2011

Sweet Sorghum Production Based On Fertilizer Rates, Varieties And Use Of Grain Sorghum Model

Ashwin Kumar Devudigari
North Carolina Agricultural and Technical State University

Sweet Sorghum Production Based On Fertilizer Rates,

Varieties and Use of Grain Sorghum Model

Ashwin Kumar Devudigari

North Carolina A&T State University

A thesis submitted to the graduate faculty

in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

Department: Natural Resources & Environmental Design

Major: Plant, Soil, and Environmental Science

Major Professor: Dr. M. R. Reddy

Greensboro, North Carolina

2011

School of Graduate Studies
North Carolina Agricultural and Technical State University

This is to certify that the Master's Thesis of

Ashwin Devudigari

has met the thesis requirements of
North Carolina Agricultural and Technical State University

Greensboro, North Carolina
2011

Approved by:

Dr. M. R. Reddy Major Professor	Dr. Godfrey Gayle Committee Member
Dr. Lijun Wang Committee Member	Dr. Vangimalla Reddy Committee Member
Dr. Ron Gehl Committee Member	Dr. Louis Jackai Department Chairperson

Dr. Sanjiv Sarin
Associate Vice Chancellor for Research and Graduate Dean

Biographical Sketch

Ashwin Devudigari was born on August 9, 1987, in Gundaram, Nizamabad, India. He graduated from Zilla Parishath High School, Gundaram in 2002, and then attended junior college at Shankary Junior College, Nizamabad from which he graduated in 2004. His interest in plants started after he graduated from junior college, where he majored in biological science. This led him to pursue a bachelor's degree from Acharya NG Ranga Agricultural University, Hyderabad, India in 2009 after which he was motivated to pursue graduate studies. He joined the Master of Science program in Plant, Soil, and Environmental Science in the department of Natural Resources & Environmental Design at North Carolina A & T State University in spring 2010.

Acknowledgements

I would like to convey my earnest gratitude to everyone who contributed to the completion of my thesis. First, I would like to give a special recognition to Dr. Muchha Raja Reddy (Major Advisor & Committee Member), without whose assistance the successful completion of this work would not be possible. For his understanding, patience, guidance, knowledge and financial support, I will always be grateful.

I am also grateful to Dr. Vangimalla Reddy (Research Leader, ARS-USDA, Beltsville & Committee Member), for his guidance, knowledge, effort and financial support provided for Crop Modeling workshop during my program of studies. I would like to thank my graduate committee: Dr. Godfrey Gayle, Dr. Lijun Wang, and Dr. Ron Gehl, guidance, encouragement, thesis review and input.

I would also like to thank Dr. Ramesh Ravella, Amal Elamin, Mathew Miller, Ahmad Elboid, Marvin Clarke, and Emanuel Hayden for their help and friendship during my program and thesis work. In addition, I would also like thank all of faculty and administrative staff of Natural Resources & Environmental Design at North Carolina A&T State University for their assistance and help during my program.

Finally, I would like to thank my family and friends for keeping me grounded and focused throughout this process.

Table of Contents

List of Figures

List of Tables

List of Abbreviations/Symbols

Abbreviations

ANOVA	Analysis of Variance
APSIM	Agricultural Production Systems Simulations
CEC	Cation Exchange Capacity
CERES	Crop Environmental Resource Synthesis
CSM	Cropping System Model
DAP	Days After Planting
DSSAT	Decision Support System for Agro-technology Transfer
ETBE	Ethyl *tert*-butyl ether
EVAP	Evaporation
GDD	Growing Degree Days
HPLC	High Performance Liquid Chromatography
IBSNAT	International Benchmark Sites Network for Agro-technology Transfer
NC A&T	North Carolina Agricultural and Technical
NC	North Carolina
NRCS	Natural Resources Conservation Service
PAR	Photosynthetically Active Radiation
RFA	Renewable Fuels Association
RHUM	Relative Humidity
RRF	Recommended Rate of Fertilizer
SAS	Statistical Analysis Software
TMAX	Maximum Temperature

TMIN	Minimum Temperature
US	United States
USDA-ARS	United States Department of Agriculture - Agriculture Research Service
USDOE	United States Department of Energy

Symbols

CO_2	Carbon dioxide
H_2O	Water
K_2O	Potassium Oxide
N	Nitrogen
NH_3	Ammonia
NH_4NO_3	Ammonium Nitrate
NO_2	Nitrogen dioxide
P_2O_5	Phosphorus Penta oxide
pH	Native log of hydrogen ion concentration
p	Probability of Null Hypothesis
R^2	Coefficient of Determination
in	inches
ha	Hectare
kg	Kilogram
m	Meter
$t\ ha^{-1}$	Tonnes/hectare

Abstract

Sweet sorghum (*Sorghum bicolor* (L.) *Moenich)* is a promising alternative energy crop. Biophysical crop models are advanced agronomic tools designed to predict crop growth for given conditions and to supplement field experiments. No crop model has been developed for sweet sorghum. Adapting the existing grain sorghum model is a good approach to develop a dedicated sweet sorghum model. Our experiment was conducted at the NC A&T research farm in 2010 and 2011, designed with a split plot and strip plot method, respectively. These experiments included two varieties (Dale and M81-E) and four fertilizer rates (0,168-56-168, 84-28-84-soysoap, 168-56-168-soysoap of N-P_2O_5-K_2O kg ha^{-1}) in each year. In 2010, sweet sorghum variety M81-E had greater yields of tops fresh weight and cane fresh weight than variety Dale. In 2011, biweekly observations of growth parameters were recorded to provide data for modification of existing grain sorghum model. In 2011, all fertilizer treatments produced greater yields of tops fresh weight and cane fresh weight than the zero fertilizer control (α=0.05). Sweet sorghum observed growth rates were greater in all fertilized treatments compared with the zero fertilizer control. The grain sorghum model simulation data did not accurately reflect observed sweet sorghum data at estimated genetic coefficients. More specific output parameter strings, such as sugar yield, need to be create in model growth subroutines. Additional experimental data is needed from multiple locations and for more than 2 years data for model development.

CHAPTER 1

Introduction

Energy is critical component for all activities on the planet. Currently nonrenewable fossil fuels are major source for human activities. A continuous rise in fossil fuel demand is leading to depletion of fuel resources, excessive gas prices, and energy insecurities in the world. Considering the present fuel supply and demand situation, renewable bio-fuels are a viable and achievable supplement to fossil fuel energy consumption (Heinimö & Junginger, 2009).

The predominant feedstock currently used for ethanol production in the United States is corn (*Zea mays* L.). However, most of this corn comes from the food supply chain. One promising alternative to corn for ethanol production is sweet sorghum (*Sorghum bicolor* (L.) Moench). The stalks of sweet sorghum contain abundant fermentable sugar juice that can be relatively easy to convert into ethanol. Further, sorghum bagasse remaining after juice extraction is a cellulosic source for additional ethanol production. Sweet sorghum production uses less nitrogen and water than corn (Geng, Hills, Johnson, & Sah, 1989), and can yield more ethanol per acre with fewer inputs than corn (Keeney & DeLuca, 1992).

Sorghum may be especially helpful to the farmers of North Carolina, where the tobacco acreage has decreased substantially in recent years. Currently North Carolina tobacco farmers are looking for alternative crops to replace tobacco in their fields. Sweet sorghum has good potential for production of ethanol but specific production systems for this crop have not yet been developed in North Carolina. Ethanol production from sweet sorghum involves a series of steps including biomass production, extraction of juice from stalks, and conversion to ethanol. It is important to evaluate sweet sorghum cultivars for biomass and juice production.

Traditional in-field agronomic experiments are time consuming, laborious, and expensive. Crop simulation models are useful tools to make timely and appropriate decisions in crop production and management, including input parameters, yield predictions, and determining the agronomic operations required. Crop simulation models are quick and useful in determining the impacts of certain production practices (Jones et al., 1998). Crop modeling techniques were helpful in the past for researchers and farmers in optimizing their crop production. Considering the advantages of using models for crop production, development of a sweet sorghum crop model will help determine production practices that can attain bio-fuel production goals and thus, potentially benefit farmers both regionally and nationally.

1.1 Hypothesis

Hypothesis 1: Sweet sorghum can be successfully grown as an alternative bio-energy crop in Piedmont Region of North Carolina. Hypothesis 2: In development of a sweet sorghum model, adapting a similar crop model will be an effective approach. The objectives listed below were developed to test these hypotheses.

1.2 Objectives

- Evaluate the biomass and juice production for two sweet sorghum varieties across fertilizer rate and source in the Piedmont Region of North Carolina.
- Evaluate the DSSAT grain sorghum model and determine if it can be used for sweet sorghum growth prediction by comparing DSSAT simulated data with sweet sorghum observed data.
- Develop sweet sorghum crop parameters to improve the relationship between simulated data and observed data.

CHAPTER 2

Literature Review

2.1 Bio-ethanol

There is an increasing interest in using ethanol produced from various plant species as a renewable substitute for fossil fuels in the U.S. and other regions of the world. The production of bio-ethanol in the U.S. has increased from 175 million gallons in 1980 to 13.5 billion gallons in 2011 (RFA, 2011). The U.S. Energy Independence and Security Act in 2007 set a standard renewable fuel consumption of 36 billion gallons, of which 21 billion gallons should be from cellulosic ethanol and other advanced bio-fuels by 2022 (Fred, 2007). Currently in North Carolina 9.6 billion gallons of petroleum-based liquid fuels are consumed each year. The North Carolina Strategic Plan for Bio-fuels Leadership set a goal that by 2017, 10% of North Carolina's liquid fuels or about 600 million gallons a year will be produced in state from locally grown biomass (Steven, Billy, Ghasem, Norris, & Johnny, 2007).

Corn grain is currently the major source of bio-ethanol production in United States (Perlack, 2005). To achieve the projected ethanol production, energy crops other than corn must be considered. According to the US Department of Agriculture and USDOE, the US has potential resources to produce 194 million dry tons of bio-energy and bio-products equaling 16 percent of 1.2 billion dry tons of biomass production annually (Perlack, 2005). Various feed stocks are available for ethanol production including crop residues, wood and wood waste products, municipal solids and other dedicated bio-energy crops.

2.2 Sweet Sorghum for Bio-ethanol Production

Sweet sorghum is a promising crop for production of bio-ethanol and has relatively low input requirements for growth, efficient water usage, wide adoptability to environmental conditions and high yields of readily convertible sugars (Bennett & Anex, 2009). Sweet sorghum is a C4 annual grass, with relatively greater nitrogen use efficiency and biomass yield potential (Gardner, Maranville, & Paparozzi, 1994). Sweet sorghum and sugar-cane (*Saccharum officinarum*) are advantageous energy crops compared with other crops since they have readily available sugars in their stalks, and produce bagasse (solid residue) after sugars are extracted (Monti & Venturi, 2003).

Bagasse can be used as an animal feed (Ratnavathi et al., 2010) and as a soil amendment after composting with other wastes (Negro, Solano, Ciria, & Carrasco, 1999). The bagasse is also a good source for cellulosic ethanol production and residual solids can be burned for heating (Sipos et al., 2009). An advantage of sweet sorghum over sugar-cane is that sweet sorghum grain can be used as food or feed (Ratnavathi, et al., 2010). Previous studies indicate that sweet sorghum has potential to produce 8000 L ha^{-1} ethanol, which is twice of corn ethanol yield potential and 30% greater than sugarcane productivity (6000 L ha^{-1} in Brazil) (Bennett & Anex, 2009; David & Geraldo, 2006; Guigou et al., 2011).

The growth and production characteristics of sweet sorghum are favorable for commercial ethanol production. There are approximately 4000 sweet sorghum cultivars distributed throughout the world, providing a diverse genetic pool for development of specific and high yielding varieties for each region (Grassi, Tondi, & Helm, 2004). Ethanol production from sweet sorghum involves some limitations such as laborious harvesting methods and expensive storage of harvested product, conversion must initiate soon as after harvest. Delay in conversion will lead to souring of juices and lower ethanol productivity by sugar transformation to organic acids (Parrish & Cundiff, 1985).

Feedstock from sweet sorghum is an inexpensive source for integrated bio-refineries to produce high value products from the hexose feed stream and ethanol from cellulose derived sugars (Bennett & Anex, 2009; Bohlmann, 2005). The bagasse from sweet sorghum is a potential raw material for the production of paper pulp (Andreuccetti, Bacchiet, Barbucci, Belletto, & Frati, 1991) and energy source for combustion, gasification and pyrolysis process (Venturi & Venturi, 2003). Sweet sorghum is a good source of ethyl *tert*-butyl ether (ETBE) production which can be added to gasoline to increase the octane index and reduce amount of non-combusted compounds (Amaducci, Monti, & Venturi, 2004).

2.3 Sweet Sorghum Crop Characteristics

Sweet sorghum is a subspecies of the sorghum family and has similar characteristics as other sorghum species with sugar rich stalks. There are two major types of sorghum. One is the grain, or non saccharine type, which is cultivated for grain production and to a lesser extent for forage. The second type of sorghum is the sweet or saccharine type, which is used for forage production and for making syrup and sugar. Crop production requirements including climate, soil conditions, and planting seasons are similar for both grain sorghum and sweet sorghum. Sweet sorghum has a rapid growth rate as well as high sugar and biomass accumulation, drought and water logging tolerance, and wide adaptability (Buxton, Anderson, & Hallam, 1999; Hunter & Anderson, 2010; Reddy, 2003). The water requirement for sweet sorghum production is 8000 $m^3\ ha^{-1}$, which is half that of sugar-beet (*Beta vulgaris*) and one quarter that of sugar-cane, due to the extensive root system and relatively short growing season for sweet sorghum (Soltani & Almodares, 1994).

Sweet sorghum grain yield ranges from 1.5 to 7.5 t ha^{-1}, brix index ranges from 13 to 24%, juice sugar content varies from 7.2 to 15.5%, stalk fresh yield ranges from 24 to 120 t ha^{-1}, and biomass yield ranges from 36 to 140 t ha^{-1} (Almodares, Sepahi, & M., 1997). Sweet sorghum has greater potential to produce higher biomass yield than a sugarcane crop in tropics (Monk, Miller, & McBee, 1984). The bagasse produced from sweet sorghum has higher biological value than sugarcane as animal feed (Sumantri & Edi, 1997), and greater micronutrient and mineral value (Seetharama et al., 2002).

2.4 Sweet Sorghum Nutrient Management

An ideal dedicated energy crop for commercial ethanol production should provide positive production economics, should have high energy efficiency, and should fit into the ecosystem with minimal negative environmental consequences. Nitrogen fertilization consumes 50% of the total energy inputs of crop production (Barbanti, Grandi, Vecchi, & Venturi, 2006; Kuesters & Lammel, 1999). Excessive application of nitrogen will lead to leaching of nitrate into subsurface soils and atmospheric releases as NH_3, N_2O, and NO_X forms (Bouwman et al., 1997). The forms of nitrogen loss from soil can be environmentally damaging and toxic (Hornung, Dyke, Hall, & Metcalfe, 1997). In addition to nitrogen, management of other major nutrients including phosphorous (P) potassium (K) and other secondary nutrients is important to maximize profitability and minimize environmental loss. Thus optimum fertilization has a major role in sweet sorghum production.

Crop evapo-transpiration restrains soil nutrients from downward movement via soil solution pathways, thus reducing fertilizer loses into the soil environment (Barbanti, et al., 2006). Nutrient budgets are important tools to estimate the risk of imbalances in nutrient input and output systems (Oenema, Kros, & de Vries, 2003). Considering environmental impacts with commercial fertilizers, recent bio-fertilizers may reduce the nutrient loses into environment. The bio-product SoySoap is foliar surfactant, which helps in nutrient and water uptake and achieving greater crop yields (Michela, Alessia, & Denis, 2011).

2.5 Crop Simulation Modeling

Crop simulation models are potential tools for advancement of agriculture. Crop models integrate information from various crop subsystems across disciplines and improve our understanding of how the system is performing at different levels of crop management, cultivars and environmental conditions and further help identify critical limiting factors of production (Connor, 1990; Hoogenboom, 1991; Penning de Vries, Jansen, Ten Berge, & Bakema, 1989). Development of crop simulation models is essential to adjust land use patterns from natural bio-systems to agro-ecosystems and vice versa (Ewers, Scharlemann, Balmford, & Green, 2009).

