FORAGE CATIONS AS AFFECTED BY SOIL pH AND TOPDRESSED K

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A significant number of experiments, many conducted in Wisconsin, show the benefits of adding lime to fields where alfalfa is grown (Peters and Kelling, 1989, 1997). Similarly, a substantial amount of work has documented the benefits of adding potash to soils where alfalfa is raised (Attoe and Truog, 1950; Smith and Powell, 1979; Erickson et al., 1981; Peterson et al., 1975; Kelling, 1995). Potassium functions in several physiological processes in forage legumes. These include enzyme activity, carbohydrate production and transport, and stomatal activity (Munson, 1985). Potassium uptake is also linked to increased resistance to disease and lodging, increased carbohydrate production, and improved winter hardiness of alfalfa (Schulte and Walsh, 1993).

Potassium also balances the negative charges of organic and inorganic anions within the plant and appears to be involved in starch formation, translocation of sugars, nitrogen assimilation and several other metabolic processes (Peters et al., 2000). However, it has only been in the last few years that concerns have surfaced relative to the amount of K in forage tissue and the influence this has on ration balancing for dairy cows. An ionic imbalance in the ration increases the potential for the cow to develop milk fever at freshening. One result of this concern has been the proliferation of promotions by various components of the farm service industry to apply small amounts of gypsum or other calcium sources to "rebalance" the harvested forages. For most Wisconsin forage producers the major source of Ca to their soils is aglime or the soil parent material, which contains limestone. This experiment was established to examine the interactive effects of soil pH and lime source along with changing topdressed potassium rates on alfalfa forage mineral balance, yield and quality.

Methods and Materials

This study was conducted at the long-term pH plots located at three UW Agricultural Research Stations. These plots at Spooner, Marshfield and Hancock have pH levels ranging from about 4.8 to 7.0 in five, six and six levels, respectively. In addition, Hancock also has two pH levels (6.0 and 7.0) limed with either calcitic or dolomitic lime. The potassium variable in this study consists of an annual application of 0, 100, 200 and 400 lbs K_2O per acre, applied following first cutting in each year of the study.

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The Marshfield plots were direct seeded on a Withee silt loam soil to Innovator+Z alfalfa in the spring of 1997. Potassium treatments were not applied in the seeding year and yield measurements were not made. The first cutting in 1998 was discarded due to excessive weed pressure and the initial topdress K treatments were applied following this cutting. Two subsequent harvests were made in 1998 and three in 1999 and 2000, with additional applications of topdressed K made following the first cutting in both 1999 and 2000.

The studies at Spooner and Hancock were begun a year later, with direct seedings of Dekalb DK 133 and LegenDairy 2 alfalfa, respectively, made in the spring of 1998. An application of 150 lbs NH_4SO_4 was made at the time of seeding because of the relatively low organic matter content of the soils at these locations. The soils at these sites are a Plainfield loamy sand at Hancock and a Pence sandy loam at Spooner. In both cases, the first cutting in this seeding year was discarded due to excessive weed pressure. The first application of topdressed K was made following this first cutting and one measured harvest taken at both locations in August 1998. Three harvests were made at each location in 1999 and 2000, with the additional applications of K made after first cutting in each of those years. An application of 200 lbs/a of NH_4SO_4+B was made in April 2000 at all three locations to ensure that S and B were not limiting.

Harvests were made using a small plot harvester that cuts a 34-inch swath. A forage tissue sample was taken from each plot for dry matter determination and subsequent fiber and mineral analyses. These samples were analyzed by ICP spectroscopy and NIR analysis and used to study the interaction of tissue mineral levels with soil pH and topdressed K levels. Soil samples were taken from all plots following the final cutting in all of the study years. Stand counts and weed evaluations were done at the Hancock location following third cutting in 1999 and 2000. Stand evaluations were made at the Marshfield and Spooner locations following third cutting in 2000. The UW Soil and Forage Analysis Laboratory at Marshfield and the UW Soil and Plant Analysis Laboratory at Madison performed all analyses.

