Critical Phosphorus Concentration in Cool Season Forage Grasses

By Gilles Bélanger and Noura Ziadi

Improved methods for predicting fertilizer P requirements of field crops, including forage grasses, are required to minimize the risk of surface and groundwater contamination from excessive fertilization, while still applying sufficient P to optimize crop yield.

Because soil P tests are not always reliable predictors of fertilizer P requirements, the crop P status could be an alternative or a complement as an indicator of soil P availability.

Plant-based methods for quantifying the crop nutrition status, including P, depend on the definition of a critical concentration, that is, the minimum concentration of a given nutrient required to achieve maximum crop growth and yield. Crop P concentration decreases during growth as does N concentration, and it also decreases with decreasing N concentration associated with N deficiency (**Figure 1**). This strong dependence between crop P and N concentrations was confirmed for several field crops, including corn (Ziadi et al., 2007), wheat (Bélanger et al., 2015a), canola (Bélanger et al., 2015b), and forage grasses (Bélanger and Ziadi, 2008), and led to the development of models of critical P concentration (P_c) defined as a function of shoot N concentration.

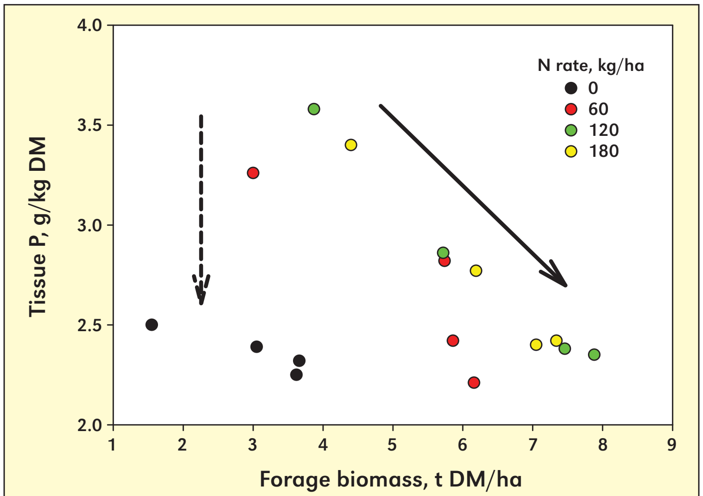

Figure 1. Example illustrating the decrease in P concentration during timothy spring growth (solid arrow) and the decrease due to a N deficiency (dash arrow). Drawn from data presented in Bélanger and Ziadi (2008).

Models of critical P concentration as a function of forage N concentration were first developed in France for perennial grasses and permanent pastures (Duru and Ducrocq, 1997), and later for timothy, the main forage grass species in eastern Canada and the Nordic countries (Bélanger and Ziadi, 2008). A model of critical P concentration [P_c; g/kg dry matter (DM)] as a function of N concentration (N; g/kg DM) was developed for timothy under conditions where P was assumed sufficient for growth (Bélanger and Ziadi, 2008):

$$P_c = 1.07 + 0.063N$$

Abbreviations and notes: N = nitrogen; P = phosphorus; P_c = critical P concentration; PNI = phosphorus nutrition index.

Experiment plots testing P fertilization for Timothy grass in 2011 at Lévis, Quebec.

A Multi-Site Experiment

Our initial research was based on timothy swards at one site in eastern Canada in situations of P sufficiency. Our model, however, had not been assessed in a wide range of crop P status, soils and climate conditions, and types of grassland swards. This led us to undertake a multi-site study to confirm our model of critical P concentration for both timothy and multi-species swards (Bélanger et al., 2017). An experiment with varying rates of P fertilization was conducted for two to five consecutive years at sites with timothy swards in Canada [Lévis (QC), Normandin (QC), and Charlottetown (PE)] and Finland [Maaninka], and at sites with multi-species swards from long-term P fertilization experiments in Switzerland [Les Verrières] and France [Ercé]. Dry matter yield, and forage N and P concentrations were measured on four dates with one-week intervals from the vegetative to late heading stages of development during spring growth. We then identified data points of forage P and N concentrations for which there was no further increase in shoot biomass with increasing P fertilizer rates; those data points characterized non-limiting P conditions.

