Effect of P Fertilization Management on Alfalfa Forage Production, and on Soil Available P

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Abstract

A field experiment designed to determine the effect of P fertilization on forage production of alfalfa seeded in pure stands or mixed with Russian Wildrye was started in 1997 on a Swinton Silt Loam at Swift Current. Phosphorus as triple superphosphate was applied either prior to seeding at rates of 20, 40 or 80 (P20, P40, and P80, respectively) or as annual mid-row band applications of 10, 20 or 40 kg P2O5/ha (A10, A20, and A40, respectively). The A40 treatment was the only fertilizer regime that consistently produced the highest forage yields and forage P concentration. While the P40 and P80 treatments produced the same forage yields as A40 in the first two years of the study, their forage yields declined thereafter. All P treatments increased forage P concentration, especially A40 that consistently produced the highest P concentration. In the last year, however the preplant treatments failed to increase P concentration. Cumulative P balances for the check and preplant treatments had identical negative slopes and intercepts proportional to the rate of P applied. Balances for the annual treatments had intercepts proportional to applied P; while the A10 treatment had a zero slope; A20 andA40 had positive slopes proportional to the application of P. The level of Olsen P in the soil followed a trend similar to that described for the balance.

Introduction

There is renewed interest in alfalfa for pasture in the prairie region due to its productivity, forage quality, and new technologies for ruminant bloat control (Popp et al. 2000). Grass mixtures with alfalfa have been used in the past to reduce ruminant bloat hazard and Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski) is recommended for summer and fall grazing in the Brown Soil zone. However, alfalfa persistence in these mixtures is reduced due to the competitive nature of this grass species (Kilcher et al. 1966).

Soils in the Brown soil zone are generally deficient in available phosphorus but P is known to improve the persistence of legumes growing in mixtures with non-legumes. The objective of this study was to determine the response to P fertilization of dry matter yield, P balances, and soil available P of monoculture alfalfa and alfalfa-Russian wildrye grass mixtures (RWRM).

Materials and Methods

The trial was seeded on 16 May 1997 at the dryland research area of SPARC in Swift Current in a Swinton loam. The crop was seeded into plots 6 m long by 6 rows spaced 30 cm experimental design is a split plot with four replicates. Main plot treatments are monoculture alfalfa, Russian wildrye and alfalfa seeded in alternate rows, and Russian wildrye and alfalfa seeded in the same row. Seven P fertility treatments were imposed on the subplots: 0 kg P_2O_5 ha^{-1} (check); 20 kg P_2O_5 ha^{-1} preplant (P-20); 40 kg P_2O_5 ha^{-1} preplant (P-40); 80 kg P_2O_5 ha^{-1} preplant (P-80); 10 kg P_2O_5 ha^{-1} annual (A-10); 20 kg P_2O_5 ha^{-1} annual (A-20); and 40 kg P_2O_5 ha^{-1} annual (A-40). These P rates are equivalent to 4.4, 8.7, 17.5 and 34.9 kg P ha^{-1}. Both preplant and annual P rate treatments were applied as triple superphosphate banded (ca 2 cm) in the center of every mid-row space. Preplant applications were made once just before seeding in 1997; annual applications were made just before seeding in 1997, and repeated annually early in the spring. After forage establishment in 1997, neutron access tubes were installed in each plot to permit determination of soil water.

Forage yield was determined by harvesting with a flail-type plot harvester. Forage sub samples were removed and analyzed for moisture content and N and P concentration. Botanical composition was determined for the RWRM at each harvest by hand clipping a portion of an intact row, and separating species by hand. In 2002 and 2003, concentration of P in these tissue samples were determined separately for Russian Wildrye and alfalfa. In fall 2002, after forage harvest, soil samples were taken with a 73 mm diameter core sampler from the alfalfa monoculture treatments. Soil samples were removed from the mid-row band and from the plant row. Cores were separated into 0-7.5, 7.-15, 15-30, and 30-60 cm depth increments and available PO_4-P was determined by the Olsen method (Olsen et al. 1954).

