AGCLIMATE: CROP YIELD RISK DECISION SUPPORT SYSTEM FOR THE SOUTHEASTERN USA

C. W. Fraisse

Agricultural & Biological Engineering Department

University of Florida

Introduction

Seasonal climate variability is a major source of production risks. The majority of crop failures in the U.S. are associated with either a lack or excess of rainfall (Ibarra and Hewitt, 1999). Climate variability is also associated with other sources of production risks such as pest and disease incidence. Weather patterns, including high temperature and humidity, and the potential for daily rainfall, can favor the outbreak of fungal diseases. They can also impact the reproductive cycle of other pests and insects that function as disease vectors (Fraisse et al., 2006). Crop yield variability differs geographically and depends on soil type and quality, climate, and management practices such as irrigation and fertilization. In the U.S., yield variability tends to be the lowest in irrigated areas and in the central Corn Belt, where soils are deep and rainfall dependable (Hardwood et al., 1999). In the Southeast, in spite of annual average precipitation around 60 inches in certain areas such as the Florida panhandle, yield variability can be substantial due to low water holding capacity soils and the potential for the lack of rainfall during critical phases of crop development.

The El Niño Southern Oscillation (ENSO) phenomenon is the strongest driver of interannual climate variability around the world (Ropelewski and Halpert, 1996) and affects crop production in many regions. ENSO phases are characterized by sea surface temperature anomalies in the eastern equatorial Pacific Ocean. When sea surface temperature (SST) is higher than normal the phenomenon is referred as El Niño. Associated with the warmer surface temperatures is an increase in convective activity, and at a certain stage, a persistent reduction of the normally westward flowing winds (Cane, 2001). When the sea-surface temperature is lower than normal, the phenomenon is referred to as La Niña. During La Niña events, the equatorial trade winds strengthen, resulting in colder water being brought up from the ocean's floor. Neutral is the term for when neither El Niño nor La Niña are present in the Pacific. Under Neutral conditions, trade winds blow from east to west near the Equator in the Pacific Ocean.

Previous research has demonstrated that ENSO exerts a substantial influence on the climate of the Southeastern U.S. El Niño years tend to be cool and La Niña years tend to be warm between October and April (Kiladis and Diaz, 1989; Sittel, 1994, Mearns et al., 2003). Although the influence on rainfall is spatially less consistent, El Niño years tend to be wet and La Niña years dry during these months. The ENSO signal in the region is strongest in the fall and winter months; some evidence exists that La Niña summers tend to be slightly wetter than normal (Sittel, 1994). The impact of climate variability on crop yields in the southeastern U.S. has been well documented. Hansen et al. (1998) analyzed the historical (1960-1995) response of total production value and its components (yield, area harvested and price) to ENSO phases and quarterly SST for six crops (peanut, tomato, cotton, tobacco, corn and soybean) in four southeastern states (Alabama, Florida, Georgia and South Carolina). ENSO phase significantly influenced corn and tobacco yields, the areas of soybean and cotton harvested, and the values of corn, soybean, peanut and tobacco. ENSO phases explained an average shift of $212 million, or 25.9%, of the value of corn. They also identified significant responses of corn, soybean and cotton yields, and peanut value to SST across the region. Additionally peanut and tobacco yields, and tomato and soybean values in particular states were significant effected.

Based on the strong evidence that climate variability plays an important role on crop yields in the southeastern USA, a crop yield risk analysis component was developed under the framework of a web-based climate decision support system (http://www.agclimate.org) designed to help producers analyze and mitigate risks associated with climate variability.

AgClimate.org

AgClimate is a web-based climate forecast and decision support system developed by the Southeast Climate Consortium (SECC) in partnership with the Cooperative State Extension Service. The SECC is a coalition of six universities - Florida State University, University of Florida, University of Miami, University of Georgia, Auburn University, and University of Alabama-Huntsville. AgClimate and the other programs of the SECC are designed around broad themes of product assessment and evaluation, program evaluation, and economic analysis and highlight research done into the fields of climate, forestry, agricultural risk, extension, and natural resources and the environment. Information available in *AgClimate* includes climate forecasts combined with risk management tools and information for selected crops, forestry, pasture, and livestock.

