Economic Effects of Extreme Heat on Rice Yield and Milling Quality in Arkansas

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Introduction

Current climate change models project mean global temperature increases between 1.8 °C and 4 °C by 2100,[1] threatening roughly one billion people who depend on rice cultivation as their primary income source, and the food security of roughly 3.5 billion people.[2] Past analyses of extreme heat effects on rice production have focused on paddy yield,[3,4] and have not accounted for the detrimental impact of extreme heat on milling quality outcomes which ultimately determine edible (marketable) rice yield. Therefore, existing estimates[3,4] of the implications of future increases in mean growing season temperature likely understate true economic and food security implications.

Objectives

I. To model impact of extreme heat on
1. Paddy (rough) rice yield (kg·ha^{-1}); and,
2. Milling quality elements:
   a. Milled rice yield (MRY, %);
   b. Head rice yield (HRY, %); and,
   c. Chalk content (CHALK, %).

II. To estimate changes producer and miller revenue per hectare given results from (I).

III. To accomplish (I) and (II) in such a way that accounts for unique genotypic responses to extreme heat.

Methods

Paddy Yield

OLS fixed-effects multiple regression is used to estimate paddy yield:

(1) $Y_{isj}^{p} = \boldsymbol{aW}_{isj} + \boldsymbol{b}_s + \boldsymbol{c}_j + \varepsilon_{isj}$,

where, Y_{isj}^{p} is the natural logarithm of yield; $\mathbf{W}_{isj}$ is a vector of growth window specific explanatory variables including mean daily temperature and solar radiation, extreme heat exposure variables (defined below); $\mathbf{b}_s$ is a vector of station intercepts; $\mathbf{c}_j$ is a vector of varietal intercepts; and ε_{isj} is the error term.

Milling Quality

Generalized method of moments (GMM) is used to estimate the following milling quality system for each variety:

(2) $Y_{is}^{C} = \boldsymbol{\alpha}^{C}\boldsymbol{X}_{is} + \boldsymbol{b_s} + u_{is}^{C}$,
(3) $Y_{is}^{H} = \boldsymbol{\alpha}^{H}\boldsymbol{X}_{is} + \gamma^{H} Y_{is}^{C} + \beta_{21}^{H} HMC_{is} + \beta_{22}^{H} HMC_{is}^{2} + \boldsymbol{b_s} + u_{is}^{H}$, and
(4) $Y_{is}^{M} = \boldsymbol{\alpha}^{M}\boldsymbol{X}_{is} + \beta_{31}^{M} HMC_{is} + \boldsymbol{b_s} + u_{is}^{M}$,

where, $\mathbf{X}_{is}$ is a vector of extreme heat exposure variables corresponding to the grain filling stages at which extreme heat affects milling quality outcomes; HMC_{is} is harvest moisture content (%) which affects milling quality independently of temperature; and $\mathbf{b}_s$ is a vector of station intercepts.

We define total (day and night) extreme heat exposure (TDN) during growth window k ($W_k \; \forall \; k = 1, 2, 3$) as:

$$TDN_{W_k} = \left[\sum_{D \in W_k} \sum_{t \in D} T(t) - 33\right] + \left[\sum_{N \in W_k} \sum_{t \in N} T(t) - 22\right]$$

D = {t | T(t) > 33, sunrise < t < sunset }
N = {t | T(t) > 22, sunrise > t > sunrise }

This measure approximates the sum of the red and orange areas shown in Figure 1.

