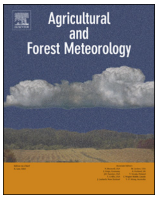
Agricultural and Forest Meteorology 263 (2018) 409–416

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet



Ratooning as an adaptive management tool for climatic change in rice systems along a north-south transect in the southern Mississippi valley

Lewis H. Ziska[a,*], David H. Fleisher[a], Steve Linscombe[b]

[a] USDA-ARS, Adaptive Cropping Systems Laboratory, Beltsville, MD, 20705, USA
[b] Steve Linscombe, LSU Ag Center, 1373 Caffey Road, Rayne, LA, 70578, USA

ARTICLE INFO

Keywords:
Climate change
DD50
Modeling
Rice
Ratooning

ABSTRACT

The effect of climate change on recent and projected increases in surface temperatures is well-documented. For agriculture, such changes can impact crop phenology and production, but the degree of impact will depend, in part, on contemporaneous changes in crop management. In the current study, we quantified recent (last 40 years) and projected (to 2095) changes in air temperature and associated changes in growing season duration for rice along a latitudinal north-south gradient of the lower Mississippi valley. Recent and projected climate data indicated an ongoing increase in air temperature and growing season length with latitudes above ~31 °N. We then applied the DD50 growing degree day model to these data to determine if ratooning, a management practice that produces a second rice harvest with minimal resource input, could be employed. The model results were analyzed and used relative to the southernmost location, Cameron Parish, where the season length and daily temperatures currently allow for ratooning to be a common practice for long-grain cultivars (e.g., Cocodrie, Catahoula). The recent and projected increases in temperature and seasonality indicate that ratooning could already be adopted in Avoyelles Parish, and is potentially possible as far north as Cape Girardeau County (37 °N) by the end of the 21 st century. While additional information regarding possible effects of heat stress, water availability, rising carbon dioxide (CO_2) levels, and other factors will be necessary to fully assess ratooning potential, our research indicated that ongoing increases in temperature and season length may allow agronomic management practices, such as ratooning, to help adapt rice production to climatic uncertainty.

1. Introduction

To maintain current production levels, it will be necessary to adapt existing production systems to accommodate greater climatic uncertainty (Boote et al., 2011; IPCC, 2014). Research regarding potential adaptation approaches frequently focuses on evaluation of crop genotypes and/or traits that confer tolerance to drought or heat stress, improved yield quality or nutritional content (e.g. Ramirez-Villegas et al., 2015; Tao and Zhang, 2010). Such studies include and evaluate a broader range of genetic traits designed to maximize genetic by environment interactions (i.e. GxE) (Ziska and McClung, 2008; Godfray et al., 2010; Wang et al., 2016).

Rice (*Oryza* sativa) cropping systems are of global importance in terms of food security (Sandhu and Kumar, 2017). With respect to climatic uncertainty, changes in mean, night-time or the frequency of extreme temperatures pose a serious risk for rice production, particularly during anthesis (e.g., Peng et al., 2004), and such impacts are likely to occur in major rice growing regions, including the U.S. (Parry et al., 2004). Because of these risks, adaptive research in rice has been directed towards understanding temperature induced yield limits and the counter-means by which rice systems may improve resilience, both quantitatively and qualitatively (Ziska and Manalo, 1996; Matsui et al., 2001; Prasad et al., 2006).

Yet, in addition to a GxE approach, assessing environment by management (i.e. ExM) practices can also play a significant role in adapting major cropping systems in the U.S. For example, Lobell et al. (2002) indicated that adaptive agronomic management at the farm level, (the ExM component), can have a major impact on maintaining regional wheat production in response to climate variability. Similarly, for rice systems, water savings methods such as alternate-wetting drying (AWD) are being evaluated to determine cost-benefit savings and yield impacts (Massey et al., 2014). Espe et al. (2016) has suggested that rice farmers may already be adapting to a warming climate by planting earlier to take advantage of earlier Spring temperatures and longer growing seasons. Thus, simple management strategies may be effective in responding to changing temperature conditions, either

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[*] Corresponding author.
E-mail address: l.ziska@ars.usda.gov (L.H. Ziska).

https://doi.org/10.1016/j.agrformet.2018.09.010
Received 7 June 2018; Received in revised form 11 September 2018; Accepted 12 September 2018
0168-1923/ Published by Elsevier B.V.

without, or in concert with, GxE adaptation approaches.

The ability of ratooning as an adaptive ExM tool in the context of climate uncertainty has not, however, been evaluated. Ratooning is a management option in rice systems that allows for rice regrowth leading to a second or ratoon crop (RC) harvest following that of the main crop (MC). The ratoon crop yield can be as high as 50% of that produced from the main crop, with lower production costs due to savings in land preparation, labor and water use (Harrell et al., 2009).

Because temperatures and growing season duration are limited in the northern rice growing areas, at present, in the United States, ratooning is only implemented in the most southern region of the Mississippi valley. However, the practice may be an effective ExM adaptation approach as projected changes in climate could result in a warmer and extended growing season (Negalur et al., 2017). In this context, ratooning management could serve as an approach for U.S. rice growers to benefit from a warmer climate by increasing annual grain production with only a minimal increase in input and operational costs.

