0.78	0.73	0.82	0.98
mean	0.69	0.61	0.68	0.59	0.60	0.64
LSD @ 0.05	0.07	0.10	0.12	0.07	0.07	0.06

Table 13. Regression equations and statistics showing the relationship between N fertilizer rate and biomass N concentration. Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		*Lamberton*		*Rosemount*	
	2008	2009	2008	2009	2008	2009
Model	Linear	Linear	Linear	Linear	Linear	Linear
p-value	<.0001	<.0001	0.0009	0.0009	<.0001	<.0001
R^2	0.5461	0.5281	0.1109	0.4695	0.6198	0.8417
Equation:						
%N =	0.5013 + 0.0019N	0.3779 + 0.0023N	0.5961 + 0.0009N	0.4444 + 0.0014N	0.4135 + 0.0019N	0.3107 + 0.0033N

Table 14. ANOVA results showing the level of statistical significance for N, K, or P treatment effects on biomass P concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		Lamberton	
	2008	2009	2008	2009
Ntrt	<.001	<.001	0.55	0.25
Ptrt	0.03	0.01	<.001	<.001
Ntrt*Ptrt	0.72	0.11	0.62	0.14

	Rosemount	
	2008	2009
Ntrt	0.04	0.01
Ktrt	0.33	0.67
Ntrt*Ktrt	0.55	0.52

Table 15. Effect of nitrogen fertilizer rate on biomass P concentration (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		Lamberton		Rosemount	
N rate	2008	2009	2008	2009	2008	2009
0	0.079	0.074	0.050	0.054	0.126	0.095
50	0.084	0.070	0.048	0.046	0.131	0.103
100	0.089	0.103	0.047	0.046	0.143	0.110
150	0.102	0.090	0.046	0.049	0.130	0.113
200	0.105	0.086	0.044	0.050	0.127	0.113
mean	0.091	0.084	0.047	0.049	0.131	0.107
LSD @ 0.05	0.011	0.012	NS	NS	0.012	0.011

Table 16. Effect of P_2O_5 fertilizer rate on biomass P concentration (% dry matter basis) at Austin and Lamberton in 2008 and 2009.

	Austin		Lamberton	
P rate	2008	2009	2008	2009
0	0.089	0.071	0.036	0.034
30	0.085	0.091	0.039	0.060
60	0.086	0.082	0.050	0.053
90	0.097	0.090	0.052	0.056
120	0.101	0.088	0.058	0.041
mean	0.091	0.084	0.047	0.049
LSD @ 0.05	0.011	0.012	0.007	0.008

Table 17. Regression equations and statistics showing the relationship between P_2O_5 fertilizer rate and biomass P concentration. Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model

	Austin		*Lamberton*	
	2008	2009	2008	2009
Model	Linear	NS	Linear	Linear
p-value	0.0296		<.0001	<.0001
R^2	0.0479		0.3536	0.324
Equation:				
%P =	0.0843 + 0.0001P		0.0356 + 0.0002P	0.0356 + 0.00022P

Table 18. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass K concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	0.02	0.13	0.13
Ptrt	0.38	0.38	0.15	0.27
Ntrt*Ptrt	0.15	0.41	0.91	0.28

	Rosemount	
	2008	2009
Ntrt	0.01	0.01
Ktrt	0.04	<.001
Ntrt*Ktrt	0.11	0.00

Table 19. Effect of nitrogen fertilizer rate on biomass K concentration (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	0.285	0.283	0.287	0.263	0.398	0.273
50	0.325	0.258	0.298	0.274	0.438	0.329
100	0.365	0.292	0.328	0.328	0.475	0.325
150	0.404	0.301	0.305	0.318	0.438	0.296
200	0.493	0.365	0.348	0.338	0.460	0.307
mean	0.374	0.300	0.313	0.304	0.442	0.306
LSD @ 0.05	0.063	0.063	NS	NS	0.037	0.027

Table 20. Effect of K_2O fertilizer rate on biomass K concentration (% dry matter basis) at Rosemount in 2008 and 2009.

K rate	2008	2009
0	0.4051	0.2485
40	0.459	0.3035
80	0.447	0.312
120	0.4432	0.3185
160	0.455	0.3465
mean	0.442	0.306
LSD @ 0.05	0.03657	0.027

Table 21. Regression equations and statistics showing the relationship between K_2O fertilizer rate and biomass K concentration. Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Rosemount	
	2008	2009
Model	NS	Linear
p-value		<.0001
R^2		0.2453
Equation:		
%K =		0.2636 + 0.00053K

Table 22. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass S concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	<.001	0.57	0.01
Ptrt	0.23	0.01	0.06	0.13
Ntrt*Ptrt	0.03	0.66	0.05	0.53

	Rosemount	
	2008	2009
Ntrt	0.01	<.001
Ktrt	0.02	0.69
Ntrt*Ktrt	0.43	0.27

Table 23. Effect of nitrogen fertilizer rate on biomass S concentration (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	0.050	0.037	0.047	0.042	0.051	0.040
50	0.046	0.037	0.052	0.039	0.050	0.039
100	0.054	0.047	0.046	0.045	0.057	0.048
150	0.059	0.053	0.046	0.046	0.057	0.052
200	0.063	0.056	0.046	0.054	0.062	0.059
mean	0.054	0.046	0.047	0.045	0.055	0.047
LSD @ 0.05	0.007	0.007	NS	0.007	0.006	0.004