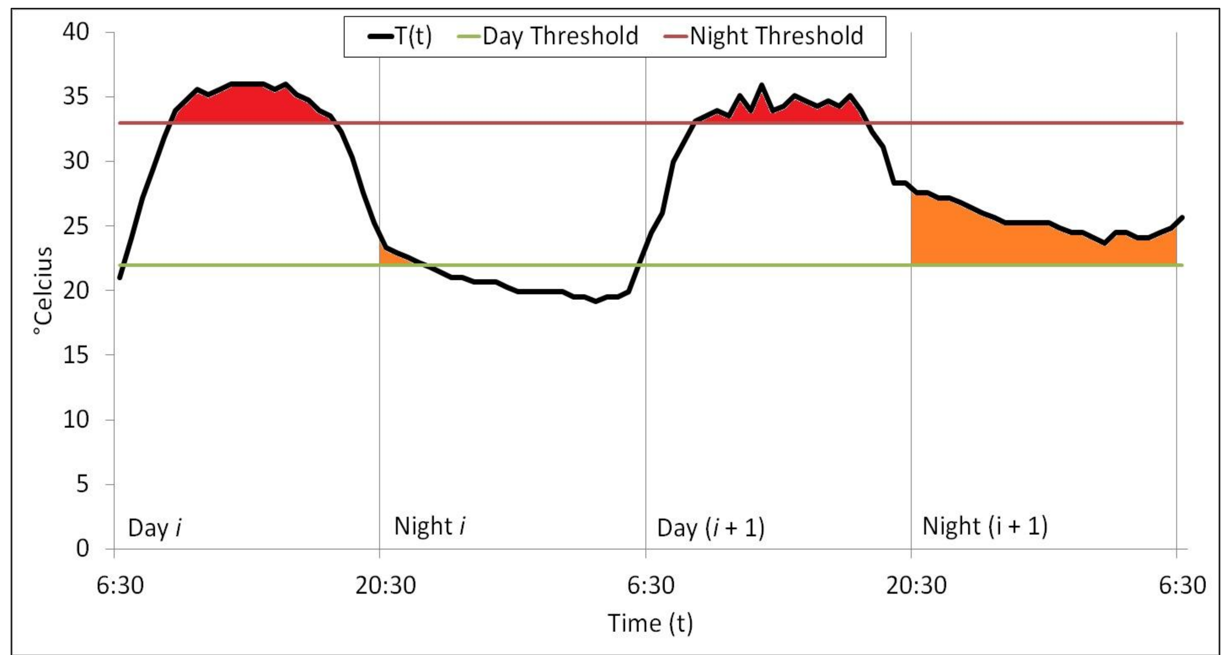


Figure 1: Extreme heat accumulation variable description.

Results & Discussion

Paddy Yield

Estimated effects of extreme heat on paddy yield are negative and statistically significant at the vegetative and early reproductive stages.

Figure 2 | Extreme temperature effects on paddy rice yield.

