Climate and Soil Nitrogen Effects on Maize-Velvetleaf Competition Analyzed through an Individual Based Model

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Introduction

The impacts of soil nitrogen (N) status on competition between rainfed maize and weeds is difficult to discern in the field, given year-to-year climatic variability and the dynamic and multiple interactions that may arise among soil N, soil water, and weather, and maize and weed growth. When weeds are present, the plant community may develop leaf area faster than crop monocultures and several hierarchies of plants may be formed. The position of each individual plant within these hierarchies depends on the spatial arrangement of the plants, the initial sizes, and the availability of resources as determined by management, soil properties, weather, and competition. Together, these factors establish a highly dynamic system with nonlinear responses to the availability of resources (e.g. soil nitrogen and water) that is reflected in high levels of site and regional variability in crop yield losses due to weed interference.

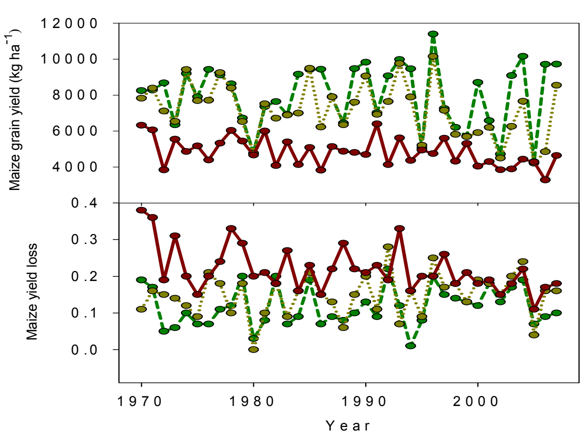
Materials and methods

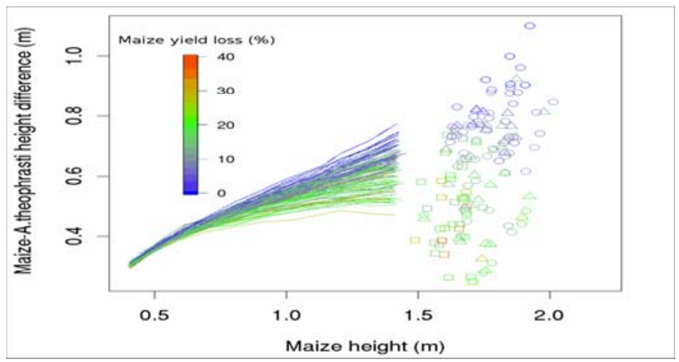
We developed a spatially-explicit, individual based model of plant competition to evaluate dynamic outcomes of crop-weed interactions. The model simulates the growth of individual plants using the light interception algorithms of the forest model MAESTRA, and estimates photosynthesis, respiration, and growth using algorithms from the crop model GECROS. Photosynthate allocation, root growth and plant architecture was calculated using allometry, including a novel approach to estimate profile water uptake by scaling the root zone of influence (volume of soil exploited by each individual plant) to plant biomass. The model includes a detailed representation of soil processes (PNM), including organic matter mineralization, heat flux, water transport, and N losses through denitrification and leaching. To test model performance, additive field experiments were established in Ithaca, NY (42°27'N, 76°27'W) with maize in monoculture (MZ) and in combination with high-density stands of a common annual weed species (*A. theophrasti* M.) emerging simultaneous with maize.

Results

The model simulated the growth of individual plants and reflected competition for light, water, and soil nitrogen. The results of our simulations confirm that even for the simple case of crop competition with a single weed species at a uniform density, yield loss can vary markedly from year-to-year when fertilizer management is constant. Low nitrogen (LN) fertilizer rates were associated with higher average relative yield losses (22%) compared to high nitrogen (HN) rates (12%) (Figure 1). However, yield losses were unaffected by N level in many years whereas in other cases the differences were substantial (e.g. 10% vs. 35% for HN and LN, respectively).

Figure 1. Interannual variability of weed free maize grain yield and relative *A. threophrasti*-induced yield losses ([weed free yield - yield with weeds] /weed free yield) at high (352 kg ha^{-1}) (- - -), medium (203 kg ha^{-1}) (···), and low (88 kg ha^{-1}) (—) soil nitrogen.





When the climate-defined yield potential for maize was low (i.e. 'weed-free maize grain yield'), there was very little difference in yield losses from weed competition across N levels. As the yield potential of the system increased, the divergence between relative yield losses under low (LN) and high (HN) nitrogen also increased. In contrast, there was little difference between the medium (MN) and high (HN) treatments as a function of yield potential (Figure 2).

Figure 2. The difference in relative yield loss at low (LN) or medium (MN) compared to high soil nitrogen (HN) levels as a function of weed-free maize yield at LN and MN respectively.

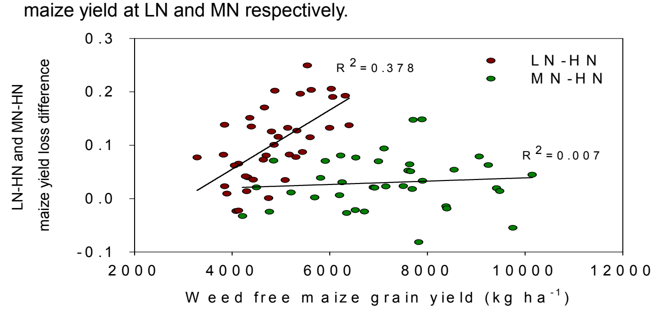


Figure 3. Difference in the average height of maize and the average height of *A. theophrasti* plants as a function of maize height during the mid-vegetative growth stage (lines) and at maize anthesis (symbols) for different years and soil nitrogen treatments (n=138). Line and symbol colors correspond to degree of yield loss as indicated by the color bar. HN (○), MN (Δ), LN (□) stand for high, medium and low soil nitrogen fertilization levels.

Our simulations demonstrate that the direct and indirect effects of growing-season weather can be substantial, independent of other considerations such as species composition, plant densities and time of emergence. The model proved extremely sensitivity to initial conditions as the result of nonlinearities between early plant size, capacity to capture resource in competition, and subsequent plant growth (e.g. 'size asymmetric competition') (Figure 3). As such, other potential drivers of competition must be understood in the context of early-season hierarchy formation.

Conclusions

- Model simulations agree with results from field experiments with respect to biomass accumulation, plant heights, light interception and water use.
- Results indicate that there is considerable year-to-year variability in weed-induced maize yield losses at all levels of N additions.
- Maize yield loss induced by velvetleaf competition is frequently greater under low compared to high soil N additions, but this depends on weather. As climate factors elevate maize yield potential, with only low N additions relative yield losses due to weeds generally increase.
- These trends would be difficult to discern through field experiments alone, as this study indicates that weed competitiveness is highly dynamic, and dependent on climate, as well as interactions between weather and soil N.