Table 24. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass N uptake (removal) in lb/acre by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		Lamberton	
	2008	2009	2008	2009
Ntrt	<.001	<.001	<.001	<.001
Ptrt	0.01	0.31	0.41	0.54
Ntrt*Ptrt	0.05	0.79	0.27	0.12

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.46	0.91
Ntrt*Ktrt	0.92	0.13

Table 25. Effect of nitrogen fertilizer rate on biomass N uptake (removal) in lb/acre at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		Lamberton		Rosemount	
N rate	2008	2009	2008	2009	2008	2009
0	30	13	20	14	26	7
50	35	28	30	20	38	15
100	47	39	29	23	49	25
150	57	46	31	28	56	29
200	71	45	36	34	72	38
mean	48	34	29	24	48	23
LSD@0.05	7	8	7	3	6	4

Table 26. Regression equations and statistics showing the relationship between N fertilizer rate and biomass N content (lb/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		Lamberton		Rosemount	
	2008	2009	2008	2009	2008	2009
Model	Linear	Quadratic	Linear	Linear	Linear	Linear
p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
R^2	0.6226	0.5485	0.1549	0.6392	0.7124	0.7277
Equation:						
N uptake =	27.040 + 0.211N	12.714 + 0.370N - $0.0010N^2$	23.035 + 0.064N	14.338 + 0.095N	26.761 + 0.214N	7.948 + 0.149N

Table 27. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass P uptake (removal in lb/acre) by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		Lamberton	
	2008	2009	2008	2009
Ntrt	<.001	<.001	0.13	0.01
Ptrt	<.001	0.07	<.001	<.001
Ntrt*Ptrt	0.57	0.12	0.63	0.17

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.39	0.07
Ntrt*Ktrt	0.61	0.78

Table 28. Effect of nitrogen fertilizer rate on biomass P uptake (removal) in lb/acre at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		Lamberton		Rosemount	
N rate	2008	2009	2008	2009	2008	2009
0	4.3	2.4	1.7	1.7	7.6	2.0
50	5.4	4.5	2.1	1.8	10.3	3.6
100	6.1	5.0	2.1	1.8	11.8	4.2
150	7.5	5.3	1.9	2.1	10.7	4.1
200	8.4	5.5	2.0	2.3	11.1	4.4
mean	6.4	4.5	2.0	1.9	10.3	3.7
LSD@0.05	1.1	0.8	NS	0.3	1.2	0.6

Table 29. Regression equations and statistics showing the relationship between N fertilizer rate and biomass P content (lb/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		Lamberton		Rosemount	
	2008	2009	2008	2009	2008	2009
Model	Linear	Quadratic	NS	Linear	Quadratic	Quadratic
p-value	<.0001	<.0001		0.0063	<.0001	<.0001
R^2	0.3649	0.4083		0.0744	0.3296	0.4321
Equation:						
P uptake =	4.291 + 0.021N	2.557 + 0.037N - $0.0001N^2$		1.657 + 0.003N	7.831 + 0.055N - $0.0002N^2$	2.107 + 0.030N - $0.0001N^2$

Table 30. Effect of P_2O_5 fertilizer rate on biomass P uptake (removal) in lb/acre at Austin, Lamberton, and Rosemount in 2008 and 2009

	Austin		Lamberton	
P rate	2008	2009	2008	2009
0	5.7	NS	1.4	1.2
30	5.8		1.6	1.6
60	5.7		2.2	2.1
90	7.2		2.2	2.3
120	7.4		2.4	2.5
mean	6.4		2.0	1.9
LSD @ 0.05	1.1		0.3	0.3

Table 31. Regression equations and statistics showing the relationship between P_2O_5 fertilizer rate and biomass P content (lb/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		Lamberton	
	2008	2009	2008	2009
Model	Linear	NS	Linear	Linear
p-value	0.0065		<.0001	<.0001
R^2	0.0739		0.3263	0.3653
Equation:				
P uptake =	5.412 + 0.015P		1.458 + 0.008P	1.307 + 0.010P

Table 32. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass K uptake (removal in lb/acre) by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		Lamberton	
	2008	2009	2008	2009
Ntrt	<.001	<.001	<.001	<.001
Ptrt	0.14	0.54	0.26	0.15
Ntrt*Ptr	0.03	0.23	0.73	0.14

	Rosemount	
	2008	2009
Ntrt	<.001	<.001
Ktrt	0.03	<.001
Ntrt*Ktrt	0.13	<.001

Table 33. Effect of nitrogen fertilizer rate on biomass K uptake (removal) in lb/acre at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		Lamberton		Rosemount	
N rate	2008	2009	2008	2009	2008	2009
0	16	9	10	8	24	6
50	21	17	13	11	35	12
100	25	18	15	13	40	13
150	30	18	13	13	37	11
200	39	19	16	16	41	12
mean	26	16	13	12	35	10
LSD @ 0.05	5	4	3	3	5	1

