Do phosphorus and nitrogen contents in young corn leaves represent contents in shoots?

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Abstract: For corn grown on two light-textured soils, leaf P and N concentrations at the six-leaf stage represented their respective concentrations in shoots. At the seven/eight-leaf stage, the P concentration was higher in leaves than in shoots. Biomass at the seven/eight-leaf stage is linked to the N to P ratio in leaves and shoots at the six-leaf stage.

Key words: development stage, phosphorus and nitrogen concentration, shoot, youngest fully developed leaf, Zea mays.

Sufficient phosphorus (P) content in corn (Zea mays L.) shoots from seeding to the six-leaf stage is essential for optimum yields at harvest (Barry and Miller 1989). However, evaluation of short-term P and nitrogen (N) availability in soils with unevenly distributed nutrients is complex and may require plant analyses. Previous studies linking P and N availability in soil to corn growth have focused on concentrations in shoots or in leaves (e.g., Mallarino 1996; Plénet and Lemaire 2000; Bélanger et al. 2011). Analyses of nutrient concentrations in the youngest fully developed leaf (YFDL) are more feasible than harvesting shoots to evaluate crop N (e.g., Chapman and Barreto 1997) and P status (e.g., Frydenvang et al. 2015). Previous studies relating leaf to shoot concentrations considered plants beyond the V8 to V10 development stage (e.g., Ziadi et al. 2009; Bélanger et al. 2011) and it remains unclear if P and N concentrations in the YFDL represent concentrations in shoots during earlier growth stages, where optimal nutrient availability is critical for obtaining maximal final yields. Our objectives were to test if (i) P concentration in the YFDL was related to that in the shoot during the early growth of corn and (ii) P and N concentration or N to P ratio in the YFDL and shoots could serve as indicators of subsequent shoot dry matter (DM) yield.

We sampled leaves and shoots of corn grown on two soils with a wide range of P uptake potentials, capitalizing on a previous experiment by Pedersen et al. (2017). Briefly, corn grew in pots in climate-controlled chambers. The soils were coarse sand (7% clay + silt) and sandy loam (20% clay + silt) with initial Olsen-P contents of 48 and 40 mg P kg$^{-1}$, respectively. The coarse sand classifies as Orthic Haplohumod and the sandy loam as Typic Hapludalf (USDA Soil Taxonomy System). Each pot had 6.9 kg dry soil with a bulk density of 1.3 g cm$^{-3}$. Soil water content was adjusted to 60% of field capacity before corn planting. The different P uptake potentials were established in the previous experiment by combinations of acidified cattle slurry [untreated slurry (pH6.5), moderately acidified slurry (pH5.5), or strongly acidified slurry (pH3.8)] and slurry application technique and treatments with and without mineral P (Na$_2$HPO$_4$). Each treatment had three replicates for each soil type. The number of pots totaled 99 of each soil type.
sufficient for harvest at three growth stages. The P application rate corresponded to 20 kg P ha\(^{-1}\) for all treatments. Each pot received NH\(_4\)-N and NO\(_3\)-N corresponding to 40 and 19 kg N ha\(^{-1}\), respectively, and sufficient rates of macro and micronutrients [potassium (K), sulfur (S), manganese (Mn), zinc (Zn), boron (B), copper (Cu), cobalt (Co), and molybdenum (Mo)].

Three corn seeds (Zea mays L. ’Adept’) were planted per pot. Non-germinated seeds were replanted with spare maize seedlings grown in separate pots. Climate conditions simulated late spring/early summer conditions, with a mean daily temperature of 15 °C with an amplitude from 11 °C to 19 °C during the first 10 d and then a mean temperature increase of 0.1 °C day\(^{-1}\). The relative mean air humidity was 75% and the photoperiod was 16 h, with light intensities ranging from 170 to 1060 μmol photons m\(^{-2}\) s\(^{-1}\). The pots were irrigated with demineralized water to a water content of 60% of field capacity during the first 35 d of growth and then to 70% until harvest.

Plant development was recorded 45, 60, and 75 d after planting and corresponded to the five (V5), six (V6), and seven/eight (V7+V8) leaf stage, respectively. The YFDL from each plant (in total three leaves per pot) were sampled when the leaf collar was fully visible. Subsequently, all three plants were cut 1 cm above the soil surface. The three leaves from each pot were pooled, as were the three whole plants from each pot. Leaves and shoots were oven-dried at 60 °C to a constant mass (min. 48 h) for determination of DM content. The dried plant samples were ball-milled prior to analysis.

