Climate Risk Management 3 (2014) 24–38

Contents lists available at ScienceDirect

Climate Risk Management

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

Tailoring wheat management to ENSO phases for increased wheat production in Paraguay

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ARTICLE INFO

Article history:
Available online 17 June 2014

Keywords:
Climate variability
ENSO-persistence-based forecast
GCM-based forecast
APSIM-Nwheat
Wheat modeling
Paraguay

ABSTRACT

Reported regional wheat yields in Paraguay vary from 1 to 3 t/ha from year to year, but appear not to be correlated with El Niño-Southern Oscillation (ENSO) phases. Historical weather data from two locations in representative wheat-growing regions of Paraguay, Encarnación-Itapúa and Ciudad del Este-Alto Paraná combined with crop modeling, were analyzed to optimize nitrogen (N) fertilizer application rates according to the ENSO phase of a growing season. The ENSO phase of a growing season was defined based on the average of the sea surface temperature (SST) anomalies in the Eastern Equatorial Pacific region for the period June–October using the El Niño region 3.0 index (Niño 3.0). Simulated average yields in Alto Paraná were higher in the drier and cooler La Niña wheat-growing seasons (average of 3.5 t/ha) compared to the other phases (average of 3.2 t/ha) and in Itapúa, in Neutral seasons (average of 3.8 t/ha) compared to the other phases (average of 3.7 t/ha). Accordingly, optimal N fertilizer applications ranged between 20 and 60 kg N/ha between phases depending on the sowing date, soil type and initial amount of soil water content. Applying an ENSO or General Circulation Model (GCM)-based forecast for ENSO-season-type specific N fertilizer applications resulted in benefits of >100 US$/ha when compared with current farmers' practice of consistently low N fertilizer applications in Paraguay. When N management based on forecasts was compared with optimized N application without forecast, the benefits of the forecast was only up to 8 US$/ha. The ENSO-persistence-based forecast showed higher values than the GCM-based forecasts with two lead-times but lower skill. Using climate information can significantly increase current wheat yields and gross margins in Paraguay by tailoring N fertilizer applications to the Niño 3.0-defined ENSO phases, which can be forecasted with moderate skill at the beginning of the growing season.

Introduction

Wheat is one of the most important food crops covering about 22% of the worlds cultivated land (Licker et al., 2010). It is grown in a wide range of growing conditions, and yields often vary from year to year due to seasonal climate variability in

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http://dx.doi.org/10.1016/j.crm.2014.06.001
2212-0963/Published by Elsevier B.V.

rainfall and temperature (Lobell et al., 2009). Wheat is sown in Paraguay during autumn and early winter between May and June, following soybean grown over the summer. In Paraguay, 65% of wheat production is concentrated in two regions, Alto Paraná (37%) and Itapúa (28%). In 2008, wheat production reached 800,000 t with an average yield of 2.1 t/ha (Cardozo et al., 2010).

Most studies on El Niño-Southern Oscillation (ENSO) anomalies in southeastern South America have focused on precipitation as the main cause for seasonal yield variability (Barreiro, 2010; Grimm and Tedeschi, 2009; Barros et al., 2008; Silvestri, 2005). But, some correlation between ENSO and seasonal temperature anomalies has been suggested for Paraguay (Barreiro, 2010; Barros et al., 2002), but this has not been considered in analyzing seasonal yield variability in this country. Hence, understanding seasonal rainfall and temperature variability and its association with ENSO phases in Paraguay would allow farmers to develop management practices tailored to anticipated climate conditions and yield potential (Podesta et al., 2002).

