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Abstract

In the province of Québec, about 35 000 ha of land are devoted to growing wild lowbush blueberry (*Vaccinium angustifolium* Ait.). Blueberry fields are located on acidic, well-drained soils with low nutrient levels. To ensure high crop productivity, fertilizers are applied in the spring of the sprout year. The objective of this study was to determine the effect of phosphorus (P) fertilizer applications on soil P mobility under field conditions. Experiments were conducted in commercial stands of wild blueberries between 2004 and 2008 in the Lake St. Jean area, Québec, Canada. Four P rates (0 to 90 kg P_2O_5 ha^{-1}) were applied in May of the sprout year. Soil P was determined in the 0–5, 5–15 and 15–30 cm soil layers after Mehlich 3 (P_{M3}) extraction. Following P application, soil P_{M3} increased significantly in the surface soil layer and in the 5–15 cm soil layer in both the sprout and production years. Phosphorus addition had no significant effect on the 15–30 cm soil layer. The $P/(Al+Fe)_{M3}$ molar ratio reached 10.7% in the soil surface with the highest P application rate. In the other soil layers, the molar ratio was below 3.10%. Under field conditions, P leaching was limited to the 5–15 cm soil layer but a P build-up occurred in the soil surface. Furthermore, the $P/(Al+Fe)_{M3}$ molar ratio that was measured in the surface soil layer was very close to the critical value (11.3%) beyond which there is a risk of surface water contamination.

Key words: *Vaccinium augustifolium* Ait., leaching, P accumulation, P molar ratio

Introduction

In the province of Québec, about 35 000 ha of land are devoted to growing wild lowbush blueberry (Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec 2016). Blueberry fields are managed on acidic, well-drained soils with low nutrient levels. These soils have a thin layer of organic matter overlying a sandy mineral horizon (Raymond et al. 1965). Wild blueberry is well adapted to these soil conditions (Hall 1978) and high crop productivity is attributable to effective weed control and adequate fertilization (Yarborough et al. 1986; Penney and McRae 2000).

According to crop management practices, fertilizers are applied in the spring of the sprout year; however, continuous phosphorus (P) applications can lead to soil P accumulation in the soil surface (0-15 cm) (Eaton et al. 1997; Eaton et al. 2009; Lafond and Ziadi 2013). In low soil pH conditions, P from fertilizers may not be available for plant utilization (Warman 1988) and consequently, P addition is required to replace soil P that is adsorbed or leached. Phosphate availability in acid sandy soils is controlled mainly by fast and slow reactions with oxalate-extractable Fe and Al (Lookman et al. 1995). To account for the important role of Al and Fe in the retention and release of soil P, Sims et al. (2002) proposed the $P/(Al+Fe)_{M3}$ molar ratio as an agri-environmental indicator that can be used to avoid excess P addition. In acidic, sandy, cranberry soils, an environmental threshold of 11.3% has been established for this molar ratio to prevent surface water contamination (Parent and Marchand 2006). A recent study indicated that soil P extracted with Mehlich 3 solution, considering soil Al and Fe contents extracted with Mehlich 3, could be a good indicator of the availability of soil P for blueberry production (Lafond and Ziadi 2013). An agronomic threshold of 2.8 % of the molar ratio $P/(Al+Fe)_{M3}$ was established and over this value, no significant response to P fertilizer is measured.

Since soil P accumulates on the soil surface, soil P is not necessarily determined for the entire soil profile in the most of the studies. A laboratory column (15 cm) experiment showed that no leaching of soil P occurred after 30 days of water addition (1000 mL) (House et al. 2004). Furthermore, addition of P solution did not affect the movement of P through the soil column. Phosphorus saturation at the top of the column increased but large additions of P would be required to saturate the entire soil profile and generate significant P leaching. In a field study conducted in Maine on many locations and soils (sandy loam or loam), it was predicted that soil P would migrated below the top 10-cm layer because there was a lack of P accumulation; but P was not measured under this soil layer (Ohno and Severy 2013). Thus, given the intensification of blueberry production, it is essential to gain a better understanding of the fate of P in these acidic soils to avoid over-fertilization and decrease the risks of leaching or loss through erosion. The objective of this study was to determine the effect of P fertilizer applications on soil P mobility under wild blueberry fields in eastern Canada.