Table 34. Regression equations and statistics showing the relationship between N fertilizer rate and biomass K content (lb/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Austin		Lamberton		Rosemount	
	2008	2009	2008	2009	2008	2009
Model	Linear	Quadratic	Linear	Linear	Quadratic	Quadratic
p-value	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
R^2	0.4200	0.2386	0.1384	0.1741	0.3026	0.349
Equation: K uptake =	14.890 + 0.112N	10.053 + 0.119N - $0.0004N^2$	10.621 + 0.027N	8.729 + 0.036N	25.554 + 0.183N - $0.0006N^2$	6.445 + 0.095N - $0.0004N^2$

Table 35. Effect of K_2O fertilizer rate on biomass K uptake (removal) in lb/acre at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Rosemount	
K rate	2008	2009
0	30	8
40	36	10
80	38	11
120	35	11
160	37	12
mean	35	10
LSD @ 0.05	5	1

Table 36. Regression equations and statistics showing the relationship between K_2O fertilizer rate and biomass K content (lb/acre). Regression equations were developed based on a significant "fit" of the data to a linear or quadratic model.

	Rosemount	
	2008	2009
Model	NS	Linear
p-value		0.0026
R^2		0.0887
Equation:		
K uptake =		8.903 + 0.019K

Table 37. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass C5 sugar (xylan and arabinan) mg/g (% dry matter basis) concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	0.0016	0.0001	0.6439	<.0001
Ptrt	0.0193	0.5236	0.0193	0.1560
Ntrt*Ptrt	0.0239	0.4152	0.1730	0.4009

	Rosemount	
	2008	2009
Ntrt	<.0001	<.0001
Ktrt	0.6309	0.0293
Ntrt*Ktrt	0.7643	0.0116

Table 38. Effect of nitrogen fertilizer rate on biomass cell wall C5 sugars (xylan and arabinan) mg/g (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	238.3	233.2	205.3	254.1	276.7	268.3
50	235.7	228.4	206.2	242.0	271.2	251.8
100	227.9	211.3	205.4	228.7	264.9	243.0
150	228.8	213.8	213.3	238.1	259.6	237.7
200	223.4	201.5	202.8	229.2	254.9	232.0
mean	230.8	217.6	206.6	238.4	265.4	246.5
LSD @ 0.05	7.8	14.2	NS	10.8	3.3	2.7

Table 39. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on biomass C6 sugar (glucan, galactan, and mannan) mg/g (% dry matter basis) concentration as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin		*Lamberton*	
	2008	2009	2008	2009
Ntrt	<.001	0.01	0.09	0.02
Ptrt	0.01	0.02	0.17	0.74
Ntrt*Ptrt	0.06	0.58	0.35	0.50

	Rosemount	
	2008	2009
Ntrt	0.22	<.001
Ktrt	0.72	0.94
Ntrt*Ktrt	0.91	0.99

Table 40. Effect of nitrogen fertilizer rate on biomass cell wall C6 sugars (glucan, galactan, and mannan) mg/g (% dry matter basis) at Austin, Lamberton, and Rosemount in 2008 and 2009.

	Austin		*Lamberton*		*Rosemount*	
N rate	2008	2009	2008	2009	2008	2009
0	377.7	381.3	354.8	382.6	389.1	381.0
50	378.3	384.7	359.7	379.3	389.6	380.2
100	370.6	379.1	355.9	378.1	390.0	375.0
150	369.5	375.7	359.0	378.5	390.3	370.9
200	365.3	371.8	350.4	375.8	386.0	366.2
mean	372.3	378.5	356.0	378.8	389.0	374.7
LSD @ 0.05	4.4	6.4	NS	3.8	NS	2.2

Table 41. Average soil test results (nitrogen, phosphoryus, and potassium) from Austin, Lamberton, and Rosemont. Samples taken fall 2009. P, K, and pH tests are from 0-6 inch.

	pH	N(lbs)	P (ppm)	K (ppm)
Austin	6.2	4.7	40	180
Lamberton	6.5	7.6	13	241
Rosemount	6.7	4.9	44	135

Table 42**.** ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on soil pH as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

	Austin 2008	*Lamberton* 2008		*Rosemount* 2008
Ntrt	0.0336	0.0512	Ntrt	<.0001
Ptrt	0.7945	0.5464	Ktrt	0.1000
Ntrt*Ptrt	0.3275	0.4074	Ntrt*Ktrt	0.6837

Table 43. The effect of N fertilizer rate on soil pH in the fall of 2009 from three locations.

N rate	*Austin*	*Lamberton*	*Rosemount*
0	6.21	6.66	6.76
50	6.25	6.58	6.76
100	6.14	6.43	6.72
150	6.17	6.42	6.56
200	6.11	6.34	6.64
mean	6.17	6.49	6.69
LSD@0.05	0.09	NS	0.09

Table 44. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on soil N level at 0-6 inches, 6-12 inches, and 0-12 inches as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

0-6

	Austin 2008	*Lamberton* 2008		*Rosemount* 2008
Ntrt	0.0526	<.0001	Ntrt	0.0009
Ptrt	0.5035	0.3573	Ktrt	0.4375
Ntrt*Ptrt	0.9735	0.9234	Ntrt*Ktrt	0.2927

6-12

	Austin 2008	*Lamberton* 2008		*Rosemount* 2008
Ntrt	0.1323	<.0001	Ntrt	<.0001
Ptrt	0.9430	0.8852	Ktrt	0.1359
Ntrt*Ptrt	0.7565	0.7809	Ntrt*Ktrt	0.0930

