Alfalfa response to phosphorus and potassium in association with calcium and magnesium and harvest time

M. Anowarul Islam and Michael M. Baidoo[1]

ABSTRACT

Phosphorus (P) and potassium (K) combination can provide alfalfa (*Medicago sativa* L.) with essential nutrients to improve production. However, fertilizing alfalfa with a balance of P and K (P × K) alone may not warrant their availability for effective plant uptake until other interrelated factors (e.g., levels of exchangeable calcium [Ca], magnesium [Mg], and harvest time) are considered. The experiment was conducted at the University of Wyoming James C. Hageman Sustainable Agriculture Research and Extension Center from 2019 to 2021 to determine alfalfa's response to P and K in relation to Ca and Mg levels along with harvest time. Treatments were 10 selected combinations of three P (0, 34, and 67 kg P_2O_5 ha^{-1}), three K (0, 168, and 336 kg K_2O ha^{-1}), two Ca (0 and 560 kg CaO ha^{-1}), and two Mg (0 and 56 kg MgO ha^{-1}); and two harvest times (early harvest, late bud to early [10%] bloom; late harvest, 7 days after early harvest) arranged in randomized complete block with three replications. Alfalfa fertilized with P × K generally produced higher forage accumulation than the unfertilized alfalfa. This trend was generally observed for treatments with and without the association of Ca and Mg ($Ca_{560}Mg_{56}$). On average of two years, the $P_{67}K_{336}$ and $P_{67}K_{336}Ca_{560}Mg_{56}$ treatments produced the greatest (>11 Mg ha^{-1}) annual forage accumulation, whereas P_0K_0 produced the lowest (8.1 Mg ha^{-1}) annual forage accumulation. Harvest time affected ($P < 0.05$) forage accumulation such that higher forage accumulation was produced at late harvest (12.7 Mg ha^{-1}) than at early harvest (11.7 Mg ha^{-1}) in 2020, and the opposite was observed in 2021. Overall, the study results suggest that high rates of P and K are needed irrespective of amounts of K along with Ca and Mg present in the soil for maintaining high alfalfa productivity.

Key Words: Balanced nutrition, calcium, magnesium, harvest time, alfalfa response

INTRODUCTION

In production areas of the western United States, most soils have sufficient levels of essential plant nutrients, especially potassium (K). Reports by soil fertility and forage extension specialists therefore suggest that applying K to crops (e.g., alfalfa) is not often recommended in these areas (Blaylock et al., 1996; Koeing and Barnhill, 2006). As a result, alfalfa-fertility works have often been conducted on soils that are responsive to applied fertilizers (e.g., ≤150 mg K kg^{-1} initial soil test). Studies have investigated the relationship between cationic soil nutrients and their availability to plants, and found that the relative proportion of multiple cations (Ca^{+2}, Mg^{+2}, K^+, Na^+) ought to be considered rather than a single cation (Loide, 2004; Haliu *et al*., 2015; Laekamariam *et al*., 2018). Phosphorus and K have been shown to have a positive relationship with high alfalfa production (Berg *et al*., 2005; Burayu and Mostafa, 2021). Alfalfa's high requirement of P and K often leads to the removal of significant amounts of these nutrients from the soil following harvest and baling. Thus, to sustainably increase crop productivity, replenishing P and K to be readily available for effective uptake by alfalfa can depend on the threshold of soil cationic nutrients. Harvest time, an important management decision in alfalfa forage systems, is also crucial to the plant's ability to take-up nutrients for enhanced growth, due to the duration of plant growth prior to harvest. There is limited information available on alfalfa's response to P and K in relation to high levels of soil Ca and Mg under different harvest regimes. It is, therefore, necessary to explore alfalfa's response to P and K in association with high levels of soil Ca and Mg, and harvest management.