The application of ENSO phases as a planning tool in agriculture has been reported for different parts of the world (Jones et al., 2000; Hammer et al., 2001; Potgieter et al., 2002; Mauget et al., 2009), showing that tailoring management practices to anticipated rainfall can increase farmerś profits (Asseng et al., 2012; Hansen et al., 2009; Moeller et al., 2008). The planning tool's profitability, however, varies between regions and crops (Meza et al., 2008). In South America, studies on the interaction between ENSO phases and wheat yields have led to contradicting results. For example, in Argentina, studies on the impact of ENSO on wheat yield found no interaction between ENSO and yields (Podesta et al., 1999). In contrast, in Santa María, Rio Grande do Sur in Brazil, La Niña seasons were more favorable for high wheat yields (Alberto et al., 2006). A study of summer-grown soybeans in Paraguay showed lower precipitation patterns during the early (sowing–blooming) and late (seed-podding to maturity) developmental stages of the crop during La Niña seasons compared to El Niño seasons (Fraisse et al., 2008). However, no such analysis has been carried out for wheat growing over winter in Paraguay. Hence, the objectives of this study were (1) to explore differences in wheat yields due to seasonal ENSO phases in the main wheat-growing region of Paraguay and (2) to evaluate ENSO- and GCM-based forecasts for managing seasonal variability to increase farmerś gross margins.

Methods and materials

Experiment

Historic climate data records of two weather stations were used in the simulation: Encarnación-Itapúa, with sixty seasons (1951–2010) and Ciudad del Este-Alto Paraná, with forty seasons (1967–2006). The same weather data records were previously used in a soybean study in Paraguay (Fraisse et al., 2008). Longer historic weather data was not available for any of the locations in Paraguay. The treatments in the experiment were: (1) two clay soils with different field capacity per location: in Alto Paraná, a soil with lower plant available water holding capacity (LWH) of 240 mm and a soil with higher plant available water holding capacity (HWH) of 290 mm; in Itapúa, a soil with LWH of 200 mm and with HWH of 300 mm; (2) four different sowing dates: May 10, May 20, May 30 and June 10; (3) six different nitrogen (N) applications: 0, 20, 40, 60, 80 and 100 kg N/ha as ammonium nitrate fertilizer applied in one application at sowing; and, (4) two different initial soil water contents: wet (soil water content at drained upper limit) and dry (soil water content at plant lower limit). Soil input values were obtained from a previous soil characterization (Lopez-Gorostiaga et al., 1993). The selected wheat cultivar br23 is a medium maturity cultivar developed in Brazil and widely used in Paraguay (Anonymous, 2002). The timing of wheat developmental stages in Paraguay was parameterized in the simulation using expert information from an extension group in Paraguay.

ENSO classification

The ENSO is a coupled ocean–atmosphere interaction driven by the anomalously warm (El Niño phase) or cold (La Niña phase) sea surface temperatures (SST) in the Eastern Equatorial Pacific. Typically, the ENSO phase is established in austral summer and persists for a number of months thereafter (Rasmusson and Carpenter, 1983). The atmospheric (teleconnection) response to a given ENSO phase can be seen in the precipitation and temperature patterns at numerous locations around the globe, including South America (Halpert and Ropelewski, 1992; Ropelewski and Halpert, 1987). The remote atmospheric response to ENSO is typically delayed by 1–3 months (Kumar and Hoerling, 2003).

There is no consensus in the scientific community on which ENSO index defines better the ENSO phase (Hanley et al., 2003). The Southern Oscillation Index (SOI) (Hammer et al., 1996), the Multivariate ENSO Index (MEI) (Ganguli and Reddy, 2013), the El Niño region 3.0 index (Niño 3.0) (Baawain et al., 2005) and the Japan Meteorological Agency Index (JMA) (Hanley et al., 2003; Fraisse et al., 2006; Gimeno et al., 2002; Hansen et al., 1999; Izaurralde et al., 1999) have been used in categorizing seasons among others. The weather data for this study were categorized into ENSO phases using the Niño 3.0 information (Baawain et al., 2005; Trenberth, 1997). The average of the Niño 3.0 index monthly anomalies for June–October was used to classify the wheat growing-season into El Niño seasons (>0.5 °C), La Niña seasons (<−0.5 °C) and Neutral seasons. Continuously updated monthly Niño 3.0 anomalies are available on the Internet (COAPS, 2014).