Results and Discussion

At the Marshfield location, soil pH had a significant effect on alfalfa yield for all three cuttings and total yield in 2000 (Table 1). Total yield was increased from 1.56 t/a at pH 4.25 to 3.80 t/a at pH 6.96. The K rate and interaction of K rate and soil pH also had a significant influence on alfalfa yields in most cases. Total yield was increased from 2.61 t/a at the zero K rate to 3.09 t/a at the moderate rate of 200 lbs K_2O/a annual application. Adding an additional 200 lbs/a K_2O annually did not appear to enhance alfalfa yields at Marshfield in 2000. The number of alfalfa crowns and percent alfalfa in the stand measured following third cutting in 2000, were also significantly affected by pH, K rate

Table 1. Effect of lime treatment and topdressed potash levels on alfalfa yield and stand quality at Marshfield, WI 1998-2000.

Target pH	Soil pH Fall - 2000	2000 Yield cut 1	cut2	cut3	Total	2000 Stand Crowns	2000 Evaluation Visual	Overall Total Yield
		T/a	T/a	T/a	T/a	plt/ft2	%	1998-2000 T/a
Statistical Analysis (Pr > F)								
pH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
K rate	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
pH x K rate	0.18	0.12	0.27	< 0.01	0.01	0.06	< 0.01	
Main effects								
Target pH								
4.8	4.25	0.82	0.58	0.15	1.56	0	2	3.95
5.3	4.89	1.43	0.57	0.08	2.09	1	7	5.65
5.8	5.83	1.99	0.88	0.36	3.23	6.5	39	8.53
6.3	6.48	1.90	0.97	0.49	3.36	6.4	60	9.17
6.8	6.96	2.16	1.05	0.59	3.80	7.4	67	9.80
7.3	7.11	2.08	0.99	0.56	3.63	8.2	70	9.42
$LSD_{0.05}$	0.18	0.37	0.14	*	*	*	*	
K_2O rate								
0	5.99	1.61	0.76	0.25	2.61	4.4	32	7.26
100	5.93	1.74	0.87	0.38	2.99	4.4	45	7.87
200	5.93	1.82	0.87	0.41	3.09	5.3	49	7.98
400	5.83	1.75	0.87	0.46	3.08	5.6	52	7.92
$LSD_{0.05}$	0.07	0.12	0.07	*	*	*	*	

* Interaction significant at $pr \leq 0.10$.

and the interaction of pH and K rate. At the lowest pH level there was virtually no alfalfa remaining (0 crowns and an average stand evaluation of 2% alfalfa). The best stands were found at the highest pH level (pH 7.11) with an average of 8.2 plants per square foot and a 70% stand rating. Total yield for the three years of the study to date indicate that yields were lowest at the lowest pH (3.95 t/a) and highest as soil pH approached 7.0 with a total yield of 9.80 t/a (Table 1).

Soil pH had a significant effect on the 2000 alfalfa yield at Spooner (Table 2). The 2000 total yield was increased from 0.94 t/a at the lowest pH level (pH 4.81) to 3.76 t/a at the recommended pH level for alfalfa (pH 6.79). Soil pH had a significant effect on the number of alfalfa crowns and percent alfalfa in the stand, which was determined following third cutting in 2000. In both cases, stands were weakest at the lowest pH and best as pH approached 7.0. Both the K rate and the interaction of K rate and pH did not have a significant effect on yield or percent alfalfa in the stand determined following third cutting in 2000. Three year total dry matter yields were increased from 2.05 t/a at the lowest pH (pH 4.81) to 8.37 t/a as soil pH reached the optimum level for alfalfa (pH 6.79).

Table 2. Effect of lime treatment and topdressed potash levels on alfalfa yield and stand quality at Spooner, WI 1998-2000.

Target pH	Soil pH Fall - 2000	2000 Yield cut 1	cut2	cut3	Total	2000 Stand Crowns	2000 Evaluation Visual	Overall Total Yield
		T/a	T/a	T/a	T/a	plt/ft2	%	1998-2000 T/a
Statistical Analysis (Pr > F)								
pH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
K rate	0.01	0.28	0.59	0.10	0.22	0.65	0.39	
pH x K rate	0.55	0.70	0.38	0.13	0.39	0.37	0.76	
Main effects								
Target pH								
4.7	4.81	0.40	0.27	0.26	0.94	1.4	20	2.05
5.2	5.39	1.01	0.67	0.42	2.10	3.3	56	4.68
5.7	5.74	1.07	0.71	0.44	2.22	4.4	59	4.72
6.2	6.79	1.67	1.22	0.88	3.76	6.2	96	8.37
6.7	7.02	1.62	1.18	0.90	3.70	6.6	97	8.36
$LSD_{0.05}$	0.27	0.33	0.29	0.18	0.77	1.4	25	
K_2O rate								
0	5.86	1.11	0.78	0.54	2.43	4.2	63	5.54
100	5.90	1.16	0.82	0.58	2.56	4.6	65	5.67
200	6.00	1.18	0.80	0.59	2.58	4.3	67	5.61
400	6.06	1.17	0.82	0.61	2.61	4.5	67	5.71
$LSD_{0.05}$	0.13	NS	NS	0.06	NS	NS	NS	

