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CLIMATOLOGICAL CONSTRAINTS OF A WHEAT-SOYBEAN
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CLIMATOLOGICAL CONSTRAINTS OF A WHEAT-SOYBEAN DOUBLE-CROPPING SYSTEM IN THE GREAT LAKES REGION

By

Colleen Marie Garrity

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ABSTRACT

CLIMATOLOGICAL CONSTRAINTS OF A WHEAT SOYBEAN DOUBLE CROPPING SYSTEM IN THE GREAT LAKES REGION

BY

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Double cropping soybeans following winter wheat has traditionally been limited to areas hundreds of miles south of the Great Lakes Region. Primary climatological constraints for the secondary soybean crop include dry topsoil for germination and establishment, lack of available moisture during vegetative and reproductive stages due to dry subsoil layers, and limited frost-free growing season length. In the study, the potential for successful wheat-soybean double cropping across the region is examined. Historical risk of the cropping system is assessed using the DSSAT crop simulation system given weather data from stations across the region, 1895-1996. Given the potential for future climate change, the cropping system is also evaluated given weather data derived from the HadCM2 transient general circulation model to the year 2099. Simulated yield potentials increased from north to south across the region, and yields improved with earlier planting dates, greater mean seasonal precipitation, and greater plant extractable soil water. Future simulated yield potentials increased over historical levels in response to warmer, wetter growing seasons, and CO_2 enrichment further boosted yields. Mean yields increased significantly in the latter half of the 21st century; by 2099, mean yields under CO_2 enrichment improved by at least 50% over the historical mean.

for Mark

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INTRODUCTION

Net cash farm income (gross cash income minus gross cash expenses) for agricultural operations in the United States has decreased in recent years and further decreases are likely in the future, attributable largely to changes in economic factors, such as low commodity prices and the phase-out of governmental support programs (Collins, 1999). Continued low commodity prices in coming years will create further financial stress for producers who are already financially leveraged.

In the face of such trends, farmers retain a limited number of adaptive strategies. One managerial option that allows farmers the opportunity to increase profits with only a small increase in risk is a double-cropping system, in which two crops are produced in overlapping or succeeding order. Double-cropping systems allow farmers to increase potential income, to diversify by spreading financial risks over two crops, and to make more efficient use of land resources. The practice of double cropping winter wheat followed by soybeans has been commonplace in the U.S. from the Ohio River Valley southward for much of the past few decades. In more northerly areas of the central U.S., however, double cropping has generally been possible only in certain years and only with significant production modifications due to climatological limitations such as growing season length.

During the 1998 growing season, farmers in southern Michigan reported success at double cropping wheat and soybeans. The 1998 season was characterized by an abnormally mild, early spring (the warmest January – May on record for the Great Lakes region) which led to a very early winter wheat harvest, followed by timely late summer rainfall, mild fall temperatures, and a delayed first killing freeze of the fall season (NOAA, 1999; NCDC 1998; MASS 1998). Growers who attempted a secondary soybean crop reported yields as high as 2.5 ton/ha, which translated into cash receipts up to $500/ha with total production cost of $175/ha or less (Ned Birkey, MSU Extension, personal communication; Mike Staton, MSU Extension, personal communication).

This success raises climatological questions as to the potential for this type of agricultural practice in the Great Lakes region: How often do extended growing seasons conducive to double cropping occur? Is the recent long growing season indicative of a larger change of climate, with increasing probabilities of success for double cropping in the region? Or are longer growing seasons only an intermittent phenomenon, with limited long-term possibilities for successful double cropping? Assuming current levels of technology, what is the historical potential for double cropping winter wheat and soybean in Michigan?

How might anticipated future climate change affect wheat-soybean double-cropping potential in the Great Lakes region? Global climate change and its potential impacts on weather and climate dependent processes are under investigation worldwide. Increasing concentrations of CO_2 and other atmospheric trace gases have been projected to lead to global increases in temperature on the order of 0.9-3.5°C by the end of the next century (Houghton et al., 1996), with even further increases possible due to future reductions in sulfur dioxide emissions (Wigley, 1999). Climate change projected for the Great Lakes region during the next century includes trends toward a warmer and potentially wetter climate (Wigley, 1999). Will this projected climate change result in increased opportunities for double cropping in the region? With the potential for a warmer climate and increasing levels of atmospheric carbon dioxide in the future, what might the potential for double-cropping systems be, based on current levels of technology, for producers in the Great Lakes region? The purpose of this thesis is to examine the historical and future potential of wheat-soybean double-cropping systems in the Great Lakes region.

Chapter 1

BACKGROUND

Definitions

Double cropping refers to the planting and harvesting of a second crop after the harvest of the first crop in the same growing season at the same location. The seasonal chronology of a typical wheat-soybean double-cropping system in the Ohio Valley is illustrated in Figure 1.

Several variations of the double-cropping system described above are commercially used in the U.S. Chief among these is relay intercropping, in which the second crop is planted directly into the first crop while it is still actively growing, with subsequent harvest of both crops during the same growing season. This cropping method is an adaptation of double cropping and is practiced in regions with cooler climates that cannot otherwise produce two crops in a single season.

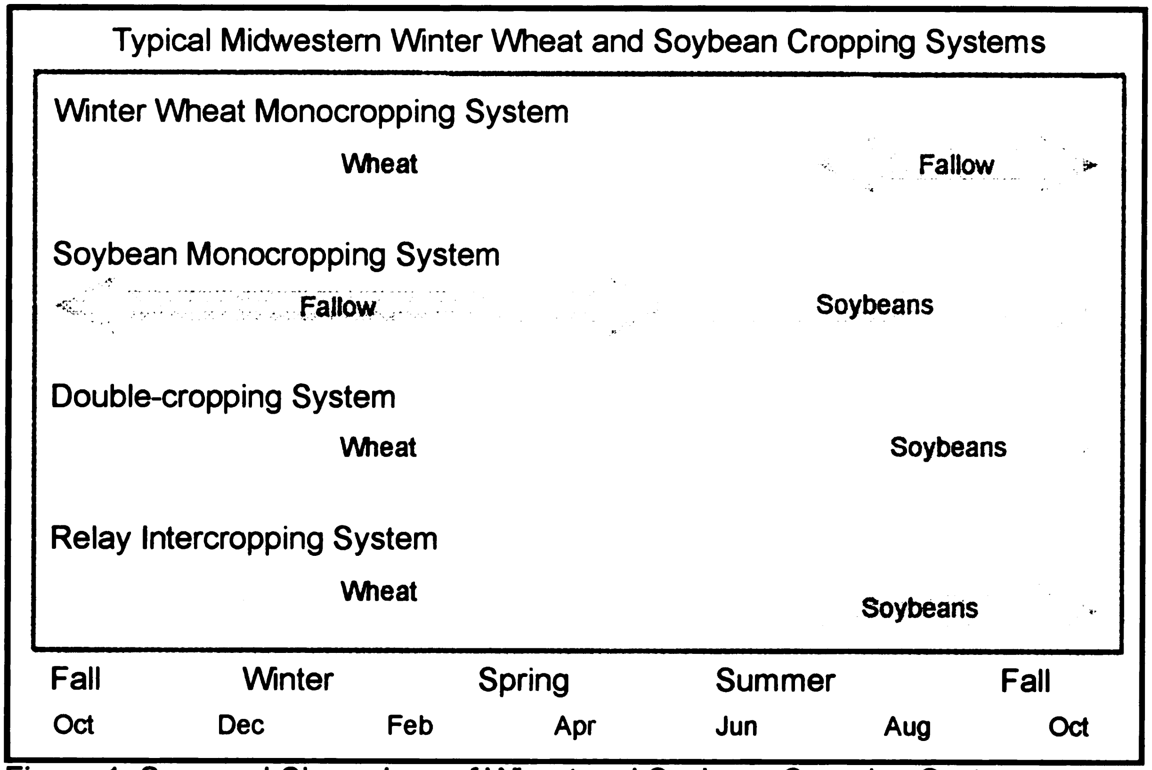

Figure 1 Seasonal Chronology of Wheat and Soybean Cropping Systems

Fall—Wheat planting

Winter—Vernalization, soil water accumulation (when/if snowmelt occurs)

Spring—Wheat growth and development

Early Summer—Wheat harvest/soybean planting

Summer—Soybean growth and development

Fall—Soybean harvest, wheat planting

Benefits

The most common justification for the use of a double-cropping system is potential economic advantage. Other potential advantages include soil nitrogen credits (from the leguminous soybean crop) for future crops, crop rotational benefits related to insect and disease pressure, and the potential for use as animal forage if the secondary soybean crop isn't successful (LeMahieu & Brinkman, 1990).

Constraints

Shapiro et al (1992) demonstrated that risk perception is key to explaining adoption of wheat-soybean double-cropping practices. Producers in northern regions of the U.S. face climatological constraints that render the prospect of adopting the practice less profitable and more risky. What risks do producers face in making the decision to double crop wheat and soybeans?

The potential for success with two crops in a single season involves a number of constraints, but three factors related to climatology are most significant. The first constraint is length of frost-free growing season. If the season is too short, the soybean crop won't have enough time to mature before the first killing freeze of the fall. Soybean killed prior to maturity may suffer significant reductions in yields, test weights, and quality (Halvorson et al, 1995). In Indiana, Schweitzer (1981) found that a minimum 90-day frost-free growing season was necessary for double-cropped soybean to reach maturity and still maintain a yield potential of 1881 kg/ha (30 bushels/acre) or higher. Timing of the soybean planting is also critical. For every day after June 15th that soybean planting is delayed, Jeffers (1987) found yield potential to decrease 31 to 47 kg/ha (½ to ¾ bushels/acre) and recommends that double crop soybeans not be planted after July 10th.

The second constraint is adequate soil moisture for soybean germination and establishment. The adage "if June is dry, do not try," is based on the requirement of adequate moisture for germination of the soybean seed (Jeffers, 1995). If moisture in the upper several centimeters of the soil profile is insufficient to facilitate germination at planting time, the soybean seeds will remain dormant until sufficient moisture occurs, possibly resulting in poor stand establishment and subsequent delays in phenological development and progress (Pearce et al, 1993; Jeffers, 1995).

A third climatological limitation to wheat-soybean double cropping is the lack of available moisture to the soybean crop during vegetative and reproductive phenological stages. Total evapotranspiration from the primary wheat crop typically ranges from 350 to 700 mm between emergence and maturity (Musick & Porter, 1990). This moisture must usually come from a combination of precipitation and antecedent soil water. In Midwestern climates, wheat crops generally leave the secondary soybean crop with a moisture-depleted soil profile and at risk of moisture shortages should precipitation not be sufficient to meet the secondary crop needs.

Due to climatological and other factors, yields in double-cropping systems are generally lower than those of single-season crops. In Indiana, double-crop soybean yields are generally 60% of full-season yields (Schweitzer, 1981), while

Mississippi State University data (taken in a warmer and wetter climate) indicate that, on average, double-crop yields are 15-30% lower than full-season yields (Blaine, 1998). Jeffers (1987) found well-managed double-crop soybean yields in Ohio to average 50% of single-crop yields, while intercrop wheat and soybean yields produce roughly 85% and 75% of monocrop yields, respectively.

Once the decision to plant a double crop has been made, a number of tactical concerns must also be addressed. The most critical tactical decisions concern the timing of wheat harvest and soybean planting in the summer. The farmer can opt for the conventional practice—harvest the wheat, till the field, and plant the soybeans. However, this method is time-consuming and can create soil moisture problems for the soybeans, as tilling tends to dry the soil. Tilling and planting at night can reduce soil moisture losses, but any tilling practice will still cause more moisture losses than other methods of preparing the field for planting soybeans (Crabtree et al, 1990).

A second option is no-till planting the soybean seed directly into the wheat stubble. This option allows maximum moisture retention in the soil, which promotes soybean germination. Standing wheat stubble also prevents soil erosion and can encourage the soybean plants, once established, to grow taller and flower more quickly, competitively accelerating growth in an already short growing season. While benefiting growth and development to some degree, the wheat residue, if left on the field, still poses some problems, as it is difficult for the planter to cut through, can impede soybean harvest, can harbor diseases and limit weed control practices, and may hinder initial establishment of the soybean plants (Blaine, 1998). To alleviate some of these problems and advance soybean emergence, the wheat residue can be chopped, shredded, or baled as straw after the wheat harvest, but these reductions in the amount of straw present were associated with lower volumetric soil moisture content (Vyn et al, 1998). Because soybean establishment is commonly difficult in stubble, a seeding rate 25% greater than normal was suggested by Schweitzer (1981).

No-till is a common practice with several possible variations. The standard no-till method is to harvest the wheat and plant the soybeans into wheat stubble. An alternative no-till method is intercropping, where soybeans are planted into a standing wheat crop that will be harvested shortly after soybean establishment (Jeffers, 1995; Moomaw and Powell, 1990). A related alternative method is aerially seeding the soybean seed into a standing wheat crop. In both of the latter cases, wheat can be harvested above young soybean plants if the cutter bar on the combine harvester is set to a level high enough to avoid damaging the soybean plants.

Still another alternative no-till method is to harvest the wheat, burn the wheat stubble in a controlled manner, and then plant the soybeans in the burned stubble. Research in Mississippi demonstrated that while fast-burning fires in wheat stubble can be dangerous, the burning practice tends to result in higher yields than both conventional and no-till practices (Blaine, 1998).

The double-crop production system generally requires a high level of management and a restricted time budget (Jeffers, 1995). Given climatological restrictions, conventional double-cropping methods have traditionally been restricted to the Ohio River Valley, the Lower Mississippi Valley, and the Southeastern United States. Modifications of traditional double-cropping strategies have allowed the practice to spread to formerly marginal regions, such as the Southern Great Plains, where the availability of water has historically limited double-crop potential. Other specialized double-cropping practices are adapted to colder climates in the northern U.S. For instance, in Wisconsin, winter small grains are sometimes planted and used as forage in the spring before a soybean crop is planted (LeMahieu & Brinkman, 1990).

