Report to Phosphate and Potash Institute of Canada

Preliminary evaluation of point-injection for P and K fertilization of forage grass

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Abstract

A greenhouse experiment was conducted to determine the feasibility of point-injection for the phosphorus (P) and potassium (K) fertilization of forage grasses. Orchardgrass (*Dactylis glomerata*) was established in columns and P or K was applied by the following methods: point-injection (to a depth of 10 cm), broadcast granular fertilizer, and broadcast solution fertilizer. In addition, the experiments included two check treatments (with and without P or K applied prior to seeding). After the application of the fertilizer treatments, the grass was grown for 5 to 7 successive harvests (at approximately 2 to 3 week intervals) and yield and nutrient uptake were determined as a measure of fertilizer effectiveness. The experiments showed that solution fertilizer may be more effective than granular fertilizer for the alleviation of P deficiency in established forage stands under some conditions. Point-injection, however, offered little advantage over broadcast application methods for P fertilization of forage crops, provided the latter were applied in solution form. Point-injection could conceivably have some advantage under conditions of drought stress if inadequate precipitation occurs to make surface applied P accessible to the crop. Further evaluation of point-injection for application of P to forage grasses is recommended based on the results observed in our experiment. There appears to be little benefit of point-injection relative to other methods of application for the K fertilization of forage grasses. In part, this absence of significant benefit may reflect the relative mobility of K in the soil. Under conditions where precipitation is inadequate to mobilize surface-applied K, there could conceivably be some advantage to point-injection.

Introduction

The efficiency of fertilizer use by mature forage stands is often limited by ineffectual placement. In conventional fertilizer practices, the fertilizers are normally applied to the soil surface (top-dressed), a process which relies on subsequent precipitation to leach the nutrients into the soil before it can be utilized by the crop. This procedure is reasonably effective for elements such as nitrogen, which are not immediately absorbed by the soil and which can therefore be readily leached into the rooting zone. For nutrients like potassium and, in particular, phosphorus, however, fertilizer applied to the soil may be positionally unavailable to the crop for some time after application. Traditional banding techniques are often inappropriate because they result in excessive disruption and disturbance of the crop.

Point-injection is a relatively new concept in fertilizer application that may allow effective placement of P and K into the rooting zone with minimal disruption of the soil or crop. This method uses a spoked wheel to penetrate the soil to a predetermined depth and inject appropriate volumes of fertilizer solution at regular intervals. Point-injection could conceivably be a cost-effective method for the rejuvenation of mature forage stands through efficient alleviation of P and K deficiency. Very little research attention, however, has been devoted to this promising method of P and K application.

The objective of this study was to determine the crop recovery of P and K applied by various methods and to compare the efficiency of point-injection to traditional methods of application. This preliminary evaluation, carried out in a controlled environment, was conducted to determine if more comprehensive evaluations under field conditions were justified.

Phosphorus Study

Materials and Methods

The effectiveness of various P application methods was determined using orchardgrass (*Dactylis glomerata*) as a test crop. The experiment included five treatments: 1. check receiving no P fertilizer (check -P), 2. check receiving adequate P prior to seeding (check +P), 3. top-dressed granular P (BC-G), 4. top-dressed P solution (BC-S), and 5. point-injected P solution (PI-S). All treatments were replicated four times in a completely randomized design in each of two soils (Table 1).

Table 1: Selected properties of Chernozemic soils used to evaluate the effectiveness of point-injection for P and K fertilization of grass.

Soil†	OM§	Extr. N	Extr. P	Extr. K	CEC	pH	EC
	(%)	----------- mg kg^{-1}	-------		meq kg^{-1}		mmho cm^{-1}
P experiment							
Vauxhall	3.0	54	11	375	174	6.9	1.6
Lethbridge	2.6	12	9	391	206	7.7	0.5
K experiment							
Purple Springs	2.1	13	17	274	160	7.9	0.8
Edmonton	7.0	25	25	156	295	6.9	0.8

† soil names indicate general geographical region from which soils were obtained

§ OM=organic matter (Walkley Black), Extr. N = 1 N KCl-extractable NH_4 and NO_3, Extr. P=0.5 N $NaHCO_3$-extractable P, Extr. K= sodium acetate-extractable K, CEC = cation exchange capacity, pH was determined in water, EC = electrical conductivity of staturation paste extract

Phosphorus solution for the BC-S and PI-S treatments was prepared by dissolving appropriate amounts of $NH_4H_2PO_4$ and $(NH_4)_2HPO_4$ in water to produce a solution containing 40.5 mg P mL^{-1} and 27.5 mg N mL^{-1}. (This solution contains N and P in the same ratio as in the commercial 10-34-0 fertilizer). The BC-G treatment was established using commercial monoammonium phosphate fertilizer (11-51-0).

