ALFALFA YIELD AND NUTRIENT UPTAKE AS AFFECTED BY pH AND APPLIED K

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For many years it has been suggested that the two major limiting factors to alfalfa (*Medicago sativa*) growth in the upper Midwest are soil pH and exchangeable soil potassium (Brown, 1928; Hull, 1934). Recent research reaffirms the benefits of raising pH to near neutral by adding lime to fields where alfalfa is to be grown in Wisconsin (Peters and Kelling, 1989; Peters and Kelling 1997).

Potassium is removed from the soil by alfalfa in amounts greater than any other nutrient and there is substantial documentation of the benefits of adding supplemental potash to soils where alfalfa is to be raised (Attoe and Truog, 1950; Peterson et al., 1975; Smith and Powell, 1979; Erickson et al., 1981; Kelling, 1995). Research from Wisconsin has shown that potassium is required to enhance resistance to disease and lodging, and winter hardiness of alfalfa (Kelling, 1991; Schulte and Walsh, 1993). Additionally, potassium is involved in carbohydrate production and transport, enzymatic activity, and stomatal function in alfalfa (Munson, 1985). Potassium also balances the negative charges of organic and inorganic anions within the plant and may be involved in metabolic processes including the formation of starch and assimilation of nitrogen (Peters et al., 2000).

Dairy cattle nutritionists have been placing increased importance on balancing the ionic composition (cation:anion ratio) of rations in recent years. Concern has been raised as to the amount of potassium in forage tissue, and the impact this has on the ionic balance of dairy feeds. High cation:anion diets fed to dry cows have been shown to increase the potential for cattle to develop milk fever at freshening (Moore et al., 2000). Furthermore, in lactating diets, excessively high potassium levels have been shown to interfere with magnesium absorption. In an attempt to "rebalance" the ions in harvested forages, various components of the farm service industry have promoted the application of small amounts of calcium to alfalfa fields. For most producers in Wisconsin, the primary source of soil calcium is applied aglime or limestone containing parent material. This experiment was established to examine the interactive effects of soil pH and topdressed potassium applications on alfalfa forage mineral balance, yield and quality.

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Materials and Methods

This study was conducted at long-term pH plots located at three University of Wisconsin Agricultural Research Stations. These plots, located at the Hancock, Marshfield and Spooner stations, had pre-established pH treatment levels ranging from 4.5 to 7.3 in six, six and five levels, respectively. Annual applications of KCl at rates of 0, 100, 200, and 400 lb K_2O/acre following first cutting provided the potassium variable for this study.

The plots located at Marshfield were direct seeded on a Withee silt loam soil (*Aquic Glossoboralf*) to Innovator+Z alfalfa in the spring of 1997. Potassium treatments were not applied in the seeding year, nor were yield measurements taken. The first harvest in 1998 was discarded due to excessive weed pressure and the initial topdressed K treatments were applied to plot areas following this cutting. Two subsequent harvests were made in 1998, followed by three harvests in 1999 and 2000. Topdressed K was again applied following the first cutting in both 1999 and 2000. NH_4SO_4+B was applied in April 2000 at a rate of 200 lb/acre to assure that S and B were not limiting.

The plots at Spooner and Hancock were established in the spring of 1998 by direct seeding Dekalb DK 133 and LegenDairy 2 alfalfa, respectively. The plots at Hancock were located on Plainfield loamy sand (*Typic Udipsamment*) and those at Spooner located on Pence sandy loam (*Typic Haplorthod*). To compensate for the relatively low organic matter content of these soils, 150 lb/acre of NH_4SO_4 was applied at time of seeding to provide supplemental nitrogen to assist in stand establishment. At both locations, the first cutting of the seeding year was discarded due to excessive weed pressure. Topdressed K applications were made following this first cutting at both sites, and the only measured harvest of the year was taken at both locations in August 1998. Three harvests were made at each location in 1999, 2000, and 2001, with the additional K treatments applied after first cutting in all three years. An application of 200 lb/acre NH_4SO_4+B was made to all treatments at both plots in April 2000 to assure that S and B were not limiting production.

A specialized small plot harvester that cuts a 34-inch swath was used for all harvests. Forage tissue samples were taken from each plot for dry matter determination and nutrient analysis. Replicates were combined for first and second cutting, but all individual replicate samples for third cutting were evaluated for mineral content by ICP spectroscopy and for protein and fiber content by near infrared spectroscopy (NIR). Overall stand assessments were taken following the final cutting in each year in most instances. Soil samples were taken from all pH treatment blocks at seeding and from all individual treatments following final harvest in each year of the study. 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

For alfalfa production on Wisconsin soils, it is recommended that the soil pH be nearly neutral (approximately 6.8). Some soils, particularly in eastern areas of the state are naturally at that level or higher, but many others require the periodic application of agricultural limestone to achieve and then maintain this target pH. Results from this study confirm that in these areas of the state where soil pH is inherently somewhat acidic, the pH should be adjusted into the 6.5 to 7.0 range if alfalfa is to be grown. When results are averaged across all K treatments, the average annual dry matter yields when the soil pH was at least pH 6.5 or higher were approximately 187, 250, and 410% of the yields found at the lowest treatment levels (pH 4.5 to 4.8) for the Hancock, Marshfield and Spooner locations, respectively (Table 1). Significant interaction between soil pH and K application rate is observed for dry matter yield at all three locations. This interaction shows that there is little yield response to K at the lower pH levels, but if the soil is limed adequately, substantial response to topdressed K was observed.

