Interactive Effects of Nitrogen and Phosphorus Deficiency on Photosynthesis and Leaf Growth in Maize.

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Problem / Question

Nitrogen (N) and phosphorus (P) are often limiting in agricultural systems and must be augmented through fertilization. Simulation models that can account for N and P limitations are important tools for assessing the impact of nutrient limitations on crop yield. Both P and N affect photosynthesis and carbon assimilation but differ in their mechanism. A study was conducted to using outdoor sunlit growth chambers to evaluate the interactive effects of Nitrogen (N) and Phosphorus (P) on corn growth, development, chlorophyll content, and canopy photosynthesis. We evaluated quantitative effects on P and N on leaf addition rate, canopy and leaf photosynthesis, carbon assimilation and biomass partitioning to stem and leaf. The goal is to modify or develop new algorithms for the maize model MAIZSIM (Kim et al., 2012) to simulate the effects of P deficiency. Based on the study results, P and N appear to affect growth mainly through its effect on photosynthesis and carbon assimilation.

Objectives

- The objectives of this study are to
  - Quantify the interactive effects of N and P on maize leaf growth and photosynthesis
  - Develop approaches to model N and P effects

Growth (SPAR) Chamber Experiments

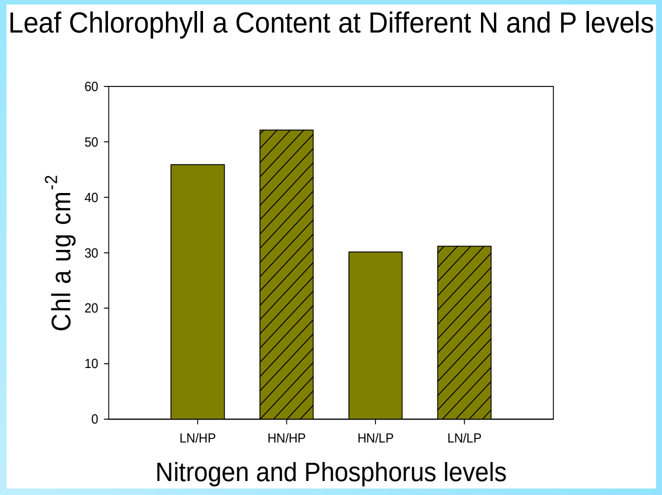
- Com plants were grown in 12 outdoor, sunlit Soil Plant Atmosphere Research (SPAR) chambers with soilbins.
- 45 plants were germinated June 6, 2010 to allow for 4 destructive harvests
- Nutrient treatments were applied as a factorial (12 treatments):
  - four levels of phosphorus i.e., 0, 0.01, 0.05 and 0.2 umol l^{-1}
  - three levels of nitrogen 2.0, 5.0 and 12.0 mmol l^{-1}
- Plants were fertigated three times a day for three minutes each @ 4 1 per minute through an automated fertigation system.
- The maize plants were grown at constant 400 mmol CO_2 $mole^{-1}$ and 28/18 °C day/night temperatures.
- Canopy photosynthesis, dark respiration, and transpiration were measured at every 5 minutes throughout crop growth period automatically using computer controlled instrumentation.
- Leaf level response and A/ci curves were measured with Li-Cor 6400 photosynthesis system. Additional plants were grown outdoors in pots to allow for destructive leaf measurements.
- Chlorophyll content was measured on leaf samples in the lab
- Destructive measurements were taken four times by harvesting the six to nine plants while maintaining the uniform spacing at the end of each harvest.
- Leaf area was measured on destructively sampled leaves.
- Non-destructive measurements of leaf number and length were taken on tagged plants 3 times a week.
- Total leaf nitrogen was measured using combustion analysis.
- Total leaf phosphorus was measured spectrophotometrically on digested tissue.