Orchardgrass was established in polyvinylchloride cylinders (10.16 cm inside diameter X 45 cm) containing 3.582 or 3.780 kg oven-dry soil (Vauxhall and Lethbridge soils, respectively). The soil was fertilized with nutrient solution at the following rates (mg nutrient pot^{-1}): N - 325, K - 325, S -276, Zn - 16.25, Mo - 1.625, B - 6.5, and Cu - 3.25. After nutrient additions, the soil was moistened and thoroughly mixed to ensure uniform distribution of fertilizers. Phosphorus was then applied to the Check+P treatment at a rate of 40.5 mg P pot^{-1} using KH_2PO_4 solution by placing 10 mLs of solution in a 'band' 10 cm below the soil surface. The orchardgrass was then seeded at a rate of 16 seeds per cylinder which were then moved into a greenhouse with supplemental lighting. After establishment, the grass was thinned to 8 plants per pot. The orchardgrass was regularly watered to weight as required to prevent moisture stress. To induce P deficiency, the crop was grown for an extended period and harvested 7 times before applying experimental treatments. All treatments were periodically fertilized with N, K, and S to prevent deficiencies of these nutrients.

Phosphorus treatments (BC-S, BC-G, and PI-S) were applied immediately after removal of shoot growth at a rate of 40.5 mg pot^{-1}. Point-injection to a depth of 10 cm was achieved using a syringe equipped with a stainless steel needle. Nitrogen applications were equalized across treatments by application of NH_4NO_3 as required.

The orchardgrass was cropped as before for an additional 5 (Vauxhall soil) or 7 (Lethbridge soil) successive harvests (designated 0, 1, 2 and so on, where 0 is the harvest just prior to P application). At each harvest, shoots were cut 6 cm above the soil surface and dried to determine dry matter yield. The shoots were then ground and digested using sulfuric acid and hydrogen peroxide to permit colorimetric analysis of phosphorus concentration.

Results

Dry matter yields in the Lethbride soil showed few significant differences in response to P application treatment (Table 2). Average yields in the various treatments in post-P application harvests (1 to 7) tended to follow those observed in the harvest prior to establishment of P treatments (0). The Vauxhall soil demonstrated larger response to P application than the Lethbridge soil. Dry matter yields in this soil were consistently highest in the treatments receiving soluble P fertilizer (BC-S and PI-S) though increases over the BC-G treatments were not significant, perhaps in part because of high treatment variability. In both soils, yields declined appreciably over time in all treatments.

Phosphorus concentrations of the grass were more sensitive than yields to P treatments (Table 3). In both soils, the treatments receiving post-seeding P applications exhibited large increases in P concentration in harvest 1 (first harvest after P application) and values were usually significantly higher concentrations than those in the check treatments. Among the former, concentrations tended to be higher in the treatments receiving soluble P (PI-S and BC-S) than in the granular P treatment (BC-G).

Total P yield exhibited trends similar to those described for P concentration (Table 4). Of the non-check treatments, highest P uptake was usually observed in the treatments receiving soluble P fertilizer (BC-S and PI-S) in both soils. This difference was statistically significant in a number of the harvests, particularly in the Vauxhall soil.

Cumulative P uptake further demonstrates the greater response to soluble P fertilizer ((PI-S and BC-S) than to granular fertilizer in the Vauxhall soil. After five harvests, total P yield of the orchardgrass was 31.5, 30.6, and 23.4 mg pot^{-1} for the PI-S, BC-S, and BC-G treatments respectively (Fig. 1). Estimated fertilizer uptake (P yield in fertilized treatments - P yield in unfertilized check) was 18.7, 17.7, and 10.5 mg P pot^{-1}, respectively. These values suggest fertilizer recovery of 46, 44, as 26% of that applied respectively. Cumulative P yields in the Lethbridge soil showed few significant differences among the P treatments, largely because of the apparent high indigenous P fertility.