Alfalfa dry matter yields in 2000 were significantly affected by soil pH for all three cuttings and total yield at the Hancock location (Table 3). Total dry matter yields ranged from 1.98 t/a at pH 5.32 to 3.76 t/a as soil pH levels reached 6.6. Stand counts were not significantly influenced by soil pH, but the visual percent alfalfa in the stand evaluation was, particularly at pH levels below 6.0. The K rate had a significant affect on 2000 total dry matter yields. Alfalfa yields were optimized by the addition of 100 lbs K_2O/a annually, with no significant increase in yields with higher applications. Total yields for the three years of the study ranged from 3.45 t/a at the lowest pH level (pH 5.32) to 7.53 t/a as pH was increased to 6.68.

Soil pH and the annual application of various rates of K were significantly correlated to virtually all third cut tissue parameters measured at Marshfield in 1999 (Table 4). In general, as soil test K increased, tissue K increased and tissue P, Ca and Mg decreased. This effect is likely the result of competition for the soil exchange sites at increasing annual application rates of K. This is also seen in the 2000 soil test results, which are also found in Table 4. As soil K increases, soil test Ca and Mg tend to decrease somewhat.

Table 3. Effect of lime treatment and topdressed potash levels on alfalfa yield and stand quality at Hancock, WI 1998-2000.

Target pH	Soil pH Fall - 2000	2000 Yield cut 1	cut2	cut3	Total	2000 Stand Crowns	2000 Evaluation Visual	Overall Total Yield
		T/a	T/a	T/a	T/a	plt/ft2	%	1998-2000 T/a
Statistical Analysis (Pr > F)								
pH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.20	< 0.01	
K rate	0.88	0.08	0.17	0.13	0.02	0.71	0.69	
pH x K rate	0.73	0.67	0.07	0.23	0.45	0.55	0.99	
Main effects								
Target pH								
4.5	5.32	0.49	0.66	0.83	1.98	3.3	73	3.45
5.0	5.66	0.64	0.75	1.00	2.38	3.5	81	3.98
5.5	5.76	0.93	1.03	1.02	2.98	3.6	98	5.42
6.0	6.02	1.21	1.16	1.10	3.47	3.5	100	6.85
6.5	6.33	1.28	1.13	1.09	3.51	3.6	100	7.04
7.0	6.61	1.36	1.23	1.18	3.76	4.3	100	7.41
6.0 Cal	6.02	1.31	1.17	1.12	3.60	3.7	100	7.21
7.0 Cal	6.68	1.36	1.20	1.21	3.77	4.6	100	7.53
$LSD_{0.05}$	0.32	0.24	*	0.09	0.48	0.9	11	
K_2O rate								
0	6.04	1.03	1.01	1.02	3.06	3.7	94	5.91
100	6.06	1.08	1.06	1.08	3.22	3.6	94	6.18
200	6.04	1.08	1.05	1.10	3.23	3.7	94	6.20
400	6.07	1.10	1.04	1.07	3.21	3.6	93	6.15
$LSD_{0.05}$	NS	0.06	*	0.06	0.12	NS	NS	

* Interaction significant at $pr \leq 0.10$.

At Spooner, soil pH and K rate had a significant effect on all third cut tissue nutrients measured in 1999 (Table 5). As soil test K increased, tissue K increased and tissue Ca and Mg tended to decrease. There was also a pattern for increasing soil test K resulting in a decrease in soil test Ca and Mg as measured following third cutting in 2000.

Third cut tissue data from the Hancock location in 1999, also showed that soil pH and K rate had a significant effect on all tissue mineral levels measured (Table 6). Tissue K levels were increased from 2.16% at the zero K rate (marginally deficient) to 2.67% at the highest K rate. Once again, tissue and soil test Ca and Mg tended to decrease with increased levels of soil test K.