Results

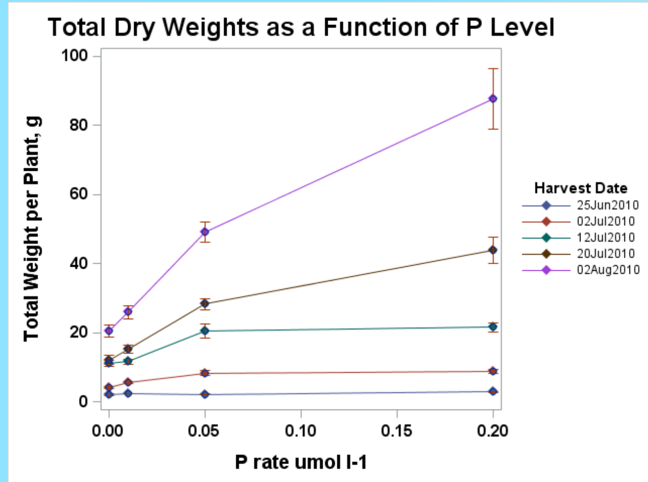
Equipment used to deliver nutrients. Each chamber had its own tank

Corn was also planted in pots for sampling phosphorus and taking leaf photosynthesis and measurements

View of corn in growth chambers with curtains to simulate row effects

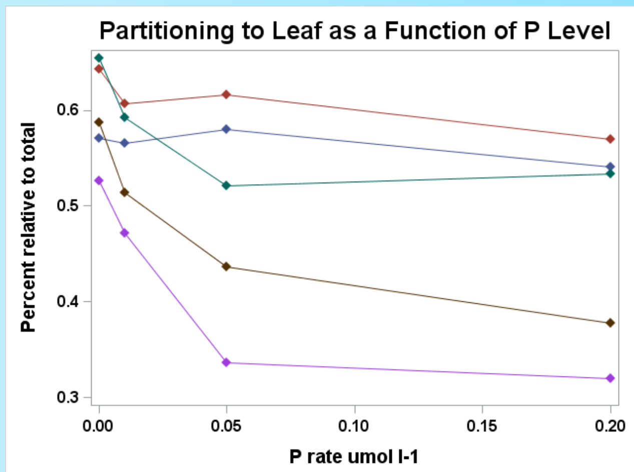


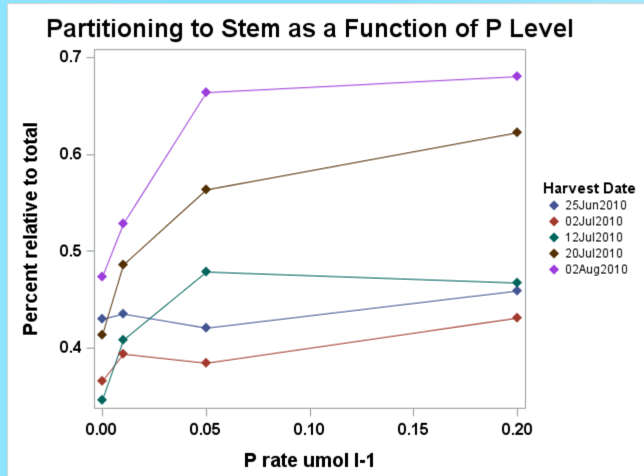
P appeared to have a larger effect on leaf chlorophyll a than did N. We did find that the N content of plant tissue (mg/g) increased as P level decreased (data not shown). This could have offset some effects of N deficiency at low P levels.