The crop simulation modeling concept was initiated in the early 20th century by simplifying Liebig's 'Law of Minimum' and Blackman's (1905) 'Law of Single Factor Limitation' and 'The Compound Interest Law'. British scholars initiated a classic plant growth analysis method using these principles by describing the dynamics of multi-factor controlled biological processes including plant photosynthesis and plant growth (Watson, 1952). Several concepts were then developed to compute plant growth such as the classic model of plant canopy light interception and transmission based on the 'Beer-Lambert' Optic Law by Monsi and Saeki in Japan (1953); the aerodynamics principles for estimating canopy photosynthesis by Inoue et al (1958); and the concepts of analogy model for gas diffusion resistance (H2O & CO_2) around plant leaves in Netherlands (M. El-Sharkawy & Hesketh, 1965).

The first computer modeling efforts initiated on leaf canopy architecture, light distribution in canopy, CO_2 flux, and leaf photosynthesis were compiled by de Wit in the Netherlands (1965) and, Duncan et al. in United States (1967). These efforts laid a solid foundation for further mechanistic and sophisticated crop simulation models in green house and field conditions (Loomis, Rabbinge, & Ng, 1979). In the late 1960's, Mississippi State University and USDA-ARS together started building a crop growth model for cotton which led to the development of the GOSSYM cotton simulation model. After numerous research efforts, a number of crop simulation models have since been developed (M. A. El-Sharkawy, 2011).

2.6 DSSAT Crop Simulation Models

Advancement in computer programming have led to more efficient crop simulation models, such as DSSAT (Decision Support System for Agro-technology transfer), and APSIM (Agricultural Production Systems Simulator). These packages incorporate models of different crops in single program that facilitates the evaluation and application of the crop models for various purposes. The DSSAT was built by an international network of cooperative scientists work in the IBSNAT (International Benchmark Sites Network for Agro-technology Transfer) project with a goal of in advancing agronomic research by modeling using a systems approach (Jones, et al., 1998).

The DSSAT development was driven by the interest of transferring crop production technology to wider locations seeking better decisions by integrating knowledge of soils, climate, crop, and management (Uehara & Tsuji, 1998). The systems approach facilitated an improved platform to research and understand how cropping systems and its components function. The information obtained through the systems approach was integrated into models and allows one to predict the performance of the system for specified conditions. Once the models simulate the real performance adequately, field experiments can be replaced by computer simulation experiments under specified environmental conditions to determine better management decisions in crop production. DSSAT is a tool developed to execute this approach for global applications and to aid decision makers on efficiency of time and resources in analyzing complex alternative decisions (Uehara & Tsuji, 1998).

Before the development of DSSAT, crop models were used mostly in the labs where they were developed. The pilot version of DSSAT was built based on originally developed crop models including the CERES (Crop Environmental Resource Synthesis) models for maize and wheat, SOYGRO for soybean, and PNUTGRO for peanut. The original crop models had different file and data structure, and modes of operation. The IBSNAT project provided a framework for cropping system analysis, where the original models were revised to make them compatible for data inputs and execution (Jones et al., 2003). DSSAT was first released (v2.1) in 1989; additional releases were made in 1994 (v3.0) and 1998 (v3.5) (Hoogenboom et al., 1999; Tsuji, Uehara, & Balas, 1994).

Revisions to the original DSSAT eventually led to a new cropping system model (DSSAT CSM) developed as version 4, which incorporates all crops as modules using a single soil model, and single weather module. The DSSAT v4 cropping system model incorporates changes to both the structure of the crop models and the interface to the models and associated analysis and utility programs. The DSSAT package incorporates models of more than 27 different crops, including the CERES grain sorghum model with new tools that facilitate the creation and management of experimental, soil, and weather data (Jones et al., 2003).

DSSAT v4 includes improved application programs for seasonal and sequence analyses that asses the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability and precision management. DSSAT is built with many modules and sub-modules to accommodate ease of analysis and use. The DSSAT CSM is designed to simulate the mono-crop production system based on weather, genetics, soil water, soil carbon and nitrogen, and management across seasons. The program can simulate the effect of other significant abiotic and biotic factors such as soil phosphorous and plant diseases by incorporating separate modules. Recent modifications were developed in DSSAT to improve the soil module components, crop rotation effects, and further fixed potential bugs in sets of code. The DSSAT program was written in FORTRAN programming (Jones et al., 2003).

The DSSAT was designed using a systems approach, where the weather, soil, genetics, pests, experiments, and economics are a function input window for the crop model to run with multiple applications such as sensitivity analysis, seasonal analysis, sequence analysis, and spatial analysis linked in main interface (Figure 1).

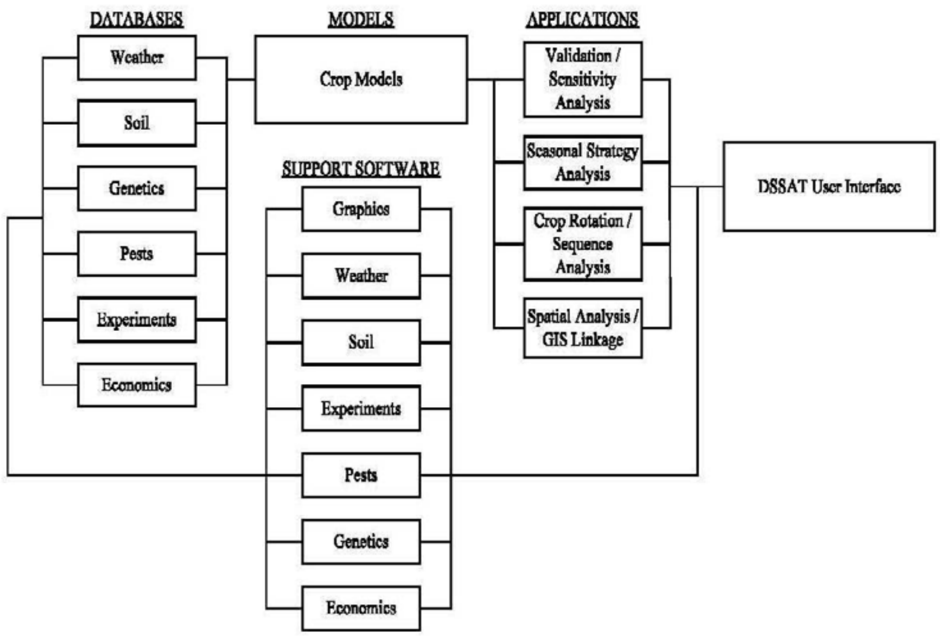


Figure 1. DSSAT v3.5 software database, applications, and supporting components used with crop models for applications.

The DSSAT is a package of independent programs that operate together to make complete crop simulation model. Subroutines and databases are set up with weather, soil and experimental conditions and measurements, and genotype coefficients for the models to run under specified conditions. The software is developed in such a way that the user can prepare a database specific for their environment and compare simulated results with observed results to determine modifications needed in model coefficients to adapt for local conditions (Jones, et al., 1998). The DSSAT program allows users to simulate crop management options over a number of years to analyze the risks associated with each option.

2.7 CERES Model

Initially, the CERES (Crop Environment Resource Synthesis) crop model was developed by Ritchie (USDA-ARS, 1970s) for wheat and maize crops. Godwin (CSIRO, 1980) developed models for sorghum, millet, rice, and barley. CERES is a user-oriented, daily-incrementing simulation model of crop growth, development, and yield. This model simulates the effects of genotype, weather, and soil properties on crop growth and yield (Castrignano, Di Bari, & Stelluti, 1996).

The CERES crop model was developed to simulate grain sorghum production(Jones, et al., 2003). However, no crop models have yet been developed or modified for sweet sorghum production. Since there is an increasing interest in using sweet sorghum for bio-ethanol production, it will be valuable to have a mechanistic, process level simulation model for sweet sorghum which can help further improve the crop productivity, optimize inputs, and increase net profits to growers while increasing yields. Simulations using crop modeling tools can be run to evaluate the response of sweet sorghum to various input parameters (Birch, Carberry, Muchow, McCown, & Hargreaves, 1990).

In CERES model plant growth and development processes are simulated based on growth factor responses (Table 1). Plant growth mass accumulation process depends on solar radiation and photo-synthetically active radiation (PAR) factors; plant expansion process depends on temperature factor. Plant growth process accumulated necessary biomass for plant development process. Plant development has phasic and morphological developmental process. Phasic development involves major changes in growth stages based on biomass partitioning patterns. Morphological development includes the number of leaves, tillers, and grain. Both developmental rates are affected by environmental factors such as temperature, sunlight, precipitation and cultivar characteristics. These processes are categorized to determine the effect individual plant growth factors on crop production (J.T. Ritchie, U. Singh, Godwin., & Bowen, 1998).

Table 1

Factors of plant growth and development processes

Factor	**Growth**		**Development**	
	Mass	**Expansion**	**Phasic**	**Morphological**
Principal environmental factor	Solar radiation	Temperature	Temperature photoperiod	Temperature
Degree of variation among cultivars	low	low	high	Low
Sensitivity to plant water deficit	Low - stomata Moderate - leaf wilting and rolling	High - vegetative stage Low- grain filling stage	Low - delaying vegetative stage	Low
Sensitivity to nitrogen deficiency	Low	High	Low	Low - main stem High - tillers and branches

According to J.J. Ritchie et al (1998) the basic principle involved in a CERES crop simulation model is total biomass of a crop is the product of the average growth rate and the growth duration. The model simulates growth and partitions the growth into organs (root, leaf, stem, ear, grain) according to each growth stage duration and accumulation of biomass. In each stage the partition ratio of total growth and degree days to complete each stage are different among plants (Table 2).

Table 2

Growth stages in CERES sorghum model and the organs growing during those stages

Growth Stage	Duration	Organs Growing
7	Fallow	
8	Sowing to germination	
9	Germination to emergence	Root
1	Emergence - end juvenile	Leaf, root
2	End juvenile - panicle initiation	Leaf, stem, root
3	Panicle initiation - end leaf growth	Leaf, stem, root, ear
4	End leaf growth - begin grain filling	Stem, ear, root
5	Begin grain fill - physiological maturity	Grain, root
6	Physiological maturity - harvest	

2.8 Sweet Sorghum Modeling

Sweet sorghum crop growth modeling was initiated in 1981 and was independent of the CERES family of models. Leaf area, stalk length, and dry leaf biomass of sweet sorghum were measured periodically to develop a series of appropriate equations for growth simulation studies (Shih, Gascho, & Rahi, 1981). They developed a series of equations and estimated sweet sorghum biomass for that experiment, however further testing was needed to evaluate the response patterns under wide growing conditions and varieties (Shih, et al., 1981). There was no significant development after initial efforts by Shih et al in continuation of modeling for sweet sorghum.

2.9 CERES Model Adoptions and Grain Sorghum Model Development

The initial CERES grain sorghum model was developed by adapting the CERES - Maize model. The modification of CERES- Maize model in phenology, leaf growth, leaf senescence, assimilation and grain growth were based on a small set of sorghum data and later validated against large scale field data. After the modification, model predicted sorghum grain yield accurately with 0.97 root mean square deviation to the observed data collected over a range of sowing dates and water regimes. However, the grain sorghum model simulation was close to that of the CERES- Maize parent model simulated yields (Birch, et al., 1990).

The grain sorghum root growth model was developed based on the CERES crop growth models, which simulates the depth of rooting and root length density in each soil layer. The developed model simulated the root growth and analyzed the root length and distributions in sub-humid subtropics of Australia, on oxisol and vertisol soils. Later the model was validated using other independent data to determine the precision of root growth predictions. The model simulated root distribution reasonably accurate but the accumulated root length was less reliable (Robertson, Fukai, Hammer, & Ludlow, 1993).

The CERES-sorghum nitrogen model was tested using Kansas state climatic conditions. The response of sorghum phenology and leaf area development was determined under conditions of nitrogen stress. The resulting information was used to develop N stress leaf growth and development functions and integrated the relationships in the sorghum model (Zewdie, 1999).

CHAPTER 3

Methodology

3.1 Experimental Site

A sweet sorghum field experiments were conducted at the research farm of North Carolina A & T State University, Guilford County, North Carolina in 2010 and 2011 years. The research plots were located at longitude 36.06, latitude -79.73, and 241.4 m above sea level. The soils at the experimental location were Mecklenburg Sandy Clay Loam, 2 to 6 percent slopes, moderately eroded and classified as fine, mixed, active, thermic Ultic Hapludal-fs (J. Fortner, K. Harward, D. Lytle, & Williamson, 2006).

3.2 Treatments

The experiment included two varieties of sweet sorghum and four fertilizer rates. The varieties Dale and M81-E (produced at Mississippi Foundation Seed Stocks) were used as main plots. The fertilizer rates ($N\text{-}P_2O_5\text{-}K_2O$ in kg ha^{-1}, 2 foliar SoySoap sprays at 0.6 L ha^{-1}) 0 fertilizer control, 168-56-168, 84-28-84 plus SoySoap, and 168-56-168 plus SoySoap were used as sub-plot treatment. The fertilizers $N\text{-}P_2O_5\text{-}K_2O$ (14-14-14), triple super phosphate (0-45-0) and muriate of potash (0-0-60) at planting and NH_4NO_3 (34-0-0) for nitrogen side-dressing were used to complete the recommended fertilizer rates. SoySoap was applied as a foliar surfactant.

3.3 Experimental Design and Statistical Analysis

In 2010, experiment design was 2×4 factorial split plot with 4 replications. After 2010 sweet sorghum harvest, the field plots were leveled to improve the topography of the experimental area. In 2011, a 2×4 strip plot with 4 replications was used to improve homogeneity in the plots; the same treatments were used in both 2010 and 2011 experiments. Individual subplots measured 6×10m each year. The variety treatment was randomized to main plots and fertilizer rates were randomized to sub-plots.

Sweet sorghum yield response to treatments was tested using analysis of variance by the PROC ANOVA model (SAS Inc., Cary, NC). Regression analysis was conducted on the grain sorghum model simulated data and sweet sorghum field observed data to determine coefficients of determination. All statistical results were considered significant at 95% confidence level ($p \leq 0.05$).

3.4 Soil Sampling

In both years six random soil cores to 15 cm were collected and composited from each plot at planting and harvest. The composite soil samples were air dried for 48 hours, ground to pass a 2 mm sieve, and was then used for soil physical and chemical analysis. Soil pH, CEC, organic matter, particle size, and bulk density were determined. For chemical analysis (P, K, Ca, Mg, Cu, Mn), the soil samples were extracted using Mehlich-III reagent and analyzed on ICP (Inductively coupled plasma spectrometer). Soil total nitrogen was determined using Perkin Elmer 2400 Series II CHNS/O Elemental Analyzer.

3.5 Plant Sampling

In 2010, 3 randomly selected plants were selected in each plot for measurement of plant height. Height was determined from soil surface to the uppermost position of each plant, and height was measured and recorded 3 times (54, 71, 99 days after planting) during the growing season. Additionally, 15 randomly selected leaf samples from each plot were collected 3 times (43, 71, 86 days after planting) to analyze leaf nitrogen concentration, and 3 randomly selected plants per plot were used to determine leaf number 2 times during the growing season (54 and 71 days after planting) considering all greens leaves including top tip opened leaf.

In 2011, a specific set of parameter data was measured from a randomly selected 0.5 m^2 area of each plot, in two week intervals after planting. These parameters included: number of plants, number of leaves per plant, plant height, fresh biomass weight (including roots, cane, leaves and panicles), dry biomass weights of tops, root fresh weights, roots dry weights, from 4^{th} sampling onwards cane fresh weight, cane dry weights, leaves fresh weight, leaves dry weights. Dry weights were determined by collecting a sub-sample from each fresh sample and drying at 70^{o} C until dry weights were constant. Sweet sorghum juice was extracted in both seasons at harvest and analyzed for total sugar (sucrose, fructose, and glucose) content using HPLC (High performance liquid chromatography). The juice samples were oven dried at 105^{o} C for 48 hours to determine water content.

3.6 Sweet Sorghum Field Production

In both years the soil was disked to 30 cm prior to planting and designating plot establishment. One-third of N and all of the P_2O_5 and K_2O were applied at planting and the remaining two-thirds of the N requirement was side-dress incorporated in a band 5cm deep and 10 cm from the row 30 days after planting.

Sweet sorghum varieties Dale and M81-E were planted on June 28, 2010, then again on May 23, 2011. The spacing between rows was 75 cm with 25 cm in-row spacing. The crop was irrigated using overhead sprinkler system supplementing rainfall in both years. The crop was thinned 3 weeks after planting to maintain 25 cm spacing within the row. During first 30 days after planting, weed infestation was severe including crab grass, johnson grass, blue grass, other grasses and some broad leaf weeds. In 2010, weed control was done only through manual methods. In 2011, in addition to manual weeding, post emergence (atrazine) and pre-emergence herbicides (Dual Magnum, Syngenta Corp, Greensboro, NC) were applied three weeks after planting at label rates. Shoot borer (*Chilo patillus*) infestation was severe from 40 days after planting and anthracnose stalk rot disease was severe after cane formation. An insecticide (Sevin, Bayer Crop Scicence, US) and a fungicide (Dithane M45, Dow AgroScicences) were applied at label rates to control the pest infestation. The M81-E variety was tall and strong in 100%RRF plus soysoap treated plot compared to zero fertilizer control plot (Figure 2).