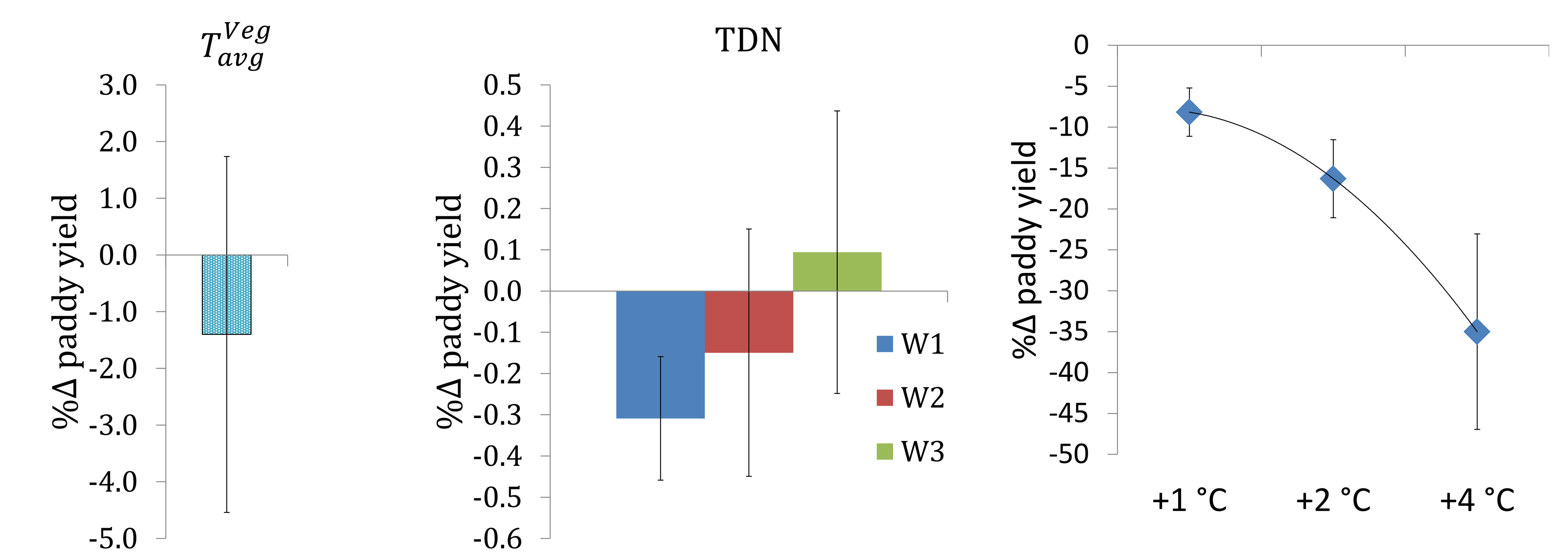


Figure 2 illustrates the nonlinear effect of extreme heat on paddy yield. These results are consistent with past analyses of paddy yield[3,4] and provide a baseline for determination of milling quality effects on mass milled rice per unit area depicted below. Extreme heat has a clear, negative effect on the quantity of edible, milled rice and distribution of quality given increased temperatures. The approach followed in this study provides a template for future analyses of the economic impacts of climate change on rice production.

Milling Quality

Figure 3 | Nonlinear response of mean milled rice outcomes given 1, 2, and 4 °C increases in mean growing season temperature, by genotype