Crop Yield Risk Tools in AgClimate

Production or yield risk comes from the unpredictable nature of the weather and uncertainty about the performance of crops under the pressure of diseases and pests or other unpredictable factors. Production and price risks, together with other forms of risk such as institutional and financial risks are significant factors affecting the profitability and long term sustainability of the farm enterprise. Several strategies can be adopted by producers to help minimize the impacts of adverse climate on crop yield. Changing crops or varieties, planting dates, and investing in irrigation equipment are a few examples of the decisions that a producer can contemplate. Nevertheless, the process to minimize yield risk must include an understanding or quantification of the risk involved; the ability to simulate what-if scenarios for evaluating potential adaptation strategies, and real time information and weather monitoring.

Figure 1 illustrates the various components of the yield risk analysis component available in *AgClimate.* Past yield records can be analyzed in conjunction with historical weather information to help producers understand the effects of ENSO phases on crop yield. Crop models can be used in conjunction with climate forecasts for evaluating alternative management practices such as planting dates, crops and varieties. Yield potential (future) at a given location under different climate scenarios and management practices can be simulated to help producers in their decision making process. Once a season starts and the crop is planted (present) risks associated with climate variability can be minimized by monitoring real time weather and taking the necessary actions when possible. Information provided by *AgClimate* does not include real time weather monitoring capabilities but it links to agricultural weather networks in the States of Florida (Florida Automated Weather Network, FAWN) and Georgia (Georgia Automated Environmental Monitoring Network). In addition to links to real time weather monitoring networks, climate outlooks and agricultural outlooks released throughout the year provide producers with an update on current conditions and a summary interpretation of the latest climate forecast. In the case of agricultural outlooks, potential impacts are listed and adaptation strategies are discussed. Agricultural outlooks are produced by climate extension specialists in partnership with commodity specialists.

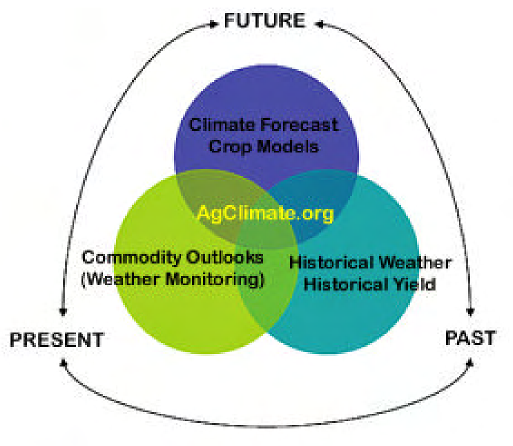

Figure 1. Framework for crop yield risk analysis in AgClimate.

Historical Yield Tools

Historical yield records at the county level can provide a valuable perspective of the possible influence of ENSO on crop yield. However, in addition to climate variability, historical crop yield data integrates a number of factors such as technological advances (improved varieties or management, shifts from rainfed to irrigated production) and price cycles. The data needs to be processed to separate the effects of seasonal climate variability from other factors that tend to change more slowly. Long term trends need to be removed from the dataset to allow the analysis of more frequent shifts related to climate variability.

Historical yield trends can be analyzed in *AgClimate* using two different approaches. First, users can plot county level time series based on records from the USDA-National Agriculture Statistics Service (NASS). This dynamic tool (Figure 2) allows users to plot county historical yield for several crops including corn, cotton, peanut, soybean, potato, and others. The user can plot crop yield time series for one or more counties allowing yield comparison among counties. The tool calculates summary statistics based on the records for the selected counties for each ENSO phase and also for all years in the database. The user has also the option to review yield values by year in a table format by clicking on “Yield Report” or to plot seasonal total rainfall or average temperature by selecting the appropriate radio button in the left side menu. This last option is only available when only one county is selected. A linear trend line is fitted to represent yield trends of each individual county and residuals (the deviations from the fitted line to the observed values) can be visualized to allow a better evaluation of climate variability impacts on yield (Figure 3). The plot of residuals also includes a small bar graph on the top right corner of the page displaying average residuals for each ENSO phase. In the case of the example shown in Figure 3, it can be observed that corn yields are, on average, lower during El Niño years (-8.9%). It can also be noticed that yield variability in Appling County was more intense during the last 10 to 15 years than the observed for Baker County. This could be potentially explained by a shift to irrigated production in Baker County, which would also help explain the more significant upward trend in actual yields (Figure 2).