0-12

	Austin	*Lamberton*		*Rosemount*
Ntrt	0.0455	<.0001	Ntrt	<.0001
Ptrt	0.9997	0.4340	Ktrt	0.3009
Ntrt*Ptrt	0.8182	0.9699	Ntrt*Ktrt	0.2052

Table 45. Effect of nitrogen fertilizer rate on soil nitrogen (lb/acre) at 0-6, 6-12, and 0-12 inches depths at Austin, Lamberton, and Rosemount in 2008 and 2009

Soil N (lb.) at 0-6"

N rate	*Austin*	*Lamberton*	*Rosemount*
0	2.25	2.45	2.50
50	2.45	2.78	2.10
100	2.20	3.88	2.25
150	2.45	6.43	2.85
200	3.05	9.20	3.65
mean	2.48	4.95	2.67
LSD 0.05	NS	2.57	0.76

Soil N (lb.) 6-12"

N rate	*Austin*	*Lamberton*	*Rosemount*
0	2.00	2.10	2.00
50	2.05	2.06	2.05
100	2.30	2.16	2.00
150	2.20	2.72	2.25
200	2.75	4.10	3.05
mean	2.26	2.63	2.27
LSD@0.05	NS	0.73	0.32

Soil N 0-12"

N rate	*Austin*	*Lamberton*	*Rosemount*
0	4.25	4.55	4.50
50	4.50	4.85	4.15
100	4.50	6.03	4.25
150	4.65	9.14	5.10
200	5.80	13.30	6.70
mean	4.74	7.58	4.94
LSD@0.05	1.07	3.12	0.95

Table 46. ANOVA results showing the level of statistical significance for N, K, or P fertilizer treatment effects on soil P and K as indicated by *P* values. *P* values of <0.05 are considered statistically significant.

Soil PBray 1 – ppm

	Austin	*Lamberton*		*Rosemount*
Ntrt	0.8254	0.0188	Ntrt	0.0293
Ptrt	<.0001	<.0001	Ktrt	0.6234
Ntrt*Ptrt	0.6941	0.3674	Ntrt*Ktrt	0.9167

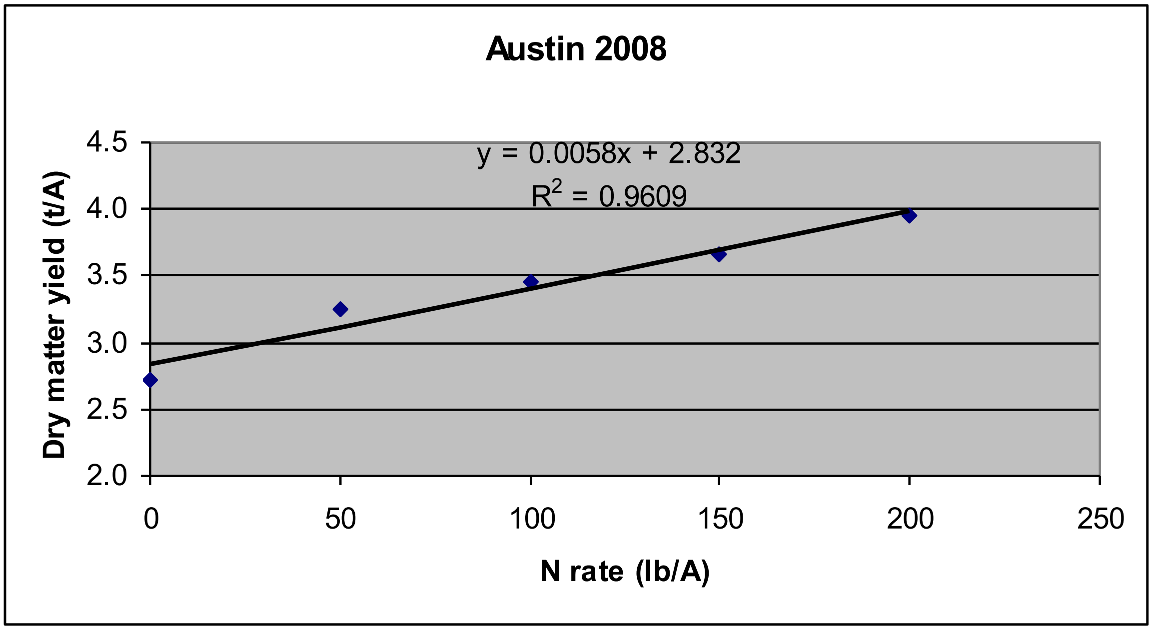
Soil K – ppm

	Austin	*Lamberton*		*Rosemount*
Ntrt	0.4858	0.4930	Ntrt	0.3249
Ptrt	0.1234	0.6564	Ktrt	<.0001
Ntrt*Ptrt	0.0655	0.1426	Ntrt*Ktrt	0.1046

Table 47. Effect of phosphorus fertilizer application rate (lb/acre) on Bray P soil test at Austin and Lamberton and the effect of potassium fertilizer application (lb/acre) on soil test K at Rosemount in fall 2009.