One of the key factors in the yield response is the influence that soil pH has on alfalfa stand survival. The final crown count taken at each location showed an increase of from 3.3 to 4.4 plants per square foot (pl/ft^2) at Hancock, 0 to 7.3 pl/ft^2 at Marshfield and 1.2 to 7.8 pl/ft^2 at Spooner, when comparing the lowest pH level with the 6.5 to 6.8 pH treatment level. The greatest influence of pH on stand was found on the heaviest textured soil of the three (Withee silt loam at Marshfield) and the least impact on the lightest textured soil (Plainfield loamy sand at Hancock). Apparently, the increased likelihood of periodic wet soil conditions with soils that are not as well drained increasing the impact of the adverse effects of attempting to grow alfalfa at less than optimum pH levels. The significant interaction of pH x K on stand at this site also shows that benefits from K on stand survival are only possible if the soil pH is greater than 5.5. This interaction was not significant at the other sites nor did K alone seem to affect stand at Hancock and Spooner.

At all three locations when the yield results are averaged across all pH levels, an annual application of at least 100 lbs K_2O/acre is required to optimize yields. When the data from only the optimum pH range (6.5 to 6.8) are considered, the annual 100 lb K_2O/acre rate is adequate for the lighter textured soils at Hancock and Spooner, but 200 or more lb K_2O/acre are required on the somewhat poorly drained soil at Marshfield.

Third-cut tissue was analyzed for cation content in each of the years of the study at all three locations. At Hancock, the average K content increased from 2.24% at the lowest pH range to 2.62% at the optimum level (Table 2). The calcium content also increased form 0.70 to 1.01% when these same pH levels are compared. This is due to the higher soil test Ca levels resulting from earlier lime additions at the higher pH ranges. It is interesting to note, that at the above optimum pH range (7.0 to 7.3) tissue K was decreased which is likely the results of increased ion competition on the soil exchange sites where the relatively high levels of aglime had been applied. At all locations, past aglime treatments involved the use of dolomitic lime that supplies appreciable amounts of

Ca and Mg to soils in addition to adjusting pH. At both Marshfield and Spooner, tissue K levels were being influenced by pH and topdressed K rate with the greatest increase in tissue K from added K only exhibiting itself at pH levels above 5.0. At higher pH levels there may be a tendency for tissue K to decrease somewhat as pH continued to increase. Once again, this is probably largely due to increased ion competition from Ca and Mg at the higher pH levels. The impact of ion antagonism/competition is clearly apparent when tissue cation levels are averaged across all pH levels and analyzed by annual K rate. At all three locations, as annual K rate increased, average tissue K level increased and average tissue Ca and Mg levels decreased.

Both K and Mg showed significant interaction between soil pH and K rate at Marshfield and Spooner, while Ca only showed a significant interaction at the Spooner location. No significant interactive effects for forage cations were noted at Hancock. When dry matter yield and tissue cation content are combined to determine the total removal of each cation in the harvested forage, significant interaction is seen for all three cations at the Spooner location, while only Mg and K show significant interaction at Hancock and Marshfield respectively (Table 3). Once again, as K rate increased, total K removed increased as well, at all three locations. Tissue Ca and Mg uptake tended to decrease significantly with increased annual K rate, with the exception of tissue Ca at the Marshfield location, and this decrease was more evident at the higher pH ranges.

Soil test K levels were monitored throughout the entire study to determine the impact of the annual K rates on these levels. Using the average tissue cation mineral content for each cutting to calculate total uptake, the approximate total amount of K removed in tissue during the course of the study can be compared with the amount applied and the impact on soil test level (Table 4). When the data from the optimum pH range (6.5 to 6.8) are evaluated, it appears that the annual level at which input approximately matches removal and soil test level is maintained, is somewhere between the 100 and 200 lb K_2O/acre applications. This confirms the recommendations provided by the University of Wisconsin-Madison Department of Soil Science, which calls for the application of approximately 50 to 60 lb K_2O per ton of dry matter removal. Dry matter yields for all three locations averaged about 3.7 tons/acre at the optimum soil test level. This yield level would correspond to about 200 lb of K_2O removal. Where no K was added during the course of the study, soil test levels dropped to the very bottom of the low range at Hancock and to the very low range at Marshfield and Spooner. At the optimum pH range, adding 400 lb K_2O/acre annually resulted in soil test levels reaching the excessively high category at Marshfield and Spooner and the high category for the lower CEC soil at Hancock. Past research has also shown that soil K cannot be built above these levels due to the very low CEC of this soil.

Summary

Soil pH and annual K application rate had a significant interactive effect on alfalfa dry matter yield for all years at all locations with major responses to K seen when soil pH was above 6.5. A soil pH of at least 6.5 to 7.0 was necessary to achieve optimum alfalfa yields. Soil pH also had a significant influence on final stand of alfalfa at all locations, but K rate was only important when pH was adequate at the Marshfield location. The annual K rate had a significant influence on all tissue cation levels at all three locations. There was also a significant effect of pH on cation levels with the exception of tissue Mg at Hancock and tissue K at Marshfield. The total uptake of mineral cations in third cut forage was significantly related to soil pH and annual K rate at all locations with the exception of the K rate-tissue Ca relationship at Marshfield. At soil pH levels that are near optimum for alfalfa production, it appears that approximately 200 lb K_2O/acre is required annually to optimize yield, stand quality and maintain soil test in the optimum category.

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