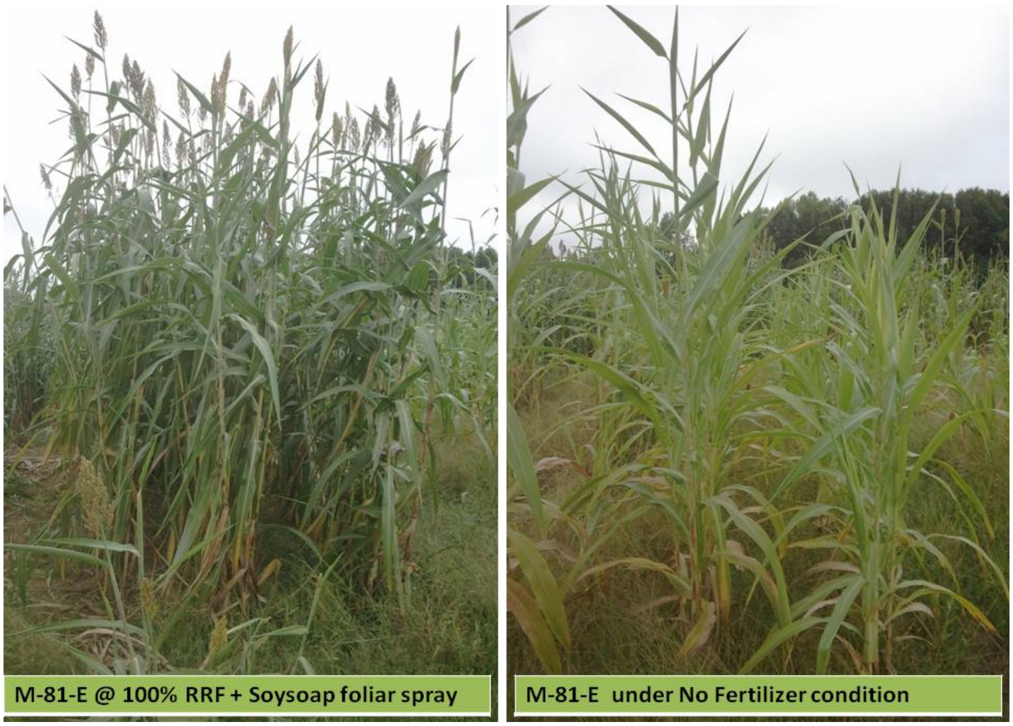


Figure 2. Sweet sorghum variety M81-E at harvest stage in 2011.

The sweet sorghum was harvested using machete manually at dough (grain filling) stage and juice was extracted using a cane crusher (sugarcane juice extractor SC300). In 2010, the Dale variety was harvested the first week of October, followed by M81-E in the second week of October. At harvest, the parameter: tops fresh weight (including cane, leaves and panicles), fresh cane weight (without leaves and panicles), and total juice were recorded. In 2011, Dale variety was harvested on September 6, followed by variety M-81-E on September 12, 2011. At harvest, tops fresh weight (including cane, leaves and panicles), fresh cane weight (without leaves and panicles), and total juice extracted were recorded. At the same time, a sub-sample of cane and leaves were collected, and then oven dried at 70^{o} C until constant dry weight.

3.7 Cover Crops

In the first week of November, 2010, sweet sorghum plots were disked to 30 cm and planted with crimson clover and rye as cover crops. In late spring of 2011, the cover crops were disked into soil at flowering stage. Before sweet sorghum planting in 2011, the field plots were tilled and leveled to get more even topography in the plots.

3.8 Soil Data for Model

The grain sorghum model requires soil data for at-least the upper 100 cm of the soil profile. Since we only sampled to 15, soil data from 15 to 150 cm were retrieved from the Web Soil Survey v.2.3 developed by Natural Resources Conservation Service (J. Fortner, et al., 2006). The soil data includes soil type, soil slope, soil texture (sand, clay, and silt percentages), soil pH, cation exchange capacity (CEC), bulk density, and organic matter (OM) (Table 3).

Table 3

Soil profile data collected through soil sampling and NRCS soil survey

Depth (cm)	**Sand** (%)	**Clay** (%)	**Silt** (%)	**Soil pH**	**BD** (g/cm^3)	**CEC** (meq/100 cm^3)	**OM** (%)
15	55.1	27.5	17.4	6.5	1.48	5.2	0.75
30	22.1	50	27.9	6.5	1.36	5.1	0.25
45	22.1	50	27.9	6.5	1.36	5.1	0.25
60	22.1	50	27.9	6.5	1.36	5.1	0.25
90	23.8	47.3	28.9	6.5	1.37	5.1	0.25
120	37	27	36	6.5	1.43	5.1	0.25
150	38.5	25	36.5	6.5	1.44	5.1	0.25

3.9 Weather Data for Model

Weather data were recorded using an automatic weather station (ECONET station) located approximately 50 m from the experimental plots. The recorded data were retrieved from

NC CRONOS Database v.2.7.2 of the State Climate Office of North Carolina website. Daily weather data included maximum (Avg. TMAX) and minimum (Avg. TMIN) temperatures, relative humidity (Avg. R HUM), average wind speed (Avg. WIND), total solar radiation, photo-synthetically active radiation (PAR), precipitation (Total RAIN), and open pan evaporation (Total EVAP). The retrieved data was used as weather input for grain sorghum model simulation. Daily data were then averaged for individual months (Table 4). In 2011, the PAR was greater than 2010 and may have affected crop growth.

Table 4

Monthly weather data during 2010 and 2011

Month-Year	**Avg. TMAX**	**Avg. TMIN**	**Avg. R HUM**	**Avg. WIND**	**Total RAIN**	**Total EVAP**	**Total Solar Radiation**	**PAR**
	(^{0}F)	(^{0}F)	(%)	(mph)	(in)	(in)	(W/m$^{2)}$	(mol/m^2)
Jan-10	45.9	26.6	61.5	4.84	4.08	2.56	6027	284.1
Feb-10	44.0	28.8	62.0	4.63	3.81	3.35	7054	328.6
Mar-10	61.6	40.4	58.5	4.80	3.35	6.41	10186	469.2
Apr-10	74.9	48.6	56.1	3.60	1.95	10.31	13968	634.3
May-10	79.0	60.1	70.9	3.93	6.69	11.57	14025	613.4
Jun-10	88.4	68.9	69.7	2.94	2.96	14.55	16184	703.0
Jul-10	89.3	69.4	68.2	2.70	7.53	14.77	16294	717.6
Aug-10	87.8	69.2	74.4	2.58	3.9	12.30	13928	607.6
Sep-10	84.7	61.7	65.0	3.16	6.53	9.97	12061	534.4
Oct-10	73.2	48.6	65.3	3.35	2.69	7.23	10516	474.8
Nov-10	60.9	37.6	64.4	3.19	0.93	1.85	2325	326.6
Dec-10	41.3	25.5	59.8	3.77	2.42	0.9	1116	263.1
Jan-11	44.6	27.0	61.5	3.90	1.35	1.1	1928	334.7
Feb-11	56.9	33.8	56.5	4.19	2.69	2.16	3904	610.9
Mar-11	59.4	40.0	61.4	5.17	4.97	3.18	4816	780.3
Apr-11	72.9	49.8	61.5	4.54	4.19	5.05	6766	1084.9
May-11	77.8	57.3	72.6	2.40	3.59	5.92	7607	1240.0
Jun-11	88.2	66.0	64.5	2.72	8.85	7.39	8699	1467.7
Jul-11	90.4	70.4	70.6	2.26	5.01	7.26	8232	1396.4
Aug-11	88.7	68.0	66.0	2.96	2.43	6.34	7369	1254.1
Sep-11	80.4	61.6	74.2	2.74	10.11	4.92	6110	737.3

3.10 DSSAT Grain Sorghum Model

The DSSAT v.4.5 crop simulation model is a program designed to simulate crop growth, development and yields under wide environmental conditions. The software was written in FORTRAN middle level mathematical programming language and graphically interfaced with Microsoft Visual Basic .NET programming language. The DSSAT program is a group of individual independent modules to simulate the growth of different crops linked in a main program. Each module runs through specific sub-routines. DSSAT has the following modules: XBuild - input crop management information in standard format, SBuild – create and edit soil profiles, GBuild – display graphs of simulated and observed data, compute statistics, ATCreate – create and edit observations from experiments, formatted correctly, WeatherMan - assist users in cleaning, formatting, generating weather data, ICSim – introductory tool to demonstrate potential yield concepts, and GLUE – generalized likelihood uncertainty estimation (Hoogenboom et al., 2010).

The daily weather data was entered into Weatherman module for 2010 and 2011 with the profile name NCAB station. Soil data were entered into the SBuild with profile name Mecklenburg sandy clay loam. The XBuild tool is the main module to run the model under provided weather, soil and treatment conditions. The treatments were defined in XBuild were the same as the treatments used in our sweet sorghum experiment. In XBuild, the conditions were provided by linking weather, soil, and cultivar profiles. After the XBuild was defined, a viable file was created to run the simulation using defined conditions. To develop a dedicated sweet sorghum model, the coefficients determined for grain production need to be modified to determine stalk juice and sugar content.

The genetic parameter coefficients were defined (Table 5) based on growing degree days (GDD) for each growth period. Generally GDD is calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature (T_{base} is the minimum temperature for plant growth).

$$GDD = \left(\frac{\text{Tmax} + \text{Tmin}}{2}\right) - \text{Tbase}$$

Table 5

Definitions of sorghum genetic parameters in cultivar file of DSSAT model

Parameter	Definition
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above TBASE during which the plant is not responsive to changes in photoperiod
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P2O, the rate of development is reduced
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O
P5	Thermal time from beginning of grain filling to physiological maturity (degree days above TBASE)
G1	Scaler for relative leaf size
G2	Scaler for partitioning of assimilates to the panicle (head)
PHINT	Phylochron interval; the interval in thermal time between successive leaf tip appearances (degree days)
P3	Thermal time from to end of flag leaf expansion to anthesis (degree days above TBASE)
P4	Thermal time from anthesis to beginning grain filling (degree days above TBASE)
P2	Thermal time from the end of the juvenile stage to tassel initiation under short days (degree days above TBASE)
PANTH	Thermal time from the end of tassel initiation to anthesis (degree days above TBASE)
PSAT	Critical photoperiod below which development is not delayed
PBASE	Ceiling photoperiod above which development is delayed indefinitely

The genetic coefficients were calculated using GLUE input parameter data of each variety in 2011. The GLUE uses ATCreate module as input. The ATCreate has two file types: A file and T file. The A-file is inputted with final yield parameter values including number of days to anthesis, number of days to harvest, maximum leaf number per stem, tops dry weights (Table 6). The T-file is a time course file, which needs growth data including tops dry weight, root dry weight, number of leaves, and leaf dry weight during different stages of crop growth (Appendix C).

Table 6

Input parameters used in the model to estimate genetic coefficients

Treatment	**Days to anthesis**		**Days to Dough stage**		**Maximum number of leaves per stem**		**Tops dry weight at Harvest (kg/ha)**	
	2010	2011	2010	2011	2010	2011	2010	2011
V1T1	72	70	108	105	14.5	11.7	7884	5717
V1T2	72	70	108	105	13.3	12.6	6657	14129
V1T3	72	70	108	105	14.9	13.2	7883	14369
V1T4	72	70	108	105	13.5	11.9	8440	10437
V2T1	82	79	114	112	15.7	16.2	9684	9043
V2T2	82	79	114	112	16.0	16.5	10709	13757
V2T3	82	79	114	112	13.7	17	10129	17880
V2T4	82	79	114	112	16.8	16.7	11276	13410

GLUE estimated the genetic coefficients with 10000 iterations in a loop for closer simulated data to observed data in ATCreate. Final estimated genetic coefficients are given in Table 7. New cultivars were created in the cultivar file located in the data genetics option of the main program. These newly defined cultivars were available in XBuild program for creating treatments. Estimated coefficients based on sweet sorghum growth data were comparatively greater than grain sorghum varieties, because of the higher growth rate in sweet sorghum. However, these genetic coefficients need to validate with experimental data of multiple locations for more than two years.

Table 7

Estimated genetic coefficients for varieties Dale and M81-E

Parameter	Dale	M81-E
P1	313.0	316.1
P2O	14.39	13.89
P2R	129.1	135.9
P5	485.3	503.1
G1	12.56	12.29
G2	5.590	5.805
PHINT	49.00	49.00
P3	218.4	236.1
P4	95.19	119.0
P2	102.0	102.0
PANTH	617.5	617.5
PBASE	0	0
PSAT	0	0

CHAPTER 4

Results and Discussion

4.1 Sweet Sorghum Yields

In 2010, the mean sweet sorghum tops fresh weights (including cane, leaves, and panicle) across fertilizer treatments was significantly different between the varieties. Variety M-81-E yielded significantly greater (38.4 ton ha^{-1}) than variety Dale (27.6 ton ha^{-1}). Fertilizer main treatment effect was not significant, nor was the interaction between variety and fertilizer treatment. In contrast, tops fresh yield was not affected by variety in 2011, but was affected by fertilizer across varieties. All plots receiving any level of fertilizer had greater yields (50.6 ton ha^{-1}) than zero fertilizer control (26.8 ton ha^{-1}). Similar to 2010, there was not a significant interaction between variety and fertilizer treatment in 2011 (Table 8).

Table 8

Sweet sorghum final tops fresh yield at harvest in 2010 and 2011

Treatment tops fresh weight tons/ha						
Fertilizer	**2010**			**2011**		
N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	29.6	34.4	32.0	21.5	32.1	26.8 ^{b}
168-56-168	27.6	36.6	32.1	50.8	52.1	51.5 ^{a}
84-28-84-soysoap	23.9	40.6	32.3	50.3	64.5	57.4 ^{a}
168-56-168-soysoap	29.1	42.1	35.6	36.0	50.0	43.0 ^{a}
Mean	27.6^{B}	38.4^{A}		39.6	49.7	

*The mean tops fresh weight with letter A was significantly greater than letter B at $p = 0.0175$ in 2010 and the mean tops fresh weight with letter “a” was significantly greater than letter “b” at $p = 0.0076$ in 2011.

Cane fresh weights (without leaves, panicle) showed a similar treatment response to that found for tops fresh weight in both 2010 and 2011. In 2010, variety M-81-E yielded significantly greater (28.6 ton ha^{-1}) than variety Dale (22.5 ton ha^{-1}). Fertilizer main treatment effect was not significant, nor was the interaction between variety and fertilizer treatment. In 2011, tops fresh yield was not affected by variety, but was affected by fertilizer across varieties. All plots receiving any level of fertilizer had greater yields (37.1 ton ha^{-1}) than the zero fertilizer control (18.1 ton ha^{-1}). Similar to 2010, there was not a significant interaction between variety and fertilizer treatment in 2011 (Table 9). The fresh tops weights of sweet sorghum was lower and or equal to the general yield range 40 – 110 ton ha^{-1} in European region (Michela, et al., 2011).

Table 9

Sweet sorghum final fresh cane yield at harvest in 2010 and 2011

Cane fresh weight tons/ha						
Fertilizer N-P-K (kg ha^{-1})	**2010**			**2011**		
	Dale	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	24.1	24.8	24.5	15.5	20.6	18.1 ^{b}
168-56-168	22.6	26.0	24.3	38.1	38.1	38.1 ^{a}
84-28-84-soysoap	19.7	31.0	25.4	37.5	46.3	41.9 ^{a}
168-56-168-soysoap	23.7	32.5	28.1	26.1	36.3	31.2 ^{a}
Mean	22.5 ^{B}	28.6 ^{A}		29.3	35.3	

*The mean fresh cane weight with letter A was significantly greater than letter B at p = 0.0500 in 2010 and the mean fresh cane weight with letter “a” was significantly greater than letter “b” at p = 0.0073 in 2011.

In 2010, final juice yield extracted from harvested canes was not affected by variety or fertilizer treatment. In 2011, final juice yield was not affected by varieties, but was affected by fertilizer treatment. All fertilizer received plots resulted in significantly greater juice yield (11504 L ha^{-1}) compared with the zero fertilizer control yield (4304 L ha^{-1}) (Table 10). This result is consistent with results observed for tops and cane yields. There was not a significant interaction between variety and fertilizer in either year.