Materials and methods

Soil characteristics are presented in Table 1. Soil pH varied between 4.3 and 4.7 for the 0–5 cm soil layer, whereas soil pH was slightly higher for the two others layers. Soil P_{M3} varied between 5 and 15 kg ha^{-1} in the soil surface. In the 5–15 cm soil layer, soil P_{M3} was low, between 11 and 53 kg ha^{-1}, and in the 15–30 cm soil layer, P_{M3} increased (36 to 160 kg ha^{-1}). Soil K, Ca and Mg contents were relatively low and decreased with depth. Soil Fe and Al contents were high in the soil surface with soil Fe decreasing and Al increasing in response to soil depth. The $P/(Al+Fe)_{M3}$ molar ratio was relatively low, and tended to decrease with soil depth. Soil organic matter content varied between 7.4 and 17.4 % on the soil surface and was below 33 g kg^{-1} for the 5–15 and 15–30 cm soil layers. These variations are associated with chemical soil properties of each site and crop management practices as burning (Raymond et al. 1965).

Soil P_{M3} increased significantly with P application rates for all sampling dates for the 0–5 and 5–15 cm soil layers. The largest increases occurred one month after fertilizer application (Figure 1). In comparison with the control, soil P_{M3} content increased significantly (by 4 to 12 kg ha^{-1}) with P application, which points to soil P accumulation in the 0–5 cm soil layer. Soil P_{M3} content in the control varied between 8.4 and 10.4 kg ha^{-1} for all sampling dates. Soil P_{M3} with P fertilizer addition decreased slightly after the second sampling date but remained significantly higher than in the control. These results confirm those of previous studies on fertilizer P response (Eaton et al. 1997; Eaton et al.

2009; Lafond and Ziadi 2013). In the 5–15 cm soil layer (Figure 1), soil P_{M3} increased significantly with P application, which is indicative of P leaching from the soils above. However, soil P_{M3} did not increase over time, indicating that leaching occurred rapidly after P application in May. These results confirm that P moved rapidly after fertilizer application, especially in connection with a high P rate as observed in a field study conducted in Maine (Ohno and Severy 2013). Thus, a significant amount of P moves below the root zone (Jeliazkova and Percival 2003) and is not available to the plant. However, P leaching was limited to the 5–15 cm soil layer. In fact, in the 15–30 soil layer (Figure 1), P application had no significant effect on soil P_{M3}. Unlike the case in the other soil layers, soil P_{M3} decreased over time, from 77 kg ha^{-1} initially to 47 kg ha^{-1}.

The $P/(Al+Fe)_{M3}$ molar ratio in the 0–5 cm soil layer was significantly influenced by P application. The molar ratio increased significantly after P application for all sampling dates (Figure 2). With the highest P rate, the molar ratio reached 10.7% one month after P application compared to 4.9% for the control. This high ratio could also be related to high carbon level in this soil layer (Table 1), which contributes to P sorption (Khiari and Parent 2005). In acidic sandy soils, Parent and Marchand (2006) previously proposed an environmental threshold of 11.3% for the molar ratio with the aim of preventing surface water contamination. In the present study, the molar ratio was close to this value. However, with the recommended P rate (about 30 kg P_2O_5 ha^{-1}), the molar ratio was below 7%, indicating relatively low P saturation. Continuous P application at the recommended rate at each crop production cycle could eventually cause soil P accumulation (Figure 1) and increase the risk of leaching. In fact, in the 5–15 cm soil layer, the molar ratio increased significantly with P rates at all sampling dates (Figure 2). On average, the molar ratio reached 2.70% for the highest P rate compared to 1.70% for the control. Even when the initial molar ratio was relatively low, the recommended P application rate had a significant effect on soil P saturation. Phosphorus application had no significant effect on the molar ratio in the 15–30 cm soil layer (Figure 2). The molar ratio decreased over time, from 3.36 % initially to 2.02% at the end of the experiment.

Results and discussion

Soil characteristics are presented in Table 1. Soil pH varied between 4.3 and 4.7 for the 0–5 cm soil layer, whereas soil pH was slightly higher for the two others layers. Soil P_{M3} varied between 5 and 15 kg ha^{-1} in the soil surface. In the 5–15 cm soil layer, soil P_{M3} was low, between 11 and 53 kg ha^{-1}, and in the 15–30 cm soil layer, P_{M3} increased (36 to 160 kg ha^{-1}). Soil K, Ca and Mg contents were relatively low and decreased with depth. Soil Fe and Al contents were high in the soil surface with soil Fe decreasing and Al increasing in response to soil depth. The $P/(Al+Fe)_{M3}$ molar ratio was relatively low, and tended to decrease with soil depth. Soil organic matter content varied between 7.4 and 17.4 % on the soil surface and was below 33 g kg^{-1} for the 5–15 and 15–30 cm soil layers. These variations are associated with chemical soil properties of each site and crop management practices as burning (Raymond et al. 1965).