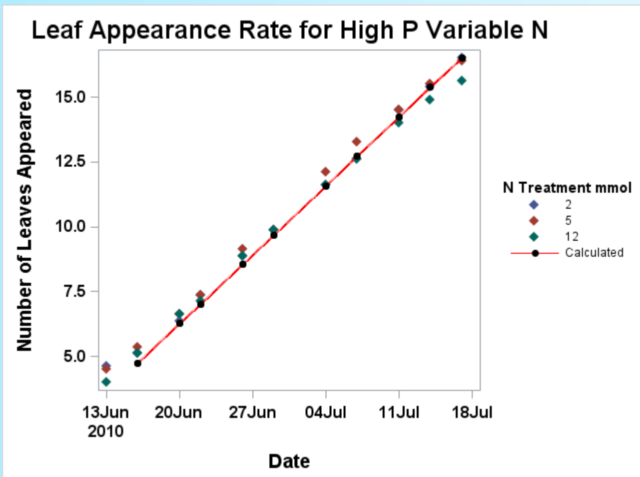
The effect of P on biomass accumulation increased as the plant became bigger. There was little effect early in the growth period because seed reserves

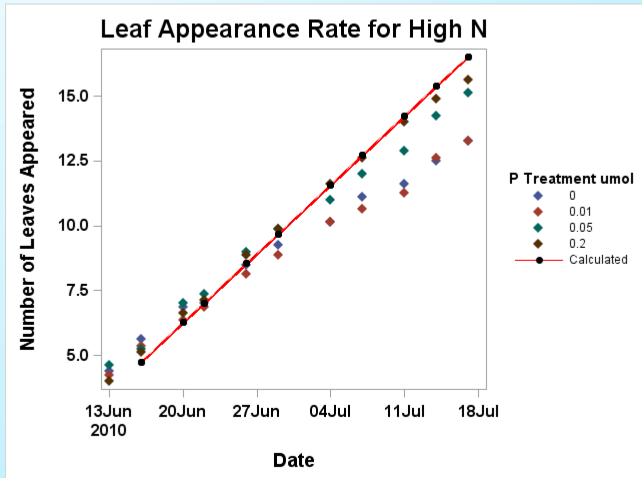
Corn plants before final harvest with 8 plants per chamber. P content increases from left to right. Plants were harvested before ear development was complete.

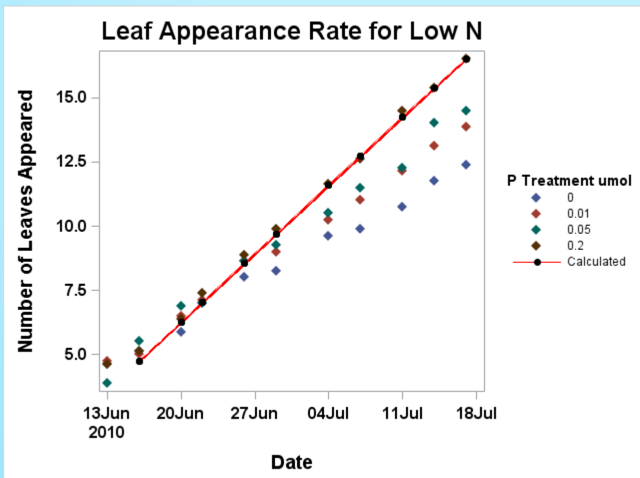


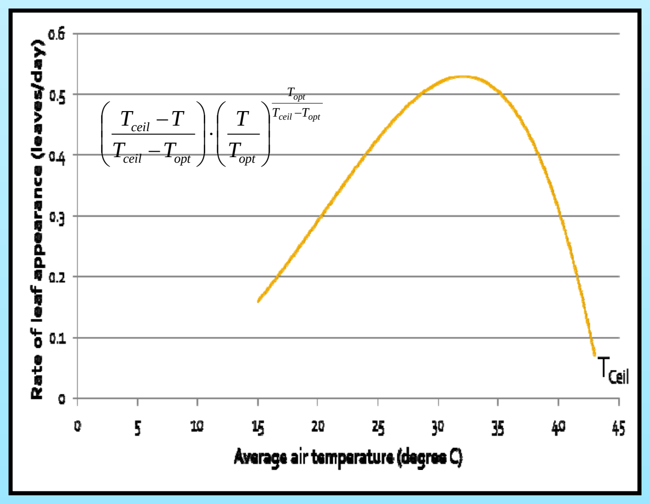


- At the first two samplings there was little effect of P on carbon partitioning to the leaf and stem. As the plant grew, more carbon was partitioned to the leaves and less to the stem at low P levels. The low P plants generally had more narrow, spindly stems.