At the four sites with timothy, the data of forage P and N concentrations under non-limiting P conditions were close to the values of critical P concentration predicted by our model initially developed for timothy (Bélanger and Ziadi, 2008; **Figure 2**). At the two sites with multi-species swards, however, the data of forage P and N concentrations under non-limiting P conditions were closer to the values of critical P concentration predicted by the model of Duru and Ducrocq (1997) than to those predicted by our model (Bélanger and Ziadi, 2008; **Figure 3**). Our results confirm the optimal relationship between forage P and N concentrations for timothy and multi-species

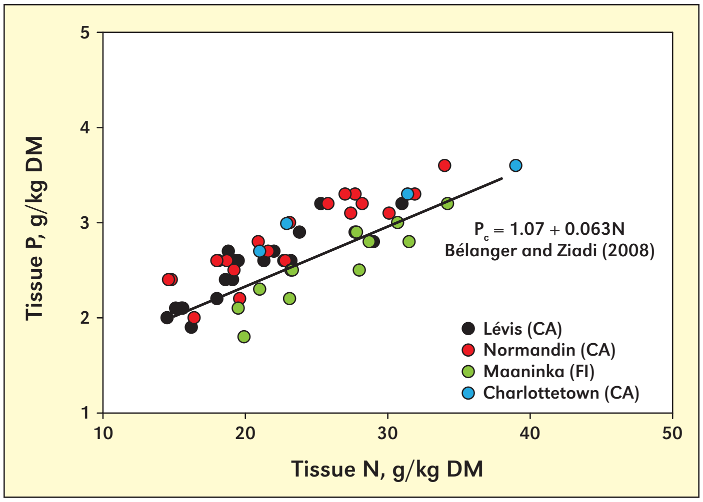

Figure 2. Forage P concentration as a function of N concentration during the spring growth of timothy grown under non-limiting P conditions at four sites along with the model of critical P concentration (P_c; line) of Bélanger and Ziadi (2008). Adapted from Bélanger et al. (2017).

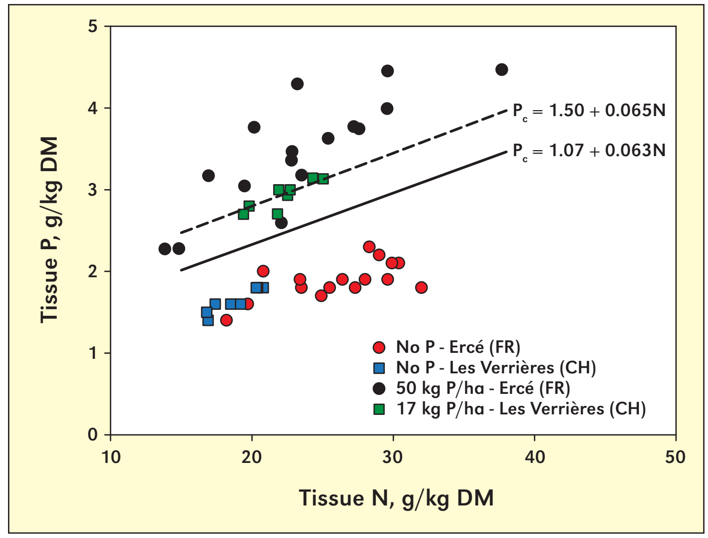

Figure 3. Forage P concentration as a function of N concentration during the spring growth of multi-species swards from long-term experiments under limiting (no applied P) and non-limiting P (highest P rate) conditions at two sites. Models of critical P concentration (P_c) are from Duru and Ducrocq (P_c = 1.50 + 0.065N; 1997) and Bélanger and Ziadi (P_c = 1.07 + 0.063; 2008). Adapted from Bélanger et al. (2017).

swards but with variations of the relationship between timothy and multi-species swards.

Limitations and Implications

Our research on forage grasses and other crops has indicated that the model of critical P concentration might not apply well in situations of severe N deficiencies or excesses (Bélanger and Ziadi, 2008; Bélanger et al., 2015a). However, producers applying adequate rates of N to optimize yield without severe N deficiencies or excesses could use our model with confidence. Establishing reliable models of P_c requires large data sets with sequential sampling during growth cycles and several P rates. In some cases [e.g., Ercé (FR)], luxury P consumption and a risk of overestimating P_c might occur if high P rates do not result in increased forage yield while increasing forage P concentration. Our timothy model for P_c was established for the spring growth and has not yet been validated for summer regrowth.

The critical P concentration is an essential tool for assessing the P status of forage grasses during the growing season and, indirectly, soil P availability. A P nutrition index (PNI) can be calculated as the ratio of tissue P concentration to P_c for a given situation. Values of PNI equal or greater than 1.0 indicate that the crop is in situation of P sufficiency, while values smaller than 1.0 indicate a P deficiency. This plant-based diagnostic method of P nutrition could be used for a predictive diagnostic aimed at adjusting P fertilization to the crop P needs during the growing season or for a post-harvest diagnostic aimed at detecting limiting factors for crops within experimental trials or fields in production. Because a P deficiency cannot be easily remedied with later applications in the same year, producers could use this tool to adjust P fertilization in the following growing seasons.

This plant-based approach of characterizing soil P availability could be an alternative or a complement to the more commonly used soil-based indicators for predicting fertilizer P requirements. In an effort to adapt this plant-based approach to field fertilization practices, we are currently investigating (i) the within-field spatial variability of the PNI in several fields in eastern Canada in order to determine the optimal number of sampling sites and (ii) the relationship between the response of forage grasses to P fertilization and both plant-based (PNI) and soil-based (soil test P) indicators of P availability. BC

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