Results and Discussion

1.- Forage production

Forage dry matter (DM) production was affected by years, crop mixture, and P fertilization treatment. Forage production was highly variable among years as they were highly dependent on growing season weather conditions. Only in 2000 and 2002 the distribution of precipitation and temperatures permitted two cuts of forage. In all other years only one cut was possible. Forage yields varied between a low of 526 kg DM/ha in 2001 to a high of 3891 (in two cuts) in 2000 (Table 1).

With the exception of the 2002-2003 winter period, when late fall and winter precipitation permitted the a substantial accumulation of available water in the soil profile, over winter precipitation permitted only partial water recharge of the soil, (Table 1). Rainfall during the growing season was normally concentrated early in the season; this uneven distribution of precipitation together with heat stress during July and August limited regrowth of the crop.

Table l. Available Water in the Soil, Rainfall, Water Use and Dry Matter (DM) Yields.

Year	SAVW[1] Spring	SAVW Cut1	Rain Cut 1	Water use Cut 1	Cut 1 DM Yield	SAVW Cut 2	Rain Cut 2	Water use Cut 2	Cut 2 DM Yield
	----------------(mm)----------------				(kg/ha)	-----------(mm)----------			(kg/ha)
1998	59	63	164	160	3086				
1999	105	52	237	290	3055				
2000	66	144	218	139	1706	53	39	130	2185
2001	68	55	86	99	526				
2002	66	76	220	209	2423	53	128	157	1110
2003	141	79	122	184	2388				

[1]Soil available water calculated as the water content to 120 cm depth minus the minimum water content observed in the study.

Overall, DM production by monoculture alfalfa was significantly higher ($P \leq 0.05$) than for the mixtures (Table 2). In the first harvests there was no differences between monoculture alfalfa and alfalfa-grass mixtures, probably because in the initial years the production of Russian wildrye was low, and did not compete much with alfalfa. However, monoculture alfalfa had higher production than either of the mixtures, with the exception of 2001 when DM production was limited by drought for all crop combinations,. This difference may be a result of the intra-species competition in the mixed-row and alternate-row configurations.

Table 2. Dry Matter Production by Crop Mixtures by Year

Year	Alfalfa-RWR mixtures		Monoculture Alfalfa	MEAN
	Alternate rows	Mixed rows		
	Kg/ha			
1998	3027^{cd}	3095^{cd}	3135^{c}	3086
1999	3139^{c}	2803^{de}	3224^{c}	3086
2000	3616^{b}	3798^{b}	4260^{b}	3891
2001	484^{g}	503^{g}	583^{g}	523
2002	3176^{c}	3171^{c}	4232^{c}	3526
2003	2275^{f}	2204^{f}	2684^{e}	2388
MEAN	2620	2696	3020	

Botanical composition of the forage in the RWR-alfalfa mixtures changed over time. The proportion of grass in the mixture increased from 10% of the harvested material in 1998 to 49% in 2001, this level has been maintained for the last three years (data not shown). This is consistent with previous results of Russian wildrye grass and alfalfa mixtures where the alfalfa established quickly and initially produced more forage than the grass (Leyshon and Campbell 1992).

2.- Phosphorus fertilization

Olsen P in the soil (0-15 cm depth) at the beginning of the field experiment was only 5.4 νg g^{-1} (95% confidence limit 5.0 to 5.5 νg g^{-1}). At these levels of Olsen P in the soil, crops respond readily to P fertilization (Read et al. 1973). Although the level of forage production was primarily affected by growing season conditions, overall, phosphorus fertilization, especially when applied annually produced large increases in the production of forage dry matter (Fig. 1); application of 40 kg P_2O_5/ha annually produced the largest increase in forage dry matter. This treatment was followed by the application of 40 or 80 kg P_2O_5/ha applied once before seeding and by the annual application of 20 kg P_2O_5/ha.