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METHODS

The experiment was conducted at the University of Wyoming James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) from 2019 to 2021 under irrigated conditions. The site has a semiarid climate and most of the precipitation is received in the month of May. After the final land preparation, 3 cores of soil were sampled (0-15 cm depth) from the experimental field and they were analyzed to determine the initial soil fertility status, following standard soil testing procedures (ASA, 1982; NCR, 2000). Treatments consisted of 10 selected combination rates of three P (0, 34, and 67 kg P_2O_5 ha^{-1}), three K (0, 168, and 336 kg K_2O ha^{-1}), two Ca (0 and 560 kg CaO ha^{-1}), and two Mg (0 and 56 kg MgO ha^{-1}); and two harvest times (early harvest, late bud to early [10%] bloom; late harvest, 7 days after early harvest). The treatments were arranged in 10 × 2 factorial under randomized complete block design with three replications. The combinations of P (triple superphosphate, TSP), K (muriate of potash), Ca (calcium oxide), and Mg (magnesium oxide) (Table 1) were broadcast on their respective experimental plots at constant rate before planting. Pre-inoculated (alfalfa specific Rhizobium bacteria) seeds of Hi-Gest 360 were planted (September 3, 2019) on all plots at a seeding rate of 22 kg pure live seeds ha^{-1}, 1.2 cm depth, and 18 cm row spacing by using a 9-row tye driller. All plots were irrigated (25 mm irrigation water) every 7 days (from June to September) based on the available soil moisture. Manuel weeding by hoeing of each plot was done during the seedling and establishment phase of the plant to reduce weed pressure. Plants were sampled by mechanically harvesting (in 2020 and 2021) two quadrats of alfalfa and leaving a stubble of about 8-10 cm. The remaining herbage were mowed and raked from the plots to mimic harvesting and baling. Harvested plant samples were oven-dried in a forced draft oven at 60°C for a minimum of 72 hrs. Dry weight of the samples was measured and recorded as weight per unit quadrat area. This was used to estimate forage accumulation per hectare as dry matter basis. Data was analyzed by using the mixed effect procedure (PROC MIXED) and the MEANS option in Statistical Analysis System. Post-hoc mean separations were conducted by using Fisher's protected least significance difference (LSD).

Table 1. Treatment combinations of phosphorus, potassium, calcium, and magnesium used for the study at SAREC

T_1: $P_0K_0Ca_0Mg_0$	T_6: $P_0K_0Ca_{560}Mg_{56}$
T_2: $P_{34}K_{168}Ca_0Mg_0$	T_7: $P_{34}K_{168}Ca_{560}Mg_{56}$
T_3: $P_{34}K_{336}Ca_0Mg_0$	T_8: $P_{34}K_{336}Ca_{560}Mg_{56}$
T_4: $P_{67}K_{168}Ca_0Mg_0$	T_9: $P_{67}K_{168}Ca_{560}Mg_{56}$
T_5: $P_{67}K_{336}Ca_0Mg_0$	T_{10}: $P_{67}K_{336}Ca_{560}Mg_{56}$

P source: Triple superphosphate (TSP, $Ca(H_2PO_4)_2.\ H_2O$); K source: Muriate of potash (KCl); Ca source: Calcium oxide (CaO); Mg source: Magnesium oxide (MgO).

RESULTS AND DISCUSSION

The soil's pH (8.31) was alkaline with high exchangeable K (243 mg kg^{-1}), Ca (3526 mg kg^{-1}), and Mg (328 mg kg^{-1}) levels, which is common with soils in the state of Wyoming. This is associated to the higher amount of potential evaporation than average annual precipitation in the region. Typically, when the soil pH approaches 8.0 or higher, the availability of some plant nutrients is constrained, and management strategies might be beneficial to unlock these nutrients and make them plant available (Norton, 2020). Alfalfa's high nutrient demand therefore necessitates nutrient build-up and downscaling of interrelated factors critical to the nutrient's availability to be taken-up by plants for adequate growth. In this study, applying P × K to alfalfa generally produced higher yield response (annual total forage accumulation) than the unfertilized alfalfa (Table 2) which is an indication that the initial high levels of P and K (control plots) was not enough to meet alfalfa's nutritional needs for an increased forage accumulation. Compared to the unfertilized alfalfa, the general higher forage accumulation of alfalfa fertilized with P × K suggests that the increased P × K levels was responsible for a possible nutrient availability and uptake by the plant with a resultant higher yield response. This finding could be elucidated by a possible constraint of the P and K by other interrelated factors (such as the relative levels of soil Ca and Mg) and rendered the nutrients not to be readily available and taken-up by alfalfa for higher yield response. The positive impact of P × K on forage accumulation and persistence of alfalfa have been shown in previous studies (Lissbrant *et al*., 2009; Burayu and Mostafa, 2021). Thus, upon their availability for uptake by the plant, the absorbed nutrient interacted to cause a synergistic effect through their physiological roles to influence the crop's performance. Over the two production years, the 2-yrs total annual total forage accumulation was greatest when alfalfa was fertilized with high rates of P × K ($P_{67}K_{336}$) with the $Ca_{560}Mg_{56}$ association (23.1 Mg ha^{-1}; 41% increase over the control) and without $Ca_{560}Mg_{56}$ association (22.7 Mg ha^{-1}; 43% increase over the control) (Table 2). Depending on their relative levels, cationic nutrients such as Ca^{2+} and Mg^{2+} are critical to the availability of P and K in the soil for plant uptake (Mallarino *et al*., 2013; Jeschke, 2017). The roles of P and K are interdependent; therefore, a blend of both nutrients interact to form strong bond that can interact with other nutrients and impact their relative thresholds in the soil (Lissbrant *et al*., 2009; IPNI, 1998). As observed from the results of this study, the high P and K levels interacted (synergistic effect), and their interaction effect might have caused P and K levels to dominate the exchange sites and soil space at the expense of soil Ca and Mg levels, which probably became readily available to be absorbed by alfalfa for higher yield response. This explains the higher yield response of alfalfa fertilized with $P_{67}K_{336}$ in a soil with high Ca and Mg levels. Harvest time had a significant effect on forage accumulation in 2020 and 2021. Late harvest produced higher forage accumulation than early harvest in 2020, and the opposite was observed in 2021 (Table 2). The decline in forage accumulation at late harvest in 2021 could probably be due to the prolonged biotic/abiotic stress suffered by the plants under late harvest system and the influence it has on the plant growth processes as the stand ages (Undersander *et al*., 2015). This suggest that alfalfa's productivity under early harvest or late harvest schedule is dependent on the stand age.