Analysis of soils after the final harvest showed appreciable recovery of P in the zone of application (Table 5). Thus broadcast treatments (BC-S and BC-G) tended to retain higher concentrations than other treatments in the surface layer and the point-injection treatment (PI-S) tended to have higher concentrations in the sub-surface layers. This trend was particularly evident in the Vauxhall soil.

Table 2: Dry matter yields of orchardgrass as influenced by method of P application in two Chernozemic soils.

Harvest	Ch +P¶	Ch -P	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	------------------- g pot^{-1}				---------------------		
Lethbridge							
0	5.1	4.8	4.5	5.2	5.0	ns	
1	4.9	4.7	4.6	5.1	5.2	ns	
2	3.5	3.4	3.6	3.9	3.9	ns	
3	3.5	3.1	3.3	3.7	4.0	0.05	0.6
4	4.0	3.6	3.8	4.5	4.2	ns	
5	3.0	2.9	3.0	2.8	3.3	ns	
6	2.2	2.3	2.3	2.2	2.5	ns	
7	2.0	1.9	1.9	2.0	2.1	ns	
Vauxhall							
0	4.3	3.0	3.4	3.0	2.9	0.04	0.9
1	4.4	2.8	3.8	3.1	3.4	0.05	1.1
2	2.8	1.9	2.9	2.3	2.6	ns	
3	2.4	1.3	2.4	2.0	2.3	0.10	0.9
4	2.6	1.5	3.0	1.8	2.8	0.09	1.3
5	1.8	0.7	2.0	1.1	2.3	0.04	1.2

¶ 'Ch +P' and 'Ch -P' denote check containing adequate P at start of experiment and check receiving no P fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution P, broadcast granular P, and broadcast solution P, respectively, immediately after harvest 0.

Table 3: Phosphorus concentration of orchardgrass as influenced by method of P application in two Chernozemic soils.

Harvest	Ch +P¶	Ch -P	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	---------- g kg^{-1} ----------						
Lethbridge							
0	2.0	1.9	1.8	1.7	2.0	ns	
1	1.7	1.6	2.3	2.1	2.3	0.0001	0.2
2	2.3	2.1	2.8	2.3	2.8	0.004	0.4
3	1.9	2.0	2.4	2.1	2.4	0.02	0.4
4	2.3	2.2	2.3	2.5	2.6	ns	
5	2.4	1.8	2.6	2.4	2.6	0.0003	0.3
6	2.2	2.2	2.3	2.3	2.2	ns	
7	2.3	1.8	2.7	2.1	2.4	0.01	0.5
Vauxhall							
0	1.8	1.7	1.7	1.6	1.7	ns	
1	1.6	1.5	2.4	2.5	2.3	0.0003	0.4
2	1.9	1.6	2.4	2.6	2.5	0.0001	0.4
3	1.9	1.6	2.3	1.9	2.4	0.01	0.4
4	1.6	1.7	2.0	1.9	2.4	0.01	0.4
5	1.7	1.6	1.9	2.1	2.0	ns	

¶ 'Ch +P' and 'Ch -P' denote check containing adequate P at start of experiment and check receiving no P fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution P, broadcast granular P, and broadcast solution P, respectively, immediately after harvest 0.

Table 4: Phosphorus uptake by orchardgrass as influenced by method of P application in two Chernozemic soils.

Harvest	Ch +P¶	Ch -P	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	----------------------------	mg cyl^{-1}	------------------------				
Lethbridge							
0	10.0	8.9	8.0	9.0	9.9	0.06	1.4
1	8.2	7.3	10.5	10.8	12.0	0.0003	1.8
2	7.7	7.0	10.0	9.0	11.0	0.004	2.0
3	6.7	6.2	8.0	7.9	9.4	0.003	1.5
4	9.3	7.8	8.7	11.0	10.9	0.008	1.8
5	7.0	5.2	7.9	6.6	8.5	0.0001	1.0
6	4.9	5.0	5.2	5.1	5.5	ns	
7	4.5	3.4	5.1	4.3	5.0	ns	
Vauxhall							
0	8.0	5.1	5.8	4.9	5.0	0.03	2.1
1	7.2	4.2	9.1	8.0	7.7	0.09	3.6
2	5.3	2.9	6.9	6.0	6.6	0.02	2.4
3	4.6	2.2	5.4	3.7	5.4	0.02	2.1
4	4.1	2.6	6.1	3.2	6.4	0.005	2.1
5	3.2	1.0	3.9	2.5	4.5	0.08	2.6

¶ 'Ch +P' and 'Ch -P' denote check containing adequate P at start of experiment and check receiving no P fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution P, broadcast granular P, and broadcast solution P, respectively, immediately after harvest 0.