Intensive management and innovative strategies are required of farmers wishing to successfully double crop in areas north of the climatic optimum. One option is early wheat harvest at high moisture levels. At high moisture levels, the farmer can artificially dry the wheat from 20-25% moisture, windrow the wheat at 30-40% moisture, or remove the wheat as silage (Schweitzer, 1981).

The climate of the Great Lakes region traditionally has not been suited for wheat-soybean double cropping, though success has been reported in exceptional growing seasons such as 1998. Based on climatology, what is the potential for a wheat-soybean double-cropping system in areas north of the traditional double-cropping region?

Chapter 2

METHODS

Ultimate determination of the potential feasibility of double cropping systems in the Great Lakes region will likely require many seasons of traditional agronomic field experimentation with data taken at a number of locations. One less time-intensive methodology available to investigators that can provide an initial assessment of the potential for this system in the region is the crop simulation model, which is a quantitative, deterministic simulation of the physiological processes that govern crop growth, development, and yield. In this study, the DSSAT (Decision Support System for Agrotechnology Transfer) v.3.5 (Tsuji et al., 1994) crop modeling system was employed to assess the historical and potential viability of double-cropping practices for eighteen stations across the Ohio Valley and Great Lakes regions. The DSSAT modeling system contains more than 12 different crop simulations and has been used for a range of agronomic simulations and impact assessment studies in the past (e.g. Adams et al, 1995; Chipanshi et al, 1997; Lal et al, 1998; Landau et al, 1998; Mearns et al, 1996; Mearns et al, 1999; Parsch et al, 1991).

For this study, the CERES-Wheat (Godwin et al, 1989; Ritchie et al, 1985) and SOYGRO (Jones et al, 1989; Wilkerson et al, 1985) crop models were used to simulate wheat and soybean, respectively, in a double cropping system under a variety of environmental conditions. CERES-Wheat and SOYGRO have been successfully utilized in many past modeling studies and production areas, and have been found to compare well with observed data and with other crop models (Mearns et al., 1997, Mearns et al., 1999; Pickering et al, 1995). In this study, the primary focus is on the constraints of the secondary soybean crop, so the wheat simulation was used essentially to initialize soil moisture conditions for the second crop. Because winter wheat parameters in double cropping are largely congruent with those of full-season crops, the CERES-Wheat model verifications by other authors were assumed to be sufficient for this study. Double-crop soybean parameters, however, differ from those of full-season soybeans. Yield data are not officially recorded for double-crop soybeans, so verification for this cultivation practice is not possible. One past simulation study of full-season soybeans found SOYGRO to adequately simulate crop growth phenology and yields in the midwestern U.S., though it performed better in southern than northern sections of the region (Kunkel and Hollinger, 1991).

The area chosen for the present study encompasses the Ohio River Valley, where double cropping is commonly practiced, and sections of the Great Lakes Region including the Lower Peninsula of Michigan, where double cropping is atypical. In the first phase of the project, a wheat-soybean double cropping system was simulated at 18 locations across the region using approximately 100 years of historical daily weather data (1895-1996). This necessitated the development of weather, soil, and other agronomic data sets for each station location. In the second phase of the project, the double cropping system was modeled at 6 of the 18 historical station locations using simulated future daily weather data for the next century (2001-2099) from the Hadley Centre HadCM2 general circulation model (Mitchell et al, 1995; Johns et al, 1997; Viner & Hulme, 1998). Extensive, detailed output from the crop models with a large number of historical and potential future scenarios provided a means of analyzing the potential for wheat-soybean double cropping in this region. In addition, a variety of sensitivity analyses were also performed on the model simulations to identify and characterize important climatological constraints.

Agronomic Assumptions

In order to run any model, assumptions must be made regarding input variables to simplify the vast array of decisions involved in the modeled process. Accordingly, some agronomic assumptions were made to represent wheat-soybean double-cropping tactical decisions in the DSSAT sequential analysis files. First, agronomic input variables were chosen as typical of current (i.e. late 1990's) technology. This includes cultivar selection, planting row width, and seeding population specifications. While soybean cultivars should vary as operators adapt to a changing climate, for example, the cultivars are kept constant here for the purpose of consistency in the simulation. Second, fertility was assumed to be non-limiting in all simulations and there was no consideration of the potentially negative impacts of weeds, pests, or diseases. These factors, while possibly important on local scales, are beyond the scope of this investigation, which focuses on the climatological constraints of a double cropping system. Third, soil profiles chosen for the analysis were assumed to generally represent typical agricultural areas in the vicinity of each station.

Finally, an important component frequently overlooked in past agronomic impact studies is the effect of ambient CO_2 concentrations, which can significantly increase plant water use efficiency, dry matter production rates, and yield (Adams et al, 1990; Rosenzweig, 1985) . In many of the studies that have taken CO_2 concentration into account, the future scenarios were adjusted by an equilibrium doubling of CO_2 concentration relative to global pre-industrial revolution levels (e.g. Rosenzweig & Parry, 1994; Mearns et al, 1996). However, comparing the effects of $1xCO_2$ scenarios with those of $2xCO_2$ scenarios may not provide a realistic transition from current concentrations to projected future concentrations of CO_2. Researchers have cited the need for transient models to be incorporated into impacts assessment modeling, as this approach offers a more realistic picture of climate change than equilibrium models allow (Rosenzweig et al, 1993). With advances in climate modeling capabilities, transient climate models have recently been made available for use in impact studies. In this study, projected atmospheric CO_2 concentrations for the years 2001-2099 were taken from the transient IPCC 92a scenario as outlined by Joos et al. (1995) and combined with the HadCM2 daily weather data. The crop models respond to the increases in CO_2 with increased photosynthetic rates and decreased transpiration for a net increase in plant water use efficiency. The combination of transient CO_2 levels with crop models able to respond to changing ambient CO_2 levels, such as the DSSAT model suite, provides a more accurate picture of the potential effects of projected climate change scenarios.

Model Requirements

The DSSAT crop model requires a wide variety of weather, soil, and other agronomic data as inputs for simulations and experiment files. The Sequential Analysis component of DSSAT is used to model multiple-year and double-cropping sequences. Sequential experiment files drive the crop model subroutines, CERES-Wheat and SOYGRO, and specify the parameters of each simulation. Parameters specified in the sequential experiment files include crop model subroutines, cultivars, field and soils information, initial conditions at the start of simulation, planting details, irrigation and water management, harvest details, and simulation controls. An example of sequential experiment files is given in Appendix A.

Weather Data

Weather variables used in the DSSAT modeling process include daily maximum and minimum temperatures, precipitation totals, and solar radiation totals. Historical daily temperature and precipitation data for the period 1895-1996 (or as close as possible to these years) were obtained from the Midwestern Regional Climate Center for eighteen stations across the Great Lakes Region and Ohio River Valley. Stations were chosen on the basis of series quality, continuity, and length, completeness of record, and by geographic location relative to other stations in the study area to ensure roughly equal spatial representation across the region. A map of the stations is given in Figure 2.

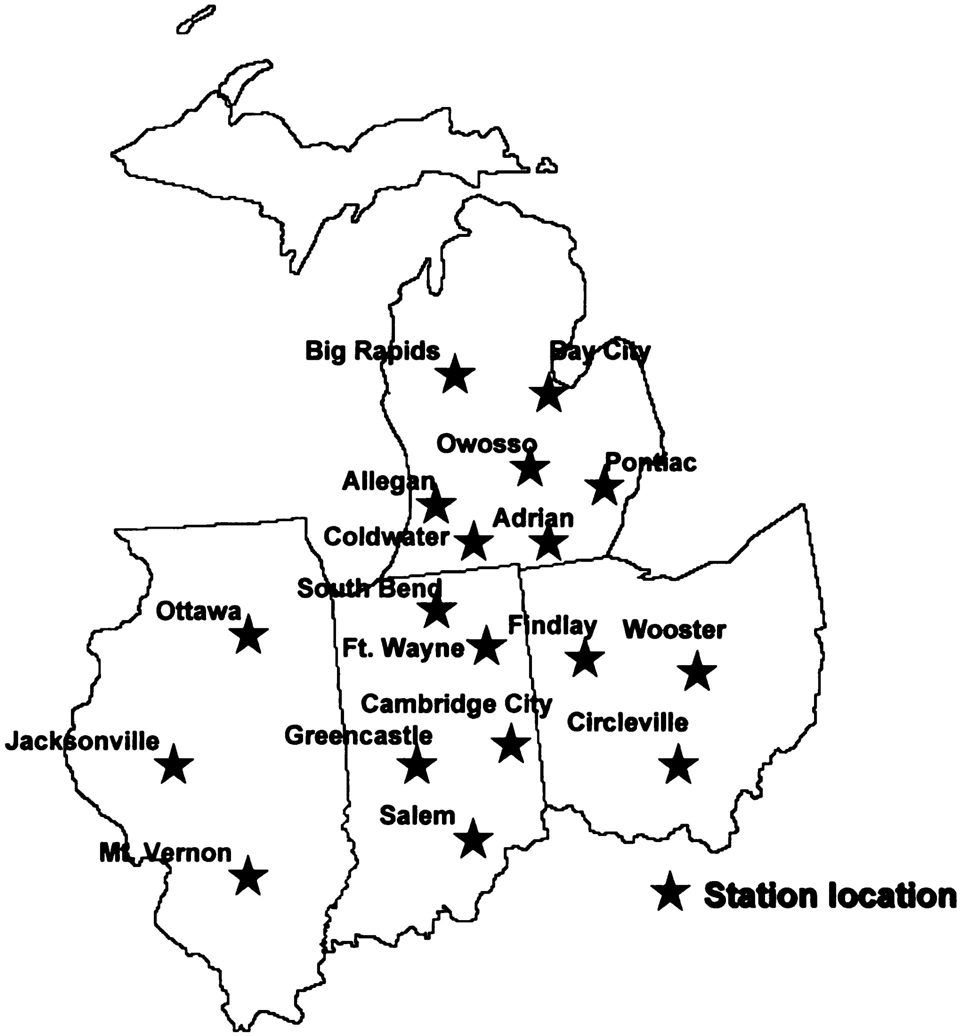

Figure 2. Stations used in the study.

The DSSAT model simulation framework requires serially complete weather files. Missing daily data in each of the station series in this study were estimated at the Midwest Regional Climate Center with a kriging objective analysis, which weights estimated values heavily on those of the nearest available neighbor stations (Ken Kunkel, personal communication). A list of the stations with periods of records and percentage of complete data is given in Table 1. To complete the historical weather data, daily solar radiation totals were synthetically generated based on historical statistics using the WGEN (Richardson and Wright, 1984) stochastic weather generation program. Prior to model simulation runs, the raw weather files were converted into DSSAT-compatible weather input files (*.WTH files). An example of the *.WTH file format is given in Appendix A.

Table 1 Stations and Weather Record Information used in the study. Percent complete refers to the percent of total weather observations during the period of record that were not missing or estimated.

State	Station	Period of Record	% Complete
MI	Adrian	1895 - 1996	99
	Allegan	1895 - 1996	99
	Bay City	1896 - 1996	90
	Big Rapids	1896 - 1996	99
	Coldwater	1897 - 1996	99
	Owosso	1896 - 1996	95
	Pontiac	1895 - 1996	99
IN	Cambridge City	1896 - 1996	91
	Ft. Wayne	1897 - 1996	99
	Greencastle	1896 - 1996	85
	Salem	1896 - 1996	94
	South Bend	1896 - 1996	99
OH	Circleville	1896 - 1996	97
	Findlay	1896 - 1996	99
	Wooster	1896 - 1996	99
IL	Jacksonville	1896 - 1996	99
	Mt. Vernon	1895 - 1996	98
	Ottawa	1895 - 1996	97

In the second phase of the project, feasibility of double cropping in a future climate is explored. Simulated daily weather data from the HadCM2 transient general circulation model for the next century were obtained in conjunction with the U.S. Global Change Research Program National Assessment (Great Lakes Regional Assessment). The original 2.5° X 3.75°-resolution HadCM2 general circulation model data, in the form of monthly mean departures from historical averages, were converted into a gridded 0.5° x 0.5° and daily time step format for VEMAP (Kittel et al., 1997; Kittel et al., 1995) using stochastic weather generation techniques. The future daily weather series were obtained from the nearest model grid on land for each of six stations in north to south and east to west transects across the study area and converted to DSSAT-compatible weather input file (*.WTH) format.

Soils Data

Because DSSAT models simulate plant growth and development above and below the surface, detailed soil profile data input files are required for each site. Representative agricultural soils were chosen for each site using USDA County Soil Survey publications (USDA—NRCS County Soil Survey Series). For each site, the two most prevalent agricultural production soils in the county (by percentage of area) were selected as representatives of soils potentially suitable for double cropping. Many, but not all, of these soils have sample profile data available, which are required by DSSAT to run the crop simulations. Final soil series selection for each site was determined first by the degree of agricultural potential and second by availability of soil profile data. A listing of soil series, texture, and taxonomy by site is given in Table 2. Detailed soil series profile data were obtained from the National Soil Survey Center (NSSC, 1999).

When a representative soil was chosen for each site, soil data files (*.SOL) were created in DSSAT for use in crop simulations. Information required to create soil data files includes texture of uppermost horizon in the soil profile, number of horizons in the profile and the depth of each, coarse fraction, bulk density, saturated hydraulic conductivity, total nitrogen, pH 1:1 in water, cation exchange capacity, and root quantity for each horizon. A sample soil data file is given in Appendix A.