Average residuals can be visualized in a map format by selecting the regional yield trend maps tool. Maps showing average crop yield residuals for each ENSO phase can be displayed providing a regional overview of potential production risks for each ENSO phase. It is important to recognize that regional averages are a good first piece of information but do not include any probabilistic information that must be taken into consideration when dealing with effects of climate variability on crop yield. Figure 4 shows the average soybean yield residuals observed during El Niño years in the states of Alabama, Florida, and Georgia. It can be noticed that, on average, soybean yields tend to be below average in the northern regions of Alabama and Georgia during El Niño years. This information by itself can trigger producers in those regions to consider better crop insurance coverage during years when an El Niño is taking place.

Crop Model-Based Yield Tools

A crop modeling effort was undertaken for selected commodities with the objective of providing base lines for evaluating crop production risk under alternative climate forecasts. The crops that were initially selected are peanut, tomato, and potato. The Decision Support System for Agrotechnology Transfer – Cropping System Model (DSSAT-CSM) suite of crop models (Jones et al., 2003) was used for this effort. The DSSAT-CSM Version 4.0 (Hoogenboom et al., 2004) crop models are process based models that simulate crop growth and development, soil water processes, and nitrogen balances. Long-term historical weather compiled from the National Weather Service was used for the simulations. A solar radiation generator, WGENR, with adjustment factors obtained for the Southeastern USA (Garcia and Hoogenboom, 2005) was used to generate daily solar radiation data. Soil profile characteristics for the main agricultural soil types in each county were obtained from the soil characterization database of the USDA National Resource Conservation Service.

