Interactive Effects of CO_2 and Warming on Cereal Leaf Beetle Dynamics and Winter Wheat Yield in the Pacific Northwest USA

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Introduction

Cropping system models used as a decision support tool to predict crop growth and yield under different soil, climate and management scenarios, are most often limited by a lack of incorporated constraints from pests, diseases and weeds). Coupling cropping system models with non-linear temperature-dependent process based pest phenology modules (direct effect) and $C0_2$ driven feeding rates (indirect effect) can help explain the gap between potential and actual yield and evaluate global warming scenarios. Here we present results for winter wheat obtained by a version of the CropSyst model (Stöckle et al., 1994) that incorporates population dynamics and daily feeding injury to the crop caused by cereal leaf beetle (CLB), *Oulema melanopus* (L.) (Coleoptera: Chrysomelidae).

CLB as Pest of Winter Wheat: The CLB (Fig. 1), a native of Eurasia, is often a devastative foliage feeder pest of wheat in North America (Haynes and Gage 1981), especially in the PNW (Buntin et al., 2004). One larva per stem causes 5.9% -12.65% yield loss (Buntin et al., 2004). Established economic threshold levels (ETL) for CLB on wheat in the PNW region is 3 eggs or larvae per tiller before the boot stage and one larva per flag leaf after the boot stage (Roberts & Walenta, 2012). Although ETL and phenological models have been developed for CLB (Ruesink, 1972), attempt to incorporate CLB phenology, feeding behavior and crop growth into coupled, predictive models (Boote et al., 1983). Such models can help anticipate responses of the system to changing climatic conditions.

Objectives

1.Develop and parameterize a phenology and feeding dynamics model for CLB on winter wheat and couple the output to CropSyst.
2. Investigate the interaction of indirect effects of CO_2 and direct effects of warming on cereal leaf beetle dynamics and winter wheat biomass at below or above ETL of CLB infestation for select locations in Washington State.

Methods

Weather: Data for 2004-2005 at Pullman (high rainfall, >20 inches per year) and Lind (low rainfall, 9-14 inches/year) in Washington were taken from Agweathernet (http://weather.wsu.edu/awn.php). A Single-Sine approach was used to calculate cumulative degree days using a base temperature for CLB of 9 ºC (48.2 ºF).

CLB Phenology: Model was parameterized with non-linear temperature dependent direct effects on daily reproduction, development and mortality rates for CLB larva estimated from published research (Guppy & Harcourt, 1978). Corresponding temperature dependent feeding rates for different larval instars of CLB was estimated using data from feeding bioassay experiments in our lab. Specifically, leaves from plants grown at ambient [400 ppm] and elevated [950 ppm] CO_2 were fed to larval instars reared at 22, 25, 28 and 31˚ C to capture the direct effect of temperature on CLB phenology and indirect effect of on feeding behavior. Leaves were replaced daily, followed by recording of fed leaf area (sq. mm) and larval molting. A second order exponential polynomial was fit to daily leaf area fed, to estimate instar specific feeding rates for each level of CO_2. R 3.1 freeware was used to estimate parameters. ANOVA on defoliation data was performed with SAS 9.2.

Winter Wheat Biomass : We simulate and compare the wheat biomass for two study locations, at temperatures set to +1, +2, and + 3 ºC above baseline for both ambient and elevated level of CO_2 and at varying initial spring female adult densities of 20,30, 40 and 50 per sq. meter field. Biomass loss is computed relative to the biomass for same year without infestation at corresponding temperature and CO_2 level (i.e., reference scenario).

Figure 1: Study Site, CLB Adult and Larva, and Skeletonized Leaf in the Wheat Field