Table 2. Soil series, texture, and taxonomy at each site.

Station	**Soil Series**	**Texture**	**Taxonomy**
Adrian	Hoytville	Clay Loam	Fine illitic mesic mollic ochraqualf
Allegan	Blount	Loam	Fine illitic mesic aeric ochraqualf
Bay City	Iosco	Loamy Sand	Sandy over loamy mixed frigid alfic haplorthod
Big Rapids	Coloma	Loamy Sand	Sandy mixed mesic psammentic hapludalf
Cambridge City	Crosby	Silt Loam	Fine mixed mesic aeric ochraqualf
Circleville	Brookston	Loam	Fine-loamy mixed mesic typic argiaquoll
Coldwater	Fox	Loam	Fine loamy over sandy mixed mesic typic hapludalf
Findlay	Blount	Loam	Fine illitic mesic aeric ochraqualf
Ft. Wayne	Miami	Silt Loam	Fine-loamy mixed mesic typic hapludalf
Greencastle	Fincastle	Silt Loam	Fine-silty mixed superactive mesic aeric epiaqualf
Jacksonville	Ipava	Silty Clay Loam	Fine montmorillonitic mesic aquic argiudoll
Mt. Vernon	Bluford	Silt Loam	Fine-silty mixed mesic aeric ochraqualf
Ottawa	Catlin	Silty Clay Loam	Fine-silty mixed mesic typic argiudoll
Owosso	Conover	Sandy Loam	Fine montmorillonitic eutroboralf
Pontiac	Conover	Sandy Loam	Fine montmorillonitic eutroboralf
Salem	Crider	Silt Loam	Fine-silty over clayey mixed mesic typic paleudalf
South Bend	Brookston	Loam	Fine-loamy mixed mesic typic argiaquoll
Wooster	Bennington	Silt Loam	Fine illitic mesic aeric ochraqualf

Sequential Experiment Files and Study Treatments

Once weather and soil data input files were complete, sequential experiment files (*.SQX) were created in the DSSAT program framework. For both the 100-year historical and future double cropping simulations, sequential program experiment files were created to simulate each multi-year sequence of CERES-Wheat followed by SOYGRO simulations. Eight sequential experiment files were created for each of the eighteen sites in the historical analysis to evaluate the effects of different soybean planting dates and water availability. Sequential experiment files for four planting dates (June 1, June 15, July 1, and July 15) were created for each site using both dryland and irrigated situations. These dates were chosen to represent a range of possible soybean planting dates across the regions, with mid-July considered the latest possible planting date in the region (Jeffers, 1987). Simulations for each planting date were run twice, one for dryland (water limiting) and one for irrigated (water non-limiting) conditions.

Future sequential experiment files were created for six sites using the July 15 soybean planting date to simulate the potential effects of water stress and carbon dioxide enrichment. Experiment files were created to compare the potential effects of both dryland and irrigated CO_2-enriched and non-CO_2-enriched future scenarios on double cropping. To account for the effects of the transient climate model CO_2 enrichment, sequential files were created by decade, beginning with 2001-2010, using the median CO_2 value for each decade given in the Joos et al (1995) series.

In all of the sequential experiment files, both historical and future, the simulation beginning date was January 1st. For the wheat simulations, a generic U.S. Soft Red Winter variety was used at all sites. The CERES-Wheat sequence begins using the automatic planter feature, which plants the wheat within a specified window of dates, weather, and soil moisture conditions. In all simulations, the planting window was defined as the 30-day period after the Hessian fly-free date for each site, with planting generally occurring in early October. Seeding populations were set to 300 seeds per square meter and row spacing was set to 10cm. CERES-Wheat model harvest details were set to automatically harvest the day before the scheduled soybean planting date.

For the soybean simulations, generic soybean cultivars of differing maturity group were selected for each site according to latitude, ranging from maturity Group 0 in the northern region of the study area to maturity Group 3 near the Ohio River, the southern boundary of the study area. The SOYGRO sequences were set to plant soybeans on a specified date for each model run, June 1, June 15, July 1, or July 15. Seeding rates were set to 50 seeds per square meter and row spacing was set at 38cm. Irrigated simulations were set to automatically water the soybean plants with 25mm of water when a threshold of 50% of maximum available soil moisture was reached. SOYGRO harvest details were set to harvest the soybeans automatically at maturity.

Model Output Analysis

DSSAT created five output files for each of the simulations (wbal.out, water.out, summary.out, growth.out, and overview.out). Because of the large volume of data produced in 156 century-long historical and 120 decade-long future series of daily simulations, output generation frequency was restricted to once every 10 days. For examples of the output files, refer to Appendix B. To analyze the model run results, text output files were converted to Microsoft Excel 97 (*.XLS) format. The analysis focuses primarily on the double-cropped soybeans. Answers to the research questions in this study were addressed first for the historical analysis and second for the future scenario.

In the assessment, it was necessary to define a breakeven soybean yield level, at which economic input costs equal output costs for the secondary soybean crop. Based on estimated current production costs, including seed/technology fees, planting costs, one herbicide application, harvesting costs, and the market price for soybeans, the breakeven yield is estimated at 1000 kg/ha (15 bushels/acre). Because production costs may vary by location, this breakeven yield is not exact, but can be considered a liberal cost, conservative yield estimate as some of the actual costs may be cheaper or may not be applicable in some cases.

Chapter 3

RESULTS AND DISCUSSION

Historical Analysis

On average, later planting dates resulted in lower simulated soybean yields than earlier planting dates. Table 3 lists mean simulated double crop soybean yields for each of the eighteen sites, for both dryland and irrigated crops across four different planting dates.

Table 3. Mean simulated historical double-crop soybean yields (kg/ha) by site and planting date for dryland and irrigated simulations, 1895-1996.

State	**Site**	**Dryland**				**Irrigated**			
		1-Jun	15-Jun	1-Jul	15-Jul	1-Jun	15-Jun	1-Jul	15-Jul
MI	Adrian	549	377	260	188	3758	3365	2651	1638
	Allegan	1009	716	491	329	3719	3140	2580	1611
	Bay City	420	279	200	264	3488	3071	2346	1398
	Big Rapids	950	802	506	210	3245	2675	1645	582
	Coldwater	1124	986	815	621	3697	3295	2609	1624
	Owosso	723	458	307	209	3589	3175	2428	1371
	Pontiac	789	539	426	320	3739	3344	2645	1736
IN	Cambridge City	1982	1593	1149	861	3888	3518	2823	1821
	Ft. Wayne	1350	960	694	592	3890	3535	2915	2056
	Greencastle	2088	1741	1521	1393	4049	3731	3159	2435
	Salem	1995	1723	1609	1469	4146	3832	3315	2595
	South Bend	1667	1232	905	721	3881	3509	2865	1993
OH	Circleville	1714	1332	1192	1101	3984	3666	3115	2384
	Findlay	1386	952	668	518	3953	3597	2940	2011
	Wooster	1785	1306	891	592	3749	3356	2626	1512
IL	Jacksonville	1517	1379	1236	1164	4181	3837	3270	2454
	Mt. Vernon	1596	1461	1472	1467	4204	3914	3469	2834
	Ottawa	1254	1069	911	887	3798	3476	2914	2234

At Coldwater, mean yield decreased from 986 kg/ha at June 15 dryland planting dates to 621 kg/ha for the July 15 planting dates, a 37% decrease. Irrigated yields decreased by 51% for the same planting dates at Coldwater. Exceptions occurred at Bay City, where the simulated mean dryland soybean yield increased slightly (by 64 kg/ha) from July 1st to July 15th, and at Mt. Vernon, where the mean dryland yields remained relatively constant from June 15th through July 15th.

Table 4. Historical mean season length (days) and yield (kg/ha) for soybeans at Adrian, 1895-1996.

	Dryland		**Irrigated**	
PDAT	**Mean season Length**	**Mean Yield**	**Mean season Length**	**Mean Yield**
1-Jun	113	549	111	3758
15-Jun	110	377	105	3365
1-Jul	105	260	99	2651
15-Jul	97	188	94	1638

Mean season length and mean yield at Adrian given in Table 4 further illustrate this point. For both dryland and irrigated simulations, mean yield decreased with later planting dates. Dryland mean yields decreased by 66% between the June 1 and July 15 planting dates with a 14% (16-day) decrease in mean season length. Irrigated mean yields decreased by 56% with a 15% (17-day) decrease in mean season length.

One method of analyzing the character of a given series, including both frequency and magnitude, is estimation of the probability distribution of the series, which can be obtained empirically by rank ordering the data and then calculating frequency/probability. Probability distributions are useful in illustrating risk involved in decision-making processes (Chipanshi et al., 1997). The cumulative probability distributions of soybean yields for the four different planting dates given in Figure 3 at Ft. Wayne illustrate the risks involved with later soybean planting dates through a lower probability of attaining a given yield level, such as the breakeven 1000 kg/ha yield.

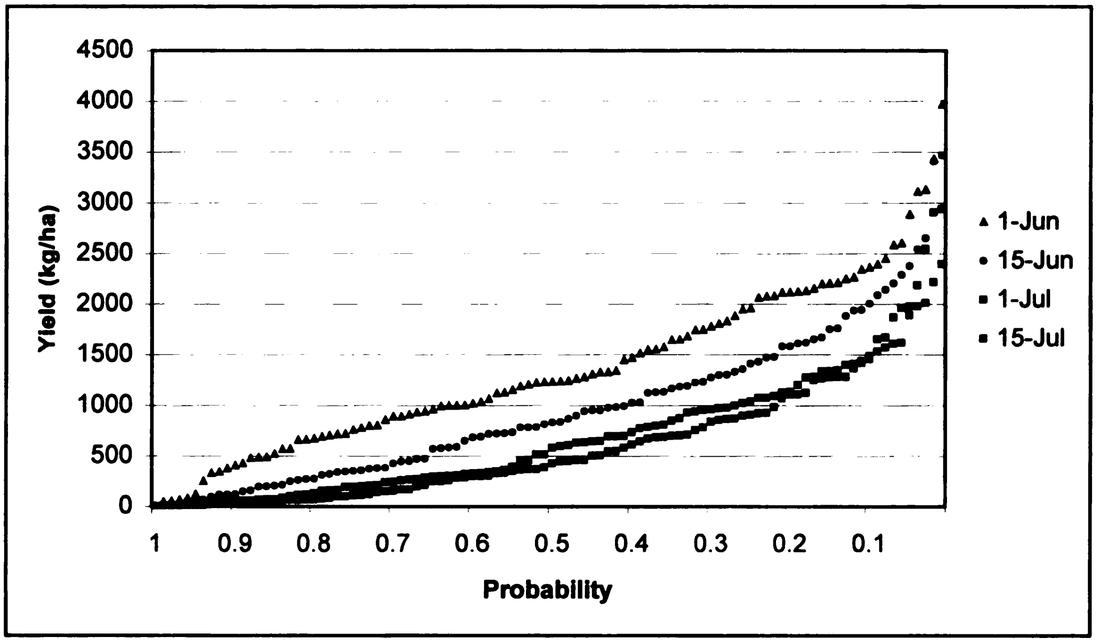

Figure 3. Simulated historical cumulative probability distribution of dryland soybean yields by planting date at Ft. Wayne (1897-1996).

A planting date of June 1 is associated with approximately a 63% chance of achieving a breakeven 1000 kg/ha yield. The probability of reaching breakeven yields decreases with later planting dates; 43% at June 15, 27% at July 1, and 22% at July 15.

Frequency of breakeven growing seasons also varied by location from north to south across the study region, with generally greater simulated yields at sites in the southern portion of the study area. For example, the July 1st dryland simulation at Mt. Vernon averaged 561 more kg/ha yield than the analogous simulation at Ottawa. This result was expected, as Mt. Vernon and other sites in the Ohio Valley are traditionally double-cropping areas with warmer climates, longer growing seasons, and greater precipitation than northern sites, such as Ottawa, which are primarily monocultural production regions. The probability distribution for the July 1st planting date in Figure 4 illustrates

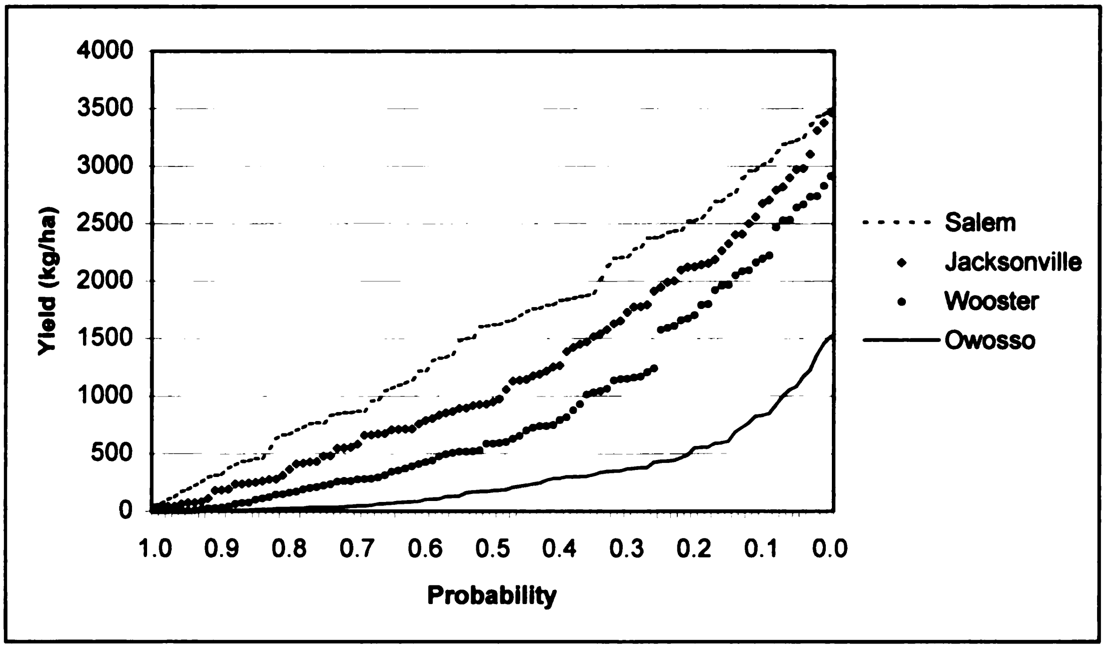

Figure 4. Simulated historical cumulative probability distribution of dryland soybean yields for a north-south transect of sites for the July 1 planting date (1896-1996).

the increasing potential for dryland double-crop soybean yields from north to south across the study area. Salem, the southernmost site in the region, shows a near-70% probability of attaining 1000 kg/ha yields. Jacksonville, Wooster, and

Owosso show progressively lower probabilities of attaining 1000 kg/ha yields with increasing latitude.