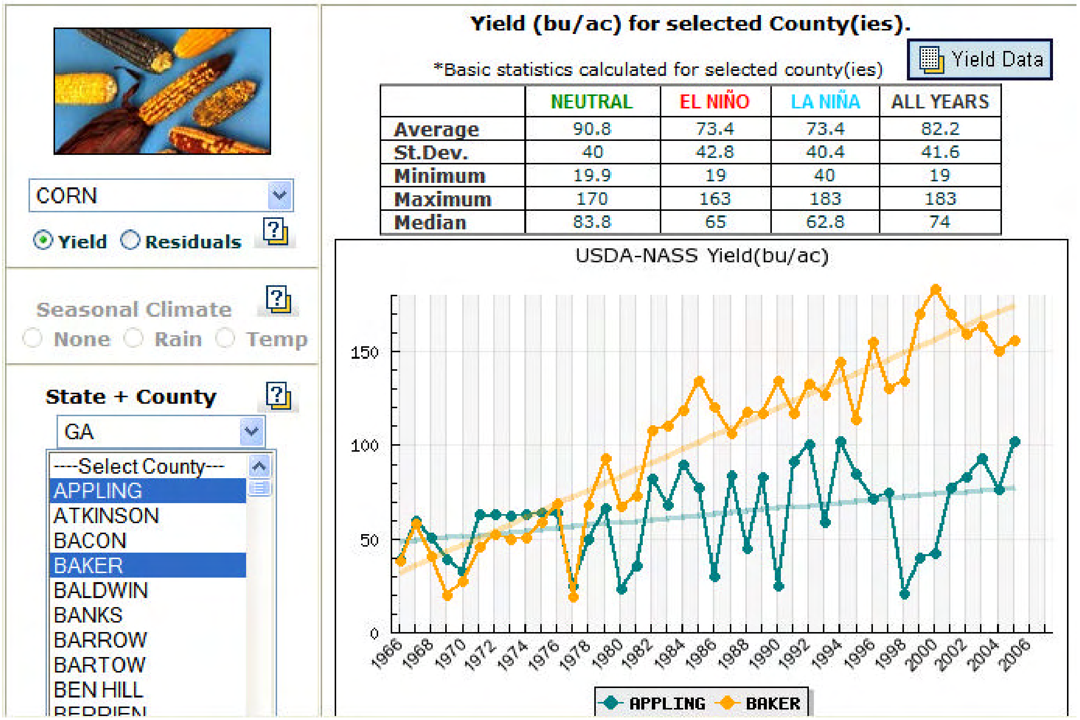

Figure 2. Corn historical yield time series for Appling and Baker counties, GA.

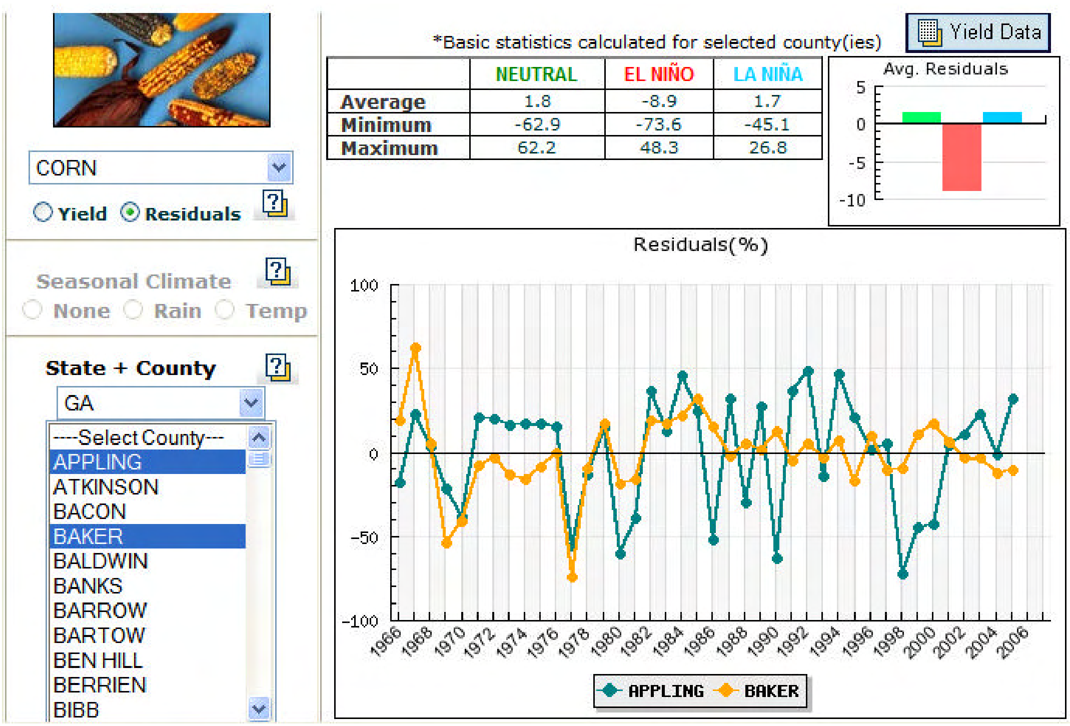

Figure 3. Corn yield residuals (%).