Table 1 Site characteristics

Soil layer	pH_{water}	P[1]	K	Ca	Mg	Fe	Al	$P/(Al+Fe)_{M3}$ molar ratio	Organic matter
(cm)		kg ha^{-1}						%	g kg^{-1}
0–5	4.3–4.7	5–15	16–50	68–272	9–22	121–141	374–569	2.82–6.50	74–174
5–15	4.6–5.2	11–53	13–32	11–58	1–14	258–373	2471–2731	0.7–2.99	18–33
15–30	4.6–5.2	36–160	10–20	4–23	1–11	79–118	2453–2633	1.49–6.94	9–15

[1]Soil nutrients were extracted with Mehlich 3 solution.

Soil P_{M3} increased significantly with P application rates for all sampling dates for the 0–5 and 5–15 cm soil layers. The largest increases occurred one month after fertilizer application (Figure 1). In comparison with the control, soil P_{M3} content increased significantly (by 4 to 12 kg ha^{-1}) with P application, which points to soil P accumulation in the 0–5 soil layer. Soil P_{M3} content in the control varied between 8.4 and 10.4 kg ha^{-1} for all sampling dates. Soil P_{M3} with P fertilizer addition decreased slightly after the second sampling date but remained significantly higher than in the control. These results confirm those of previous studies on fertilizer P response (Eaton et al. 1997; Eaton et al. 2009; Lafond and Ziadi 2013). In the 5–15 cm soil layer (Figure 1), soil P_{M3} increased significantly with P application, which is indicative of P leaching from the soils above. However, soil P_{M3} did not increase over time, indicating that leaching occurred rapidly after P application in May. These results confirm that P moved rapidly after fertilizer application, especially in connection with a high P rate as observed in a field study conducted in Maine (Ohno and Severy 2013). Thus, a significant amount of P moves below the root zone (Jeliazkova and Percival 2003) and is not available to the plant. However, P leaching was limited to the 5–15 cm soil layer. In fact, in the 15–30 soil layer (Figure 1), P application had no significant effect on soil P_{M3}. Unlike the case in the other soil layers, soil P_{M3} decreased over time, from 77 kg ha^{-1} initially to 47 kg ha^{-1}.

The $P/(Al+Fe)_{M3}$ molar ratio in the 0–5 cm soil layer was significantly influenced by P application. The molar ratio increased significantly after P application for all sampling dates (Figure 2). With the highest P rate, the molar ratio reached 10.7% one month after P application compared to 4.9% for the control. This high ratio could also be related to high carbon level in this soil layer (Table 1), which contributes to P sorption (Khiari and Parent 2005). In acidic sandy soils, Parent and Marchand (2006) previously proposed an environmental threshold of 11.3% for the molar ratio with the aim of preventing surface water contamination. In the present study, the molar ratio was close to this value. However, with the recommended P rate (about 30 kg P_2O_5 ha^{-1}), the molar ratio was below 7%, indicating relatively low P saturation. Continuous P application at the recommended rate at each crop production cycle could eventually cause soil P accumulation (Figure 1) and increase the risk of leaching. In fact, in the 5–15 cm soil layer, the molar ratio increased significantly with P rates at all sampling dates (Figure 2). On average, the molar ratio reached 2.70% for the highest P rate compared to 1.70% for the control. Even when the initial molar ratio was relatively low, the recommended P application rate had a significant effect on soil P saturation. Phosphorus application had no significant effect on the molar ratio in the 15–30 cm soil layer (Figure 2). The molar ratio decreased over time, from 3.36 % initially to 2.02% at the end of the experiment.