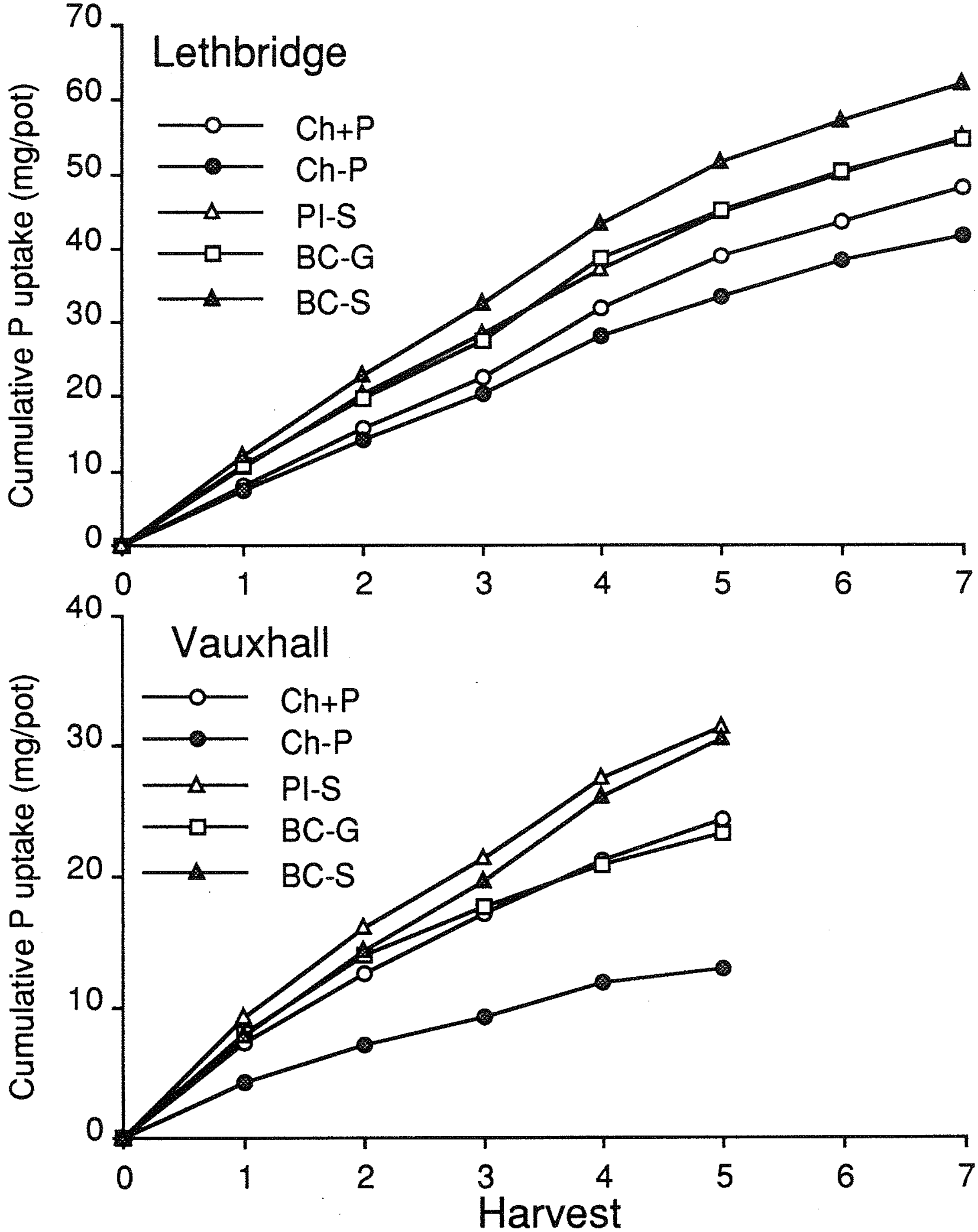

Fig. 1. Cumulative P uptake over suucessive harvests by orchardgrass in two soils as influenced by method of P application. 'Ch +P' and 'Ch -P' denote check containing adequate P at start of experiment and check receiving no P fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution P, broadcast granular P, and broadcast solution P, respectively, immediately after harvest 0.