P rate	Austin	Lamberton	K rate	Rosemount
0	32.9	5.2	0	127.5
30	39.2	7.6	40	157.4
60	36.5	13.5	80	159.0
90	45.1	19.3	120	175.7
120	48.6	21.4	160	197.1
mean	40.4	13.4		134.7
LSD @ 0.05	5.2	3.8		16.8

Figure 1. Biomass yield response to N and P_2O_5 fertilization of a mixed native prairie poloyculture near Austin, MN. The response to fertilizer was significant (P<0.05) for both N and P_2O_5.



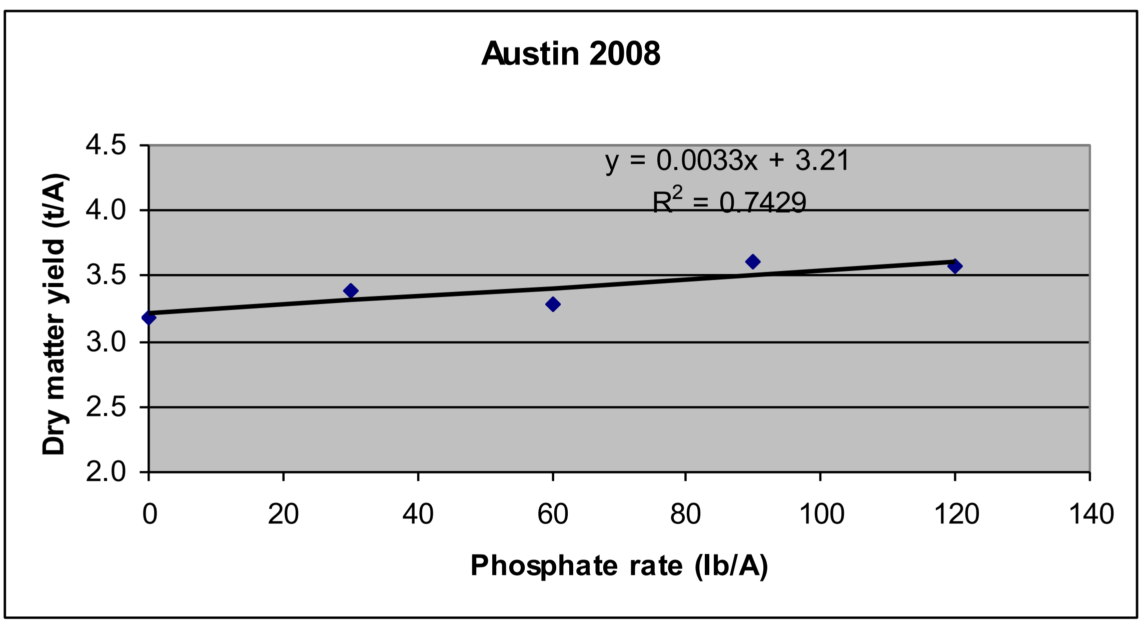
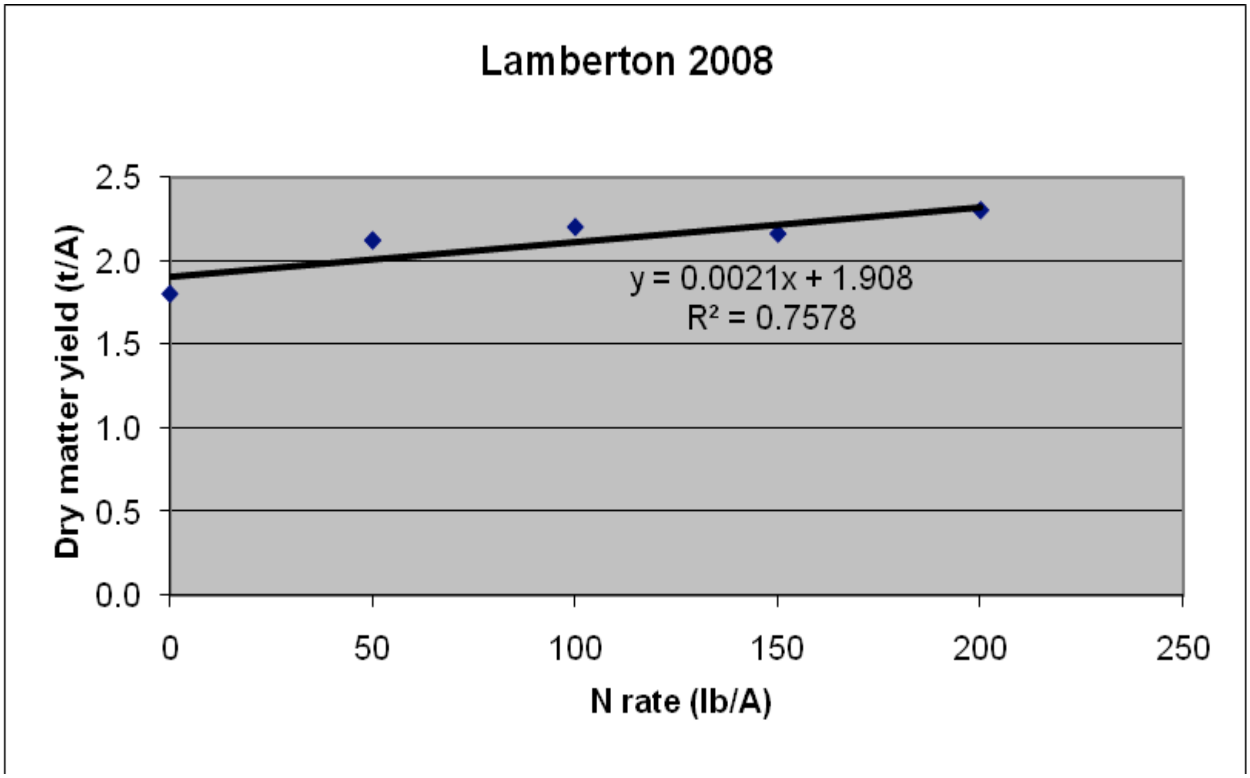