Table 2. Forage accumulation (dry matter [DM] yield) of alfalfa (Hi-Gest 360) treated with phosphorus and potassium in association with calcium and magnesium, and harvest time at the SAREC in 2020 and 2021

Treatment (kg ha^{-1})	2020	2021	2-yrs total	2-yrs avg	Percent yield increase†
	---------------------- DM yield (Mg ha^{-1}) ----------------------				(%)
P_0K_0	9.6 g¶	6.5 d	16.1 f	8.1 f	-
$P_{34}K_{168}$	12.2 d	8.6 a	20.8 cd	10.4 cd	29
$P_{34}K_{336}$	13.0 c	8.7 a	21.7 bc	10.9 bc	35
$P_{67}K_{168}$	12.5 cd	8.7 a	21.2 c	10.7 c	32
$P_{67}K_{336}$	13.8 b	8.9 a	22.7 a	11.3 a	41
$P_0K_0Ca_{560}Mg_{56}$	11.4 e	7.2 c	18.6 e	9.3 e	16
$P_{34}K_{168}Ca_{560}Mg_{56}$	10.7 f	8.0 b	18.7 e	9.3 e	16
$P_{34}K_{336}Ca_{560}Mg_{56}$	12.1 d	8.0 b	20.1 d	10.0 d	25
$P_{67}K_{168}Ca_{560}Mg_{56}$	12.4 d	8.5 ab	20.9 cd	10.4 cd	30
$P_{67}K_{336}Ca_{560}Mg_{56}$	14.5 a	8.6 a	23.1 a	11.5 a	43
Average	12.2	8.2	20.4	10.2	--
Harvest time					
Early harvest‡	11.7 b	8.5 a	20.2 a	10.1 a	-
Late harvest§	12.7 a	7.8 b	20.5 a	10.3 a	2
Average	12.2	8.2	20.4	10.2	--

† Percent yield increase = ([Treatment yield – control yield]/ control yield) x 100.

‡ Early harvest (late bud to early [10%] bloom stage.

§ Late harvest (7 days after early harvest).

¶ Within each column, means followed by the same lower-case letter are not significantly different at 0.05 probability level.

CONCLUSIONS

Alfalfa's forage accumulation potential increased when it received P × K nutrition in soils with high levels of exchangeable Ca and Mg. The levels of soil exchangeable Ca and Mg relative to levels of P and K have great potentials to limit the availability of P and K to be taken-up by alfalfa for high yield response. Forage accumulation of alfalfa under early harvest and late harvest schedule changed with stand age. To maintain higher alfalfa productivity for sustainable production, growers and other stakeholders ought to check the current nutritional status of their soil and consider fertilizing an improved alfalfa cultivar with high rates of P and K (even in a soil with high K levels), and make harvest schedules decisions based on stand age.

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