Table 5: Bicarbonate-extractable P concentrations after final harvest of orchardgrass as influenced by method of fertilizer application in two soils.

Depth	Ch +P¶	Ch -P	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	mg kg^{-1}						
Lethbridge							
0-5 cm	11	10	12	17	12	ns	
5-10 cm	7	6	8	6	7	ns	
10-20 cm	6	2	14	3	4	0.0001	3
Vauxhall							
0-5 cm	7	8	6	20	16	0.001	7
5-10 cm	7	7	15	8	7	ns	
10-20 cm	9	4	21	6	5	0.004	8

¶ 'Ch +P' and 'Ch -P' denote check containing adequate P at start of experiment and check receiving no P fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution P, broadcast granular P, and broadcast solution P, respectively, immediately after harvest 0.

Discussion

Dry matter yield responses to fertilizer P treatments showed relatively few differences among P application treatments. In part, these differences can be attributed to relatively high apparent availability of indigenous soil P, particularly in the Lethbridge soil. As well, the results appeared to show some random differences in crop vigor among treatments that remained throughout much of the experiment. For example, in treatments excluding Ch+P, dry matter yields of application harvests paralleled those observed prior to P application. For example, the R^2 for the relationship between yield at harvest 0 and subsequent yields was 0.78, 0..68, and 0.45 (all significant at P=0.05) for harvests 1, 2 and 3, respectively in the Lethbridge soil. Corresponding R^2 values for the Vauxhall soil were 0.60, 0.47, and 0.28, respectively.

Phosphorus concentration and uptake probably provide a better measure of fertilizer effectiveness than dry matter yields. From these parameters it appears that P solutions provide a more efficient source of plant-available P than granular P. In the Vauxhall soil, apparent P fertilizer recovery from the two solution fertilizer treatments (PI-S and BC-S), which averaged 45% , was almost twice that of the granular P treatment (BC-G) which exhibited a recovery of only 26%. The reason for this difference can not be definitively determined without detailed examination of P chemistry in the soil, but may be linked to different reaction products of the various sources in the soil.

There were few apparent differences between point-injection and surface broadcast of solution P fertilizer. Even though point-injection provided more effective placement of P into the rooting zone, as determined by soil analysis, plant P concentrations and uptake were generally the same in bith treatments. Evidently, the plants were able to utilize P residing very near the soil surface. This observation, however, may in part be an artifact of greenhouse conditions where surface soil moisture may be much higher than in the field because of higher humidity and frequent watering. In the field, where the surface soil layer may remain dry for extended periods of time, P present near the surface may have greatly reduced availability to the crop.

Potassium Study

Materials and Methods

The experimental design for evaluation of K application techniques was similar to that used in the P study and included the following treatments: 1. check receiving no K fertilizer (check -K), 2. check receiving adequate K prior to seeding (check +K), 3. top-dressed granular K (BC-G), 4. top-dressed K solution (BC-S), and 5. point-injected K solution (PI-S). All treatments were replicated four times in each of two soils (Table 1) in a completely randomized design.

Orchardgrass was established in cylinders as described before and fertilized with adequate basal rates of nutrients other than K: 400 N, 400 P, 154 S, 20 Zn, 2 Mo, 8 B, and 4 Cu (where all rates are expressed in mg pot^{-1}). Mass of soil (oven-dry basis) added to each cylinder was 4.275 and 3.682 kg for the Purple Springs and Edmonton soils, respectively.

After establishment, the orchardgrass was harvested two times before the K treatments were applied. Solution fertilizer treatments (BC-S and PI-S) were applied using a KCl solution while the granular treatment (BC-G) was established using commercial grade KCl fertilizer.

The orchardgrass as harvested seven times after application of the K treatments at approximately 2 week intervals (designated 0, 1, 2 and so on, where 0 is the harvest just prior to P application). Harvested shoot growth was dried for measurement of dry matter yield, and subsequently ground and analyzed for K concentration in the tissue using wet digestion following by K analysis by flame photometry.

Results

Dry matter yields showed few significant responses to K fertilizer application. In most cases, yields in the various K treatments were no higher than those in the check receiving no K (Table 6). In the later harvests in the Purple Springs soil, yields in the PI treatments tended to be lower than those in other treatments.