Table 10

Sweet sorghum final juice yield at harvest in 2010 and 2011

Total Juice liters/ha						
Fertilizer	**2010**			**2011**		
N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	7942	7666	7804	4277	4331	4304 [b]
168-56-168	6414	8733	7573	12887	10273	11580 [a]
84-28-84-soysoap	6762	9133	7948	13411	13950	13681 [a]
168-56-168-soysoap	6995	10357	8676	8348	10154	9251 [a]
Mean	7028	8972		9731	9677	

* The mean juice yield with letter “a” was significantly greater than letter “b” at p = 0.0042 in 2011.

Total sugar (including sucrose, fructose, and glucose) concentration in juice extracted from harvested cane was significantly greater for fertilized plots (9.6%) compared with the control (7.06%) in 2010. Sugar concentration was similar for each variety tested. Total sugar concentration in juice was not affected by variety or fertilizer treatment in 2011 (Table 11). The interaction affect of variety and fertilizer treatments was not significant in either year.

Table 11

Sweet sorghum total sugar level of sucrose, fructose, and glucose in juice at harvest in 2010 and 2011

Total Sugar level in %						
Fertilizer	**2010**			**2011**		
N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	11.2	8.0	9.6 [A]	10.4	11.74	10.89
168-56-168	6.3	7.0	6.6 [B]	11.81	11.31	11.56
84-28-84-soysoap	6.7	8.5	7.6 [B]	10.07	10.77	10.42
168-56-168-soysoap	7.2	6.8	7.0 [B]	13.10	10.19	11.64
Mean	7.8	7.6		11.25	11.00	

* The mean total sugar level with letter "A" was significantly greater than letter "B" at p = 0.0204 in 2010.

In 2010, BRIX was significantly greater for the zero fertilizer control (13.5%) compared with all fertilizer rates (11.3%), but was not affected by variety. BRIX in 2011 was significantly greater for variety Dale (14%) compared with variety M-81-E (13%), but was not affected by fertilizer rate. There was not a significant interaction between variety and fertilizer treatments for BRIX, which is consistent with the pattern observed for sugar concentration (Table 12). The sweet sorghum stress for the fertilizer in control plot resulted greater sugar concentration in 2010. Total sugar and BRIX should have a similar response pattern, since BRIX is a measure of solid sugars in juice samples. However, the values of sugar content and BRIX are different based on the fact that total sugar level is measure of sucrose, fructose, and glucose detected in HPLC which was not able to detect all types of sugars in the juice.

Table 12

BRIX index in sweet sorghum juice samples at harvest in 2010 and 2011

BRIX reading of juice at Harvest in %						
Fertilizer	**2010**			**2011**		
N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	14.0	13.0	13.5 ^{A}	11.6	12.4	12.0
168-56-168	9.9	11.5	10.7 ^{B}	14.9	14.4	14.7
84-28-84-soysoap	11.8	12.4	12.1 ^{B}	14.9	12.8	13.9
168-56-168-soysoap	11.5	10.8	11.2 ^{B}	14.5	12.5	13.5
Mean	11.8	11.9		14.0 ^{a}	13.0 ^{b}	

* The mean BRIX index of juice with letter "A" was significantly greater than letter "B" at p = 0.0039 in 2010.

The tops fresh weights, cane fresh weights, extracted juice, and total sugar levels in each year were similar to the sweet sorghum yields reported in previous research (Almodares, et al., 1997). Tops, cane, and juice yields tended to be greater in 2011 than in 2010. Greater photo-synthetically active radiation was recorded in 2011 compared with 2010 during crop period (Table 4), which may have influenced the crop yield measured in 2011.

Sugar yield from the juice harvested was calculated based on the sugar concentration of juice in Table 13. There was not an effect of variety or fertilizer on sugar yield in either year. However, differences in sugar yield among fertilizer treatments were significant at $p = 0.07$ in 2011, when all fertilized treatments produced greater sugar yield (1290 L ha^{-1}) than the zero fertilizer control (501 L ha^{-1}).

Table 13

Sweet sorghum sugar yield in 2010 and 2011

Sugar yield in L ha^{-1}						
Fertilizer	**2010**			**2011**		
N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	889	613	751	448	553	501
168-56-168	454	763	608	1567	1146	1356
84-28-84-soysoap	410	592	501	1424	1506	1465
168-56-168-soysoap	500	700	600	1090	1026	1058
Mean	563	667		1132	1058	

4.2 DSSAT Grain Sorghum Model Output

The DSSAT grain sorghum model was used to simulate the growth parameters for given weather data, soil data, fertilizer treatments, and at estimated genetic coefficients. The observed data of 2011 growing season was entered into ATCreate module of model. The model simulated grain sorghum output parameters. Sweet sorghum output parameters are different from grain sorghum. However, tops dry weight, root dry weight, leaf dry weights of interest for both crops. The selected simulate data was compared with observed data for model performance at estimated sweet sorghum genetic coefficients.

Tops dry weights of sweet sorghum observed data and grain sorghum simulated datat at 2 weeks interval were plotted in Figure 3. The coefficients of determination (R^2) were calculated seven times during the crop period. The R^2 values for 14 days after planting (DAP), 28 DAP, 43 DAP, 56 DAP, and 86 DAP were negligible (below 0.01). The R^2 values were relatively greater at 70 DAP (R^2 = 0.25) and at harvest (R^2 = 0.47). However, overall the model simulation of the tops dry weights was not close to observed data.

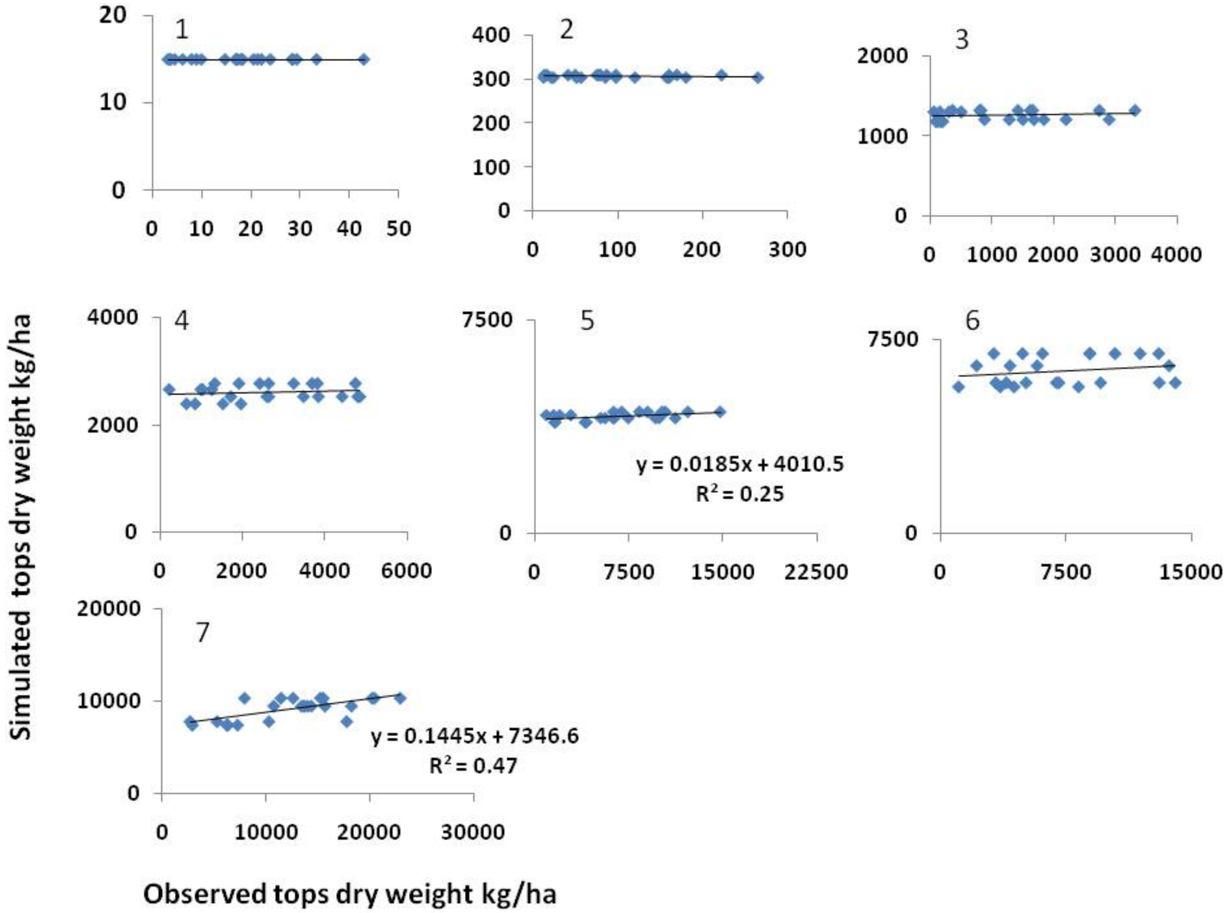


Figure 3. Comparison of sweet sorghum observed tops dry weight with model simulated tops dry weight at a two weeks interval during 2011 cropping season. Note: simulated versus observed at 14 days after planting (1), 28 DAP (2), 43 DAP (3), 56 DAP (4), 70 DAP (5), 86 DAP (6), and at harvest (7).

In grain sorghum tops weights have more biomass partition towards the panicle, whereas in sweet sorghum the biomass partition is primarily into cane. Sweet sorghum total tops dry weights were greater than grain sorghum simulated data for all treatments. Based on the output pattern between simulations and observed data, partitioning and photosynthesis rate modifications in SG_GROSUB subroutines are necessary to get a closer comparison.

The root dry weights of sweet sorghum observed and grain sorghum model simulation were not significantly correlated during any two week interval of the 2011 growing season. Root growth patterns are completely different in these two crops. The grain sorghum model simulated relatively greater root growth compared with sweet sorghum except for the first 15 days after planting (Figure 4). The pattern between simulated and observed data suggests that root growth factor modifications in the SG_ROOTGR subroutine will be necessary to develop a dedicated sweet sorghum model.

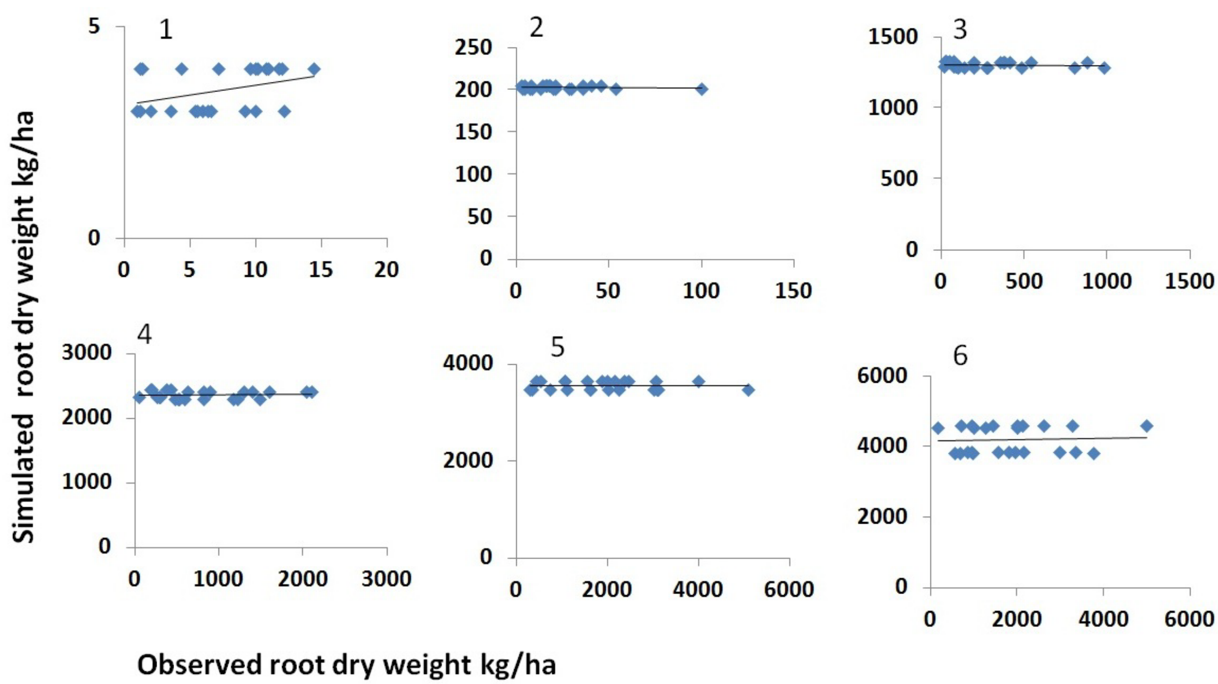


Figure 4. Comparison of sweet sorghum observed root dry weight with model simulated root dry weight at a two weeks interval during 2011 cropping season. Note: simulation versus

observed root dry weight at 14 days after planting (1), 28 DAP (2), 43 DAP (3), 56 DAP (4), 70 DAP (5), 86 DAP (6).

Compared with tops dry weight and root dry weight, model simulated leaf dry weight was more similar to the observed data with relatively greater R^2 values, respectively. Simulated leaf dry weights were closer to the observed data at 70 days after planting ($R^2 = 0.49$) (Figure 5). Grain sorghum typically has more leaf number per plant than sweet sorghum. Since sweet sorghum grows taller than grain sorghum, the internodes are expanded between each leaf and facilitate more solar radiation for biomass capture compared with grain sorghum.

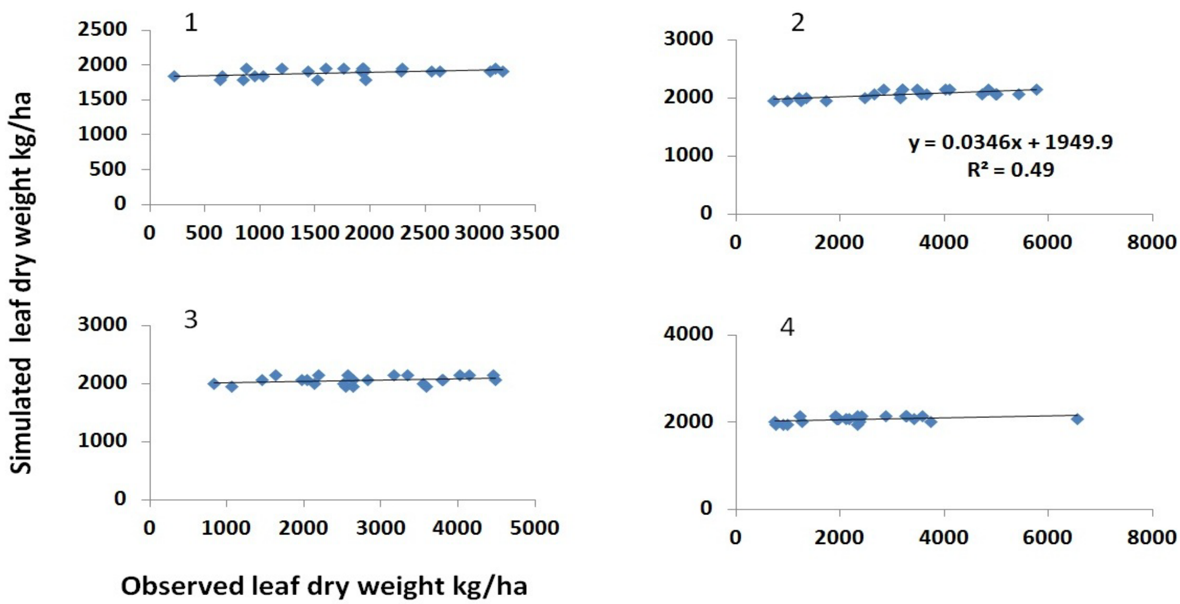


Figure 5. Comparison of sweet sorghum observed leaf dry weight with model simulated leaf dry weight at a two weeks interval during 2011 cropping season. Note: simulation versus observed dry weights at 56 days after planting (1), 70 DAP (2), 86 DAP (3), and at harvest (4).

The model output parameters including grain yield, root dry weight, leaf dry weight, and days for physiological maturity, are specific to grain sorghum production. However, some of the model output parameters share commonality to sweet sorghum observed yield parameters. While grain sorghum varieties genetic coefficients were used, the simulation dry weights (tops, root, and leaf) were very low compared with observed sweet sorghum dry weights. While estimated sweet sorghum varieties genetic coefficients were used, simulated tops and leaf dry weight were increased to an extent, but still lower than observed dry weights. The root dry weights were increased to greater than that of observed sweet sorghum root dry weights. To develop a sweet sorghum model, specific output parameters need to be written in the program. These parameters include cane fresh weight, number of days to dough stage (harvest), juice yield, and sugar content. The new output parameters can be written in the SG_CERES main subroutine.