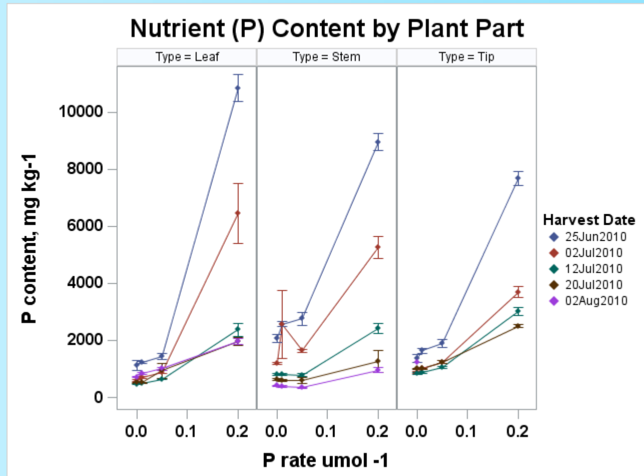








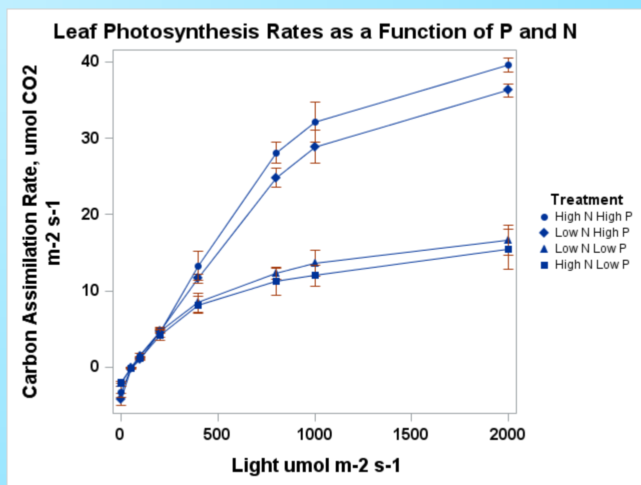
Leaf appearance was calculated using a modified Beta function with parameters derived from previous SPAR research and the literature (figure lower right). The effect of N limitation was not as strong as the effect of P. Increasing P deficit resulted in fewer overall leaves and a slower appearance rate. The lowest N rate may have been too high.

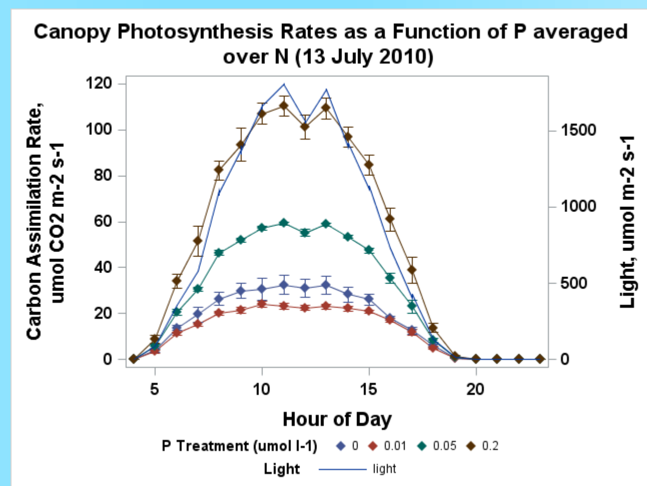


P concentration was highest in the high rate treatments and it decreased as the plant aged in all cases.