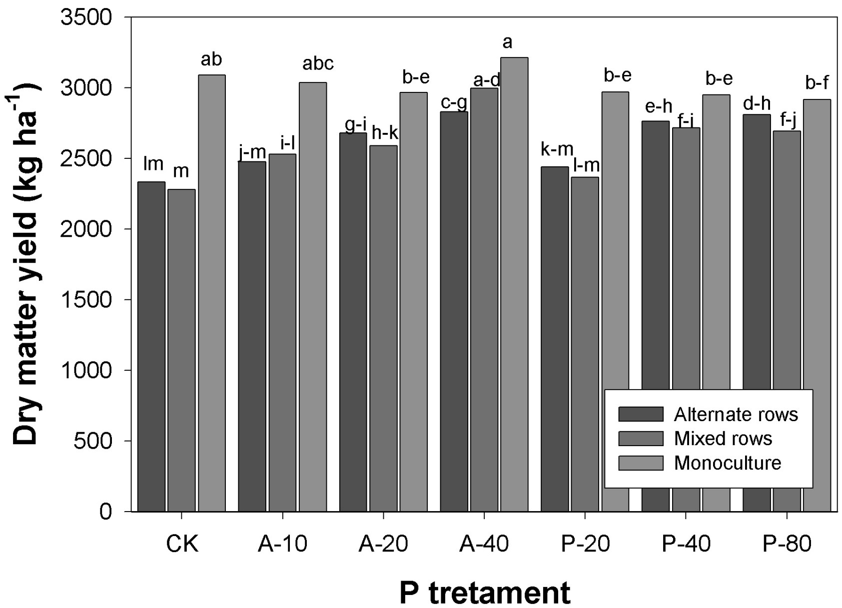

Figure 1. Dry Matter Yield Response to Phosphorus Fertility Treatments.

The response of the different crop mixes, however, was not consistent. Monoculture alfalfa did not respond to P applications, regardless of rate or application mode, in this monoculture system the dry matter production of unfertilized alfalfa produced as much as that receiving the maximum amount of P in the study (40 kg P_2O_5/ha annually), and as much or more than the well fertilized mixtures (Fig. 1). The two RWRM showed marked responses to the application of P, but there was no difference between the mixed row and alternate row cropping configuration.

This difference in response between the monoculture alfalfa and the RWRM may be an indication of differences in mycorrhizal infection between the systems. The lack of yield response by monoculture alfalfa to P fertilization, while maintaining high yield and P concentration suggests that this crop may be infected by mycorrhizae; which would allow the unfertilized alfalfa crop to satisfy its needs for P. This seems to be the case as the yield of unfertilized alfalfa is the same as that of alfalfa receiving 40 kg P_2O_5/ha annually, and furthermore is higher that that of the fertilized RWRM. It is possible that in the RWRM the presence of the RWR may inhibit the infection of mycorrhizae as well decreasing the growth of alfalfa due to intra-species competition, as evidenced by the large response to P fertilization of these mixtures.

3.- Phosphorus balances and soil available P

The amount of P removed by the crop was highly dependent on total dry matter production, as observed in previous studies (Selles et al. 1999). For this reason the cumulative balances, calculated as the sum of the annual differences between P inputs and P outputs from the system, show a separation of the treatments that received annual applications of P from those that received preplant fertilization, or no fertilization. The annual fertilization treatments were characterized by positive initial balance and positive slopes proportional to the amount of P applied annually. The treatments receiving the preplant P application had also an initial balance proportional to the amount of P applied, but were characterized by negative slopes that were common to all preplant treatments. The unfertilized treatment had a negative slope similar to the preplant treatments, but the initial year balance was negative (Fig. 2).