4.3 Sweet Sorghum Observed Growth Patterns in 2011

Sweet sorghum plants generally grow taller than grain sorghum. The sweet sorghum plant heights were recorded every other week until final harvest and daily height increment was calculated using the slopes of plant height recorded against days after planting. Plant height growth was not affected by variety or by the interaction between variety and fertilizer, but was affected by fertilizer treatments. All fertilizer treated plots had greater plant height growth rate (3.12 cm day^{-1}) than the zero fertilizer control (2.34 cm day^{-1}) (Table 14).

Table 14

Growth rate of plant heights

Parameter	**Plant height growth rate per day (cm day^{-1})**		
Fertilizer N-P-K (kg ha^{-1})	**Dale**	**M81-E**	**Mean**
0-0-0	2.34	2.34	2.34[b]
168-56-168	3.00	3.02	3.01[a]
84-28-84-soysoap	3.30	3.38	3.34[a]
168-56-168-soysoap	2.97	3.07	3.02[a]
Mean	2.90	2.95	

*The mean plant height growth per day with letter “a” was significantly greater than letter “b” at p = 0.0040 in 2011.

In 2011, sweet sorghum tops dry weight, root dry weight, leaf dry weights were recorded in 2 weeks intervals. The growth rate of each of these variables was calculated to per day biomass accumulation (Appendix C). Sweet sorghum cane dry weight was recorded 56 days after planting. Growth rates were calculated based on the slopes of growth curve plotted between cane dry weights against days after planting. The cane dry weight per day was not affected by any treatment. However, the biomass dry weight (including root, cane, leaf, and panicle) growth rate was affected by fertilizer treatments, but not by variety or interaction between the variety and fertilizer treatments. All fertilized treatments had greater growth rate per day (72.3 kg ha^{-1} day^{-1}) than the zero fertilizer control (37.5 kg ha^{-1} day^{-1}) (Table 15). The growth rate of cane was greater compared to the rate of total biomass, likely because the biomass growth rates indicative of the rate of growth from planting to harvest where the initial growth rate was lower, whereas the cane growth rate indicates from 56 days after planting. The greater growth rate in a short period is indicative of greater slopes in growth curves against days after planting.

Table 15

Growth rate of sweet sorghum cane and total biomass dry weights

Parameter	**Cane dry weight growth** (kg ha^{-1} day^{-1})			**Biomass dry weights growth** (kg ha^{-1} day^{-1})		
Fertilizer N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	46.6	64.8	55.7	41.2	33.7	37.5 [b]
168-56-168	81	78.3	79.6	64.2	65.8	65 [a]
84-28-84-soysoap	81.6	100.7	91.2	90.4	77	83.7 [a]
168-56-168-soysoap	54.5	75.3	64.9	69.4	69.6	69.5 [a]
Mean	65.9	79.8		66.4	61.5	

* The mean biomass growth per day with letter “a” was significantly greater than letter “b” at $p = 0.0003$ in 2011.

The growth rate of tops dry weight was not affected by variety, but was affected by fertilizer treatments. The 50% RRF treated plots had greater growth rates than 100% RRF plus SoySoap and the zero fertilizer control plots, but was similar to that observed for the 100 % RRF treated plots. The growth rate of root dry weight had similar pattern as biomass dry weight. The affect of variety and the interaction between variety and fertilizer was not significant on root dry weight growth rate. However, there was an affect of fertilizer rate, where all fertilized plots had greater root dry weight growth rate (52. 13 kg ha^{-1} day^{-1}) than the zero fertilizer control (23.7 kg ha^{-1} day^{-1}) (Table 16).

Table 16

Growth rates of tops and root dry weights

Parameter	**Tops dry weights growth** (kg ha^{-1} day^{-1})			**Root dry weight growth** (kg ha^{-1} day^{-1})		
Fertilizer N-P-K (kg ha^{-1})	**Dale**	**M-81-E**	**Mean**	**Dale**	**M-81-E**	**Mean**
0-0-0	32.6	39.1	35.9^{C}	23.6	23.8	23.7^{b}
168-56-168	65.3	60.8	63.0^{AB}	36.6	57.4	47.0^{a}
84-28-84-soysoap	74.3	77.8	76.0^{A}	60.7	61.1	60.9^{a}
168-56-168-soysoap	54.6	61.0	57.8^{B}	47.9	49.1	48.5^{a}
Mean	56.7	59.6		42.2	47.9	

*The mean dry tops growth per day with letter “A” was significantly greater than letter “B” at p = 0.0039 and the mean dry root growth per day with letter “a” was significantly greater than letter “b” at p = 0.0216 in 2011.

CHAPTER 5

Conclusion

In 2010, sweet sorghum variety M81-E had greater yields of tops fresh weight and cane fresh weight than variety Dale with no affect of fertilizer rate. In 2011, all fertilizer treatments produced greater tops fresh weight and cane fresh weight than the zero fertilizer control. The juice extracted from cane was greater for all fertilized treatments compared with the zero fertilizer control in 2011 but was not affected by variety. Total sugar levels and BRIX had a similar trend in both years, in that all fertilized treatments had greater sugar percentage than the control in 2010, but no difference was observed in 2011. Overall, yields tended to be greater in 2011 than 2010. In all measured variables in 2011, the 50% RRF resulted in greater yields than the control but was equal that of other higher fertilizer rates. Thus, the optimum fertilizer rate is between zero and 50% RRF for sweet sorghum production Piedmont region of North Carolina, and inclusion of SoySoap did not improve yield nor any measured growth variables.

The grain sorghum model did not simulate sweet sorghum growth reasonably, even at adjusted genetic coefficients. However, a pattern of difference between simulated and observed data was observed. When the model parameters were adjusted to simulate yields above that typical for grain sorghum, the output tended to simulate greater root growth than typical of sweet sorghum.

5.1 Suggestions for Further Study

The rate of biomass accumulation is greater in sweet sorghum than grain sorghum. To make necessary modifications to the grain sorghum model to accurately reflect sweet sorghum growth characteristics, the model source script must be modified by creating new strings that represent sweet sorghum production related output parameters, such as sugar content in juice,

juice yield, sugar yield, and cane fresh weight. The observed growth rates of sweet sorghum are useful information to make the necessary modifications in the model growth subroutines. The identification of the correct parameters strings is the next step in developing a dedicated sweet sorghum model. However, to develop a dedicated sweet sorghum model, more detailed experimental data is needed from different multiple site-years across varying landscapes.

References

Almodares, A., Sepahi, A., & M., S. (1997). Sweet sorghum cultural practices in Iran. *Chinese academy of sciences*(first international sweet sorghum conference), 175-183.

Amaducci, S., Monti, A., & Venturi, G. (2004). Non-structural carbohydrates and fibre components in sweet and fibre sorghum as affected by low and normal input techniques. *Industrial Crops and Products, 20*(1), 111-118.

Andreuccetti, P., Bacchiet, P., Barbucci, P., Belletto, A., & Frati, G. (1991). Energy Crops: farming tests in two different Italian sites, and preliminary assessment of technologies to use them for electricity production. *Grassi, G., Bertini, I (Eds.), First European Forum on Electricity Production from Biomass and Solid Wastes by Advanced Technologies. Florence, November 27-29*, 223-228.

Barbanti, L., Grandi, S., Vecchi, A., & Venturi, G. (2006). Sweet and fibre sorghum (Sorghum bicolor (L.) Moench), energy crops in the frame of environmental protection from excessive nitrogen loads. *European Journal of Agronomy, 25*(1), 30-39.

Bennett, A. S., & Anex, R. P. (2009). Production, transportation and milling costs of sweet sorghum as a feedstock for centralized bioethanol production in the upper Midwest. *Bioresource Technology, 100*(4), 1595-1607.

Birch, C. J., Carberry, P. S., Muchow, R. C., McCown, R. L., & Hargreaves, J. N. G. (1990). Development and evaluation of a sorghum model based on CERES-Maize in a semi-arid tropical environment. *Field Crops Research*, *24*(1-2), 87-104.

Bohlmann, G. M. (2005). Biorefinery process economics.Chemical Engineering Progress. *ABI/INFORM Trade and Industry, 101*(10), 37.

Bouwman, A. F., Lee, D. S., Asman, W. A. H., Dentener, F. J., Van Der Hoek, K. W., & Olivier, J. G. J. (1997). A global high-resolution emission inventory for ammonia. *Global Biogeochem. Cycles, 11*(4), 561-587.

Buxton, D. R., Anderson, I. C., & Hallam, A. (1999). Performance of Sweet and Forage Sorghum Grown Continuously, Double-Cropped with Winter Rye, or in Rotation with Soybean and Maize. *Agron. J., 91*(1), 93-101.

Castrignano, A., Di Bari, V., & Stelluti, M. (1996). Evapotranspiration predictions of CERES-Sorghum model in southern Italy. *European Journal of Agronomy, 6*(1997), 265-274.

Connor, D. J. (1990). Simulation of ecophysiological processes of growth in several annual crops: by F.W.T. Penning de Vries, D.M. Jansen, H.F.M. ten Berge and A. Bakema. Pudoc, Wageningen, 286 pp., 1989. Price Dfl. 100.00/US$ 57.00. ISBN 90-220-0937-8. *Field Crops Research, 24*(1-2), 143-144.

David, L., & Geraldo, S. (2006). Bumper Crop: As Brazil Fills up on Ethanol, It weans Off Energy Imports; After Years of State Support, Use of Cheap Fuel made is Widespread; U.S. Delegations Pay a Visit. *Wall Street Journal*(Estern Edition).

El-Sharkawy, M., & Hesketh, J. (1965). Photosynthesis among species in relation to characteristics of leaf anatomy and CO2 diffusion resistances. *Crop Science, 5*, 517-521.

El-Sharkawy, M. A. (2011). Overview: Early history of crop growth and photosynthesis modeling. *Biosystems, 103*(2), 205-211.

Ewers, R. M., Scharlemann, J. P. W., Balmford, A., & Green, R. E. (2009). Do increases in agricultural yield spare land for nature? *Global Change Biology, 15*(7), 1716-1726.

Fred, S. (2007). Energy Independence and Security Act of 2007: A Summary of Major Provisions. *CRS Report for Congress*.

Gardner, J. C., Maranville, J. W., & Paparozzi, E. T. (1994). Nitrogen use efficiency among diverse sorghum cultivars. *Crop Science, 34*, 728-733.

Geng, S., Hills, F. J., Johnson, S. S., & Sah, R. N. (1989). Potential Yields and On-Farm Ethanol Production Cost of Corn, Sweet Sorghum, Fodderbeet, and Sugarbeet. *Journal of Agronomy and Crop Science, 162*(1), 21-29.

Grassi, G., Tondi, G., & Helm, P. (2004). Small - sized Commercial Bioenergy Technologies as an Instrument of Rural Development. Biomass and Agriculture: Sustainability, Markets and Policies. *OECD Publication Services, Paris*, 277-287.

Guigou, M., Lareo, C., Pérez, L. V., Lluberas, M. E., Vázquez, D., & Ferrari, M. D. (2011). Bioethanol production from sweet sorghum: Evaluation of post-harvest treatments on sugar extraction and fermentation. *Biomass and Bioenergy, 35*(7), 3058-3062.

Heinimö, J., & Junginger, M. (2009). Production and trading of biomass for energy - An overview of the global status. *Biomass and Bioenergy, 33*(9), 1310-1320.

Hoogenboom, G. (1991). Simulation of ecophysiological processes of growth in several annual crops : Edited by F. W. T. Penning de Vries, D. M. Jansen, H. F. M. ten Berge and A. Bakema. Simulation Monographs 29. Pudoc, Wageningen, The Netherlands, 1989. 271 pp. ISBN 90-220-0937-8. Price: $100.00 (hardback). *Agricultural Systems, 36*(2), 244-244.

Hoogenboom, G., Jones, J. W., Wilkens, P. W., Porter, C. H., Boote, K. J., Hunt, L. A., et al. (2010). Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5 [CD-ROM]. *University of Hawaii, Honolulu, Hawaii.*

Hoogenboom, G., Wilkens, P. W., Thomton, P. K., Jones, J. W., Hunt, L. A., & Imamura, D. T. (1999). Decision Support System for agrotechnology transfer v3.5. *In: Hoogenboom, G., Wilkens, P.W., Tsuji, G.Y. (Eds), DSSAT version 3, 4*(ISBN 1-886684-04-9), 1-36.

Hornung, M., Dyke, H., Hall, J. R., & Metcalfe, S. E. (1997). The critical load approach to air pollution control. In R. E. Hester & R. M. Harrison (Eds.), *Air Quality Management* (Vol. 8, pp. 119-140): The Royal Society of Chemistry.

Hunter, E. L., & Anderson, I. C. (2010). Sweet Sorghum *Horticultural Reviews* (pp. 73-104): John Wiley & Sons, Inc.

J. Fortner, K. Harward, D. Lytle, & Williamson, D. (2006). Web Soil Survey. *ESRI Federal User Conference*.

J.T. Ritchie, U. Singh, Godwin., D. C., & Bowen, W. T. (1998). Cereal growth, development and yield. *Systems approaches for sustainable agricultural development, 7*, 79-98.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., et al. (2003). The DSSAT cropping system model. *European Journal of Agronomy, 18*(3-4), 235-265.

Jones, J. W., Tsuji, G. Y., Hoogenboom, G., Hunt, L. A., Thornton, P. K., Wilkens, P. W., et al. (1998). Decision support system for agrotechnology transfer: DSSAT v3 (pp. 157-177). Dordrecht: Kluwer Academic Publishers.

Keeney, D. R., & DeLuca, T. H. (1992). Biomass as an energy source for the midwestern U.S. *American Journal of Alternative Agriculture, 7*(03), 137-144.

Kuesters, J., & Lammel, J. (1999). Investigations of the energy efficiency of the production of winter wheat and sugar beet in Europe. *European Journal of Agronomy, 11*(1), 35-43.

Loomis, R. S., Rabbinge, R., & Ng, E. (1979). Explanatory Models in Crop Physiology. *Annual Review of Plant Physiology, 30*(1), 339-367.

Michela, P., Alessia, V., & Denis, P. (2011). Diffusion of a sustainable EU model to produce 1st generation ethanol from sweet sorghum in decentralised plants. *CETA*.

Monk, R. L., Miller, F. R., & McBee, G. G. (1984). Sorghum improvement for energy production. *Biomass, 6*(1-2), 145-153.

Monti, A., & Venturi, G. (2003). Comparison of the energy performance of fibre sorghum, sweet sorghum and wheat monocultures in northern Italy. *European Journal of Agronomy, 19*(1), 35-43.

Negro, M. J., Solano, M. L., Ciria, P., & Carrasco, J. (1999). Composting of sweet sorghum bagasse with other wastes. *Bioresource Technology*, *67*(1), 89-92.

Oenema, O., Kros, H., & de Vries, W. (2003). Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *European Journal of Agronomy, 20*(1-2), 3-16.

Parrish, D. J., & Cundiff, J. S. (1985). Long-term rention of fermentables during aerobic storage of bulked sweet sroghum. *Proceedings of the 5th Annual Solar and Biomass Workshop, Atalanta, GA*, 137-140.

Penning de Vries, F. W. T., Jansen, D. M., Ten Berge, H. F. M., & Bakema, A. (1989). Simulation of ecophysiological processes of growth in several annual crops. *PUDOC, Wageningen.*

Perlack, R. D. (2005). *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasability of a Billion-Ton Annual Supply* (No. ORNL/TM-2005/66; TRN: US200617%%291).

Ratnavathi, C. V., Suresh, K., Kumar, B. S. V., Pallavi, M., Komala, V. V., & Seetharama, N. (2010). Study on genotypic variation for ethanol production from sweet sorghum juice. *Biomass and Bioenergy, 34*(7), 947-952.

Reddy, B. V. S. R., P.S. (2003). Sweet Sorghum: Characteristics and Potential. *International Sorghum and Millets Newsletter, 44*, 26-28.

RFA. (2011). Historic US fuel ethanol production.

Robertson, M. J., Fukai, S., Hammer, G. L., & Ludlow, M. M. (1993). Modelling root growth of grain sorghum using the CERES approach. *Field Crops Research, 33*(1-2), 113-130.

Seetharama, N., Dayakar, R. B., Ratnavathi, C., Shahid, P. M., Binu, M., & Bharath, K. K. (2002). Sorghum as raw material for alcohol production. *Distillers Association of Maharashtra*(Seminar on Current Development in Alcohol Industry).