Figure 2. Biomass yield response to N and P_2O_5 fertilization of a mixed native prairie poloyculture at Lamberton, MN. The response to P_2O_5 fertilization was not significant (*P* >0.05).



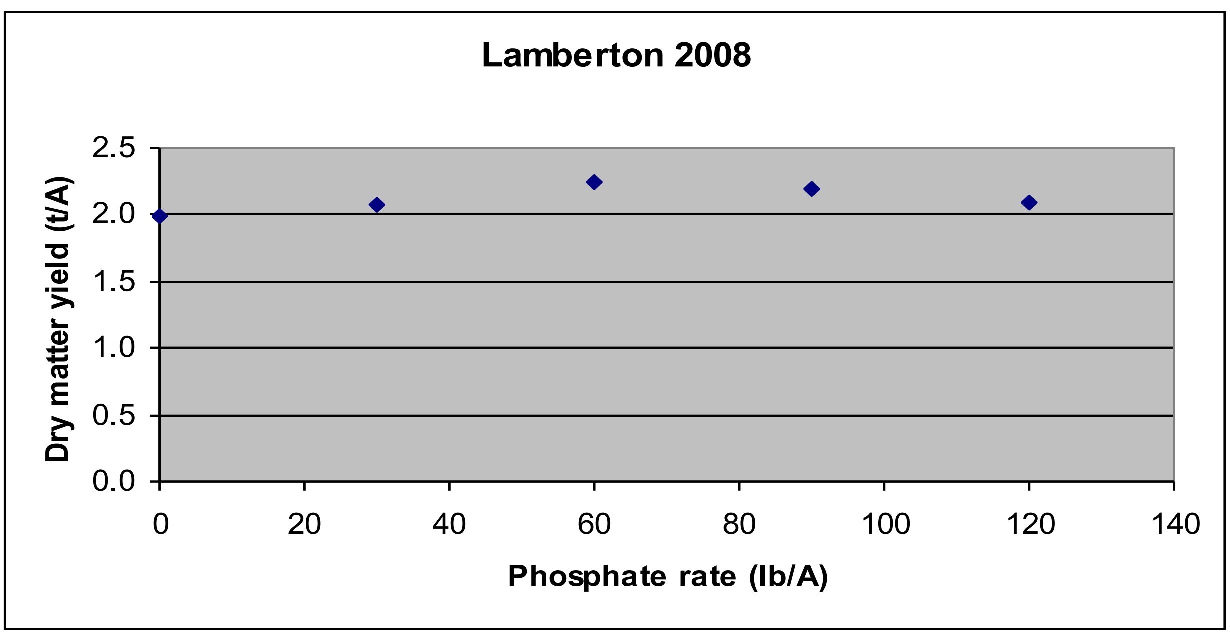
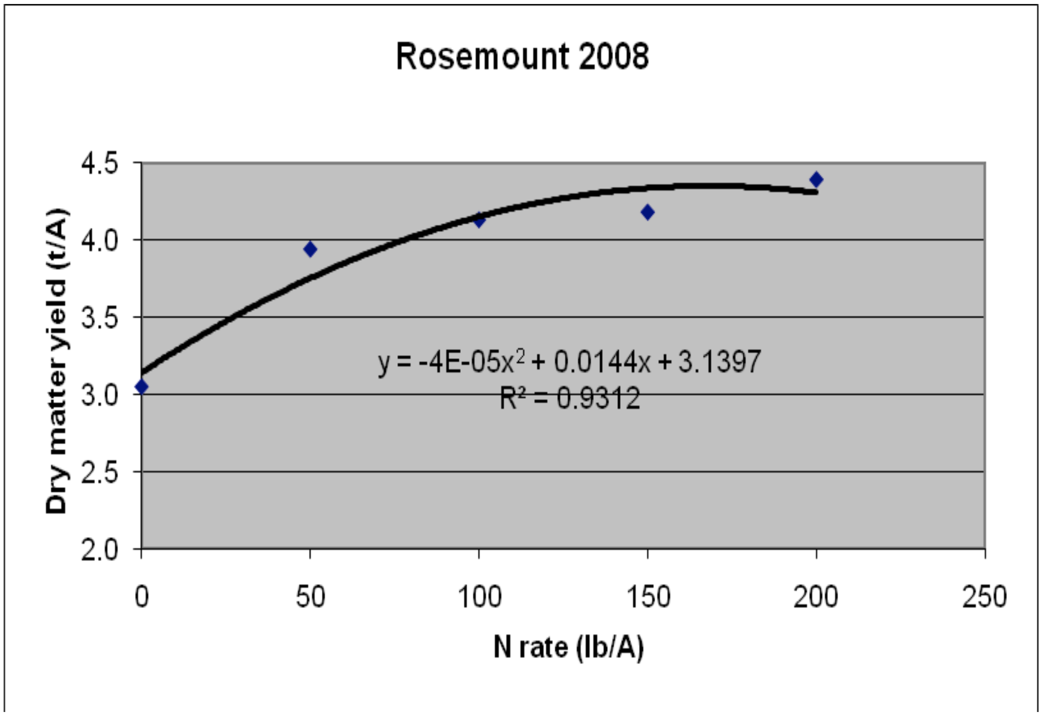