In this study, we evaluate ratooning as an adaptative ExM strategy for rice systems in the U.S. Mississippi Delta. Recent (since 1976) climate trends in this region are quantified to identify temporal changes in air temperature as well as shifts in growing season duration in a latitudinal south-north transect for five locations. The well-established DD50 model, a growing degree day based approach used by rice growers to predict rice development (Norman et al., 1998; Frizzell et al., 2007), is then utilized to evaluate changes in thermal time requirements for rice MC and RC for recent and projected climates. The southernmost transect location, Cameron Parish, Louisiana where a range of rice cultivars are grown (e.g., CL 111, Cocodrie, Catahoula, inter alia) and where ratooning is a common practice was used as a meteorological guide. Our objective was to determine if, or when, each location north of Cameron Parish would achieve the minimum thermal time requirement and season length necessary for ratooning to be implemented.

2. Materials and methods

2.1. Recent temperature changes

A web-based software program, iAIMS Climatic Data developed by Texas A&M University (Yang et al., 2010) was used to obtain daily maximum and minimum air temperatures for five rice growing locations along a south-north transect from 1976 through 2016. The weather data in this program is measured / observed daily climate data as obtained from the National Climatic Data Center of the National Oceanographic and Atmospheric Administration and other weather stations as detailed in Wilson et al. (2007). The year 1976 was chosen as the earliest date as it represents the onset of recent increases in the global land-ocean temperature index (Dieng et al., 2017). The five stations chosen are representative of the latitudinal gradient in the lower Mississippi valley where the bulk of U.S. rice is grown (Fig. 1).

Temperature data obtained from each of the five locations was used to initially calculate changes in frost free days (from last Spring to first Fall frost), where frost was defined to have occurred when minimum daily air temperature was below or equal to 32 °F. These data were then analyzed using the modified growing degree day, DD50, rice model. This model is based as follows:

$$DD50 = \Sigma\ [(T_{max} - T_{min})\ /\ 2]\ \text{-}50$$

Where DD50 is computed daily using Tmax and Tmin air temperatures. Tmax is restricted to a maximum of 94 °F (34.4 °C), Tmin to a maximum of 70 °F (21.1 °C) and minimum of 32 °F (0 °C), so that daily DD50 units are constrained from a range of 0–32 degree-days.

The DD50 data was then analyzed from 1976 to 2016 for each of the five locations to determine potential changes in seasonality in the context of rice production. The first analysis was to quantify yearly cumulative DD50 values to assess if there was a significant temporal change in air temperature during the frost-free period for that location. IN this context, DD50 values were a general metric for assessing temporal changes in relevant thermal units during the growing seasons, and thus not assessed to specific rice cultivars. The second analysis was to determine the cumulative DD50 requirement for ratooning using August 15th as a starting date (average of when the MC harvest historically occurs). We also explored effects of changing climate on varying planting dates, predicted maturity dates, and thus ratoon dates, based on DD50 unit requirements averaged across several conventional and hybrid lines grown in the Mississippi Delta region (Frizzell et al., 2007) as described later in this section. The southernmost location, Cameron Parish, Louisiana, where ratooning is a common management practice, was used to define the reference temperature and seasonal parameters associated with ratooning. We used a proximate value of 90% of the average 1976–2016 cumulative DD50 for the ratooning period from Cameron Parish as a guide to indicate a thermal time threshold for ratooning practice in the other four locations. Lastly, the number of frost-free days for ratooning (i.e. from August 15th to the first fall frost) was determined for all locations and compared to a 75-day minimal ratooning requirement (LSU Extension, Dustin Harrell personal communication).

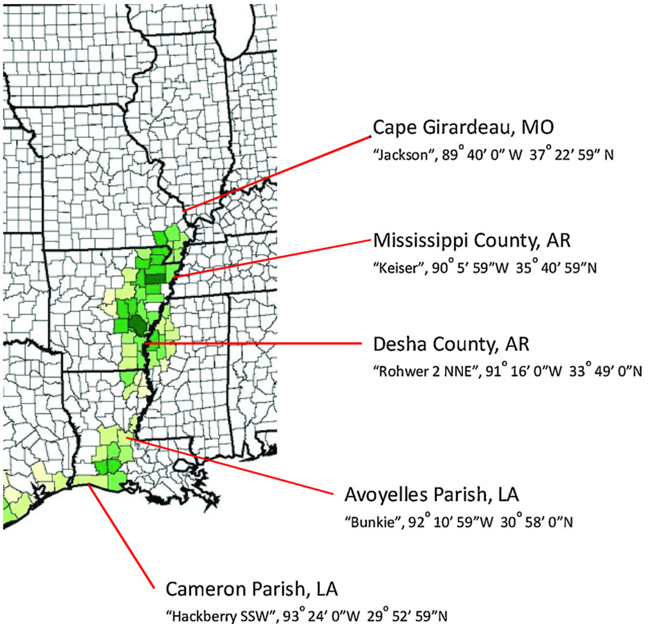

Fig. 1. Geographic description of weather stations by county/parish. Original map was extracted from USDA NASS (2010). Weather stations are from https://beaumont.tamu.edu/CLIMATICDATA/WorldMap.aspx.

2.2. Projected temperature changes

We used an average of six spatially downscaled and bias corrected general circulation models (GCMs) to estimate daily maximum/minimum air temperatures for a given location for selected years (2030, 2050, 2070, and 2095) for Representative Concentration Pathways (RCPs) 4.5 and 8.5 (Table 1) from the IPCC 5th approximation (IPCC, 2014) as per the MarkSimGCM weather generator (www.gisweb.ciat.cgiar.org/marksimgcm). The results of thirty independent runs at each of the selected years were conducted to estimate annual daily weather variability at each of the selected years. The MarkSim weather generator incorporates methodology to address differences between observed and simulated weather variables for each GCM using a 50-year hind-cast at a spatial resolution of 1 to 2°. A 5th order polynomial is used to model this difference which serves as a method to bias correct each GCM and account for hind-cast differences. A 3rd order polynomial