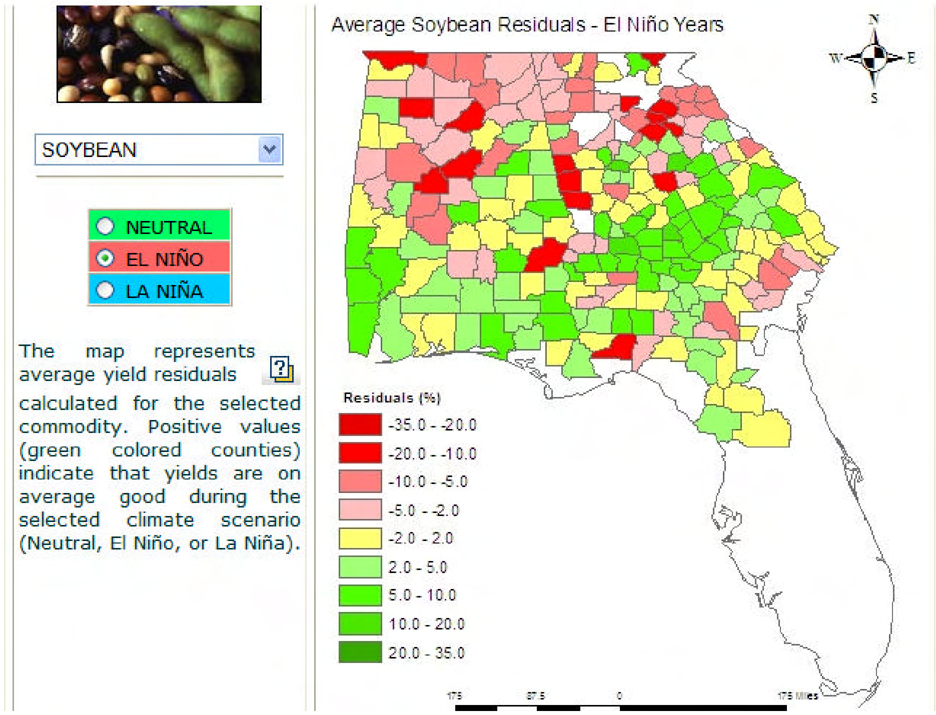

Figure 4. Regional map of average soybean yield residuals during El Niño years.

The CSM-CROPGRO-Peanut (Hoogenboom et al., 1992; Boote et al. 1998; Jones et al., 2003), CROPGRO-Tomato (Scholberg et al., 1997), and SUBSTOR-Potato (Ritchie, 1995) crop models were used to simulate crop yield under different management scenarios using weather data from 1950-2004 for several counties in Georgia, Florida and Alabama. In the case of peanut, the Georgia Green peanut cultivar, a medium maturing runner-type peanut variety, was selected as the representative variety for the main peanut producing counties in each state. The typical planting window for peanuts is between mid-April and mid-June. Peanut responses were simulated with and without irrigation. Potatoes are grown commercially in Florida in the winter and spring months when the days are warm and the nights are cool. Potato simulations were performed for the variety Atlantic which is a standard variety for processing with high yield potential. Tomato simulations focused initially on the fresh market tomato crop produced in Fall-Winter-Spring in south Florida. A common tomato cultivar, Sunny, was selected to represent the range of cultivars grown in South Florida.

The crop model-based dynamic tool available in *AgClimate* allows users to analyze yield probability distributions for various planting dates under alternative climate scenarios or ENSO phases. Figure 5 shows yield probabilities for peanut planted on April 16 and May 15 in Santa Rosa County, Florida, during neutral years. The user can select one or more planting dates to explore potential yield effects. In the example shown in Figure 5, it can be noticed that peanut planted on May 15th carries a higher chance of yielding in the top one third of all potential outcomes. A phenology table underneath the probability graph shows the period of time when flowering and maturity are expected for peanut planted in the selected dates. Crop model results are currently available for a limited number of counties and soil types. Additional crops including cotton and corn are currently under implementation and should soon be available.

Climate and Agricultural Outlooks

AgClimate releases climate outlooks four times during the year. The main purpose of the outlooks is to summarize current conditions and expected climate conditions during the next two or three months. Climate outlooks are released in order to match producers' decision calendar such as early spring before planting, mid-summer during crop development stages, and mid to late fall, when citrus and winter vegetable producers are concerned about freeze forecasts. Agricultural outlooks have been recently added to the suite of products in *AgClimate*. The main purpose of these outlooks is to translate climate outlooks into practical actions for the various crops.