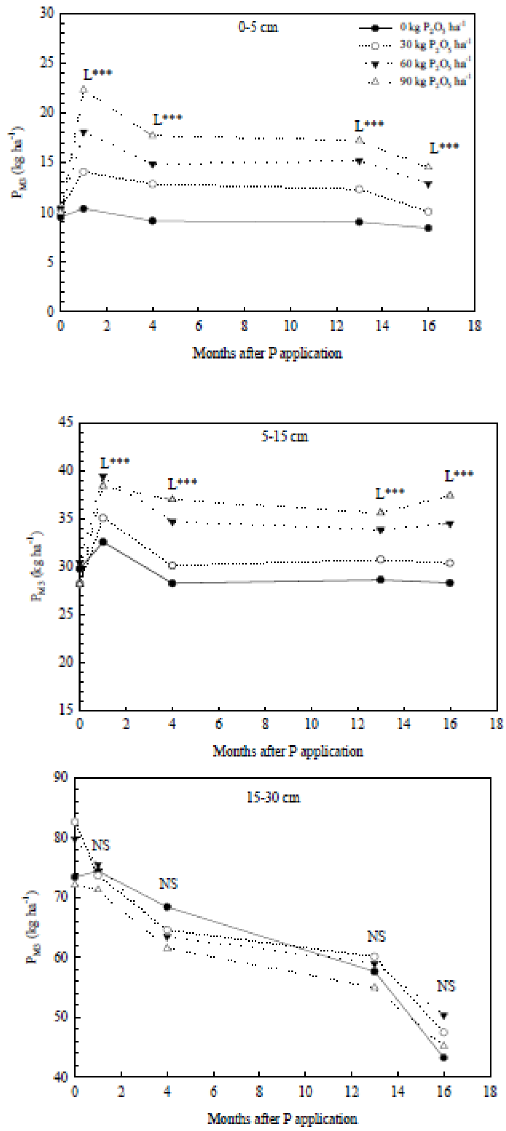

Figure 1. Effect of P application on soil P-Mehlich 3 (P_{M3}) over 16 months in three soil layers (average of the four sites).

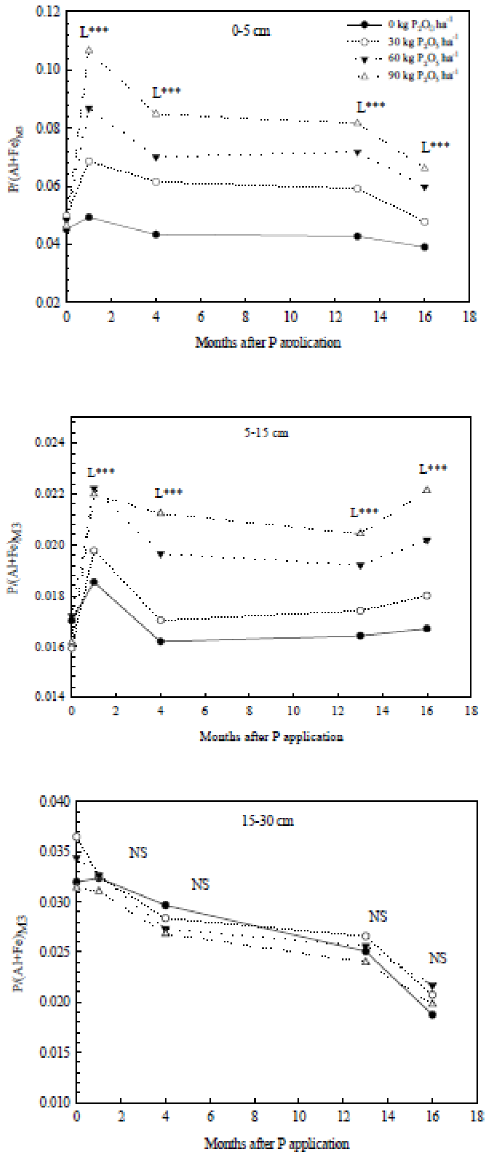

Figure 2. Effect of P application on soil $P/(Al+Fe)_{M3}$ molar ratio over 16 months in three soil layers (average of the four sites).

Conclusion

In acidic wild blueberry soils, P availability is limited. Despite the relatively low P content in the soil surface, the P sorption capacity of this soil layer is relatively low, increasing the risk of P leaching or loss through erosion. In fact, significant P accumulation was measured in the surface layer, and the $P/(Al+Fe)_{M3}$ molar ratio reached the critical environmental threshold. Phosphorus mobility was limited to the first 15 cm of the soil profile. However, the results also indicated that P can be found below the blueberry root zone, which would decrease P uptake capacity.

Previous work have established an agronomic $P/(Al+Fe)_{M3}$ molar ratio threshold of 2.8 % (Lafond and Ziadi 2013) and with the actual recommended P rate, this value can be exceeded but remains under environmental P threshold. Since wild blueberry P needs are low and P crop response is weak, P fertilizer application could be limited to once every second cropping cycle based on foliar analysis in order to ensure optimal P values. This fertilizer management could avoid over-fertilization and soil P accumulation, reduce the input cost and decrease the negative environmental impact of P addition.

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