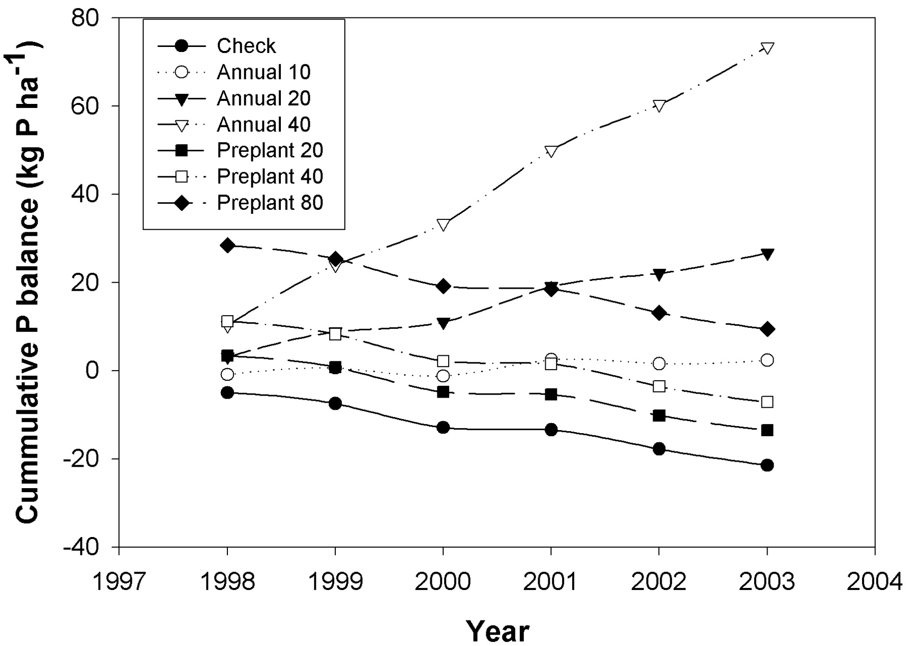

Figure 2. Evolution of P Balances for the various Phosphorus Fertility Treatments

During the study period, the concentration of available P in the soil at the 0-15 cm depth (Olsen et al. 1954) showed the combined effects of the amounts of P applied and the amount of P removal by the crop (Fig. 3). Available P concentration in the soil receiving no P fertilizer has remained unchanged throughout 6 harvests that have removed in excess of 20 kg P ha^{-1}. The treatments receiving the preplant P treatments showed at the 1999 sampling an increase in available P proportional to the amount of P applied; in subsequent years the level of available P in these treatments declined gradually at a rate proportional to the rate of P applied, to reach by 2003 levels close to those observed in the unfertilized treatment. All the treatments receiving annual applications of P increased their available P levels at a rate proportional to the amount of P applied in excess of plant needs. The changes of soil P in this study are in agreement with the results of other studies that have shown increases in Olsen-P for treatments receiving P fertilizers, and unchanged available P levels in unfertilized soils (Selles et al. 1995)