Why does the potential for successful double cropping change from north to south across the study region? Climatic limitations are often cited as reasons why double cropping is generally not practiced in northern areas of the U.S. The most important variable is moisture availability (Jeffers, 1987; Beuerlein, 1987). On a seasonal or annual basis, the overall bulk water balance of the soil profile can be described as the balance between precipitation and the sum of evapotranspiration (plant transpiration plus soil evaporation), runoff, and drainage out of the profile. The DSSAT simulations provide estimates of each of the components of the soil water balance, which in turn provides an opportunity to investigate the relationship between crop performance and moisture availability in greater detail. Simulated mean historical dryland water balance by site and planting date is given in Table 5.

Table 5. Simulated mean historical dryland soybean water balance (mm) by site and planting date (1895-1996). ET=evapotranspiration, RO=runoff, DR=drainage, and PR=precipitation.

		1-Jun				15-Jun			
State	Station	ET	RO	DR	PR	ET	RO	DR	PR
MI	Adrian	260	61	1.4	305	229	58	1.1	377
	Allegan	295	43	3.2	316	257	41	2.7	305
	Bay City	237	50	1.8	279	210	49	1.9	270
	Big Rapids	279	2.9	31	324	249	2.8	26	302
	Coldwater	306	19	10	332	272	18	9.2	315
	Owosso	274	33	3.2	296	236	32	3.2	280
	Pontiac	274	33	3.4	291	238	31	3.3	274
IN	Cambridge City	377	26	13	360	328	25	10	338
	Ft. Wayne	330	38	4.4	326	278	35	3.9	301
	Greencastle	378	27	10	367	329	25	7.6	345
	Salem	392	27	7.3	377	341	26	5.4	349
	South Bend	357	38	5.1	356	305	36	4	339
OH	Circleville	357	36	5.5	351	313	34	4.6	330
	Findlay	342	48	2.9	351	290	45	2.1	324
	Wooster	370	51	4.5	374	317	47	3.6	348
IL	Jacksonville	372	38	7.6	387	323	35	5.2	354
	Mt. Vernon	368	27	8.9	364	324	26	6.4	337
	Ottawa	307	32	5.7	317	269	31	3.7	303

		1-Jul				15-Jul			
State	Station	ET	RO	DR	PR	ET	RO	DR	PR
MI	Adrian	201	54	1.1	201	183	50	1.1	248
	Allegan	224	38	2.8	289	202	38	3.1	281
	Bay City	191	47	2	259	189	29	4.3	256
	Big Rapids	212	2.5	24	274	178	2.3	25	252
	Coldwater	238	17	10	291	214	16	12	274
	Owosso	203	28	3.3	254	183	25	3.4	234
	Pontiac	211	30	3.3	259	193	27	3.6	241
IN	Cambridge City	277	22	8.1	309	246	20	9.7	278
	Ft. Wayne	237	34	3.7	280	216	31	4	256
	Greencastle	287	22	8.2	313	262	22	9.4	288
	Salem	305	25	7.5	319	273	24	10	292
	South Bend	259	35	3.7	319	233	34	4.4	303
OH	Circleville	278	32	4.9	301	250	29	6.1	271
	Findlay	247	41	2.2	297	219	37	2.5	266
	Wooster	264	43	2.9	311	230	38	3.5	275
IL	Jacksonville	281	33	6.1	319	254	31	8.4	294
	Mt. Vernon	292	24	7.9	306	268	23	10	283
	Ottawa	237	30	4	286	222	28	5.4	267

In general, the southern sites have higher seasonal mean evapotranspiration values, which are indicative of their warmer, wetter climate. Runoff and drainage values in Table 5, however, vary across the region, likely reflecting the physical characteristics of different soils. For example, Big Rapids has very low runoff values and very high drainage values (e.g. 2.9 mm runoff and 31 mm drainage for the June 1 planting date), likely indicative of the coarse-textured, porous upper layers of the Coloma sand soil used in the simulation. In contrast, for a fine-textured soil with lower infiltration rates, such as Hoytville clay loam at Adrian, the magnitude of the runoff and drainage totals is symmetrically opposite (61mm runoff and 1.4 mm drainage for the June 1 planting date).

Seasonal precipitation totals vs. simulated yield, illustrating the importance of seasonal moisture on yield outcome, is given in Figure 5. All of the sites for all of the planting dates show a positive correlation between total seasonal precipitation and yield.

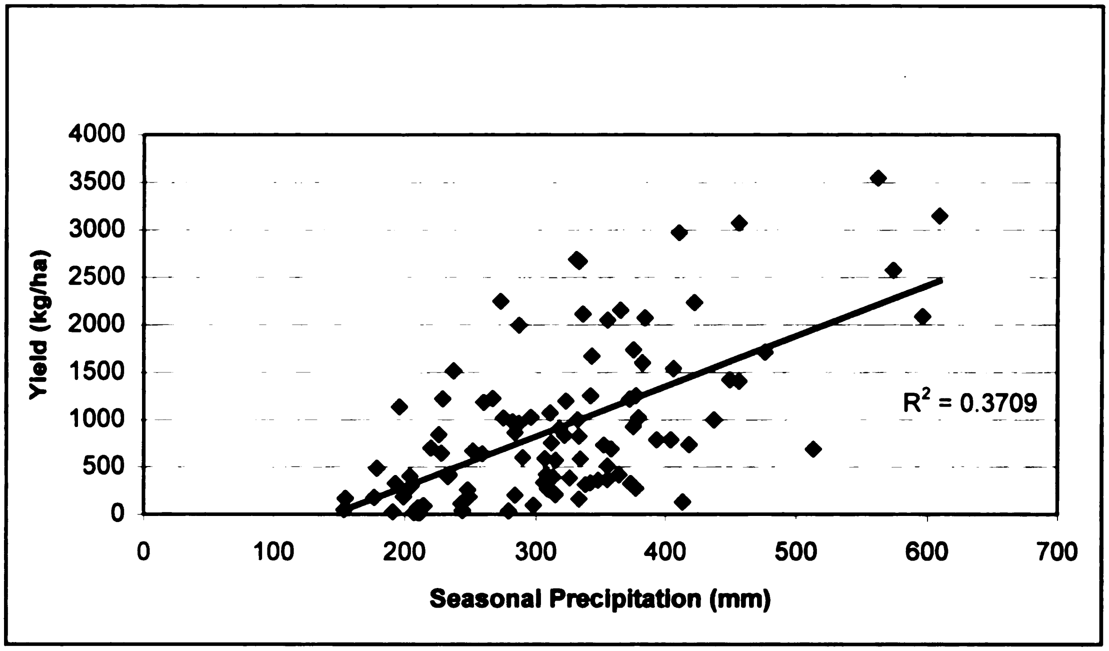

Figure 5. Seasonal precipitation totals vs. simulated dryland soybean yields for a June 15 planting date at Findlay (1896-1996).

Double cropping has special soil moisture constraints. The amount of soil water used by the primary wheat crop may leave insufficient moisture for the soybean crop. This point is illustrated in Figure 6, which depicts soil moisture conditions of three soil layers for a 12-month simulation at Circleville. The high variability of available soil moisture in the upper 0-15 cm layer relative to the lower layers is evident, as are differences in the rates of moisture drawdown and recharge.

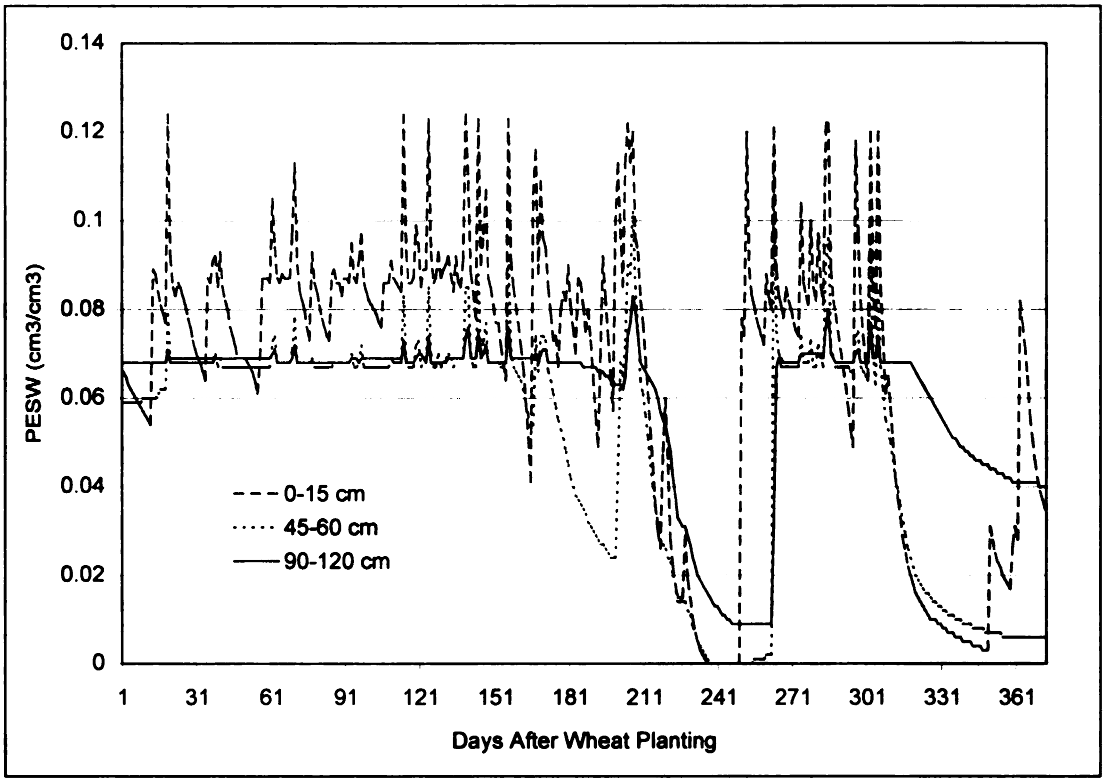

Figure 6. Simulated plant extractable soil moisture for three different layers at Circleville from 1 October 1907 through 30 September 1908. Soil type is Coloma Loamy Sand.

However, as wheat progresses through the grain-fill period towards maturity (indicated in Figure 6 between day 211 and 267), plant extractable soil moisture is severely depleted for both topsoil and subsoil layers simultaneously. This is a critical consideration for planting double-crop soybeans, as the seeds require moist soil for germination and delays in germination may negatively impact yields (Jeffers, 1987).

How much of a constraint is soil moisture on the double-crop soybeans? Simulations with irrigation serve to illustrate yield potential when moisture is not a limiting factor in plant growth and development. For simulations with the same planting dates, irrigation significantly improved mean yields. In these irrigated simulations, most sites exhibited mean yields more than double those of dryland simulations. For example, in the simulation at Cambridge City, dryland yields planted on June 15th averaged 1593 kg/ha while irrigated yields averaged 3518 kg/ha. Big Rapids more than tripled its yield for the same simulation, from 802 kg/ha yield under dryland conditions to 2675 kg/ha under irrigation. These results underscore the importance of moisture availability in determining the success of double crop soybeans. The effects of irrigation can be seen by comparing Figures 7a & 7b, which illustrate yield probabilities at Coldwater for dryland and irrigated simulations across all planting dates. For the July 15 planting date, the probability of attaining a 1000 kg/ha yield jumped from 20% in the dryland simulation to approximately 82% in the irrigated simulation.

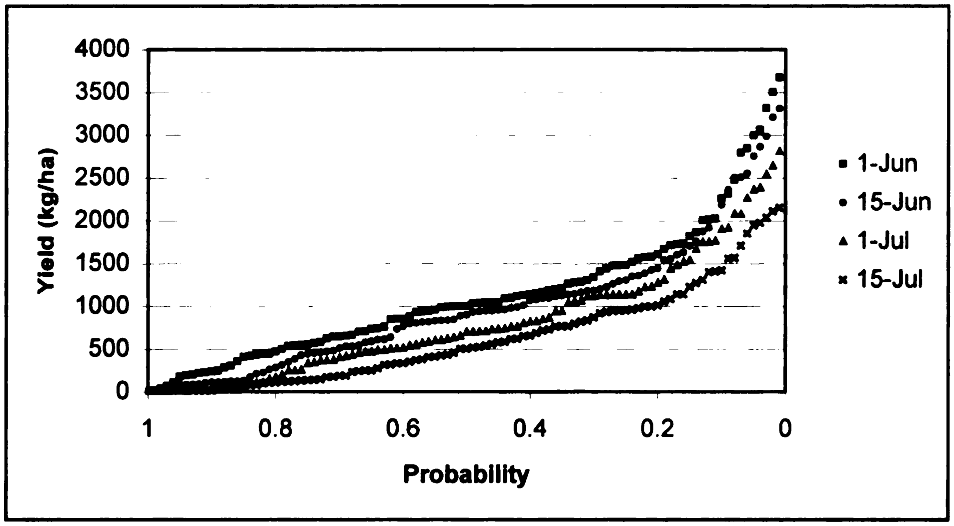

Figure 7a. Simulated historical cumulative probability distribution of dryland soybean yields by planting date at Coldwater (1897-1996).