Fig. 1. Relationship between P concentration in the youngest fully developed leaves (YFDL) and in shoots at the five-, six-, and seven/eight-leaf stage (V5, V6, and V7+V8, respectively) of corn grown on coarse sand and sandy loam. The dotted line indicates \(y = x\) while the solid line represents the linear regression across the development stages. Asterisks (*) indicate significant slopes and intercepts (\(p < 0.05\)).
The P concentration in plant tissues was determined by digesting 300 mg DM in 3 mL H₂O₂ (9.7 mol L⁻¹) and 6 mL HNO₃ (14.3 mol L⁻¹) using Teflon-coated vessels and a pressurized microwave oven (Anton Paar GmbH, Graz, Austria), with the P concentration in the diluted digest being determined by ICP-OES (Thermo Fisher Scientific, Waltham, MA). Plant tissue N concentration at V6 was determined with a PDZ Europa ANCA-GSL elemental analyser (Sercon Ltd., Cheshire, UK). The N and P concentrations are expressed on a DM basis.

The shoot biomass included the biomass removed in the corresponding YFDL. Statistical analyses were computed with the R-Project software package version 3.2.3 with data normality verified by Shapiro–Wilk statistics. We tested the relationship between P and N concentrations in leaves and in shoots, between N and P concentrations, and between N to P ratios and corn biomass by simple linear regression and Pearson’s correlation coefficient (r). Differences in the P concentration between the YFDL and the corresponding shoot at V7+V8 was examined by a paired t test. Significance was declared at the p ≤ 0.05 level of probability.

The P concentrations in the YFDL and shoots ranged from 1.4 to 6.8 and 1.2 to 6.9 g P kg⁻¹ DM, respectively. This interval represents concentrations well below and above the critical concentration of 3.4 g P kg⁻¹ DM reported by Mallarino (1996) for corn shoots at V5 to V6. The P concentrations in plant tissues decreased from V5 to V7+V8 (Fig. 1). This ascribes to increasing proportions of structural and storage tissues low in P (Grant et al. 2001).

For corn grown on coarse sand, the linear relationship between P concentration in the YFDL and in the shoot was significant at all three development stages. The relationship between P concentration in the YFDL and in the shoot at V5 and V6 was close to the y = x regression line (Fig. 1).

For corn grown on sandy loam, the linear relationship between P concentration in the YFDL in the shoot was also significant at V6 and close to the y = x regression line. The low degree of correspondence between P concentrations in the YFDL and the shoot at V5 on the sandy loam compared with the coarse sand (Fig. 1) suggests that soil properties other than P may affect the link between P uptake potentials and the distribution of P between the shoots and the YFDL. However, our experimental setup does not allow for identification of specific mechanisms.

At V7+V8, the average P concentration was 0.43 and 0.48 g kg⁻¹ DM higher in the YFDL than in the shoots on the coarse sand and the sandy loam, respectively (paired t test, p < 0.05). The higher P concentration in the YFDL compared with that in the shoot suggests P remobilization from senescing leaves to young leaves and may indicate a shift after V6 from uptake-dominated P supply to remobilization-dominated P supply, a process of particular importance in P-deficient plants (Veneklaas et al. 2012). For plants older than V6, P concentration in the YFDL can therefore remain adequate, even for corn restricted by P deficiency. Therefore using P concentration in the YFDL as a diagnosing tool after V6 may ignore growth limitations due to shortage of plant-available P.

A close relationship was also observed for N concentration in the shoots and YFDL on both soils at V6 (Fig. 2). The N concentration ranged from 18 to 44 g N kg⁻¹ DM, again representing N concentrations below and above the concentration (34 mg N kg⁻¹) that is considered critical for growth of corn plants younger than V9 (Plénet and Lemaire 2000).

We related P and N concentrations at V6 to the shoot biomass at V7+V8 to test if these nutrient concentrations at V6 could serve as an early-season indicator for subsequent biomass production. We found a significant relationship between the N to P ratio at V6 and DM yield recorded at V7+V8 (r = −0.44, p < 0.05 and r = −0.47, p < 0.05 in the shoot and YFDL, respectively). The N to P ratio in the shoots and leaves at V6 ranged from 9 to 23. Soil texture did not affect this relationship. The N and P concentrations in the six-leaf stage (V6) of corn grown on (a) coarse sand and (b) sandy loam. The dotted line indicates y = x while the solid line represents the linear regression for each soil type. Asterisks (*) indicate significant slopes and intercepts (p < 0.05).
concentrations were not significantly related to shoot biomass at V7+V8 except for a weak correlation to shoot N concentration ($r = -0.31$, $p < 0.05$). This underlines that not only the concentrations of individual nutrients but also the nutrient balance in plant tissues is important for early growth of corn. If the contents of N or P are limiting due to reduced uptake and not compensated for by redistributions within the plant, this is reflected in the N to P ratio (Veneklaas et al. 2012). The similar relationship between the N to P ratio in the shoots and YFDL at V6 and the subsequent DM yield of shoots at V7+V8 suggests that analyses of P and N concentrations in the YFDL at this growth stage may be of significant diagnostic value.

We found that the stage of plant development is decisive when P concentrations in the YFDL are used as a proxy of concentrations in shoots of young corn plants. Analyses of P and N concentration in the YFDL at V6 accurately reflected the status of these two elements in corn grown on light textured soils in a pot study. This may allow for improved nutrient management in subsequent corn crops, if validated in the field.

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