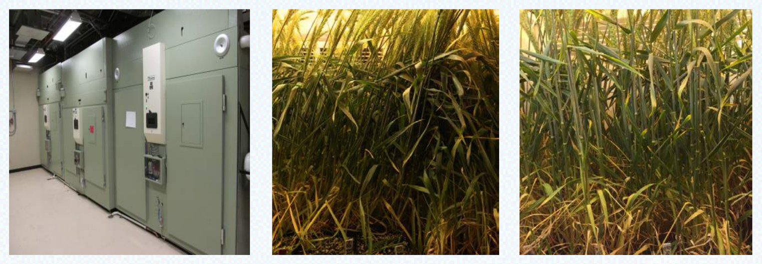
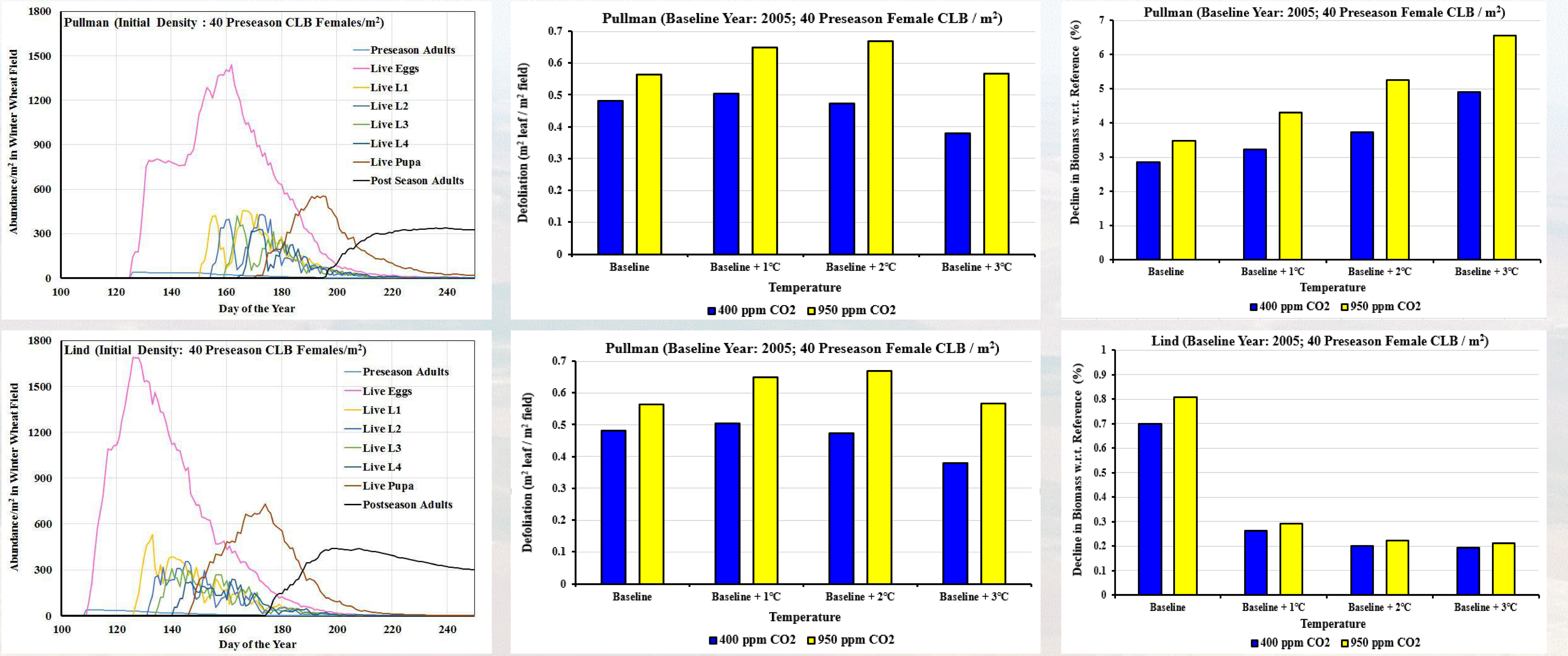


Figure 2: Pictograph of Feeding Bioassay Experiment

Upper Panel: Different steps in bioassay of CLB larva and the environmental chamber used.
Lower Panel: Plant growth chamber facility at WSU with 400 and 950 ppm CO_2 chambers.

Results: Simulated CLB Phenology, Defoliation, and Reduction in Biomass w.r.t. Baseline



Defoliation and a relative biomass loss increased linearly with CLB density at both the Lind and Pullman locations. Relative effects are the same for a range of CLB densities considered in this study (no beetle density x treatment interactions). All results are so shown for a preseason CLB density of 40 /m², that is consistent with what is observed (50:50 sex ratio) in a field at Nine Mile Falls, Spokane, Washington.

Defoliation trends were also similar at both locations, when the effects of temperature and CO_2 were considered. Simulation results suggest that defoliation increased with increasing temperatures and declined after a threshold temperature at both ambient and elevated CO_2 levels. Defoliation also increased at elevated than ambient CO_2 levels.

Responses to temperature and CO2 for reductions in biomass were similar to that observed for defoliation at Pullman, but not for Lind. At Lind, reduction in biomass relative to reference scenario declined with temperature, but increased with CO_2.

Mixed effect modeling supported the simulation results and revealed a 3 way interactive effect of CLB larval instars, CO_2 and temperature on defoliation ($F_{9,1244} = 0.39$; $p<0.0001$). In general, third and fourth instars fed more than the early larval instars.

Implications: In this example, the responses of wheat-pest complex to the same climate change scenarios at two locations approximately 100km apart were different in terms of implications for biomass accumulation and yield. The result illustrates the potential of coupled process-based models for anticipating production system responses to climate change.

Limitations & Future Work:

- The coupled model simulation considered direct effect of temperature on phenology and indirect effect of CO_2 on feeding response of CLB , but ignored the plant responses to elevated CO_2. Future work will account for this, but the observed patterns in results are expected to stay the same.
- Seasonally varying overwinter survival of CLB is completed, and future work will evaluate its implications.
- The model could be augmented with variable seasonal effects of the larval parasitoid, *Tetrastichus julis* (Walker).
- The model can now be extended to generate projections across the REACCH study region using gridded daily historical weather data and projections based on emission scenario (Abatzoglou 2013).

Selected References:

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