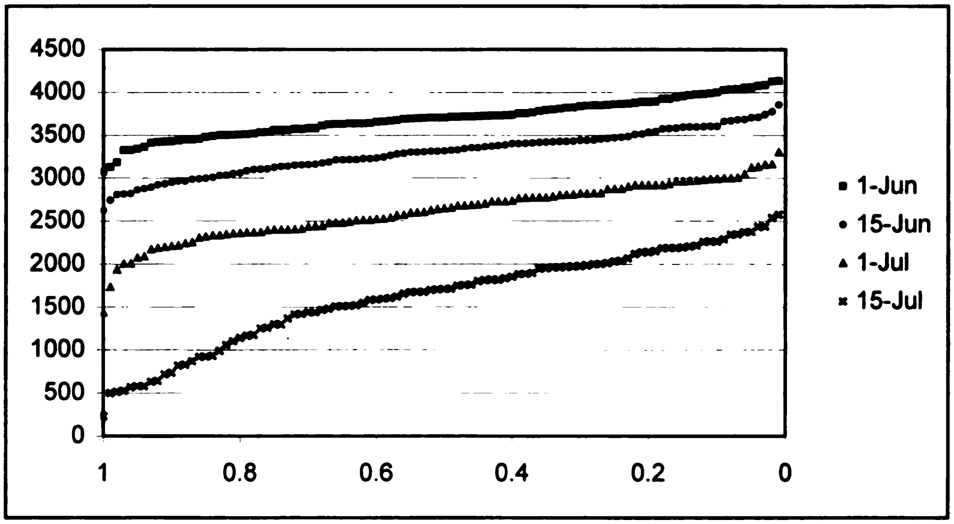

Figure 7b. Simulated historical cumulative probability distribution of irrigated soybean yields by planting date at Coldwater (1897-1996).

With irrigation, does the yield potential still differ from north to south? Figure 8 illustrates the probability distribution of simulated soybean yields for a north-south transect of sites.

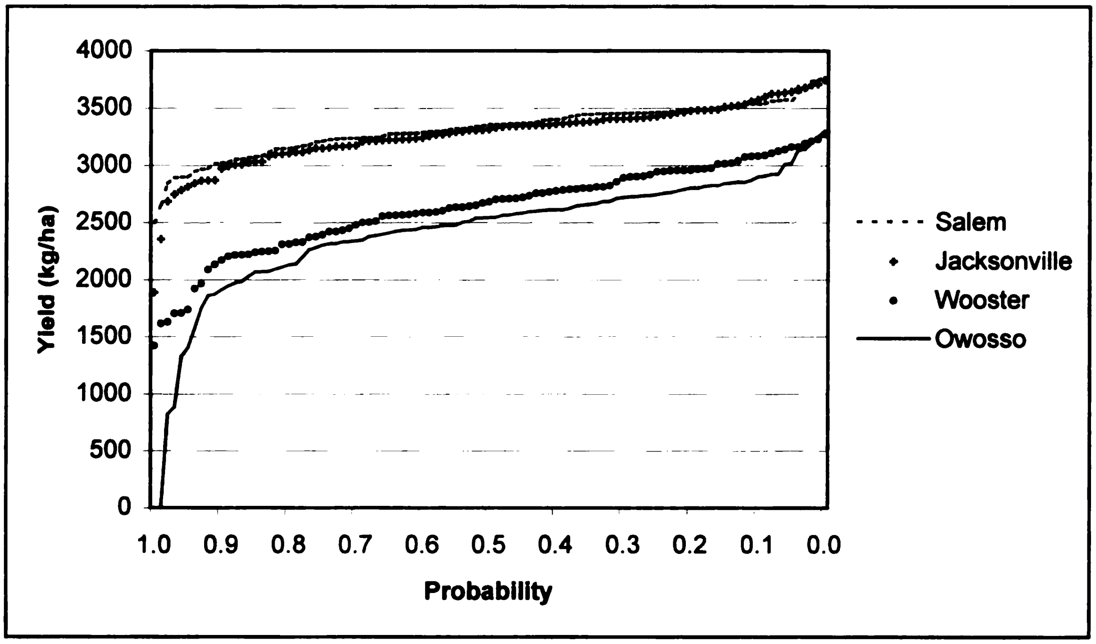

Figure 8. Simulated historical cumulative probability distribution of irrigated soybean yields for a north-south transect of sites at the July 1 planting date (1896-1996).

The distributions still reflect differences in yield potential from north to south, with Salem and Jacksonville, the southern sites, achieving substantially higher yields and potential yields than Wooster and Owosso in the northern region.

As in the dryland simulations, the probability of obtaining yields of 1000 kg/ha or better increased from north to south in the study area. Probabilities of attaining 1000 kg/ha yields for all simulations at all sites are given in Table 6. With irrigation, nearly 100% of the time for all sites, simulated double-crop soybean yields were over 1000 kg/ha. The exception was the July 15th planting date, at which point the frequency of 1000 kg/ha yields at many northern sites dropped off significantly. This is likely the effect of limited growing season on the second crop.

Table 6. Historical probability of attaining simulated soybean yields greater than 1000 kg/ha at different planting dates (1895-1996).

State	Station	Dryland				Irrigated			
		1-Jun	15-Jun	1-Jul	15-Jul	1-Jun	15-Jun	1-Jul	15-Jul
MI	Adrian	0.17	0.09	0.05	0.05	1.00	1.00	1.00	0.77
	Allegan	0.40	0.25	0.15	0.12	1.00	1.00	1.00	0.79
	Bay City	0.11	0.05	0.04	0.03	1.00	1.00	0.99	0.73
	Big Rapids	0.41	0.33	0.22	0.05	1.00	0.98	0.76	0.24
	Coldwater	0.52	0.41	0.34	0.22	1.00	1.00	1.00	0.82
	Owosso	0.24	0.13	0.08	0.03	1.00	1.00	0.98	0.74
	Pontiac	0.31	0.19	0.16	0.08	1.00	1.00	1.00	0.90
IN	Cambridge City	0.80	0.63	0.50	0.41	1.00	1.00	1.00	0.93
	Ft. Wayne	0.62	0.40	0.26	0.21	1.00	1.00	1.00	0.99
	Greencastle	0.84	0.70	0.60	0.63	1.00	1.00	1.00	1.00
	Salem	0.79	0.70	0.66	0.66	1.00	1.00	1.00	1.00
	South Bend	0.70	0.49	0.41	0.34	1.00	1.00	1.00	1.00
OH	Circleville	0.63	0.43	0.50	0.51	1.00	1.00	1.00	1.00
	Findlay	0.58	0.37	0.24	0.20	1.00	1.00	1.00	0.94
	Wooster	0.75	0.49	0.37	0.26	1.00	1.00	1.00	0.76
IL	Jacksonville	0.61	0.59	0.49	0.51	1.00	1.00	1.00	0.98
	Mt. Vernon	0.68	0.62	0.63	0.67	1.00	1.00	1.00	1.00
	Ottawa	0.46	0.39	0.33	0.38	1.00	1.00	1.00	1.00

How much moisture is necessary to eliminate moisture stress on the double-cropped soybeans? Table 7 lists the mean seasonal number and amount (in millimeters) of irrigation applications for each planting date. In the irrigated simulations, a large amount of water was required to keep soil moisture above stressful levels. For many of the northern sites, the average seasonal irrigation amounts were comparable to the mean seasonal precipitation amounts. For example, at Adrian on the June 1st planting date, an average of 315 mm of irrigation is applied in a season while the total mean seasonal precipitation is only 305 mm. At the same planting date in Ft. Wayne, an average of 257 mm of irrigation is applied per season while mean seasonal precipitation is 326 mm. For all sites, mean seasonal irrigation amounts and average seasonal number of irrigation applications were highest with earlier planting dates.

Table 7. Summary of mean number of irrigation applications (No. Apps.) and mean seasonal amounts of irrigation (Amt.) applied in historical soybean double crop simulations by site and planting date (1895-1996).

		1-Jun		15-Jun		1-Jul		15-Jul	
State	Station	No. Apps.	Amt. (mm)	No. Apps.	Amt. (mm)	No. Apps.	Amt. (mm)	No. Apps.	Amt. (mm)
MI	Adrian	12.4	315	11.6	294	9.8	246	7.7	189
	Allegan	12.5	307	11.3	278	10.7	261	8.7	209
	Bay City	12.2	311	11.4	289	9.9	248	7.6	189
	Big Rapids	13.6	260	12	227	9.8	184	7.5	138
	Coldwater	10	244	9.4	225	7.8	185	5.9	140
	Owosso	11.7	283	10.9	262	9.2	219	7	164
	Pontiac	11.4	275	10.8	259	9.3	222	7.3	170
IN	Cambridge City	7.3	199	7.1	193	6	162	4.7	124
	Ft. Wayne	9.6	257	8.9	239	7.5	199	6	157
	Greencastle	7.9	221	7.2	202	6	165	4.7	129
	Salem	8.5	239	7.7	217	6.2	172	4.3	120
	South Bend	8.9	233	8.4	217	7.1	183	5.3	136
OH	Circleville	8.8	228	8.2	212	6.8	176	5.5	141
	Findlay	10	251	9.6	237	8.3	202	6.5	158
	Wooster	7.7	207	7.4	197	6.3	167	4.9	129
IL	Jacksonville	10.6	266	9.8	244	7.9	194	6	147
	Mt. Vernon	11.2	280	10	250	8	195	6.1	149
	Ottawa	9.6	266	9.1	252	7.7	211	6.3	169

Potential yield under simulated non-limiting moisture conditions is clearly higher than dryland simulations across the region, but the mean seasonal amounts of irrigation applied to eliminate moisture stress are substantial. If used, irrigation would substantially increase the soybean production cost and the resulting breakeven yield level. However, the irrigated simulations used here are intended to show overall yield potential and to illustrate moisture deficiencies across the region. The numbers indicate that northern sites, especially in Michigan, generally have greater potential risk of moisture stress than other sites in the study area, possibly due to lower average growing season precipitation.

Looking at the seasonal water balances, the model results indicate that seasonal cumulative evapotranspiration decreased with later planting dates. Cumulative runoff also decreased with later planting dates, while cumulative drainage varied—no predictable increases or decreases with planting dates. This was likely caused by increased water uptake due to plant growth, drying the subsoil so that the soil soaks up more of the precipitation or irrigation. A comparison of mean seasonal evapotranspiration for dryland (Table 5) and irrigated double-crop soybeans (Table 8) reveals that potential evapotranspiration in an unlimited moisture simulation far exceeds actual evapotranspiration in the dryland simulation. Moisture availability plays a major role in double crop success.

Table 8. Simulated mean historical irrigated soybean water balance (mm) by site and planting date (1895-1996). ET=evapotranspiration, RO=runoff, DR=drainage, and PR=precipitation.

		1-Jun				15-Jun			
State	Station	ET	RO	DR	PR	ET	RO	DR	PR
MI	Adrian	473	75	1.4	299	427	70	1.1	279
	Allegan	471	53	3.5	316	414	51	2.9	305
	Bay City	451	61	2.2	269	410	59	1.8	259
	Big Rapids	425	3.6	48	314	373	3.4	42	294
	Coldwater	455	24	29	326	412	23	26	305
	Owosso	462	42	4.5	284	416	41	3.7	269
	Pontiac	459	42	4.5	282	414	39	4.1	262
IN	Cambridge City	481	34	19	359	434	32	15	331
	Ft. Wayne	478	47	7.5	322	428	43	5.8	294
	Greencastle	496	34	18	366	445	32	14	341
	Salem	523	36	9.9	373	466	34	8.3	341
	South Bend	488	50	6.6	351	438	46	5.2	327
OH	Circleville	489	47	9.4	348	442	44	7.3	325
	Findlay	499	60	3.8	346	448	55	2.7	316
	Wooster	479	63	6.2	370	433	58	4.5	340
IL	Jacksonville	540	49	12	380	480	45	11	352
	Mt. Vernon	544	35	10	356	484	32	8.6	328
	Ottawa	472	41	12	313	428	40	10	296

		1-Jul				15-Jul			
State	Station	ET	RO	DR	PR	ET	RO	DR	PR
MI	Adrian	366	63	1.2	256	305	59	1.2	243
	Allegan	370	46	3.8	288	316	45	4.3	280
	Bay City	356	56	2.5	248	302	54	3.7	243
	Big Rapids	307	2.9	40	268	244	2.7	39	250
	Coldwater	353	21	28	285	295	19	36	269
	Owosso	353	36	4.5	246	290	31	5.6	227
	Pontiac	359	36	3.9	245	304	34	5	235
IN	Cambridge City	371	28	14	303	312	25	18	275
	Ft. Wayne	366	40	6.9	273	310	36	9.3	251
	Greencastle	380	28	17	309	327	25	24	285
	Salem	400	32	13	316	336	29	29	289
	South Bend	373	44	5.8	307	313	41	9.3	294
OH	Circleville	382	39	8.1	298	327	34	12	269
	Findlay	383	50	3.1	289	321	43	4.7	261
	Wooster	369	53	4.2	308	305	44	5.3	272
IL	Jacksonville	403	42	13	315	336	37	20	291
	Mt. Vernon	411	30	13	300	351	27	19	281
	Ottawa	368	38	12	279	317	35	18	264

Because available soil moisture can be related to soil texture, a sensitivity analysis was performed at Adrian, MI. To explore soybean yield variability as a function of soil type, simulations contrasting three soil textures were run at Adrian keeping all other variables constant. While total seasonal precipitation was constant across the three simulations, water balance (i.e. runoff, drainage, and evapotranspiration) and PESW varied by soil texture. The sandy textured soil was associated with the greatest ET and DR and the clay loam, the least (data not shown). Simulated potential yield differences across the differing soil textures are given in Figure 9. The sandy soil, most permeable of the three, produced the highest yield potential while clay loam produced the worst. For example, at the 1000 kg/ha yield level, the frequency for the sand was 0.40, for the loam, 0.18, and for the clay loam, only 0.05. This was unexpected as loamy textured soils are often preferred soils for agriculture. This result could be a function of the model, but more likely indicates that more permeable soils, in which a relatively greater fraction of growing season precipitation reaches the rooting zone, may actually be an advantage in this type of double cropping system.