Shih, S. F., Gascho, G. J., & Rahi, G. S. (1981). Modeling biomass production of sweet sorghum. *Journal Name: Agron. J.; (United States); Journal Volume: 73:6*, Medium: X; Size: Pages: 1027-1032.

Sipos, B., Réczey, J., Somorai, Z., Kádár, Z., Dienes, D., & Réczey, K. (2009). Sweet Sorghum as Feedstock for Ethanol Production: Enzymatic Hydrolysis of Steam-Pretreated Bagasse. *Applied Biochemistry and Biotechnology, 153*(1), 151-162.

Soltani, A., & Almodares, A. (1994). Evaluation of the investments in sugarbeet and sweet sorghum production. *National convetion of sugar production from agriculture products*(Shahid chamran university, Ahwaz, Iran).

Steven, B., Billy, R. H., Ghasem, S., Norris, T., & Johnny, C. W. (2007). North Carolina’s Strategic Plan for Biofuels Leadership

Sumantri, A., & Edi, P. (1997). Sweet sorghum research and development in Indonesia. *Chinese academy of sciences*(First International Sweet Sorghum Conference), 49-54.

Tsuji, G. Y., Uehara, G., & Balas, S. E. (1994). Decision Support System for Agrotechnology Transfer (DSSAT) Version 3. *University of Hawaii, Honolulu, Hawaii*.

Uehara, G., & Tsuji, G. Y. (1998). Overview of IBSNAT (pp. 1-7). Dordrecht: Kluwer Academic Publishers.

Venturi, P., & Venturi, G. (2003). Analysis of energy comparison for crops in European agricultural systems. *Biomass and Bioenergy*, *25*(3), 235-255.

Watson, D. J. (1952). The Physiological Basis of Variation in Yield. In A. G. Norman (Ed.), *Advances in Agronomy* (Vol. Volume 4, pp. 101-145): Academic Press.

Zewdie, L. (1999). Simulation of grain sorghum nitrogen response. *dissertation, Kansas State University, United States* .

Appendix A

Experimental Design

Season 2010 - Sweet Sorghum Experimental Design

Shed side

6 m 2 m 4 m

R2 V1 T2	R2 V1 T1	R2 V1 T4	R2 V1 T3	R3 V2 T1	R3 V2 T2	R3 V2 T3	R3 V2 T4	10 m
R2 V2 T3	R2 V2 T4	R2 V2 T2	R2 V2 T1	R3 V1 T2	R3 V1 T4	R3 V1 T1	R3 V1 T3	
								6 m
R1 V2 T2	R1 V2 T3	R1 V2 T4	R1 V2 T1	R4 V1 T1	R4 V1 T3	R4 V1 T4	R4 V1 T2	
R1 V1 T4	R1 V1 T2	R1 V1 T1	R1 V1 T3	R4 V2 T3	R4 V2 T1	R4 V2 T2	R4 V2 T4	

Road side

Fall 2011 Sweet Sorghum Experimental Design

Storage shed

V1	**V2**	**V2**	**V1**	**V1**	**V2**	**V2**	**V1**
T1	T1	T3	T3	T2	T2	T4	T4
		R1					
T3	T3	T2	T2	T4	T4	T1	T1
R1		**R2**		**R3**		**R4**	
T2	T2	T4	T4	T1	T1	T3	T3
		R2					
T4	T4	T1	T1	T3	T3	T2	T2

Main Entrance **Road side**

Appendix B

Sweet Sorghum 2010 Data

B.1 Sweet sorghum final yield components

Plot	**Tops Fresh Wt (kg/ha)**	**Cane fresh Wt (kg/ha)**	**Juice (lt/ha)**	**Leaf fresh Wt (kg/ha)**	**Total Sugar (%)**	**BRIX(%)**	**BRIX**
						09/09/2010	**at harvest**
R2V1T1	32412	27414	9969	4998	9.6	11.7	14
R1V1T1	35511	28289	8896	7222	13.2	13.4	15
R4V1T1	28239	23316	7065	4923	10.7	15.0	13
R3V1T1	22316	17518	5839	4798	11.4	15.1	14
R2V1T2	20642	16493	4582	4148	7.4	13.4	14
R1V1T2	26240	23990	9792	2249	7.1	11.5	12
R3V1T2	25265	20342	6896	4923	6.3	11.7	10
R4V1T2	23566	17918	5780	5648	6.0	10.7	11
R1V1T3	27564	22366	5389	5198	8.1	12.9	11
R2V1T3	30738	26190	8448	4548	4.9	14.1	11
R4V1T3	28838	24315	7844	4523	8.1	13.1	8
R3V1T3	23141	17493	3976	5648	3.9	13.6	10
R1V1T4	44332	39484	9630	4848	5.9	15.4	11
R2V1T4	27714	23541	7980	4173	9.6	11.7	13
R3V1T4	24265	15669	4896	8597	9.8	12.4	13
R4V1T4	20142	16144	5472	3998	3.3	10.9	9
R1V2T1	44382	31887	10123	12495	8.8	9.7	11
R2V2T1	35511	27539	8884	7972	6.2	13.3	15
R4V2T1	38160	28164	8407	9996	9.0	10.6	14
R3V2T1	19592	11545	3252	8047	8.0		12
R1V2T2	46681	34086	8314	12595	7.2	9.7	12
R2V2T2	52654	44182	14486	8472	7.5	9.6	11
R3V2T2	28788	19967	5470	8821	7.7	10.4	12
R4V2T2	34236	25865	8263	8372	11.4	9.1	15
R2V2T3	31013	21666	6878	9346	6.2	10.3	13
R1V2T3	52004	35086	13759	16918	6.1	7.9	11
R4V2T3	33237	25815	8195	7422	7.2	9.6	11
R3V2T3	29988	21341	6098	8647	8.5	9.6	11
R2V2T4	55878	46531	16618	9346	7.2	7.5	11
R1V2T4	43862	33886	11487	9976	6.7	9.8	10
R3V2T4	40634	29788	9166	10846	5.3	8.9	12
R4V2T4	27889	19742	4156	8147	8.2	9.4	10

B.2 Sweet sorghum 2010 measurements during production

Plot	Plant Height (in)			Leaf Nitrogen (%)			Leaf Number	
	08/21/2010	09/07/2010	10/05/2010	08/10/2010	09/07/2010	09/23/2010	08/21/2010	09/07/2010
R2V1T1	81.0	101.9	109.3	3.2	2.4	2.4	10.7	14.7
R1V1T1	84.2	103.5	104.3	3.1	2.4	2.3	11.0	14.3
R4V1T1	81.0	101.9	109.3	3.2	2.4	2.1	10.7	14.7
R3V1T1	84.2	103.5	104.3	3.1	2.4	2.0	11.0	14.3
R2V1T2	79.4	95.8	102.6	3.1	2.2	2.0	11.7	13.3
R1V1T2	79.4	95.8	102.6	3.1	2.2	2.2	11.7	13.3
R3V1T2	79.4	95.8	102.6	3.1	2.2	1.9	11.7	13.3
R4V1T2	79.4	95.8	102.6	3.1	2.2	1.9	11.7	13.3
R1V1T3	73.6	89.9	100.9	3.0	2.3	2.2	12.3	16.0
R2V1T3	79.3	90.7	97.3	3.1	2.4	2.3	11.7	14.0
R4V1T3	85.5	99.8	102.6	3.0	2.5	2.2	11.3	14.7
R3V1T3	79.5	93.4	100.3	3.0	2.4	2.2	11.8	14.9
R1V1T4	65.6	63.3	63.7	2.8	2.4	2.3	10.7	11.7
R2V1T4	81.5	111.4	109.6	3.2	2.8	2.6	12.7	15.3
R3V1T4	65.6	63.3	63.7	2.8	2.4	2.0	10.7	11.7
R4V1T4	81.5	111.4	109.6	3.2	2.8	2.0	12.7	15.3
R1V2T1	78.9	90.1	105.8	3.0	2.1	1.9	10.0	15.7
R2V2T1	71.0	87.2	110.3	3.1	1.8	1.9	11.3	15.3
R4V2T1	77.7	91.6	102.8	2.8	1.8	1.6	11.7	16.0
R3V2T1	75.8	89.6	106.3	3.0	1.9	1.6	11.0	15.7
R1V2T2	61.8	64.7	71.1	2.9	2.3	2.1	10.3	14.3
R2V2T2	80.7	95.2	120.8	3.0	2.5	2.3	11.7	17.7
R3V2T2	61.8	64.7	71.1	2.9	2.3	2.1	10.3	14.3
R4V2T2	80.7	95.2	120.8	3.0	2.5	2.1	11.7	17.7
R2V2T3	73.1	78.1	78.2	3.5	2.4	2.1	9.7	13.7
R1V2T3	73.1	78.1	78.2	3.5	2.4	2.2	9.7	13.7
R4V2T3	73.1	78.1	78.2	3.5	2.4	2.1	9.7	13.7
R3V2T3	73.1	78.1	78.2	3.5	2.4	2.2	9.7	13.7
R2V2T4	83.2	89.9	97.3	3.4	2.6	2.4	12.3	17.0
R1V2T4	81.2	98.6	113.4	3.2	2.5	2.2	10.3	16.7
R3V2T4	83.2	89.9	97.3	3.4	2.6	2.3	12.3	17.0
R4V2T4	81.2	98.6	113.4	3.2	2.5	2.2	10.3	16.7

Appendix C

Sweet Sorghum Observed Data 2011

C.1 Leaf number during production

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP	112 DAP
R1V1T1	5.0	8.0	6.8	7.3	11.7	13.7	12.0
R2V1T1	5.3	7.7	7.3	6.0	8.0	12.0	12.7
R3V1T1	6.3	8.3	8.3	7.0	8.7	11.0	11.3
R4V1T1	5.7	8.0	8.0	7.0	9.3	9.0	10.7
R1V1T2	6.0	9.7	11.0	10.7	14.0	14.3	15.0
R2V1T2	5.7	8.7	9.3	8.7	9.0	8.7	11.7
R3V1T2	7.0	7.3	8.2	8.0	12.3	10.3	10.7
R4V1T2	6.3	9.3	12.0	9.0	11.0	38.3	13.0
R1V1T3	4.7	8.7	10.0	10.3	14.0	12.3	14.7
R2V1T3	5.0	8.7	9.7	8.3	12.0	10.3	11.7
R3V1T3	6.3	9.7	9.7	9.7	13.0	12.0	12.0
R4V1T3	5.3	10.0	9.4	7.7	13.0	12.0	14.3
R1V1T4	5.0	6.3	11.7	10.3	14.0	11.7	13.3
R2V1T4	5.3	8.3	9.7	8.7	12.0	10.3	11.0
R3V1T4	6.0	9.7	9.4	8.3	12.0	10.0	12.3
R4V1T4	4.7	10.0	7.8	9.0	11.0	11.3	11.0
R1V2T1	3.7	6.7	7.4	8.0	11.0	12.0	14.3
R2V2T1	4.7	8.3	9.8	8.0	9.3	10.0	18.3
R3V2T1	6.7	8.0	7.3	7.0	11.0	10.3	16.7
R4V2T1	5.7	9.0	8.4	7.7	8.7	7.3	15.3
R1V2T2	6.0	8.3	8.8	9.7	14.7	14.3	16.7
R2V2T2	4.3	8.7	8.3	7.7	11.0	10.0	15.7
R3V2T2	6.0	9.7	8.7	9.3	13.7	10.0	17.0
R4V2T2	3.3	9.0	9.8	10.3	12.7	13.3	16.7
R1V2T3	6.0	9.3	11.2	10.3	14.3	13.3	15.0
R2V2T3	4.3	8.0	10.0	9.0	14.7	11.0	17.7
R3V2T3	6.0	8.7	9.4	9.7	13.7	15.0	17.0
R4V2T3	6.7	9.7	10.5	8.7	11.7	11.3	18.3
R1V2T4	5.7	9.0	9.2	10.0	14.3	13.7	16.7
R2V2T4	4.3	9.3	10.0	11.7	12.0	13.3	18.0
R3V2T4	6.0	9.0	8.9	8.3	12.3	9.3	15.7
R4V2T4	6.0	10.0	9.2	8.7	11.7	12.3	16.3

C.2 Plant Heights (in)

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP	112 DAP
R1V1T1	2.4	7.1	13.3	40.4	53.0	93.7	102.0
R2V1T1	3.8	8.3	21.0	18.0	28.0	19.7	70.7
R3V1T1	5.8	10.0	24.3	39.0	43.3	75.0	97.3
R4V1T1	4.3	10.3	25.3	28.7	39.7	49.3	87.7
R1V1T2	5.4	14.7	44.3	61.0	72.3	110.7	119.0
R2V1T2	4.7	11.3	36.0	39.7	61.3	64.0	109.3
R3V1T2	6.0	13.9	31.0	42.0	73.0	83.7	107.0
R4V1T2	5.0	12.3	30.0	46.3	66.3	72.3	109.0
R1V1T3	2.8	10.7	26.3	65.3	73.7	94.0	120.7
R2V1T3	3.8	13.7	28.7	41.0	67.0	91.0	110.7
R3V1T3	7.9	17.0	37.3	49.3	80.7	71.7	118.7
R4V1T3	4.3	9.6	26.3	44.0	73.7	103.3	125.3
R1V1T4	5.1	4.0	32.7	59.0	84.0	82.7	114.0
R2V1T4	3.5	14.0	25.0	49.3	72.0	64.0	109.7
R3V1T4	3.9	11.7	30.7	47.3	68.7	75.3	114.7
R4V1T4	2.8	8.7	16.3	28.7	61.7	65.0	99.0
R1V2T1	2.6	5.9	18.7	33.7	51.0	71.3	106.0
R2V2T1	3.9	9.0	15.0	22.3	27.3	49.7	90.0
R3V2T1	8.4	10.3	19.0	28.3	49.3	61.3	117.0
R4V2T1	5.0	10.0	13.0	28.7	30.7	29.7	78.0
R1V2T2	6.4	17.3	31.0	51.3	78.0	102.0	140.3
R2V2T2	2.6	15.0	17.0	32.3	45.3	50.7	111.0
R3V2T2	4.2	16.3	27.0	47.0	64.0	67.3	120.0
R4V2T2	4.8	18.0	31.0	38.0	62.0	81.3	126.3
R1V2T3	6.7	13.7	41.0	52.7	78.0	103.0	135.7
R2V2T3	2.9	6.6	27.3	40.0	62.3	56.0	127.0
R3V2T3	6.7	17.0	31.3	46.3	80.3	92.0	133.7
R4V2T3	5.5	15.0	31.3	53.0	69.7	80.7	148.3
R1V2T4	4.1	16.7	31.3	49.0	77.3	84.0	136.0
R2V2T4	2.9	20.7	29.0	48.0	59.3	86.3	126.0
R3V2T4	5.9	17.7	35.7	38.7	68.3	69.3	121.7
R4V2T4	3.7	12.7	24.7	43.0	52.0	73.7	116.3

C.3 Biomass fresh weight (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP
R1V1T1	20	83	320	7258	20866	68040
R2V1T1	40	71	1300	688	6350	13608
R3V1T1	140	206	2220	5443	14515	30845
R4V1T1	100	417	3000	4536	9072	20866
R1V1T2	140	1370	9320	34474	90720	58061
R2V1T2	120	494	6940	9072	47174	17237
R3V1T2	100	1290	10760	14515	61690	44453
R4V1T2	100	646	6820	18144	48082	26309
R1V1T3	10	360	4680	29030	67133	71669
R2V1T3	100	533	2420	11794	45360	51710
R3V1T3	260	1688	16420	23587	84370	37195
R4V1T3	80	549	4760	17237	76205	69984
R1V1T4	60	63	7140	23587	86184	100699
R2V1T4	100	515	4380	19051	55339	21773
R3V1T4	80	564	12620	15422	57154	29030
R4V1T4	80	447	1780	9072	28123	30845
R1V2T1	16	83	1180	7258	8165	49896
R2V2T1	60	89	700	2722	9979	27216
R3V2T1	180	325	1580	3629	29030	24494
R4V2T1	80	285	720	5443	29030	4536
R1V2T2	120	2022	7520	34474	85277	101606
R2V2T2	20	623	820	9072	34474	26309
R3V2T2	60	1471	11560	23587	48082	18144
R4V2T2	120	1151	7720	16330	38102	40824
R1V2T3	120	933	11380	29030	72576	70762
R2V2T3	20	172	5000	15422	50803	39010
R3V2T3	120	1121	7720	22680	43546	58968
R4V2T3	60	731	7800	30845	86184	45360
R1V2T4	60	889	10360	23587	19051	78019
R2V2T4	20	1995	5320	23587	62597	43546
R3V2T4	80	2323	14300	9979	72576	22680
R4V2T4	40	505	7180	14515	36288	52618