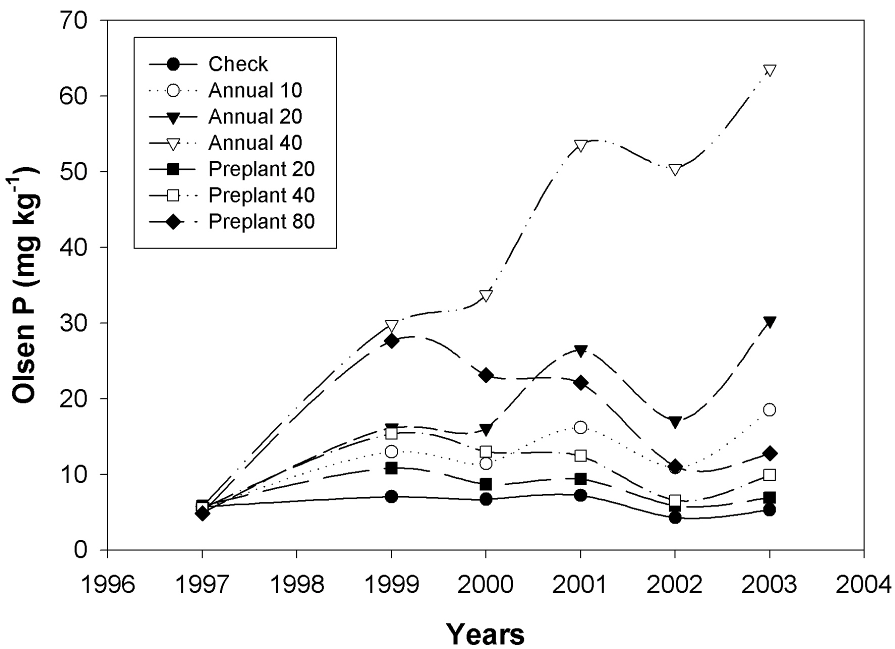

Figure 3. Evolution of Soil Available P for the various Phosphorus Fertility Treatments

A regression between the cumulative P balance and the concentration of available P shows that a large proportion of the variability in soil available P can be predicted by the cumulative P balances of each treatments ($R^2 = 0.83$, $P < 0.0001$). A spline regression model with two linear segments intersecting at a common point indicated that for systems where the cumulative P balance was 27 kg P ha^{-1} or lower the concentration of Olsen P changed by 0.29 νg g^{-1} for each kg fertilizer P applied in excess of the crop needs; for P balances in excess of 27 kg P ha^{-1}, increased the concentration of available P by 0.74 νg g^{-1} per kg P/ha applied in excess (Fig 4). The reason for this dual response P extractable by the Olsen method was explained previously as arising from the extraction the result of the build-up of available P forms in the soil in fertilized system, while in unfertilized systems, transformations of native inorganic P through dissolution and desorption reactions, and of organic P through microbial and enzymatic mineralization replace the available P removed by the crop (Paul and Clark, 1989, Selles et al. 1995). The fact that the level of soil available P remains constant in the unfertilized treatment suggests that the enzymatic mineralization of organic P forms may be the dominant mechanism for maintaining the levels of available P in unfertilized perennial forage systems.

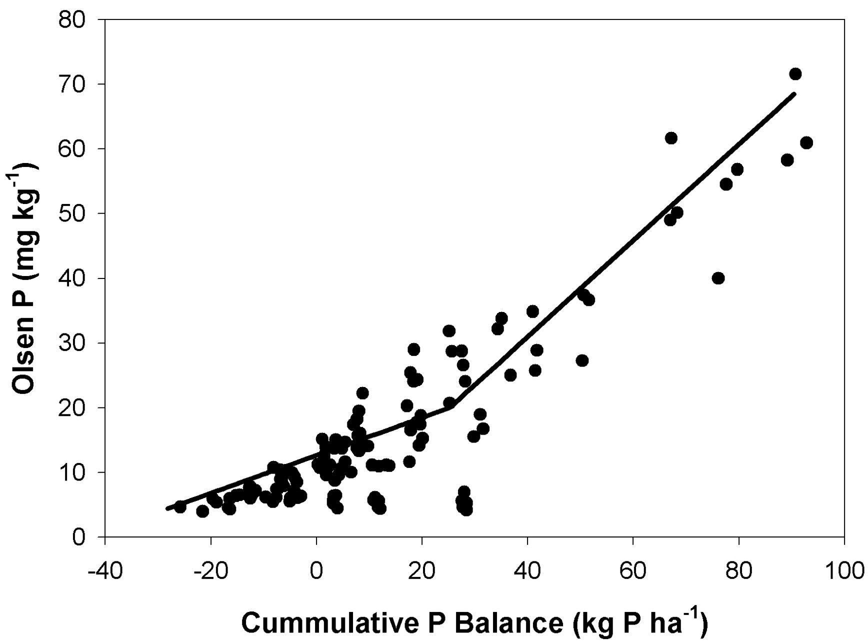

Figure 4. Relationship Between Cumulative P balances and Soil Available P.