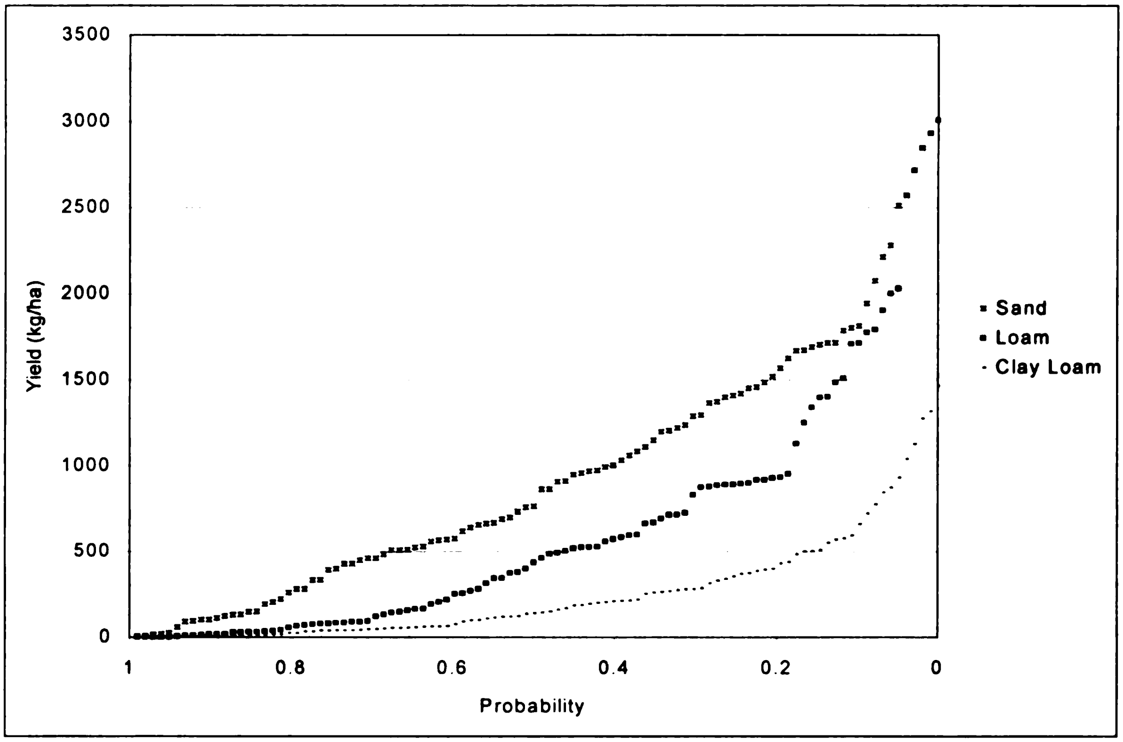

Figure 9. Simulated historical cumulative probability distribution of dryland soybean yields by soil texture at Adrian for July 1 Planting Date (1895-1996).

Given the constraints that affect the frequency of historical success at double cropping, is there a time trend in the simulated double-crop yield data? Time series of simulated soybean yields for Allegan in the northern part of the study area and Greencastle in the south are given in Figures 10a and 10b. Allegan has lower overall yields and a smaller overall yield range than Greencastle. The moving average at Allegan depicts a variable yield trend over the past century, with a marked increase in mean yield from 1965-1975. The moving average at Greencastle reflects a flatter distribution of simulated yields in the early part of the 20th century, with steady increases for much of the latter half of the century. The reasons for the periods of relatively higher and lower yield

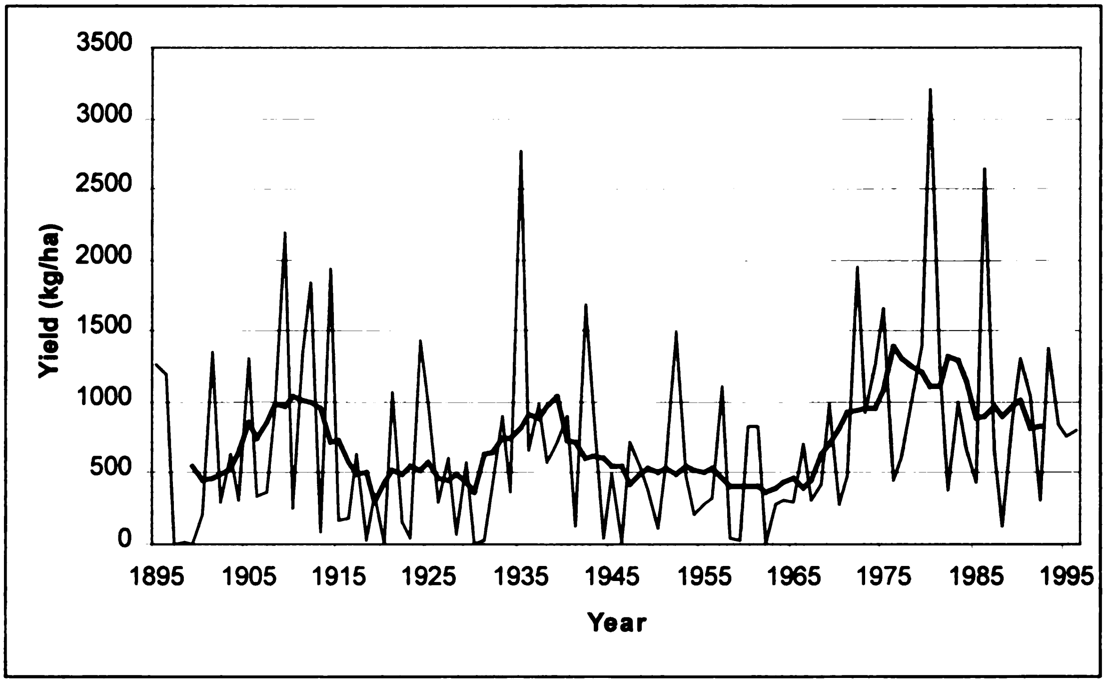

Figure 10a. Simulated historical dryland yields and moving 9-year average by year at Allegan for June 15 planting date (1895-1996).

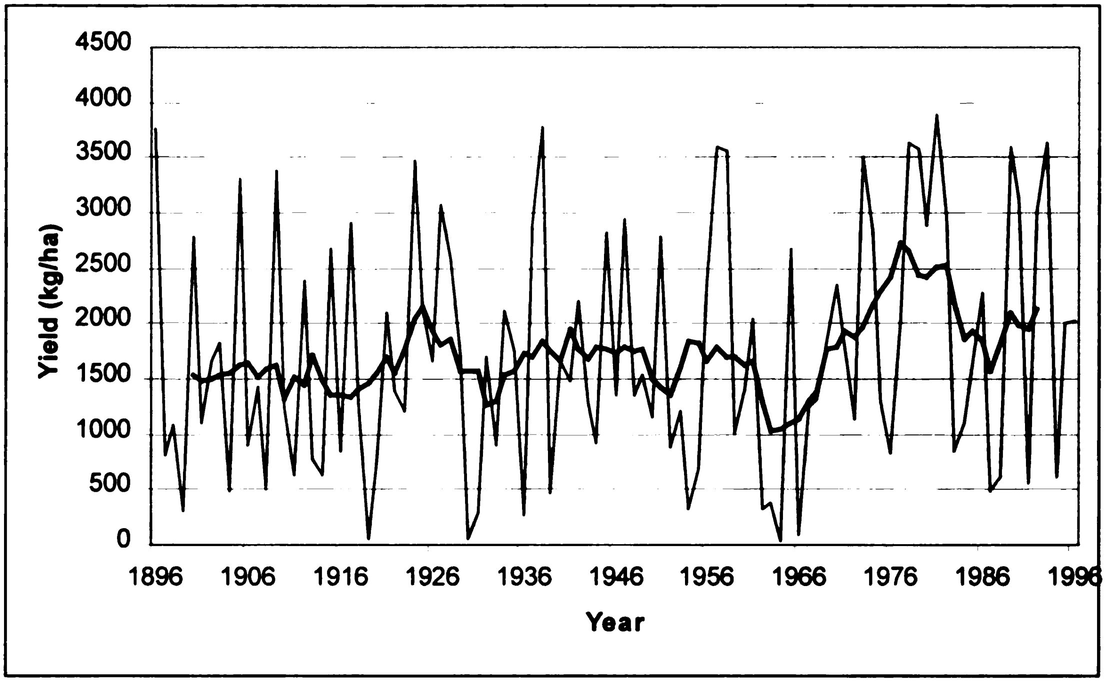

Figure 10b. Simulated historical dryland yields and moving 9-year average by year at Greencastle for June 15 planting date (1896-1996).

trends are unknown, but may be linked to long-term increases in precipitation (Karl et al., 1994) and precipitation frequency (Andresen, 1999).

Historical analysis of a wheat-soybean double-cropping system in the region resulted in several consistent trends and associations. First, mean double-crop soybean yields positively correlated with mean season length and later planting dates resulted in lower simulated soybean yields than earlier planting dates. The frequency of simulated breakeven yields increased with earlier planting dates. Yield potential increased from north to south across the study area.

Overall, however, the most important climatological factor for the Great Lakes and Ohio Valley regions is precipitation, with simulated yield potentials found to be strongly and positively correlated with plant available water. In general, the Ohio Valley sites have higher mean seasonal precipitation and evapotranspiration than the Great Lakes sites, which explained a major portion of the differences in regional yield potential. Soil moisture limitations for soybean are related to high rates of evapotranspiration and resulting depletion of subsoil moisture by the primary wheat crop during grain-fill.

Finally, some increase in simulated soybean yields is evident in time series plots of historical yield simulations for the past century, which are possibly linked to long-term changes in precipitation.

HadCM2 Future Climate Scenario Simulation

Simulating double cropping with data or output from a climate model scenario can serve as a tool to explore a range of potential effects of climate change on agricultural production. Using the HadCM2 scenario, one possible outcome on double cropping wheat and soybeans was explored for 2001-2099. The results are compared with the results of the historical analysis in the previous section.

How do mean double-crop soybean yields compare between historical and future scenarios? A comparison of simulated soybean yields at a subset of sites for each of the scenarios modeled: both dryland and irrigated, for future CO_2 – enriched, future non-CO_2 – enriched, and historical scenarios is given in Table 9 for the July 15 planting date.

Table 9. Comparison of mean future (2001-2099) and historical (1896-1996) simulated soybean yields by site for the July 15 planting date.

Station	**Dryland**			**Irrigated**		
	Future no CO2	**Future CO2**	**Historical**	**Future no CO2**	**Future CO2**	**Historical**
Big Rapids	655	1272	210	1282	2004	582
Cambridge City	1247	2346	861	2003	3148	1821
Coldwater	868	1726	621	1630	2569	1624
Ottawa	1143	2122	887	1767	2793	2234
Salem	1577	2751	1469	2274	3495	2595
Wooster	738	1608	592	1717	2686	1512

Mean yields for dryland soybeans without carbon dioxide enrichment increase more than 200% over dryland historical mean yields at Big Rapids, while Salem increased only 7% for the same scenario. With carbon dioxide enrichment, mean yield values nearly double those without carbon dioxide enrichment.

Figures 11a and 11b illustrate a comparison of changes in mean simulated dryland soybean yields for two decades in the future and the historical mean, with constant and transient CO_2 concentrations, respectively. Without CO_2 enrichment, mean yields in the 2040s, a decade of relatively low precipitation, are far lower than those in the 2090s. Mean yields for the 2040s are comparable to those of the historical mean, with the exceptions of Salem and Ottawa, which decrease markedly from the historical mean.

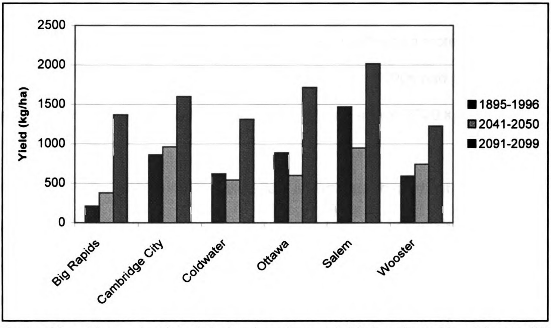

Figure 11a. Mean simulated dryland soybean yields by site, without future CO_2 enrichment, for the July 15 planting date.

