THE ALFALFA YIELD PLEATEAU: IS SOIL FERTILITY THE CAUSE?

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Alfalfa is a perennial forage legume known for its ability to produce high quality hay, earning it the title the "Queen of Forages." It is produced across the United States as feed for the beef, dairy, and equine industries. During the 1950s, alfalfa yields rose exponentially due to advances in technologies such as improved varieties, synthetic fertilizers, and pesticides. However, yields plateaued at approximately 3.3 tons per acre in the 1980s for reasons not fully understood and remain there today. This study was initiated as part of a larger study that includes Oregon and Wisconsin and was funded by the USDA-ARS. The objective of this study is to determine soil fertility's role in Kentucky's alfalfa yield plateau. Fifty-three and 61 fields were sampled in 2022 and 2023, respectively. Only 2022 data is presented. Soil samples were collected to depths of 4-, 6-, and 12- inches and analyzed for plant available nutrients. Tissue samples were collected and analyzed for nutrient concentrations and feed nutritive value. Soil analysis revealed that approximately 5% of sampled stands were low in phosphorus and 35% of stands were low in potassium. Soil pH was below the ideal range in 40% of sampled stands. However, tissue analysis indicated that phosphorus was not limiting, and potassium was below the sufficiency range in only approximately 25% of stands. Tissue analysis also reported sulfur, magnesium and boron were below sufficiency ranges in 15%, 25%, and 5% of stands, respectively. In conclusion, soil fertility is likely contributing to the yield plateau observed in Kentucky but is not the sole cause.

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is a perennial forage legume commonly referred to as the "Queen of Forages" because of its ability to produce high quality feed. In 2023, approximately 15.6 million acres were harvested across the United States with 100,000 of those acres being in Kentucky (USDA-NASS, 2023). Hay or Haylage for dairy cattle is the dominant use of alfalfa nationwide, however it is also commonly used as feed for equine and other livestock (USDA-ARS, 2020). Alfalfa yields in the United States increased exponentially from 2.1 tons per acre to 3.3 tons per acre between the 1950s and the 1980s but plateaued and remained there ever since (USDA-NASS, 2022). Yield increases during this time are attributed to advances in new technologies, such as improved yield potential, cultivars with increased pest resistance, and improved management practices (Barnes et al., 1988). This study is part of a much larger study to determine soil fertility's role in the observed yield plateau across three states in different regions of the United States. However, only data from stands sampled in Kentucky during the 2022 growing season will be presented.

MATERIALS AND METHODS

Samples were collected during the 2022 growing season. In total 53 stands were collected from 31 different alfalfa producers across Kentucky. Producers were selected based on their geographical distribution across the state and ability to obtain fertilizer and other management records. Stands in this survey were between 1 and 5 years of age and sampling occurred between the late bud to early flower stage. Samples were only collected in cuttings 1 through 3. All data was collected from a representative 20 ft by 20 ft area of each stand.

Composite soil samples were collected using a handheld soil probe at 4-, 6-, and 12-inch depths. The 4- and 6-inch composite soil samples were split to be analyzed at the University of Kentucky Soil Testing Laboratory and Kansas State University Soil Testing Laboratory. Composite 12-inch samples were only analyzed at the Kansas State University Soil Testing Laboratory. Before being sent off for analysis, soil samples were dried at 151 °F. Mehlich 3 extraction was used for the analysis of P, K, S, Ca, Mg, Mn, Cu, Fe, and Zn. Boron content was analyzed using hot water extraction. Soil pH is determined in a 1 M KCl solution, converted, and reported as a water pH. The Sikora 2 buffer pH was used to determine reserve acidity for all soil samples.

Tissue nutrient content was obtained by collecting the top 6 inches of 30 stems. After drying for 72 hours at 151°F, stem samples were ground to pass a 0.08 and 0.04 in (2 and 1 mm) screens using Wiley (Thomas Scientific, Swedesboro, NJ) and Cyclone (Udy Corp., Fort Collins, Co) mills, respectfully. Ground tissue samples were then packaged in Whirl-Pak bags and sent to Kansas State University for analysis of N, P, K, S, Ca, Mg, Mn, Cu, Fe, Zn, and B.