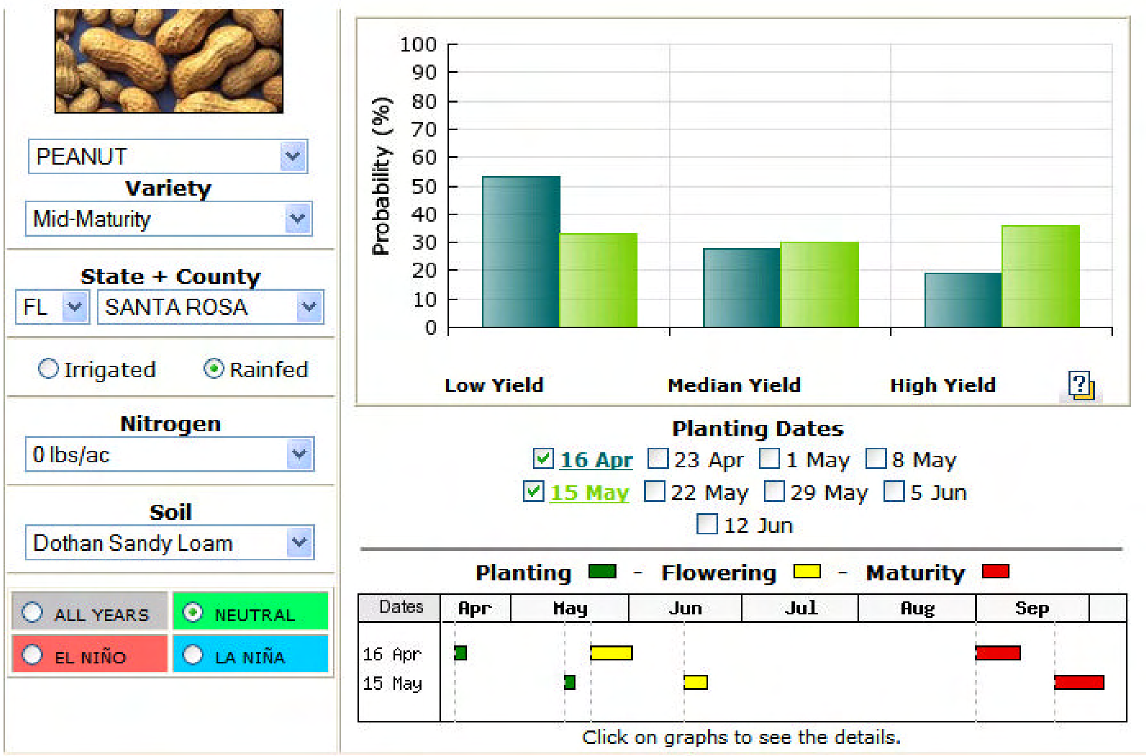

Figure 5. Yield risk tool showing yield probabilities for peanut planted on April 16 and May 15 in Santa Rosa County, Florida, during neutral years.

Summary and Conclusions

A web-based set of dynamic tools for analyzing crop yield risk associated with climate variability has been developed under *AgClimate.org*. Crop yield risk can be analyzed by means of historical yield records or by evaluating potential yield levels using crop models in conjunction with ENSO-based climate forecasts. The main purpose of this study was to provide extension agents and producers in the southeastern U.S. with a set of tools to quantify yield risk and define adaptation strategies in light of climate forecasts. Adaptation strategies must take into account a number of factors in addition to climate forecasting, such as commodity prices and availability of equipment and labor. The goal is not to provide a recommendation but information and ways to explore options for adaptation. Historical yield can be analyzed in conjunction with climate using different approaches, plotting county level yield time series based on records from the USDA-NASS database or mapping average crop yield residuals for each ENSO phase. Historical yield can be analyzed for several crops including corn, cotton, peanut, soybean, potato, sugarcane and winter wheat. Yield risk can also be quantified by analyzing simulated yields obtained by using crop models in conjunction with climate forecasts. Crop model-based analysis is available for a limited number of crops (peanut, potato, and tomato) and geographic locations. This tool allows users to estimate yield potential for alternative management practices such as planting dates and irrigation. In addition to dynamic tools, agricultural outlooks are produced by climate extension specialists in partnership with crop specialists to help producers identify adaptation strategies.