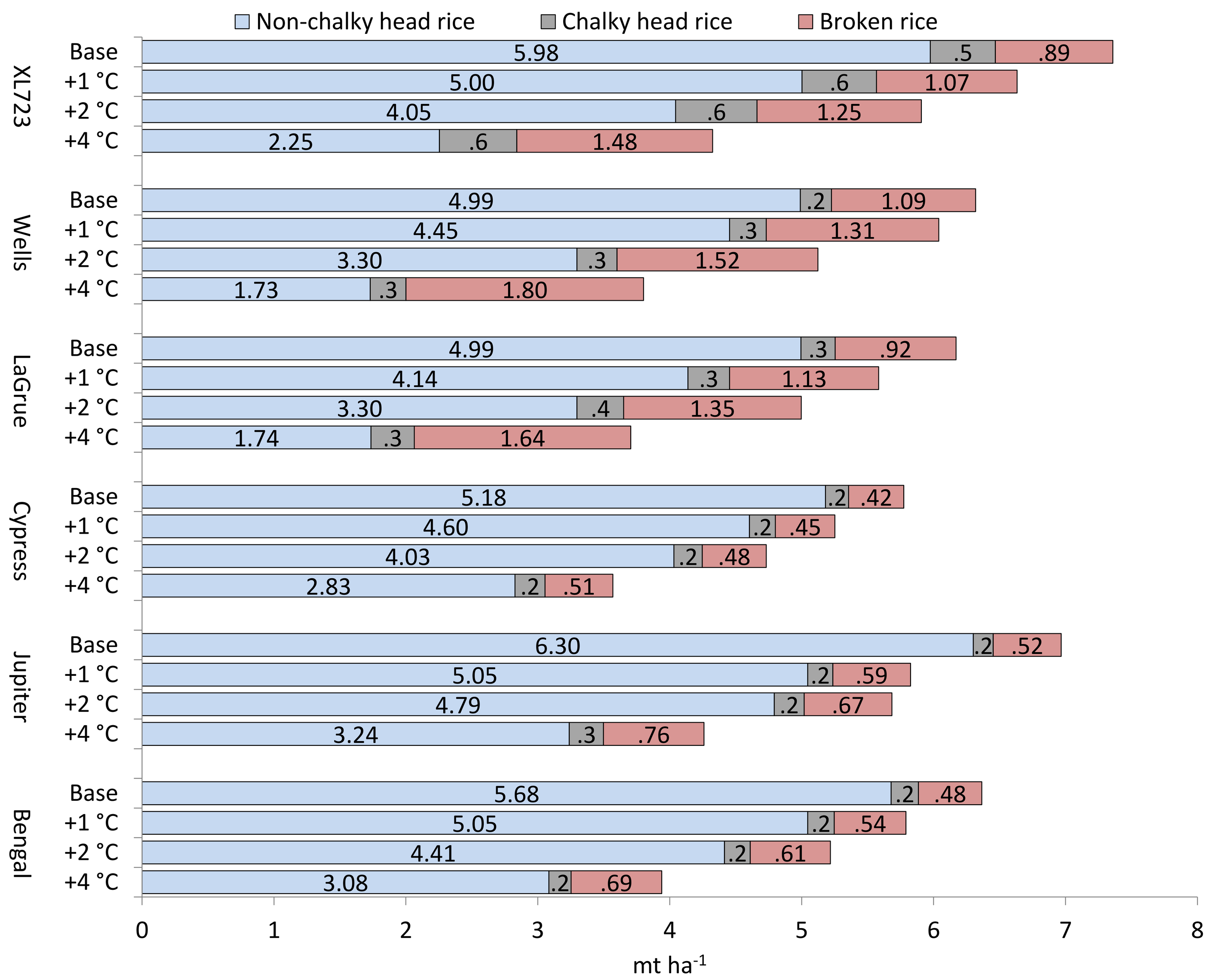
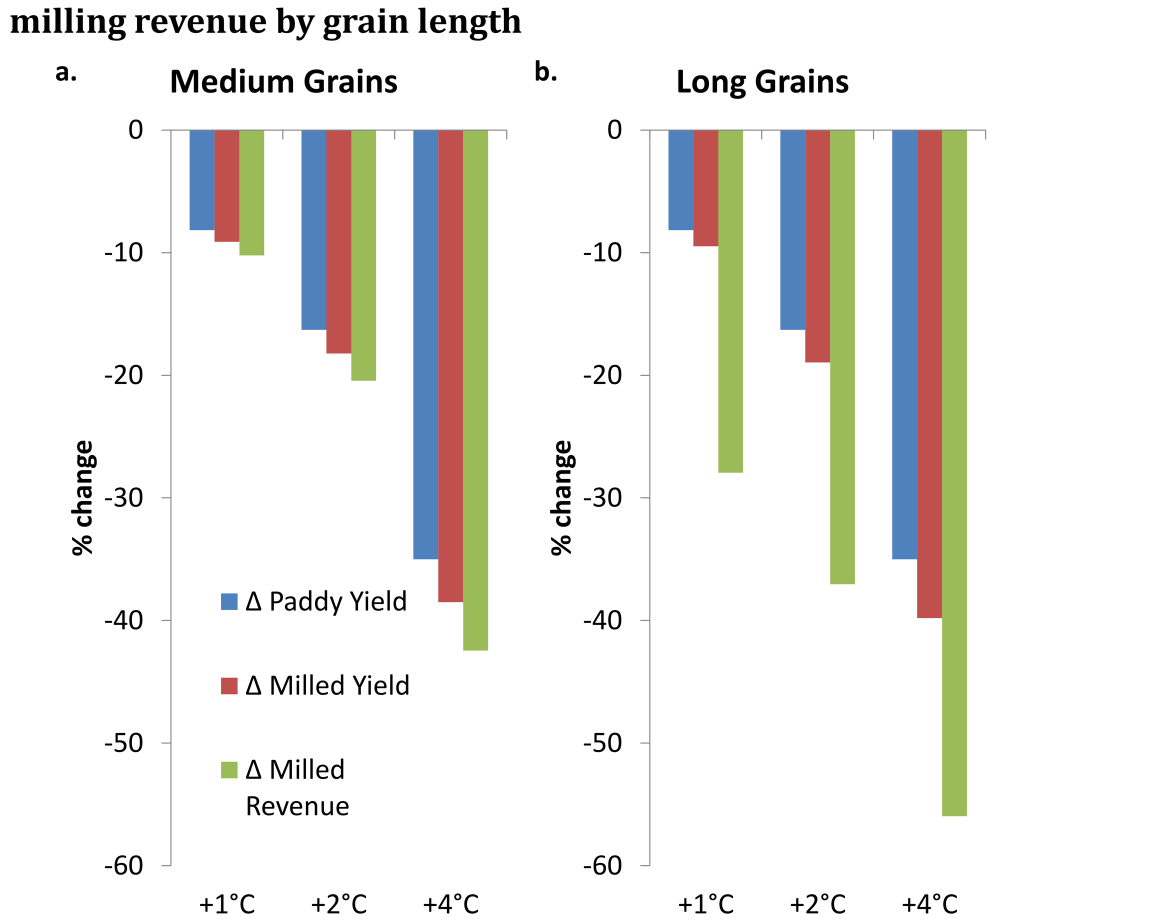


Figure 4 | Mean percentage changes in paddy yield, milled yield and milling revenue by grain length



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