C.4 Biomass dry weights (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP
R1V1T1	6	22	75	1552	4045	17393
R2V1T1	14	17	230	271	1725	2701
R3V1T1	37	50	407	1256	2392	6724
R4V1T1	28	93	584	1320	1845	4807
R1V1T2	39	211	3222	5917	17923	10448
R2V1T2	33	97	1700	1840	8603	4129
R3V1T2	29	197	2420	2507	11301	10842
R4V1T2	36	120	1931	4468	10024	5729
R1V1T3	5	65	1013	5179	13469	16344
R2V1T3	41	104	457	2896	8371	12198
R3V1T3	55	268	4300	4640	17348	8218
R4V1T3	27	98	940	3165	13316	14872
R1V1T4	16	16	1993	3203	17122	19172
R2V1T4	29	95	861	3897	11880	4494
R3V1T4	24	99	3340	2958	11412	7761
R4V1T4	26	99	388	2063	4724	5675
R1V2T1	5	19	218	2388	2103	10216
R2V2T1	19	26	148	833	2202	5648
R3V2T1	48	71	275	1048	5131	4544
R4V2T1	24	61	111	1907	5240	1239
R1V2T2	29	365	1691	6887	13948	18987
R2V2T2	8	108	191	2607	7179	4871
R3V2T2	16	235	3080	5448	9062	4002
R4V2T2	27	190	1873	3450	8121	9018
R1V2T3	30	141	3440	5725	12050	15656
R2V2T3	6	33	1074	3225	8384	7086
R3V2T3	27	195	2060	4885	8462	12812
R4V2T3	14	128	2194	6905	14322	8481
R1V2T4	20	146	3191	4997	3412	15933
R2V2T4	8	295	1784	5239	11930	9885
R3V2T4	26	341	4775	2090	13843	5099
R4V2T4	14	93	1786	3949	6908	11856

C.5 Tops fresh weights (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	13	68	280	6578	17912	57622	27095
R2V1T1	26	60	1120	0	5080	11569	11642
R3V1T1	92	178	1980	4619	13171	27478	21198
R4V1T1	66	338	2760	0	8386	18797	26006
R1V1T2	92	1101	7880	30932	80452	51538	63504
R2V1T2	79	405	6100	7622	41575	15045	45360
R3V1T2	66	1080	8320	12430	53350	39333	53222
R4V1T2	66	534	5600	15265	42985	23410	41126
R1V1T3	7	272	4120	25064	55830	64879	46570
R2V1T3	66	443	2140	10698	37661	46831	43848
R3V1T3	171	1398	13480	21299	70861	30064	48082
R4V1T3	53	464	4300	15534	63583	59264	62597
R1V1T4	40	52	5960	20826	75021	86502	30240
R2V1T4	66	433	3820	15043	47564	19268	49291
R3V1T4	53	484	10020	13316	48895	25278	36711
R4V1T4	53	365	1580	7663	24522	25782	27821
R1V2T1	11	63	1060	0	7051	42013	35078
R2V2T1	40	80	620	0	8678	22437	21168
R3V2T1	119	277	1340	0	25208	21345	62597
R4V2T1	53	251	660	0	25837	4164	9737
R1V2T2	79	1542	6300	28472	69630	81080	82253
R2V2T2	13	501	720	7024	28899	23119	30240
R3V2T2	40	1170	9160	19083	43141	15932	41126
R4V2T2	79	977	6500	13564	31210	34189	55037
R1V2T3	79	775	9440	24771	62803	61572	79229
R2V2T3	13	136	4160	13548	42700	31733	57154
R3V2T3	79	940	6500	18475	35731	47725	63504
R4V2T3	40	587	6540	24678	74693	39969	58363
R1V2T4	40	748	8240	21182	16758	68810	64109
R2V2T4	13	1662	4460	18111	54373	35905	52013
R3V2T4	53	1826	12480	8531	58116	19120	39917
R4V2T4	26	417	6040	11472	30582	46020	44150

C.6 Tops dry weight (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	5	18	57	1250	2928	13623	7301
R2V1T1	9	14	154	219	974	2157	2951
R3V1T1	29	42	300	988	2034	5756	6372
R4V1T1	17	76	500	1031	1548	4138	6254
R1V1T2	28	170	2740	4740	14830	8887	18261
R2V1T2	21	78	1420	1326	6974	3176	14046
R3V1T2	17	161	1620	1912	9045	8905	13446
R4V1T2	21	98	1660	3243	8393	4892	10785
R1V1T3	4	51	820	3689	10455	13005	13738
R2V1T3	29	88	360	2418	6339	10404	14396
R3V1T3	43	222	3320	3818	12253	6081	13661
R4V1T3	17	80	800	2634	10192	11896	15702
R1V1T4	12	14	1580	2352	13740	14158	7178
R2V1T4	19	82	680	2494	9650	3716	14331
R3V1T4	13	86	2600	2344	9160	6392	12793
R4V1T4	17	81	320	1587	3849	4271	7462
R1V2T1	3	14	167	1961	1645	8228	10318
R2V2T1	15	22	120	638	1660	4379	5337
R3V2T1	33	57	200	848	4066	3559	17808
R4V2T1	18	52	89	1525	4166	1078	2723
R1V2T2	22	265	1280	4849	9958	13995	22951
R2V2T2	6	86	140	1714	5302	3920	7972
R3V2T2	10	181	2200	3841	7495	3291	11478
R4V2T2	18	161	1500	2634	5663	6905	12649
R1V2T3	24	121	2900	4419	9672	13038	20255
R2V2T3	4	25	880	2592	6389	5099	15271
R3V2T3	17	158	1680	3479	6285	9542	20472
R4V2T3	8	98	1840	4796	11253	7059	15550
R1V2T4	16	123	2600	4174	2748	13179	16736
R2V2T4	5	244	1560	3567	8604	7771	13881
R3V2T4	19	276	4140	1667	9413	4029	10433
R4V2T4	10	78	1440	2794	5196	9900	12611

C.7 Roots fresh weight (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP
R1V1T1	7	15	40	680	2953	10418
R2V1T1	14	11	180	115	1270	2039
R3V1T1	48	28	240	824	1344	3367
R4V1T1	34	79	240	594	686	2069
R1V1T2	48	269	1440	3542	10268	6523
R2V1T2	41	89	840	1450	5600	2192
R3V1T2	34	210	2440	2085	8339	5120
R4V1T2	34	111	1220	2879	5097	2899
R1V1T3	3	88	560	3966	11303	6790
R2V1T3	34	90	280	1096	7699	4879
R3V1T3	89	290	2940	2288	13509	7132
R4V1T3	27	85	460	1703	12622	10720
R1V1T4	20	11	1180	2761	11163	14197
R2V1T4	34	83	560	4008	7775	2505
R3V1T4	27	80	2600	2106	8259	3753
R4V1T4	27	82	200	1409	3601	5063
R1V2T1	5	20	120	1194	1113	7883
R2V2T1	20	9	80	443	1302	4779
R3V2T1	61	48	240	438	3822	3149
R4V2T1	27	34	60	537	3193	372
R1V2T2	41	480	1220	6001	15647	20527
R2V2T2	7	121	100	2048	5575	3189
R3V2T2	20	301	2400	4504	4941	2212
R4V2T2	41	174	1220	2765	6892	6635
R1V2T3	41	158	1940	4259	9773	9190
R2V2T3	7	36	840	1874	8104	7277
R3V2T3	41	181	1220	4205	7814	11243
R4V2T3	20	145	1260	6167	11491	5391
R1V2T4	20	141	2120	2405	2294	9209
R2V2T4	7	332	860	5476	8224	7641
R3V2T4	27	497	1820	1448	14460	3560
R4V2T4	14	87	1140	3044	5706	6597

C.8 Roots dry weight (kg ha^{-1})

Plot	14 DAP	28 DAP	43 DAP	56 DAP	70 DAP	86 DAP
R1V1T1	1	5	19	301	1117	3770
R2V1T1	4	3	75	52	751	544
R3V1T1	7	8	107	269	358	969
R4V1T1	10	17	84	288	297	668
R1V1T2	10	41	482	1177	3093	1560
R2V1T2	12	18	280	515	1629	953
R3V1T2	12	36	800	596	2256	1938
R4V1T2	14	22	271	1224	1631	837
R1V1T3	1	14	193	1490	3014	3339
R2V1T3	11	16	97	478	2032	1795
R3V1T3	11	46	980	823	5095	2136
R4V1T3	10	18	140	531	3124	2976
R1V1T4	4	2	413	851	3382	5014
R2V1T4	10	13	181	1404	2230	778
R3V1T4	11	13	740	614	2252	1370
R4V1T4	9	19	68	476	875	1404
R1V2T1	1	5	50	426	458	1988
R2V2T1	4	4	28	195	542	1269
R3V2T1	12	13	75	200	1065	986
R4V2T1	5	9	22	381	1074	161
R1V2T2	7	100	411	2039	3990	4992
R2V2T2	1	22	51	893	1877	951
R3V2T2	6	54	880	1607	1567	712
R4V2T2	9	29	373	816	2458	2113
R1V2T3	6	20	540	1306	2378	2617
R2V2T3	2	8	194	633	1995	1987
R3V2T3	10	36	380	1406	2177	3271
R4V2T3	6	30	354	2108	3069	1423
R1V2T4	4	23	591	822	665	2755
R2V2T4	2	51	224	1672	3326	2114
R3V2T4	7	65	635	423	4430	1070
R4V2T4	4	15	346	1155	1712	1956

C.9 Cane fresh weight (kg ha^{-1})

Plot	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	2270	9438	44452	19983
R2V1T1	0	1693	7041	7020
R3V1T1	2226	7078	18070	14963
R4V1T1	0	4117	9438	19938
R1V1T2	19066	61606	40761	49054
R2V1T2	3800	27660	9804	32344
R3V1T2	6629	39131	29726	40276
R4V1T2	8597	29563	16900	30845
R1V1T3	15512	36649	48855	33228
R2V1T3	3740	25801	35614	30728
R3V1T3	11800	49769	21840	36752
R4V1T3	8263	40390	46112	49158
R1V1T4	11985	55486	56593	22105
R2V1T4	8723	31786	12794	33888
R3V1T4	7272	35287	19387	26994
R4V1T4	2933	15583	17284	21608
R1V2T1	0	2474	27962	21298
R2V2T1	0	1844	12770	14024
R3V2T1	0	13743	11540	41568
R4V2T1	0	8999	1153	5715
R1V2T2	14527	46159	65393	63331
R2V2T2	1786	12515	13363	20160
R3V2T2	10672	25547	10346	29376
R4V2T2	5531	19116	22230	39475
R1V2T3	14648	44264	45604	57239
R2V2T3	4887	27116	19613	40104
R3V2T3	7778	21973	33450	44177
R4V2T3	12492	45544	26368	43893
R1V2T4	6393	10532	45369	47223
R2V2T4	9238	31298	25493	38409
R3V2T4	3422	39880	13955	28556
R4V2T4	4058	18410	29417	31126

C.10 Cane dry weights (kg ha^{-1})

Plot	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	301	1194	10035	6387
R2V1T1	0	254	1092	2184
R3V1T1	332	788	3210	4033
R4V1T1	0	557	1496	5265
R1V1T2	1605	9397	6064	15878
R2V1T2	452	3835	1715	10629
R3V1T2	712	5485	6264	11509
R4V1T2	1316	4723	2918	8821
R1V1T3	1751	5737	8515	11785
R2V1T3	661	3683	6604	7836
R3V1T3	1530	7240	4040	11540
R4V1T3	1032	5207	8104	13529
R1V1T4	1416	8224	7354	6255
R2V1T4	1130	5603	1863	11059
R3V1T4	934	5575	4154	10286
R4V1T4	425	2043	2377	5854
R1V2T1	0	433	4679	7940
R2V2T1	0	304	1865	4068
R3V2T1	0	1594	1421	14069
R4V2T1	0	1002	248	1985
R1V2T2	1648	5119	9855	19668
R2V2T2	274	1832	1736	6739
R3V2T2	1561	3471	1653	9063
R4V2T2	711	2828	3735	10728
R1V2T3	1780	5576	8583	16672
R2V2T3	640	3185	2527	12941
R3V2T3	920	3092	5519	17210
R4V2T3	1708	5479	3715	12664
R1V2T4	853	1311	7359	13585
R2V2T4	1279	3940	4592	10940
R3V2T4	451	5434	2432	8079
R4V2T4	718	2442	5315	10821

C.11 Leaves fresh weight (kg ha^{-1})

Plot	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	4308	8475	13170	3726
R2V1T1	573	3387	4529	2568
R3V1T1	2394	6093	9408	4988
R4V1T1	3942	4269	9358	4768
R1V1T2	11866	18846	10777	10267
R2V1T2	3821	13915	5241	7889
R3V1T2	5801	14220	9607	9110
R4V1T2	6669	13422	6510	10282
R1V1T3	9553	19181	16024	7804
R2V1T3	6958	11860	11217	9322
R3V1T3	9499	21092	8224	8566
R4V1T3	7271	23193	13152	7073
R1V1T4	8841	19535	29909	5659
R2V1T4	6320	15779	6474	9756
R3V1T4	6044	13608	5891	6478
R4V1T4	4730	8940	8498	4592
R1V2T1	6064	4577	14051	7517
R2V2T1	2279	6834	9667	5557
R3V2T1	3191	11466	9805	12715
R4V2T1	4906	16838	3012	2540
R1V2T2	13946	23471	15686	13130
R2V2T2	5238	16383	9757	4271
R3V2T2	8411	17594	5586	7834
R4V2T2	8033	12094	11959	10248
R1V2T3	10124	18539	15967	13905
R2V2T3	8661	15584	12119	9846
R3V2T3	10697	13758	14276	11833
R4V2T3	12186	29148	13601	7476
R1V2T4	14789	6226	23441	9158
R2V2T4	8873	23075	10412	9202
R3V2T4	5109	18236	5165	8597
R4V2T4	7414	12172	16603	7947

C.12 Leaves dry weight (kg ha^{-1})

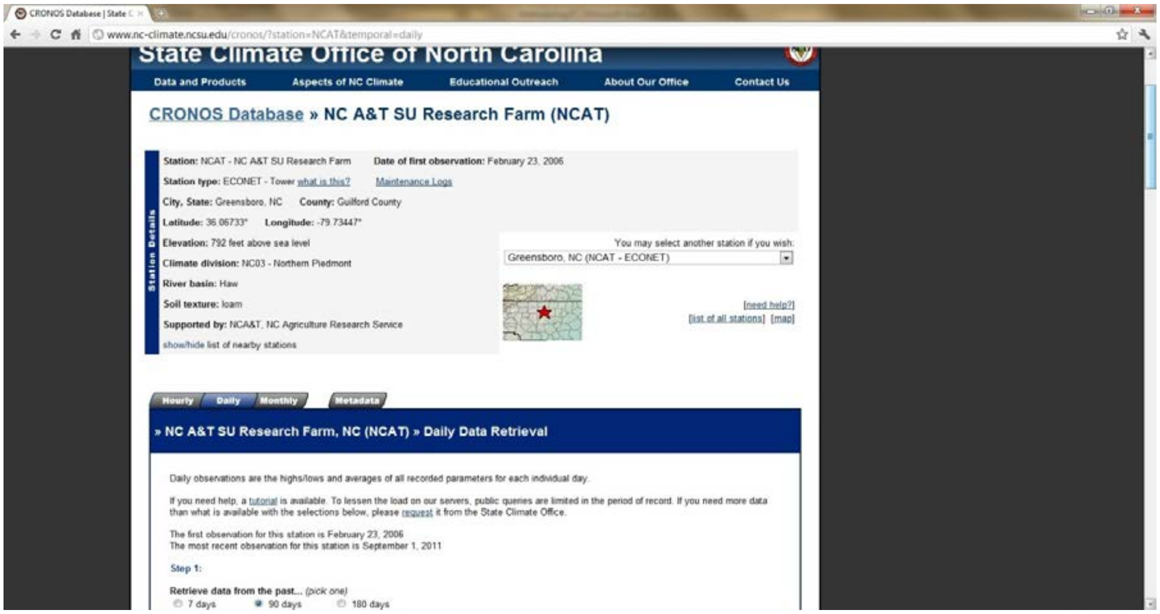
Plot	56 DAP	70 DAP	86 DAP	105 (V1) & 112 (V2) DAP
R1V1T1	949	1733	3589	914
R2V1T1	219	720	1064	767
R3V1T1	655	1245	2546	2340
R4V1T1	1031	991	2642	989
R1V1T2	3135	5433	2823	2383
R2V1T2	873	3139	1461	3417
R3V1T2	1200	3560	2640	1937
R4V1T2	1928	3670	1974	1964
R1V1T3	1938	4718	4489	1953
R2V1T3	1757	2656	3800	6560
R3V1T3	2288	5012	2041	2121
R4V1T3	1602	4986	3792	2173
R1V1T4	935	5516	6804	923
R2V1T4	1364	4048	1854	3273
R3V1T4	1410	3585	2238	2507
R4V1T4	1162	1807	1894	1608
R1V2T1	1961	1212	3549	2378
R2V2T1	638	1356	2515	1269
R3V2T1	848	2472	2138	3739
R4V2T1	1525	3164	830	738
R1V2T2	3201	4839	4140	3282
R2V2T2	1441	3470	2184	1233
R3V2T2	2280	4025	1638	2415
R4V2T2	1923	2835	3170	1920
R1V2T3	2639	4096	4455	3583
R2V2T3	1952	3204	2573	2330
R3V2T3	2559	3192	4023	3262
R4V2T3	3089	5774	3344	2886
R1V2T4	3321	1437	5820	3151
R2V2T4	2288	4664	3179	2941
R3V2T4	1216	3979	1597	2355
R4V2T4	2076	2754	4585	1790