Caution must be used when balancing dairy rations using mineral levels based on NIR forage analysis. In this study, mineral estimates by NIR were not highly correlated to traditional wet chemistry mineral analyses (Table 7). In general, NIR tends to predict

Table 4. Effect of lime treatment and topdressed potash levels on third cut alfalfa nutrient concentrations and post harvest soil tests at Marshfield, WI 1999-2000.

	1999 soil		1999 third cut tissue				2000 soil			
Target pH	pH	K	P	K	Ca	Mg	P	K	Ca	Mg
		ppm	%				ppm			
Statistical Analysis (Pr > F)										
pH	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.32	< 0.01	< 0.01	< 0.01
K rate	0.25	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.28	< 0.01	0.05	< 0.01
pH x K rate	0.50	0.56	0.40	< 0.01	0.30	< 0.01	0.75	0.59	0.38	0.31
Main effects										
Target pH										
4.8	4.36	146	0.40	2.54	0.73	0.32	49	165	688	158
5.3	5.17	148	0.40	3.27	0.81	0.35	51	171	913	233
5.8	6.01	130	0.36	2.76	0.96	0.44	46	128	112	381
6.3	6.62	110	0.35	2.67	1.11	0.35	54	122	1288	485
6.8	6.85	94	0.36	2.32	1.03	0.44	55	135	1478	586
7.3	7.13	108	0.38	2.73	1.11	0.49	55	120	1478	550
$LSD_{0.05}$	0.22	30	0.05	*	0.13	*	NS	20.6	142	64.2
K_2O rate										
0	6.08	70	0.41	2.37	1.03	0.51	53	80	1174	411
100	6.03	92	0.38	2.79	0.97	0.42	52	99	1176	408
200	6.04	122	0.37	2.96	0.95	0.38	51	140	1155	397
400	5.95	208	0.35	3.13	0.89	0.33	50	242	1133	379
$LSD_{0.05}$	NS	25	0.01	*	0.06	*	NS	17.3	33.7	19.4

* Interaction significant at pr ≤ 0.10.

low testing samples higher than what they test by traditional wet chemistry methods and predict lower values for high testing samples when compared to wet chemistry methods. This is particularly important for K as it has a significant impact on the susceptibility of dairy cows to metabolic disorders such as milk fever.

Summary

For all cuttings made at all locations in 2000, soil pH had a significant effect on alfalfa dry matter production. In 2000, the magnitude of this dry matter yield response for the total of the three cuttings ranged from 294% at Spooner to 143% at Marshfield and 90% at Hancock. The annual application of 200 lbs K_2O/a appeared to optimize dry matter yield at Marshfield in 2000, but only the 100 lb K_2O/a annual rate was needed on the lighter textured soils at Spooner and Hancock. At all locations, as soil K increased, tissue K increased and tissue Ca and Mg tended to decrease. Also, the annual application of K resulted in a buildup of soil K and a decrease in soil test Ca and Mg. Increasing soil test Ca did not appear to consistently result in reduced tissue K levels. However, liming these acid soils was essential to optimize yields of alfalfa. Keeping soil test K levels in the optimum range appears to be the best strategy for keeping forage tissue K levels in acceptable ranges for use as dairy feed.

Table 5. Effect of lime treatment and topdressed potash levels on third cut alfalfa nutrient concentrations and post harvest soil tests at Spooner, WI 1999-2000.