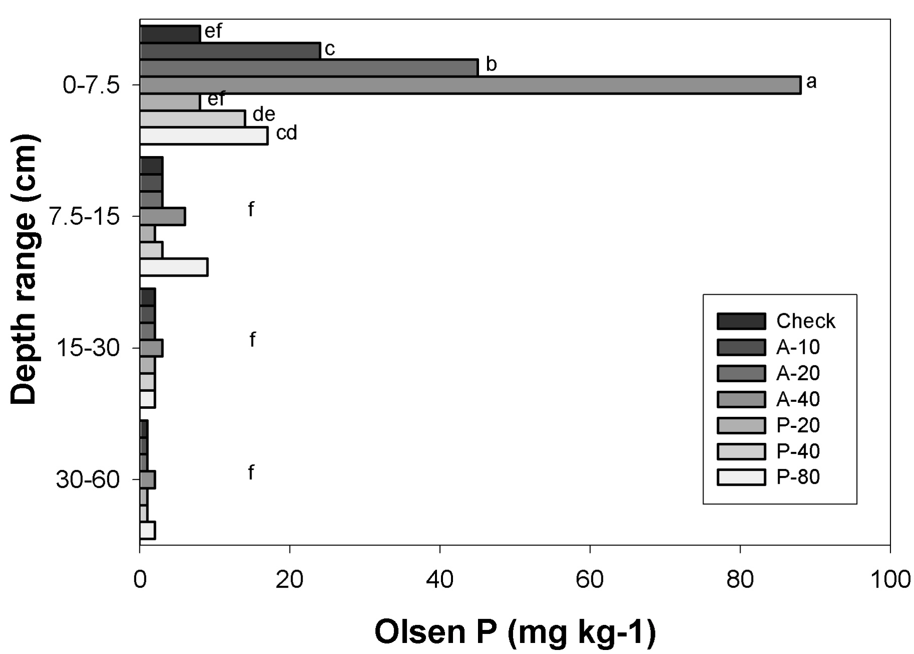

Figure 5. Distribution of Soil Available P Over the Area of Application, 2002 Sampling

Soil available P concentration in soil samples taken in 2002 from the alfalfa monoculture plots, after the fifth year, revealed that over the area of fertilizer application the annual P application treatments had increased significantly ($P \leq 0.05$) the concentration of Olsen P at the 0-7.5 cm depth, and that the concentration was proportional to the total amount of P added (Fig. 5). In the treatments receiving the preplant fertilizer treatments the concentration of available P was not significantly different from that of the unfertilized soil, although the 40 and 80 kg P_2O_5 treatments showed a slight elevation in available P. Annual applications of P are more likely to maintain higher concentrations of available P than a large application prior to seeding (Mullen et al. 2000). The concentration of available P at lower depths of the profile in the area of P banding was not different ($P > 0.05$) than that of the unfertilized and did not show evidence of downward P movement from the highly fertilized treatments. The profile of available P for the samples taken over the plant rows (away from the fertilizer band) showed no effect of fertilizer treatments (data not shown).

Conclusions

Dry matter production of forage was determined primarily by the amount and distribution of precipitation during the growing season. P fertilization increased the yield of the by up to 21 and 34% on the alternate and mix row alfalfa-Russian wildrye mixtures, respectively. Production of monoculture alfalfa was not affected by P fertilization; in this cropping arrangement the yield of the unfertilized crop was as good as that of the properly fertilized crops. This difference in response between cropping mixes, suggests that under monoculture alfalfa, microbial-root associations may be an important factor determining the capacity of this crop to use soil P.

There is a close direct relationship between the magnitude of the P balances of the cropping system and the evolution of soil available P; under conditions of low to negative P balances available soil P changes by 0.29 νg g^{-1} per unit change in P balance. For P balances above 27 kg P ha^{-1} soil available P changed by 0.74 νg g^{-1} per unit change in P balance, which may be an indication of the types of available P pools and processes present under conditions of depletion or build up of soil available P.

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