A representative yield sample was collected from 6 quadrats measuring 40 in^2 at each site. Alfalfa from each quadrat was combined in a large trash can and weighed for yield estimation. After weighing, a subsample was collected to determine harvest moisture content, dried and ground using the protocol above to determine feed quality metrics using Near Infrared Spectroscopy (NIRS). Stem counts were also collected by returning to 3 of the 6 quadrats used for the yield analysis and counting all the stems in a 12 in by 12 in quadrat. Further, the number of plants within the 1 ft^2 area were also counted. Stand height was measured in six places randomly throughout the stand.

RESULTS AND DISCUSSION

Metric	Stand Height (Ft)	Stem Counts	Number of Plants	Yield (lbs. DM/acre)
Average	1.90	45.94	4.04	176.89
Median	1.85	44.00	4.00	162.36
Minimum	0.88	15.00	1.00	63.89
Maximum	2.70	90.00	9.00	383.51
Standard Deviation	0.38	12.12	1.29	65.79

Table 1. Summary statistics for stand height, stem count, number of plants, and yield for sampled stands.

Table 1 shows the summary statistics for several stand metrics. Regressions were performed for each of these metrics to yield. Only stand height was shown have a significant correlation with an R^2 of 0.243.

Soil pH	Proportion of Stands
	-----------------------%------------------------
High (>7.0)	23.00
Ideal (6.5 to 7.0)	36.00
Low (6.0 to 6.4)	30.00
Very Low (<6.0)	11.00

Table 2. Proportion of sampled stands at each pH range.

Soil pH was low in 30% and very low in 11% of sampled stands (Table 2). Rice and coauthors (1977) found that yield declines alfalfa were reported at pH levels below 6.0. Moreira and Fageria (2010) reported that alfalfa had significantly higher dry matter yields and tissue N, Ca, and Mg concentrations after liming acidic soils.

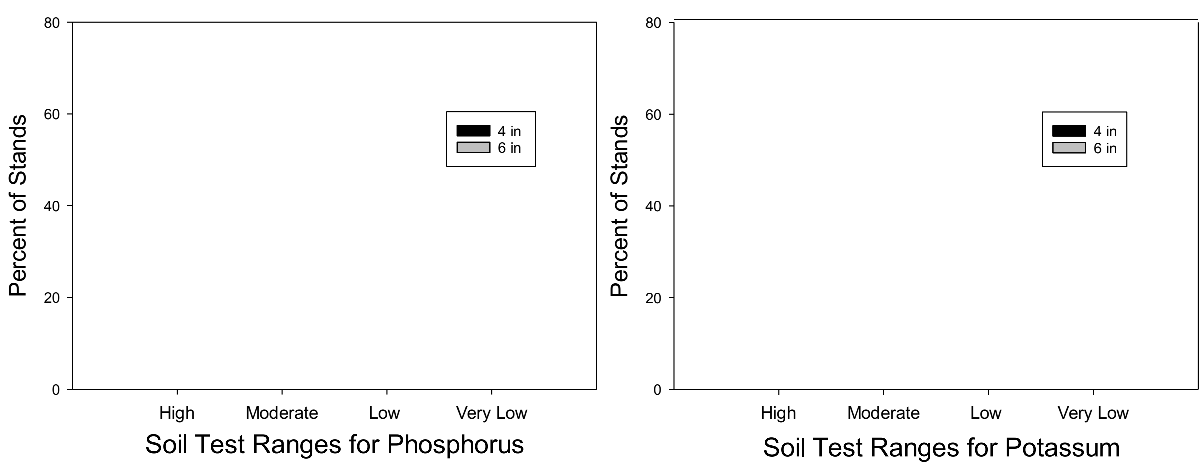

Figure 1. Soil test phosphorus and potassium ranges of sampled stands according to University of Kentucky Cooperative Extension AGR-1 (2020-2021 Lime and Fertilizer recommendations, 2020).