	1999 soil		1999 third cut tissue				2000 soil			
Target pH	pH	K	P	K	Ca	Mg	P	K	Ca	Mg
		ppm	%				ppm			
Statistical Analysis (Pr > F)										
pH	< 0.01	0.91	< 0.01	< 0.01	< 0.01	< 0.01	0.13	0.07	< 0.01	< 0.01
K rate	0.44	< 0.05	0.08	< 0.01	< 0.01	< 0.01	0.64	< 0.01	0.22	0.01
pH x K rate	0.75	0.05	0.88	0.03	0.14	0.12	0.50	0.06	0.99	0.35
Main effects										
Target pH										
4.7	4.76	162	0.28	2.27	0.59	0.23	57	179	238	124
5.2	5.40	157	0.26	2.59	0.81	0.22	61	192	376	142
5.7	5.69	153	0.27	2.75	0.91	0.20	44	169	541	131
6.2	6.78	159	0.23	2.89	0.88	0.24	44	170	836	178
6.7	7.11	165	0.22	2.50	0.95	0.21	41	148	908	174
$LSD_{0.05}$	0.35	*	0.03	*	0.12	0.03	19	*	81	31
K_2O rate										
0	5.91	97	0.26	2.31	0.87	0.25	48	90	604	161
100	5.94	141	0.25	2.56	0.85	0.22	51	128	581	153
200	5.96	165	0.25	2.63	0.81	0.21	49	191	581	150
400	6.00	235	0.25	2.66	0.79	0.19	50	278	553	136
$LSD_{0.05}$	NS	*	0.01	*	0.04	0.01	NS	*	NS	14

* Interaction significant at pr ≤ 0.10.

Table 6. Effect of lime treatment and topdressed potash levels on third cut alfalfa nutrient concentrations and post harvest soil tests at Hancock, WI 1999-2000.

	1999 soil		1999 third cut tissue				2000 soil			
Target pH	pH	K	P	K	Ca	Mg	P	K	Ca	Mg
		ppm	....	%	....		....	ppm	....	
Statistical Analysis (Pr > F)										
pH	< 0.01	0.29	< 0.01	< 0.01	< 0.01	< 0.01	0.06	0.63	< 0.01	< 0.01
K rate	0.08	< 0.01	0.04	< 0.01	< 0.01	< 0.01	0.85	< 0.01	< 0.01	< 0.01
pH x K rate	0.31	0.37	0.68	0.22	0.79	0.97	0.69	0.71	0.88	0.99
Main effects										
Target pH										
4.5	5.30	106	0.36	2.27	0.54	0.30	85	109	343	98
5.0	5.51	98	0.36	2.23	0.49	0.32	62	102	409	111
5.5	5.83	117	0.36	2.68	0.68	0.34	61	115	390	107
6.0	6.02	123	0.38	2.65	0.78	0.34	61	119	492	118
6.5	6.27	135	0.32	2.67	0.85	0.32	51	112	552	127
7.0	6.54	124	0.29	2.31	0.89	0.32	66	115	606	135
6.0Cal	6.11	133	0.31	2.62	0.93	0.31	66	124	541	109
7.0 Cal	6.80	124	0.29	2.24	1.06	0.25	68	132	796	119
$LSD_{0.05}$	0.31	NS	0.05	0.30	0.17	0.05	18	NS	77	17
K_2O rate										
0	6.07	83	0.34	2.16	0.88	0.36	64	60	557	124
100	5.94	109	0.33	2.45	0.82	0.32	64	100	535	122
200	6.03	123	0.32	2.56	0.75	0.29	66	133	500	109
400	6.08	161	0.32	2.67	0.69	0.27	66	171	473	106
$LSD_{0.05}$	0.11	27	0.01	0.12	0.06	0.02	NS	16	26	6

Table 7. Comparison of wet chemistry mineral analysis with NIR estimated minerals, third cut, 1999.

Hancock Location	
Regression Equation	R^2
$P_{NIR} = 0.22 + (0.255)(P_{WET})$	0.19
$K_{NIR} = 0.98 + (0.579)(K_{WET})$	0.58
$Ca_{NIR} = 0.55 + (0.891)(Ca_{WET})$	0.79
$Mg_{NIR} = 0.16 + (0.349)(Mg_{WET})$	0.41
Marshfield Location	
Regression Equation	R^2
$P_{NIR} = 0.29 + (0.056)(P_{WET})$	0.01
$K_{NIR} = 1.46 + (0.335)(K_{WET})$	0.60
$Ca_{NIR} = 0.57 + (0.884)(Ca_{WET})$	0.67
$Mg_{NIR} = 0.21 + (0.325)(Mg_{WET})$	0.68
Spooner Location	
Regression Equation	R^2
$P_{NIR} = 0.26 + (0.068)(P_{WET})$	0.01
$K_{NIR} = 1.07 + (0.581)(K_{WET})$	0.36
$Ca_{NIR} = 0.88 + (0.506)(Ca_{WET})$	0.59
$Mg_{NIR} = 0.16 + (0.457)(Mg_{WET})$	0.53

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