Potassium concentrations in the forage tissue were significantly enhanced by fertilization in the first harvest after application (harvest 1) in the Edmonton soil (Table 7). Concentrations in the PI-S treatments were significantly lower than those in the BC-S treatment. Potassium concentrations of orchardgrass grown in the Purple Springs soil were appreciably higher than those in the Edmonton soil and showed no significant effect of K application.

Crop K uptake in the Edmonton soil reflected trends described for K concentration. In the first several harvests after K application, crop K uptake showed a significant response to K applications (Table 8). Furthermore, uptake in the point-injection treatment was significantly lower than that from the broadcast solution treatment in harvest 1. Thereafter, no differences among K fertilized treatments were observed. In the Purple S prings soil, K uptake was not affected by fertilizer treatment except ion the later harvests, where uptake in the PI treatments was suppressed, reflecting lower dry matter yields described earlier.

Table 6: Dry matter yields of orchardgrass as influenced by method of K application in two Chernozemic soils.

Harvest	Ch +K¶	Ch -K	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	------------------- g pot^{-1}				-------------------		
Edmonton							
0	6.6	6.2	6.2	6.5	6.2	ns	
1	4.4	3.9	4.2	4.4	4.6	0.09	0.5
2	4.1	3.6	3.9	3.7	4.1	ns	
3	3.4	2.9	3.5	3.1	3.6	0.10	0.5
4	2.7	2.6	2.5	2.7	2.6	ns	
5	2.6	2.2	2.6	2.7	2.8	ns	
6	1.9	1.4	1.9	1.9	1.8	ns	
7	1.5	1.1	1.6	1.4	1.4	ns	
Purple Springs							
0	5.7	6.6	6.3	6.7	6.8	0.10	0.9
1	3.9	4.5	3.8	4.0	4.6	ns	
2	3.4	4.2	3.5	3.5	4.0	ns	
3	3.2	3.6	3.3	3.5	3.7	ns	
4	2.9	3.2	2.8	3.0	3.1	ns	
5	3.1	3.2	2.8	3.4	3.3	ns	
6	1.9	2.7	2.1	2.5	2.5	0.02	0.5
7	1.9	2.7	2.4	2.7	2.6	0.07	0.6

¶ 'Ch +K' and 'Ch -K' denote check containing adequate K at start of experiment and check receiving no K fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution K, broadcast granular K, and broadcast solution K, respectively, immediately after harvest 0.

Table 7: Potassium concentration of orchardgrass as influenced by method of K application in two Chernozemic soils.

Harvest	Ch +K¶	Ch -K	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	-------------------	g $100g^{-1}$	---------------------				
Wetaskiwin							
0	3.1	3.2	3.4	3.3	3.4	ns	
1	2.3	2.2	2.5	2.7	2.8	0.002	0.3
2	2.1	2.1	2.3	2.3	2.3	ns	
3	2.3	2.1	2.2	2.2	2.3	0.10	0.2
4	2.1	1.9	2.2	2.0	1.9	ns	
5	1.8	1.7	2.0	1.8	2.0	ns	
6	1.7	1.7	1.8	1.8	1.8	ns	
7	1.6	1.5	1.5	1.3	1.4	ns	
Purple Springs							
0	4.6	4.6	4.7	4.5	4.5	ns	
1	4.4	4.2	4.4	4.3	4.3	ns	
2	4.3	4.2	4.2	4.1	4.2	ns	
3	4.2	4.2	4.3	4.2	4.2	ns	
4	4.0	3.9	3.8	3.9	3.9	ns	
5	4.0	3.7	3.8	3.8	3.9	ns	
6	3.7	3.7	3.8	3.9	3.8	ns	
7	3.4	3.2	3.3	3.4	3.3	ns	

¶ 'Ch +K' and 'Ch -K' denote check containing adequate K at start of experiment and check receiving no K fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution K, broadcast granular K, and broadcast solution K, respectively, immediately after harvest 0.

Table 8: Potassium yield of orchardgrass as influenced by method of K application in two Chernozemic soils.