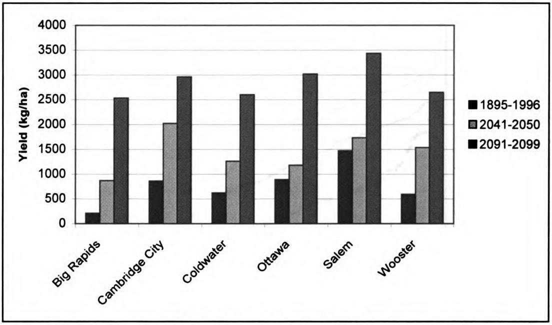

Figure 11b. Mean simulated dryland soybean yields by site, with future CO_2 enrichment, for the July 15 planting date.

With CO_2 enrichment, both future decades reflect an increased simulated mean yield over the historical mean at all sites. The 2090s had the highest simulated mean yields, with all six sites averaging above 2500 kg/ha.

Does the yield potential still reflect a north-south gradient with climate change? Cumulative probability distribution functions of simulated future soybean yields at Big Rapids, Ottawa, and Salem, (a north-south transect of the study area) for constant and enriched CO_2 levels are given in Figures 12a & 12b. The distributions indicate that the north-south gradient is still prominent, with greater yield potential at the southern sites than at the northern sites. For example, yields at Salem are 45% more likely to exceed 1000 kg/ha than at Big

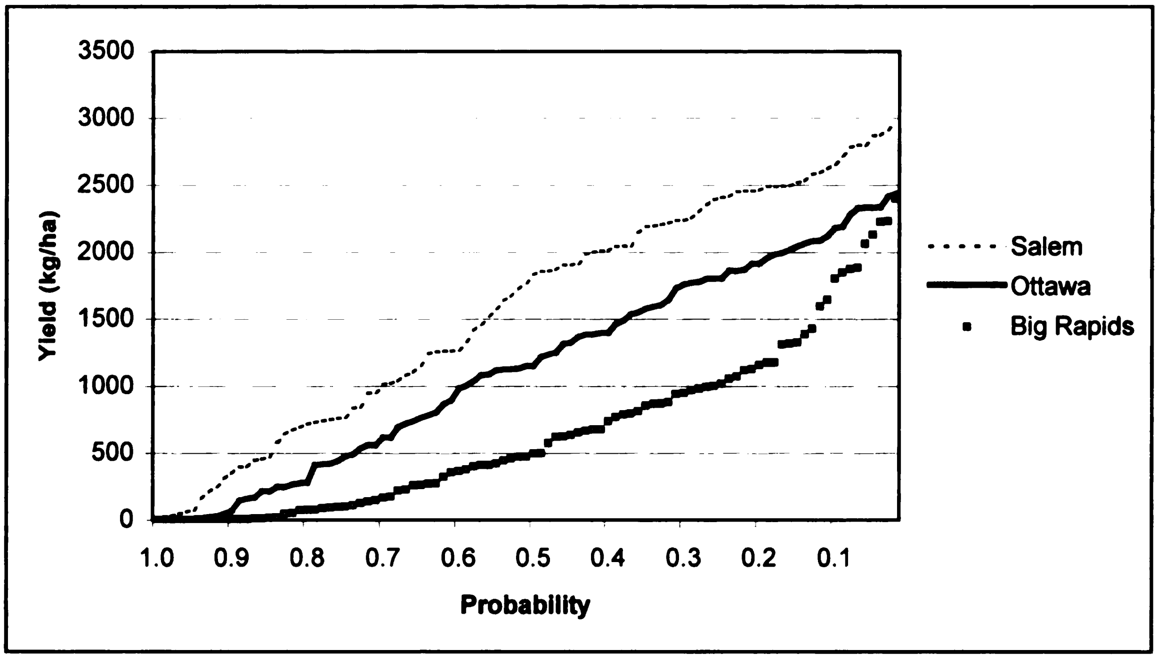

Figure 12a. Future cumulative probability distribution of simulated dryland soybean yields with constant CO_s levels for a north-south transect of sites (2001-2099).

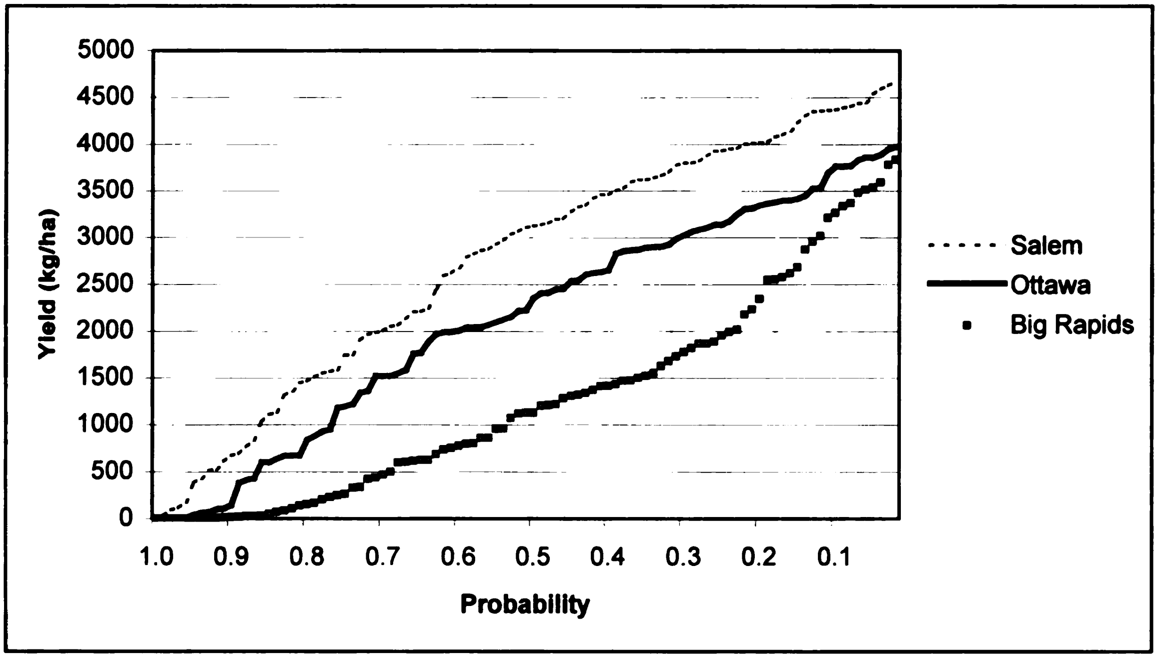

Figure 12b. Future cumulative probability distribution of simulated dryland soybean yields with enhanced CO_2 levels for a north-south transect of sites (2001-2099).

Rapids, where breakeven yields occurred less than 30% of the time. Yield potential increases for all three sites with CO_2 enrichment, but the north-south gradient remains evident across both constant and enriched CO_2 scenarios. While the probability of achieving breakeven yields at Big Rapids increased to 52% with CO_2 enrichment, the same probability at Salem increased to 85%.

Is water stress in the future as much of a limitation for the Great Lakes region as it was for the historical simulation? How does the future water balance compare with the historical water balance? Mean seasonal water balance for the six sites for both CO_2 enriched and constant CO_2 scenarios in the future are listed in Table 10 for the July 15 planting date.

Table 10. Future simulated mean seasonal water balance (mm) for the July 15 planting date (2001-2099). ET=evapotranspiration, RO=runoff, DR=drainage, and PR=precipitation.

Dryland							
no CO2				**CO2**			
ET	**RO**	**DR**	**PR**	**ET**	**RO**	**DR**	**PR**
226	2.5	40	326	210	3	48	325
284	20	13	319	268	22	19	321
250	18	22	318	233	19	27	317
261	35	18	336	244	37	23	335
307	28	40	353	293	30	46	356
260	37	1.3	315	243	40	2	314

Irrigated							
no CO2				**CO2**			
ET	**RO**	**DR**	**PR**	**ET**	**RO**	**DR**	**PR**
272	2.7	53	324	244	3	61	323
328	23	20	318	299	25	27	321
297	20	50	316	266	21	55	316
305	40	38	337	273	42	44	337
348	31	52	353	321	33	59	356
317	42	4.9	315	286	44	9	312

The southernmost site, Salem, still has the highest mean evapotranspiration value, while the northernmost site, Big Rapids, retains the lowest values across all simulations. Compared with historical dryland evapotranspiration values, the mean at Big Rapids in the future simulation increased by 48 mm without CO_2 enrichment and by 32 mm with CO_2 enrichment. Mean evapotranspiration values for Salem increased by 34 mm without CO_2 enrichment and by 20 mm with CO_2 enrichment. The difference between mean evapotranspiration in the irrigated simulation and the dryland simulation decreased from the historical to the future scenario at Big Rapids by 20 mm and at Salem by 22 mm, suggesting less potential water stress on double-crop soybeans in the future for both the Great Lakes and Ohio Valley regions.

A comparison between future and historical mean evapotranspiration and precipitation is given in Figures 13a & 13b. In all cases, mean seasonal evapotranspiration increases from the levels in the historical simulation to those in the future simulation, likely due to increased mean precipitation indicated in Figure 13b. While precipitation is greater than evapotranspiration for both future and historical simulations, yields in the future are significantly greater, likely because of reduced plant water stress (data not shown). Evapotranspiration in the future is reduced with CO_2 enhancement, reflecting increased water use efficiency. Evapotranspiration values are greatest at southern sites and decrease to the north.

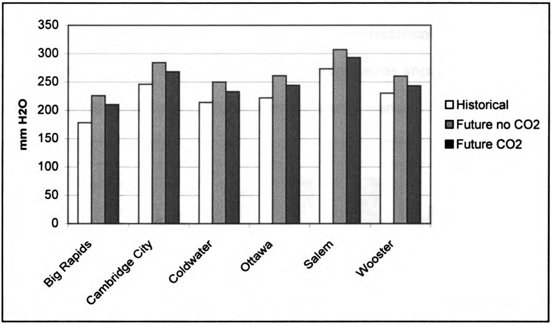

Figure 13a. Comparison of future (2001-2099) and historical (1895-1996) mean seasonal evapotranspiration for dryland soybean yields for July 15 planting date.

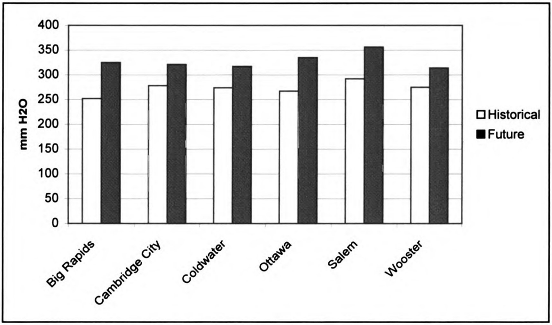

Figure 13b. Comparison of future (2001-2099) and historical (1895-1996) mean seasonal precipitation for dryland soybean yields for July 15 planting date.

To illustrate decadal changes in precipitation in the future, refer to Figure 14. Mean seasonal precipitation increases over the historical mean for both the 2040s and the 2090s. Changes simulated at Big Rapids show mean precipitation to double in the 2090s over historical means.

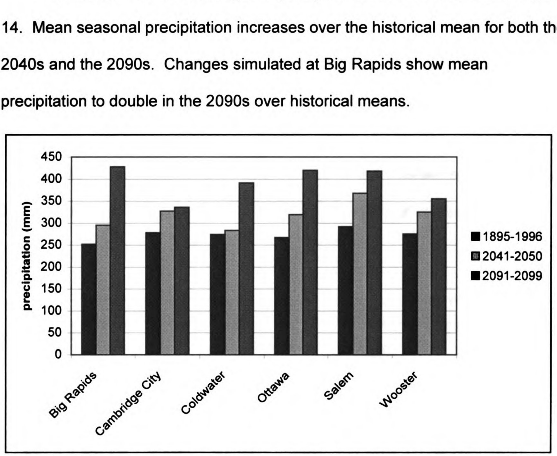

Figure 14. Mean soybean growing season precipitation (mm) for the July 15 planting date.

Changes in mean evapotranspiration for two decades of future simulated dryland soybeans are given in Figure 15 for each site under transient CO_2 conditions. In all cases, future evapotranspiration exceeds mean historical evapotranspiration levels, likely reflecting increased precipitation in the future. On average, evapotranspiration levels in the 2090s equaled or exceeded those of the 2040s. For example, the 2090s simulation at Coldwater had approximately 252 mm of mean evapotranspiration, while the 2040s had approximately 235 mm.

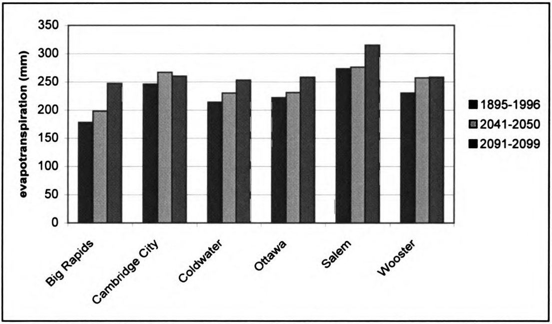

Figure 15. Mean evapotranspiration for simulated dryland soybeans, with transient future CO_2, for the July 15 planting date.

Irrigated scenarios used to illustrate water non-limiting situations in a north-south transect with both constant and enriched CO_2 levels are given in Figures 16a and 16b. Yield potential increased significantly with CO_2 enrichment when water was not limiting. For instance, Big Rapids jumps from a 57% to a

69% probability of attaining breakeven yields with CO_2 enhancement. The north-south transect is still evident in yield potential, despite the effects of CO_2 enhancement, as Salem, the southernmost site in the graph has a greater yield potential than both Ottawa and Big Rapids, the northernmost site.