Soil analysis reported approximately 5% and 28% of stands were categorized as low in P and K at the 4-inch sampling depth when compared to the University of Kentucky's Cooperative Extension's fertilizer recommendations for alfalfa (Figure 1). When analyzed using the 6-inch depth, K was categorized as low in 38% of stands and very low in 2% of stands (2020-2021 Lime and Fertilizer Recommendations).

However, tissue analysis reported no stands were below the phosphorus sufficiency level and only 25% of stands were below the potassium (Table 3). The discrepancy between soil and tissue nutrient status of P and K is likely caused by the soil test result falling on the upper edge of the low range and the wide range of nutrient contents that can support optimal plant growth.

Nutrient Status	P	K	S	Mg	B
			-------------------------------%-------------------------------		
High	0	0	0	0	0
Sufficient	100	74	87	77	94
Low	0	26	13	23	6

Table 3. Percent of sampled alfalfa fields falling into the high, sufficient, and low ranges for P, K, S, Mg, and B as indicated by plant tissue testing. Ranges from UK AGR-92. (Schwab et al., 2007).

Applications of P and K when these nutrients are deficient have been shown to increase yields. Berg et al (2005) conducted a three-year study and found that a split application of P, half after the first cutting and half at the end of the growing season, increased yields in all cuttings. They found that split applications of K did not increase yields until later in the growing season when much of the available K had been removed by previous harvests (Berg et al., 2005). Alternatively, Walworth and Sumner (1990) reported a yield increase after a spring K application in two out of three years. This result only occurred when Mg applications were applied in conjunction with K. Magnesium applications alone had no effect on alfalfa yield. Soil and tissue tests from their study indicated that Mg levels were suppressed with K applications, leading for them to conclude that these two nutrients were in competition with each other (Walworth and Sumner, 1990). This offers a potential explanation for the Mg results reported in Table 3.

Sulfur was reported to be below sufficiency ranges in approximately 13% of sampled stands. The University of Kentucky currently does not have soil test recommendations for sulfur. Gunes and coauthors (2008) found that applications of Gypsum significantly increased yields on sulfur deficient soils. Alfalfa yield in response to sulfur fertilization has not been studied as in-depth as other nutrients due to atmospheric deposition historically supplying enough S to support yields. However, due to the reduction in the use of fossil fuels, deposition levels across Kentucky have decreased from 9 - 16 lb S/ac to 0 - 5 lb S/ ac over the last 20 years (US EPA, 2021). Sulfur deficiencies are likely to increase nationwide as the decline in atmospheric deposition continues.

Boron was reported low in 6% of the sampled stands according to tissue analysis. The University of Kentucky recommends applying 1.5 to 2.0 lb B/ac of elemental boron every other year unless soil tests indicate current B levels exceed 2.0 lb B/ac. Symptoms of a boron deficiency include yellowing of the upper leaves and shortening of the upper internodes. Overall, low boron levels can result in slight yield losses and a decline in forage quality (Lanyon & Griffith, 1988).

In summary, pH was reported below the ideal range in approximately 41% of the sampled stands. Soil test results averaged over the 4- and 6- inch depths indicate phosphorus and potassium are low or very low in approximately 5% and 33% of stands. This contrasts with tissue analysis which reports no stands below the sufficiency ranges for phosphorus and only 26% for potassium. Tissue analysis also indicated that approximately 13%, 23%, and 6% of stands were below the sufficiency ranges for S, Mg, and B. More work is needed to better understand the yield dynamics of these nutrients and if they are truly limiting. All other macro and micronutrients were reported to be sufficient according to tissue analysis. Nutrient management is likely playing a role in the alfalfa yield plateau but is unlikely to be the sole cause. This survey was repeated in 2023 and 61 more stands from Kentucky and surrounding states were sampled, but data has yet to be analyzed.

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