C.13 BRIX (%) & Juice (lt ha^{-1})

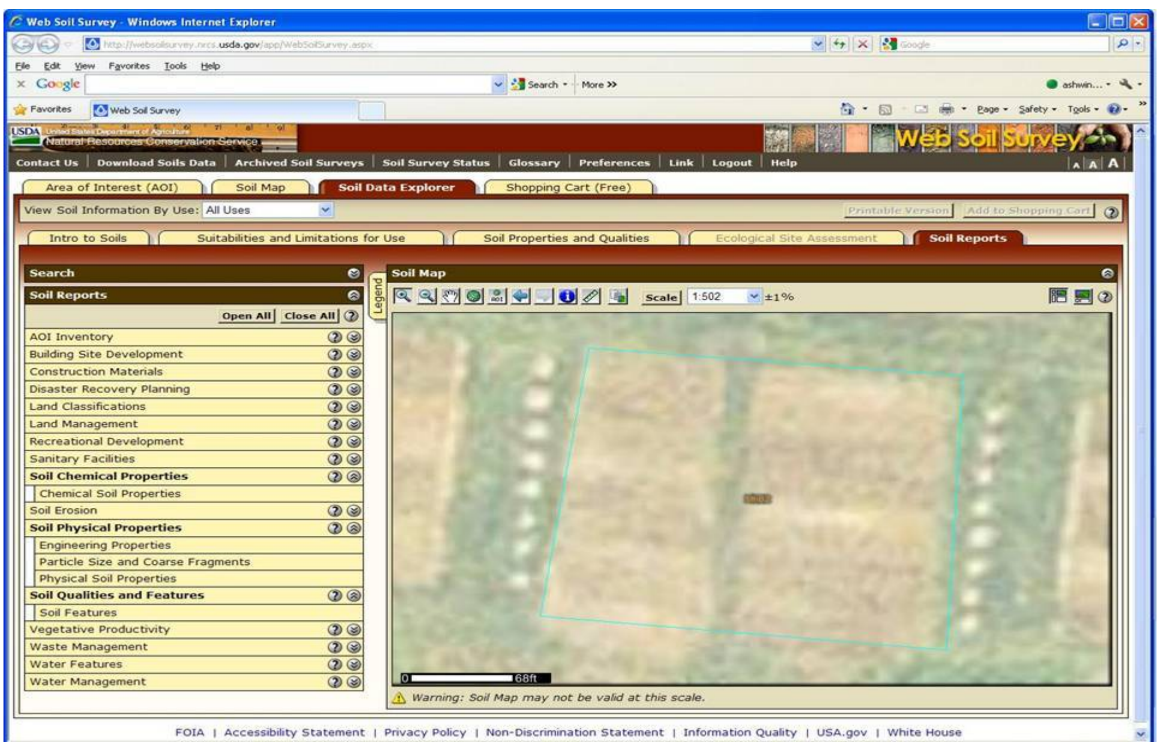
Plot	BRIX on 08/17/2011	BRIX on 9/6 (V1) & 9/11/2011(V2)	Juice lt/ha
R1V1T1	8.5	13.8	36
R2V1T1	8.1	10	12
R3V1T1	7.8	11.6	20
R4V1T1	6.1	11	35
R1V1T2	5.0	14.1	115
R2V1T2	7.4	15.2	60
R3V1T2	10.0	16.2	75
R4V1T2	9.9	14.2	60
R1V1T3	8.5	15.1	80
R2V1T3	12.5	15	62
R3V1T3	9.8	14.5	70
R4V1T3	8.0	14.8	110
R1V1T4	6.0	14.2	45
R2V1T4	10.5	14.4	61
R3V1T4	11.5	15.2	47
R4V1T4	7.0	14	48
R1V2T1	7.0	13.5	40
R2V2T1	6.0	11.3	22
R3V2T1	6.0	15	36
R4V2T1	7.5	9.6	6
R1V2T2	6.7	11.2	108
R2V2T2	4.9	15	28
R3V2T2	7.2	16	44
R4V2T2	6.1	15.2	66
R1V2T3	6.0	14	110
R2V2T3	5.0	11.2	76
R3V2T3	7.9	15	55
R4V2T3	6.2	11	94
R1V2T4	6.9	12.5	94
R2V2T4	7.4	13	73
R3V2T4	8.0	10.4	45
R4V2T4	7.0	14	31

Appendix D

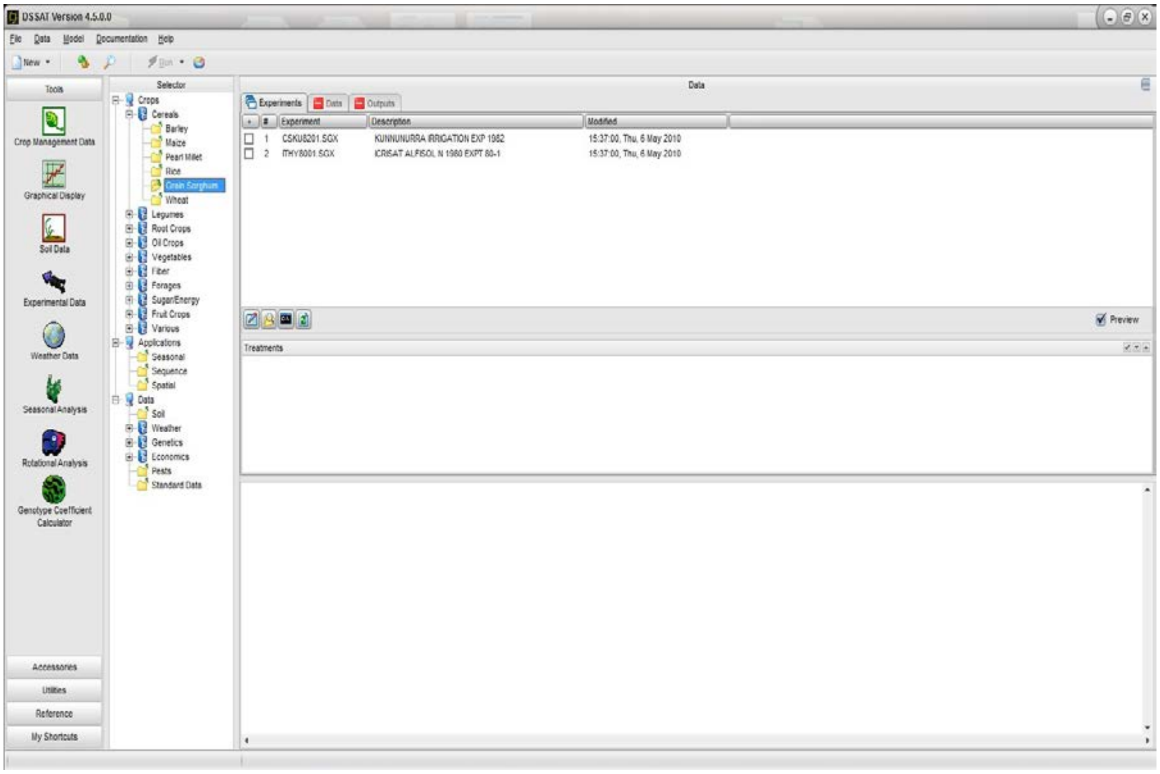
DSSAT, Web Soil Survey, and State Climate Office



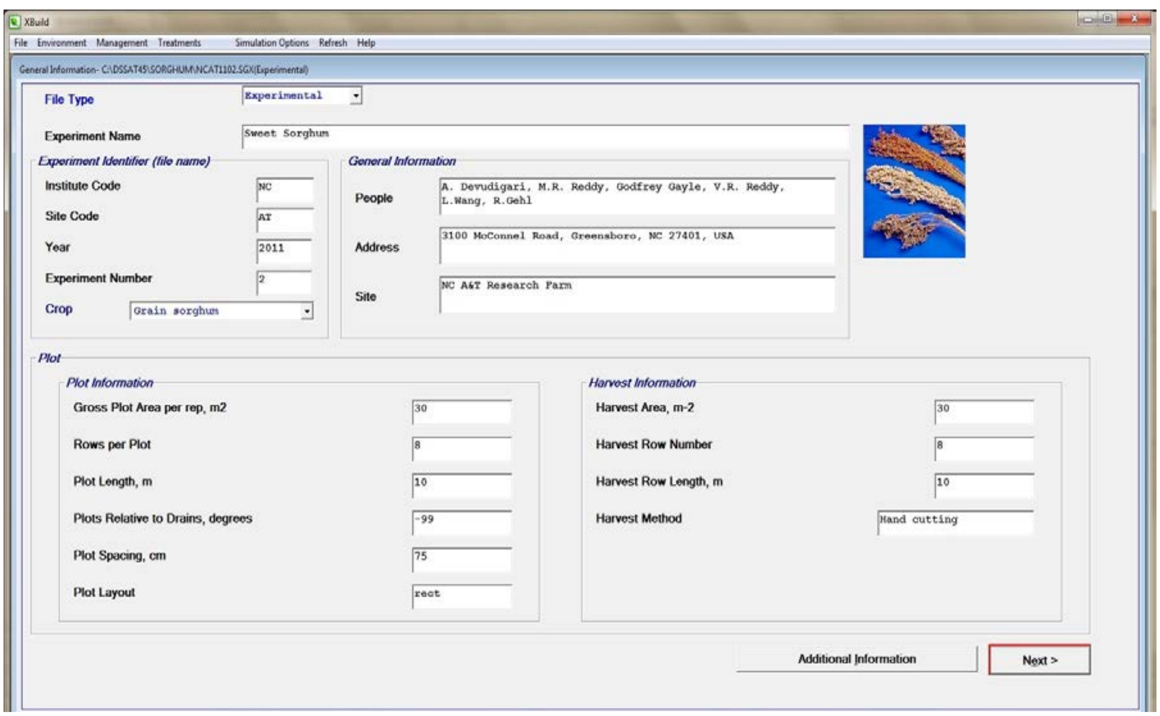
D.1. Database website of climate data of State climate office of North Carolina.



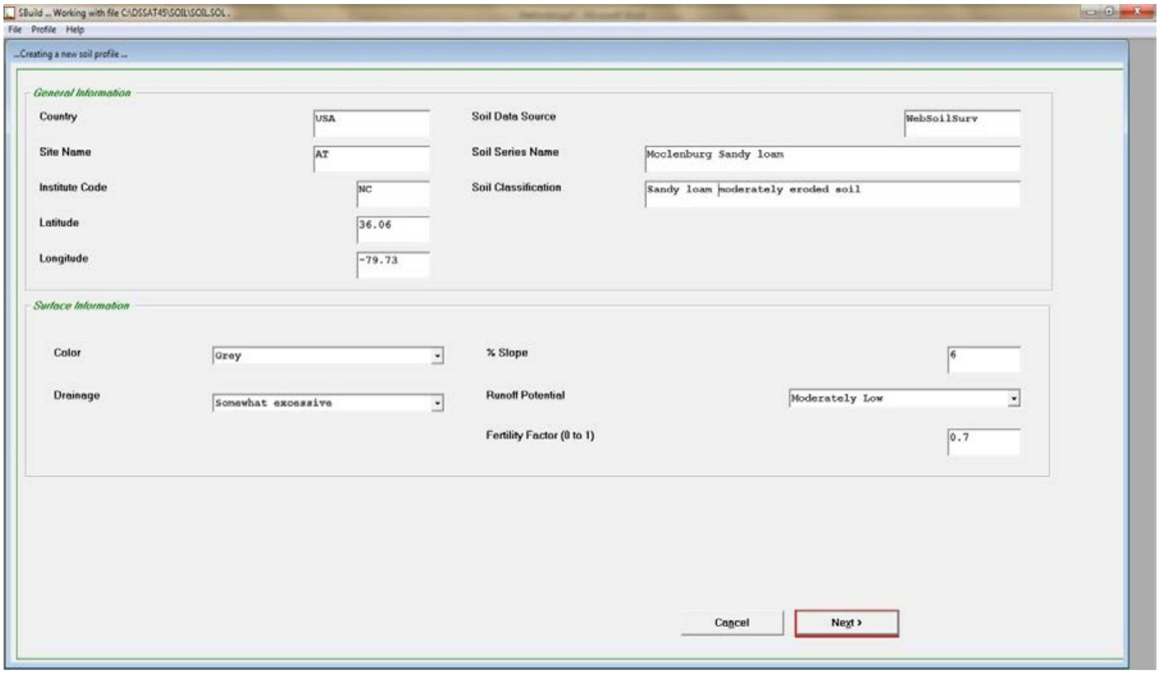
D.2. Soil database on Web soil survey by Natural Resources Conservation Service.



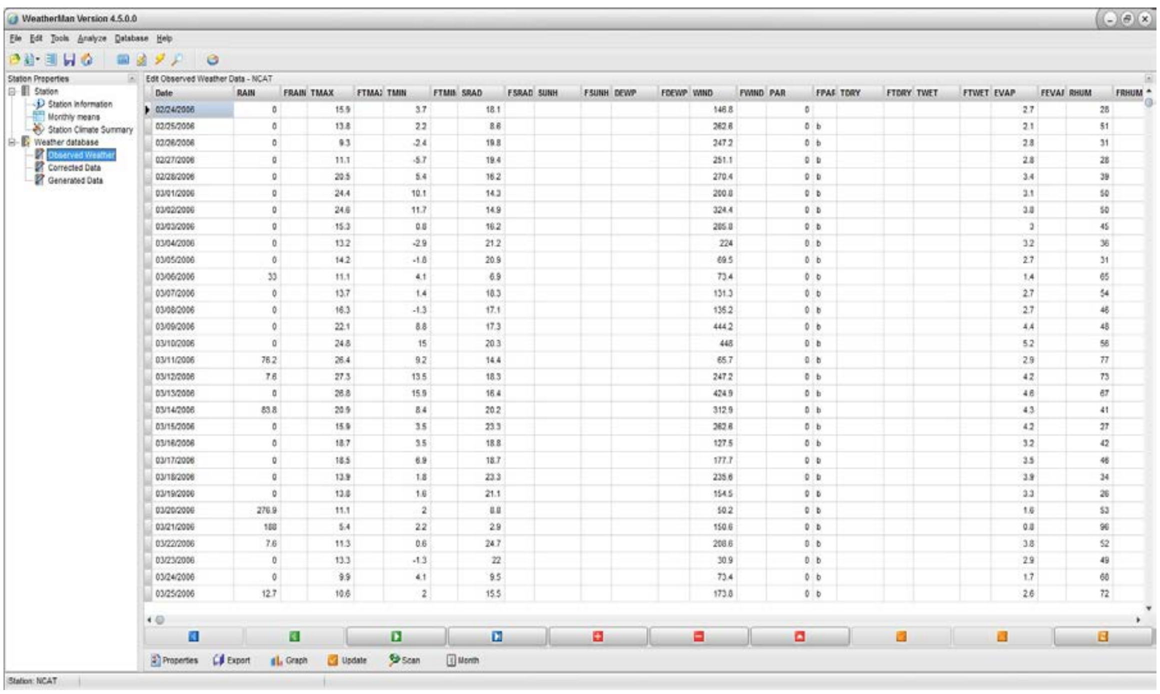
D.3. DSSAT version 4.5 software package home interface.



D.4. Main module XBuild of DSSAT v4.5 home interface.



D.5. SBuild main interface.



D. 6. Weather man module of DSSAT v4.5 software.