Figure 3. Biomass yield response to N and K_2O fertilization of a switchgrass prairie near Rosemount, MN. The response to K_2O fertilization was not significant (P >0.05).



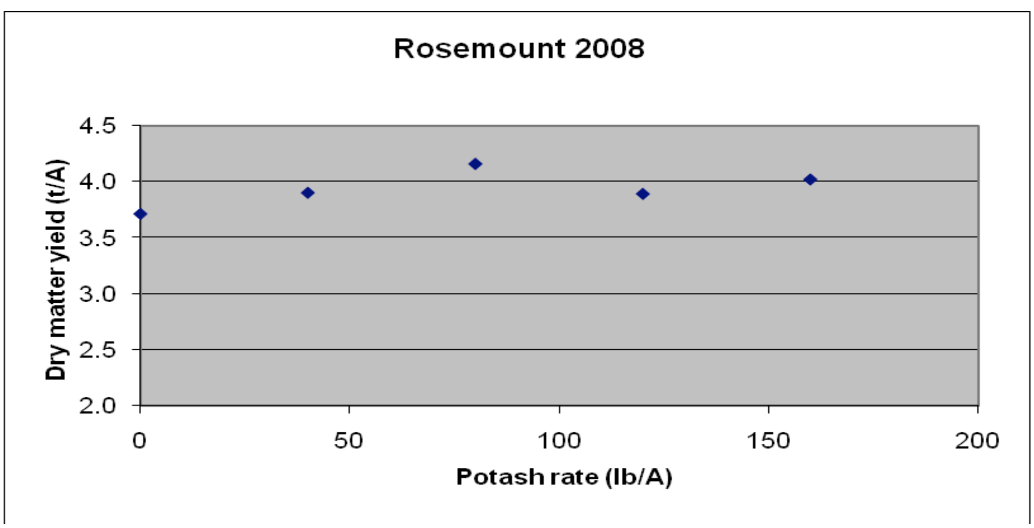


Figure 4. Graphic presentation showing the relationship between N fertilizer rate and biomass dry matter yield at Austin, MN.

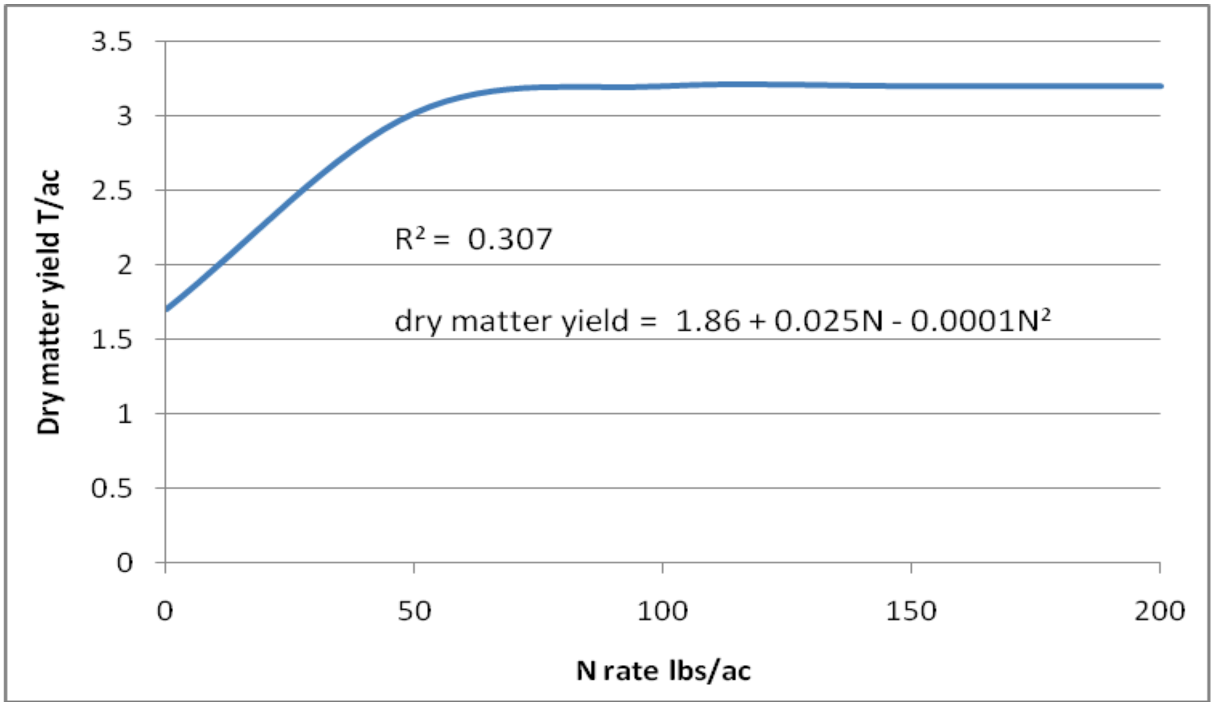


Figure 5. Graphic presentation showing thre relationship between N fertilizer rate and biomass dry matter yield at Lamberton, MN. 2009