Harvest	Ch +K¶	Ch -K	PI-S	BC-G	BC-S	signif.	$LSD_{0.05}$
	------------------- mg pot^{-1}				--------------------		
Wetaskiwin							
0	205	196	210	211	209	ns	
1	101	86	105	119	129	0.0006	16
2	86	75	89	87	94	0.08	13
3	79	61	79	70	81	0.03	13
4	53	50	55	53	50	ns	
5	46	39	51	47	56	ns	
6	33	24	33	33	31	ns	
7	24	16	23	20	20	ns	
Purple Springs							
0	264	301	295	300	309	ns	
1	171	189	165	172	195	ns	
2	145	174	147	147	170	ns	
3	135	148	141	146	156	ns	
4	114	124	107	118	122	ns	
5	128	120	107	128	127	ns	
6	69	100	78	95	95	0.01	18
7	64	87	77	91	84	0.07	20

¶ 'Ch +K' and 'Ch -K' denote check containing adequate K at start of experiment and check receiving no K fertilizer, respectively. 'PI-S', 'BC-G', and 'BC-S' denote treatments receiving point-injected solution K, broadcast granular K, and broadcast solution K, respectively, immediately after harvest 0.

Discussion

The orchardgrass exhibited only limited response to K application, particularly in the Purple Springs soil which had a relatively high concentration of extractable K (Table 1). The absence of large yield responses limited the sensitivity and resolution of the experiment for evaluating the effectiveness of the various K treatments.

Results from the Edmonton soil, where some yield differences were observed, provide little evidence of any benefit of point-injection over traditional methods of application. In fact, initial yield response to point-injection was lower than that to broadcast solution K. These observations suggest that surface-applied K is readily available for plant uptake. Particularly under conditions like those in our experiment, where the crop was regularly watered, the K would be expected to readily move into the soil profile. Under drought conditions in the field, however, it is conceivable that there may be some delay in availability of surface applied K.

There was some indication of a lower yield response to point-injected K relative to broadcast. In the Purple Springs soil, furthermore, yields in the former treatment were lower than those in the unfertilized check in one instance. This apparent negative response may have occurred simply by chance since probability levels of significance were not entirely conclusive. Alternatively, it may reflect some minor physiological injury to the crop from injection of the KCl solution. Such injury would be greatly exaggerated in our study where the injection was made in a confined space. Under field conditions, injections could theoretically be spaced at 20 to 40 cm intervals, thereby minimizing the overall effect of any damage incurred during injection.

Based on observations of this experiment, there appears to be little justification for more rigorous evaluation of point-injection for K fertilization of forages. Owing to the reasonable mobility of K within the soil profile, surface applied K may well be at least as effective as point-injected K, except in cases were there is inadequate precipitation to leach the fertilizer into the rooting zone.

Conclusions

The preliminary evaluation of point-injection for the application of P and K to forages was performed under controlled conditions and results can therefore not be quantitatively extrapolated to the field conditions. Furthermore, the absence of large yield responses to nutrients applied, particularly in the case of the K study, limited the sensitivity of the experiment for differentiating among methods of application. Nevertheless, the study provides evidence to support the following tentative conclusions:

1. Solution fertilizer may be more effective than granular fertilizer for the alleviation of P deficiency in established forage stands under some conditions. Further evaluation of the mechanism for this apparent response is required. One possible explanation for the apparent superiority of the solution P is that this fertilizer may enter the rooting zone by flowing along the stems, roots, and rhizomes of the forage crop, while the granular P remains at the soil surface or even suspended above the soil.
2. Point-injection offers little advantage over broadcast application methods for P fertilization of forage crops, provided the latter are applied in solution form. Some advantages to point-injection are conceivable in

conditions of drought stress if inadequate precipitation occurs to make surface applied P accessible to the crop. These conditions however were not evaluated in the present set of experiments and may merit some further evaluation.

3. Further evaluation of point-injection for application of P to forage grasses is recommended based on the results observed in our experiment. A variable which deserves high priority is the optimum spacing of injections. Because P is relatively immobile in the soil, spacings developed for other nutrients such as nitrogen are probably not applicable. Furthermore, much of the previous work with spacing of injections was conducted in cereal crops which are seeded in rows, unlike many of the current forage crops. Other variables that deserve consideration include: depth of injection, timing of application, form of fertilizer applied, and formulation of fertilizer (including other nutrients).
4. There appears to be little benefit of point-injection relative to other methods of application for the K fertilization of forage grasses. In part, this absence of significant benefit may reflect the relative mobility of K in the soil. Under conditions where precipitation is inadequate to mobilize surface-applied K, there could conceivably be some advantage to point-injection.

Appendix I

Acknowledgement of Financial Contributions

Source	Amount ($)
AARI (Matching Grant)	1,375
Potash and Phosphate Institute Of Canada	6,000
Total	**7,375**

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