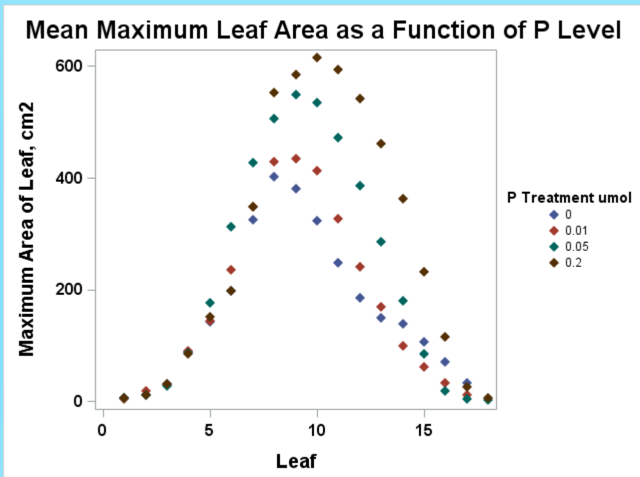
There were no tips at the last harvest as all leaves fully emerged.

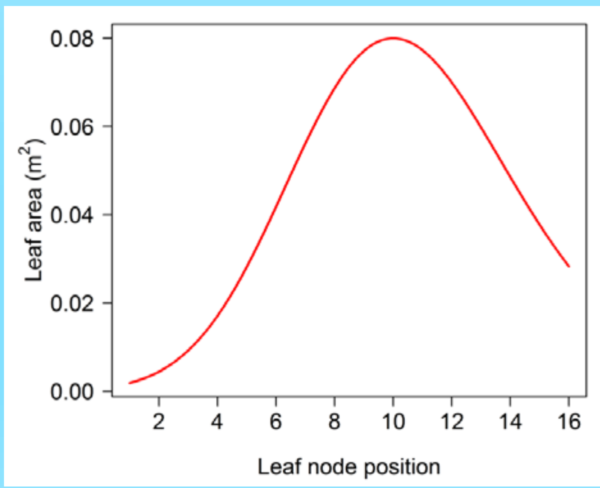
Total P as a function of biomass has a dilution curve similar to N (data not shown)





- As in the other variables, the effect of P dominates leaf photosynthesis rate. The LAI in the chambers ranged from 2.9 to 5.3 (35 days after emergence) so the effect of canopy closure on the canopy rates is small. Photosynthesis in the low P treatments did not reach their maximum potential rates under high light levels.





The maximum leaf size was also reduced at low P rates. Leaves did not reach their potential size and senesced more rapidly. The idealized relationship between maximum area of the leaf and node position for healthy plants (Stewart and Dwyer, 1994) is used to scale leaf size in MAIZSIM and many other models. The effect of P (and N) on leaf expansion will have to be accounted for on this level.

Conclusion

- Phosphorus effects on growth and photosynthesis were larger than those for nitrogen in this study. Nitrogen deficiency effects were strongest in the high P treatment. The relative nitrogen content increased as P application decreased. This could possibly offset some of the effects of low N application at lower P applications.
- It appears that the primary impact of P deficit on growth and development was through its affects on carbon assimilation. Thus for modeling purposes, the equations for photosynthesis will be modified. We have found that P deficit reduces the calculated values of V_{cMax} (maximum rate of Rubisco carboxylation) and J_{max} (maximum electron transport rate) in the Farquhar photosynthetic equations for potato (a C_3 plant).
- The effects on leaf appearance rate also need to be accounted for, possibly based on carbon assimilation rate and potential demand of carbon for leaf expansion.
- P and N stress effects on partitioning of carbon among different organs may be related to the need for the plant to increase leaf expansion over stem growth to maximize light interception

Kim, S-K, Y. Yang, D.J. Timlin, D. Fleisher, A. Dathe, V.R. Reddy. Modeling Nonlinear Temperature Responses of Leaf Growth, Development, and Biomass in MAIZSIM. Agron. J. 104:1523-1537. 2012

Stewart, D.W., and L.M. Dwyer. Can. J. A model of expansion and senescence of individual leaves of field-grown maize (*Zea mays* L.). Can. J. Plant Sci.74:37. 1994