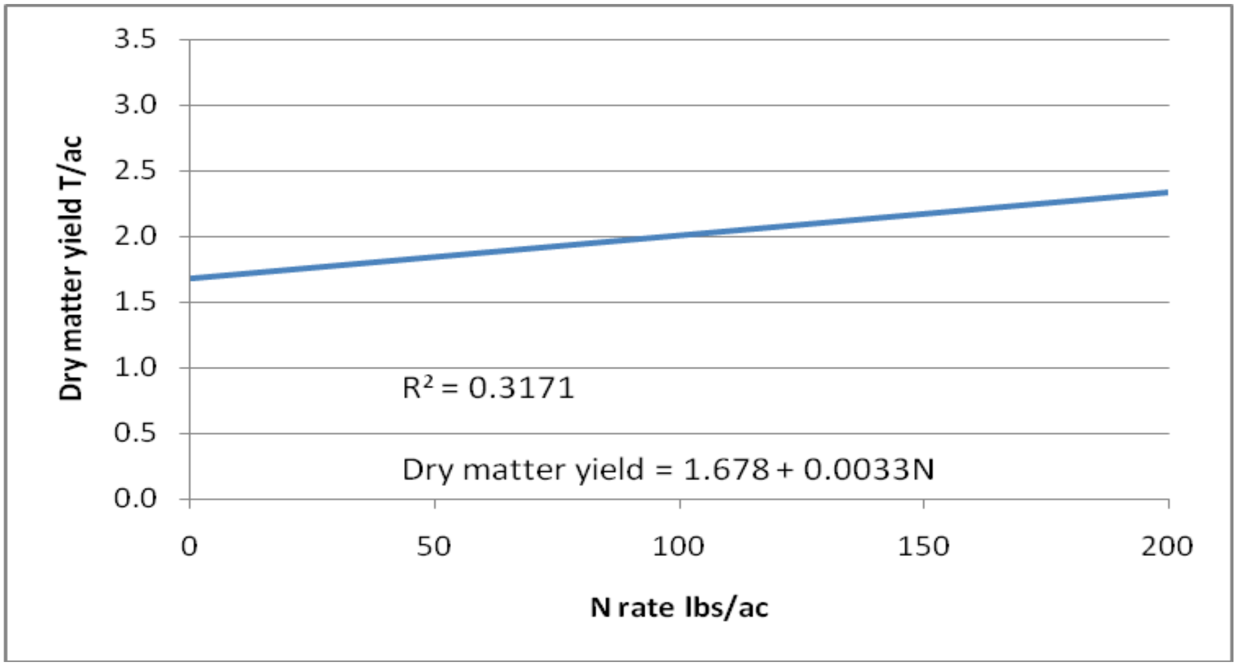
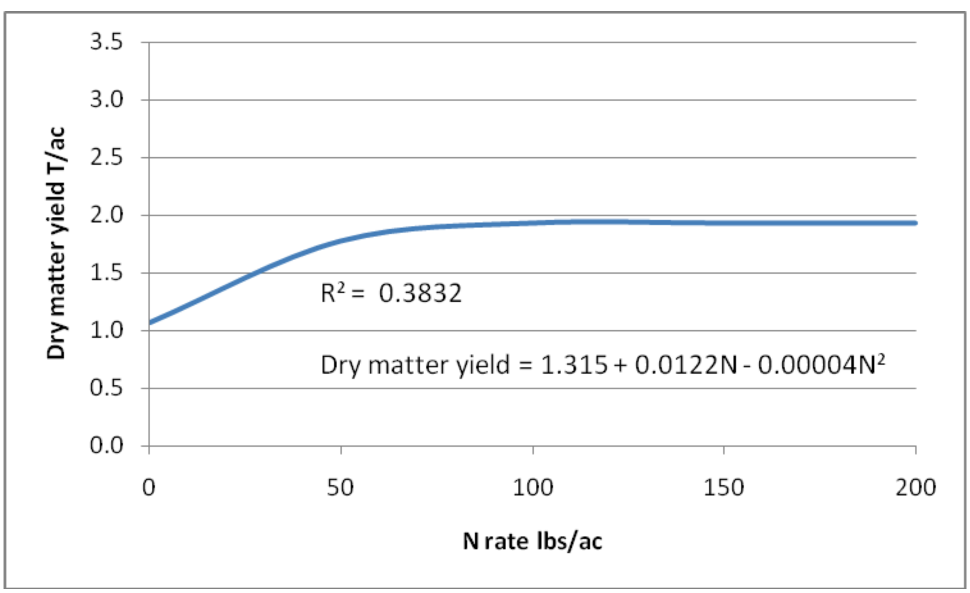


Figure 6. Graphic presentation showing the relationship between N fertilizer rate and biomass dry matter yield at Rosemount, MN. 2009



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