References

Boote, K. J., Jones, J. W., Hoogenboom, G., 1998: Simulation of crop growth: CROPGRO Model. Agricultural Systems Modeling and Simulation, R. M. Peart and R. B. Curry, Eds., Marcel Dekker, New York, 113-133.

Cane, M. A., 2001. Understanding and predicting the world's climate system. In: Impacts of El Niño and climate variability on agriculture. American Society of Agronomy (ASA) Special Publication 63.

Fraisse, C. W., N. Breuer, J. G. Bellow, V. Cabrera, U. Hatch, G. Hoogenboom, K. Ingram, J. W. Jones, J. O'Brien, J. Paz, and D. Zierden. 2006. AgClimate: A climate forecast information system for agricultural risk management in the southeastern USA. *Computers & Electronics in Agriculture* 53(1):13-27.

Garcia y Garcia, A., and G. Hoogenboom. 2005. Evaluation of an improved daily solar radiation generator for the southeastern USA. Climate Research 29:91-102.

Hansen, J. W., Hodges, A. W., Jones, J. W., 1998. ENSO influences on agriculture in the Southeastern US. *J. of Climate* 11(3):404-411.

Harwood, J., Heifner, R., Coble, K., Perry, J., Somwaru, A., 1999. Managing Risk in Farming: Concepts, Research, and Analysis. United States Dept. of Agriculture, Economic Research Service (AER-774).

Hoogenboom G., Jones, J. W., Boote, K. J., 1992: Modeling growth, development, and yield of grain legumes using SOYGRO, PNUTGRO, and BEANGRO: a review. *Transactions of the ASAE*, 35: 2043-2056.

Hoogenboom, G., J.W. Jones, P.W. Wilkens, C.H. Porter, W.D. Batchelor, L.A. Hunt, K.J. Boote, U. Singh, O. Uryasev, W.T. Bowen, A.J. Gijsman, A. du Toit, J.W. White, and G.Y. Tsuji., 2004. Decision Support System for Agrotechnology Transfer Version 4.0 [CD-ROM]. University of Hawaii, Honolulu, HI.

Ibarra, R., Hewitt, T., 1999: Utilizing crop insurance to reduce production risk, Institute of Food and Agricultural Sciences (IFAS Publication FE-198), Florida Cooperative Extension Service, Gainesville, Florida.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A.,

Wilkens, P. W., Singh, U., Gijsman, A. J., Ritchie, J. T., 2003: DSSAT Cropping System Model. *European Journal of Agronomy* 18:235-265.
Kiladis, G. N., Diaz, H. F., 1989. Global climatic anomalies associated with extremes in the Southern Oscillation. J. of Climate 2:1069-1090.
Mearns, L. O., Giorgi, F., McDaniel, L., Shields, C., 2003. Climate Scenarios for the Southeastern U.S. based on Regional Model Simulations. *Climatic Change* 60: 7-35.
Ritchie, J. T., Griffin, T. S., Johnson, B. S., 1995. SUBSTOR: Functional model of potato growth, development, and yield. In Modelling and Parameterization of the Soil–Plant–Atmosphere System: A Comparison of Potato Growth Models, 401–434. P. Kabat, B. Marshall, B. J. van den Broek, J. Vos, and H. van Keulen, eds. Wageningen, The Netherlands: Wageningen Press.
Ropelewski, C. F., Halpert, M. S., 1996. Quantifying southern oscillation: precipitation relationships. *J. Climate* 9:1043-1059.
Scholberg, J. M. S., Boote, K. J., Jones, J. W., McNeal, B. L., 1997. Adaptation of the CROPGRO model to simulate the growth of field-grown tomato. In: Kropff, M. J. et al. (Ed.), Systems approaches for sustainable agricultural development: Applications of systems approaches at the field level. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 133-151.
Sittel, M. C., 1994. Marginal probabilities of the extremes of ENSO events for temperature and precipitation in the Southeastern United States. Tech. Rep. 94-1, Center for Ocean-Atmospheric Studies. The Florida State University, Tallahassee, FL.