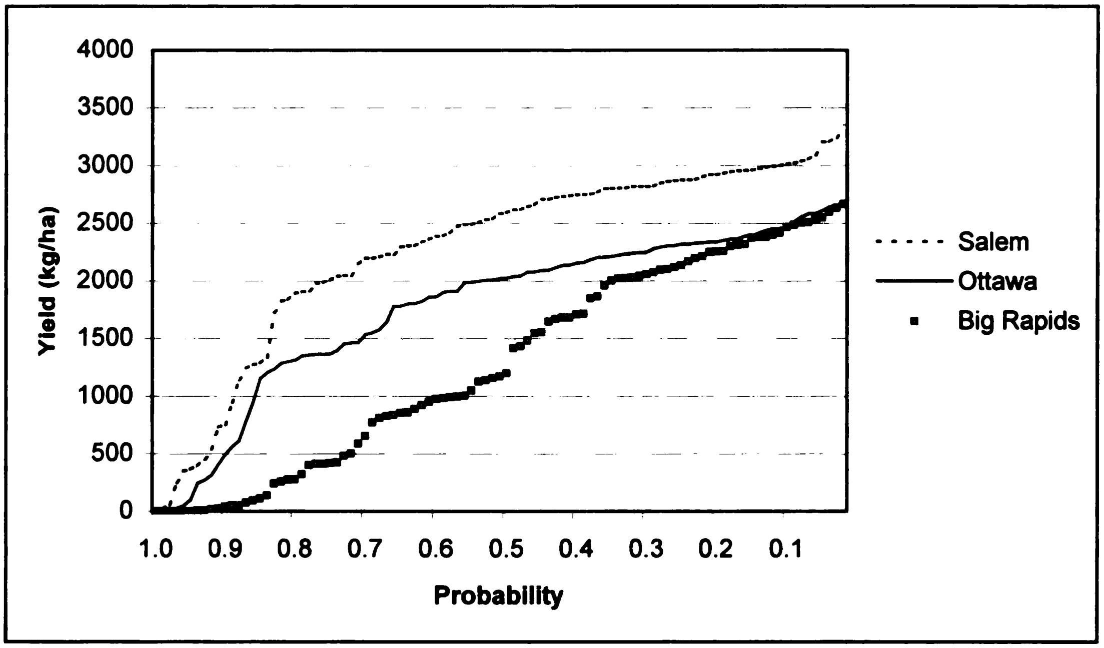

Figure 16a. Future simulated cumulative probability distribution for irrigated soybean yields under constant CO_2 levels (2001-2099) for the July 15 planting date.

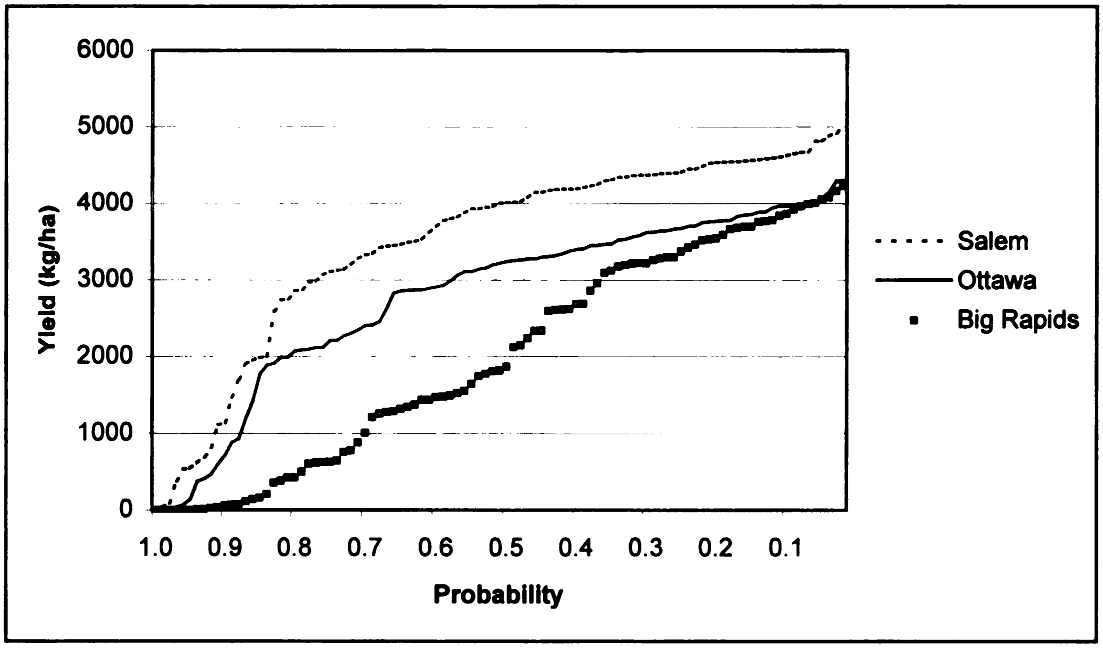

Figure 16b. Future simulated cumulative probability distribution for irrigated soybean yields under enriched CO_2 levels (2001-2099) for the July 15 planting date.

A comparison of historical and future mean frequencies and amounts of irrigation applications is illustrated in Figures 17a and 17b. Because the irrigated simulations were designed to eliminate water stress, the changes in irrigation application frequency and amounts through time are assumed to represent changes in water stress levels for the soybeans. Both frequency and amount of irrigation applied decreased from the historical simulations relative to the future simulations, indicating decreased water stress on the soybeans. Carbon dioxide enhancement scenarios exhibited less frequent and smaller amounts of irrigation. The greatest decrease was found at Ottawa, where the amount of irrigation applied decreased by more than 50% from historical to future CO_2-enhanced simulations.

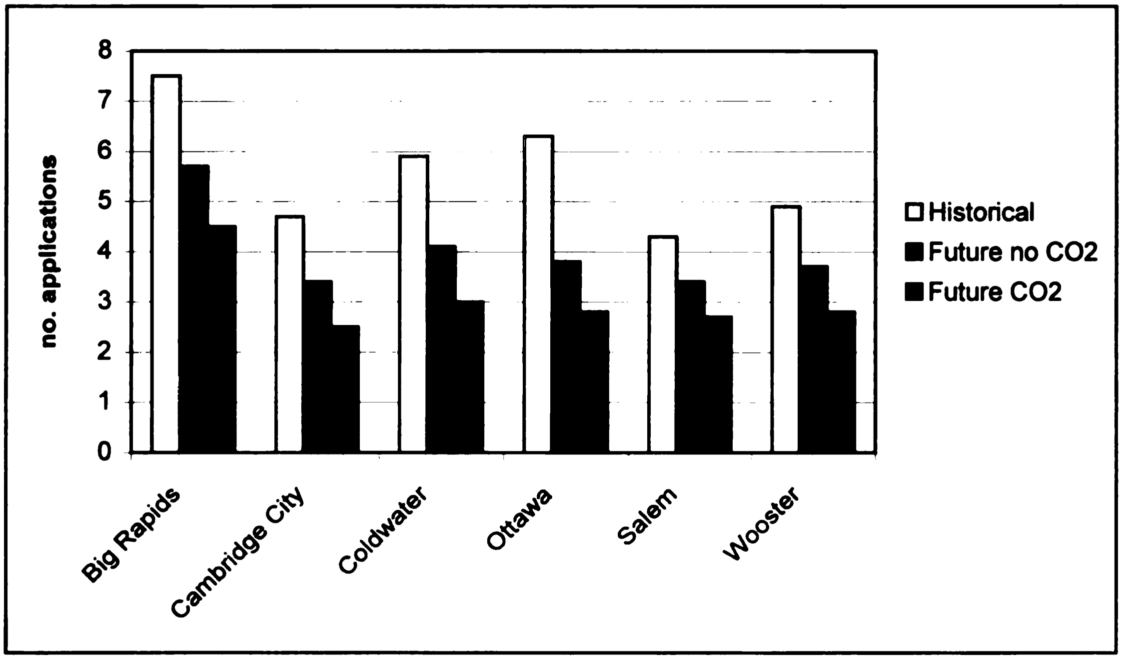

Figure 17a. Comparison of future and historical mean irrigation application frequency for the July 15 planting date.

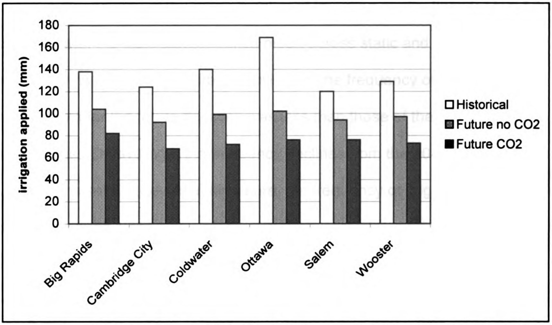

Figure 17b. Comparison of future and historical mean simulated seasonal irrigation requirements for a cross-section of sites in the Great Lakes region for the July 15 planting date.

A comparison of the mean number of irrigation applications for two future decades with the historical simulated mean across static and transient CO_2 levels is given in figures 18a and 18b. For all sites, the frequency of irrigation applications for the future decades was less than those of the historical simulations. On average, the frequency declines from the 2040s to the 2090s. Under transient CO_2 levels in the future, the frequency of irrigation applications decreases even more.

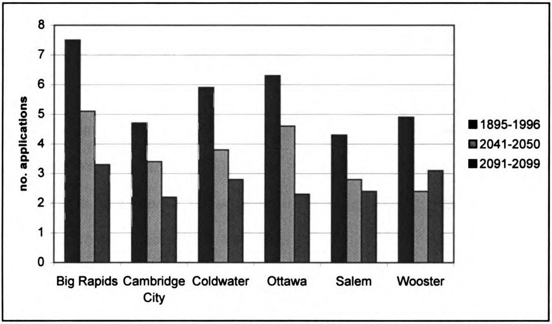

Figure 18a. Mean seasonal number of irrigation applications, without CO_2 enrichment, for the July 15 planting date.

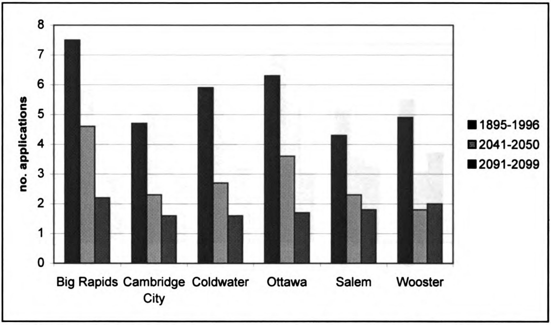

Figure 18b. Mean seasonal number of irrigation applications, with CO_2 enrichment, for the July 15 planting date.

Mean seasonal amounts of irrigation applied are given in Figures 19a and 19b for static and transient CO_2 levels. Total applied irrigation decreases from historical to future levels. On average, the amounts also decreased through time in the future simulations from the 2040s to the 2090s. For example, at Coldwater in the non-CO_2-enriched scenario, mean irrigation decreased from 140 mm in the historical simulation to 90 mm in the 2040s, to 67 mm in the 2090s. With CO_2 enrichment, future irrigation amounts decreased even more. At Coldwater under transient CO_2, an average 67mm of irrigation was applied in the 2040s and 40 mm in the 2090s.

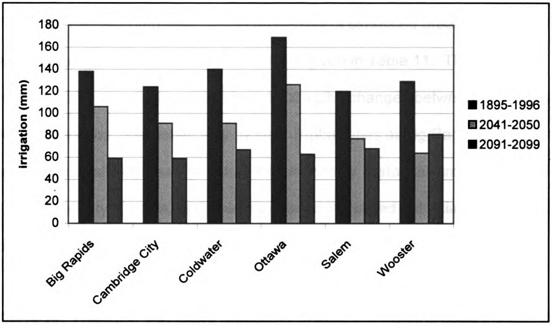

Figure 19a. Mean seasonal irrigation application amounts, without CO_2 enrichment, for the July 15 planting date.

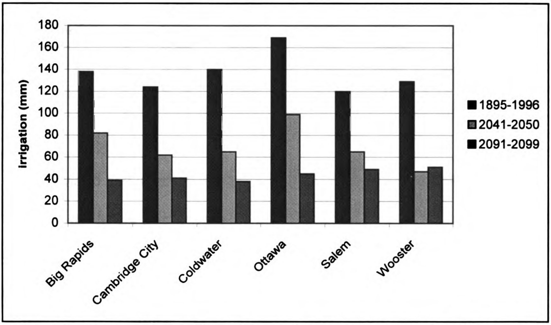

Figure 19b. Mean seasonal irrigation application amounts, with CO_2 enrichment, for the July 15 planting date.

An overall comparison of the probability of simulated breakeven yields for each of the six sites (historical vs. future) is given in Table 11. The probability of reaching soybean yields greater than 1000 kg/ha changes between historical and future scenarios, but results vary by site. Probabilities at Big Rapids, Coldwater, and Wooster all increased for future simulations vs. historical simulations, while Cambridge City, Ottawa, and Salem exhibited increased potential yields for dryland simulations in the future, but decreases for the irrigated simulation.

Table 11. Historical and future probability of attaining yields greater than 1000 kg/ha for July 15 planting date.

Station	Dryland			Irrigated		
	Future no CO2	Future CO2	Historical	Future no CO2	Future CO2	Historical
Big Rapids	0.25	0.53	0.05	0.56	0.70	0.24
Cambridge City	0.60	0.80	0.41	0.87	0.89	0.93
Coldwater	0.44	0.71	0.22	0.83	0.86	0.82
Ottawa	0.59	0.76	0.38	0.85	0.87	1.00
Salem	0.70	0.86	0.66	0.88	0.91	1.00
Wooster	0.32	0.60	0.26	0.80	0.84	0.76

Dryland and irrigated yield probability distribution functions comparing historical and future yield potentials at Big Rapids for the July 15 planting date are given in Figures 20a & 20b. Both future simulations at Big Rapids reflect decreased risk versus the historical levels. The future scenario without CO_2

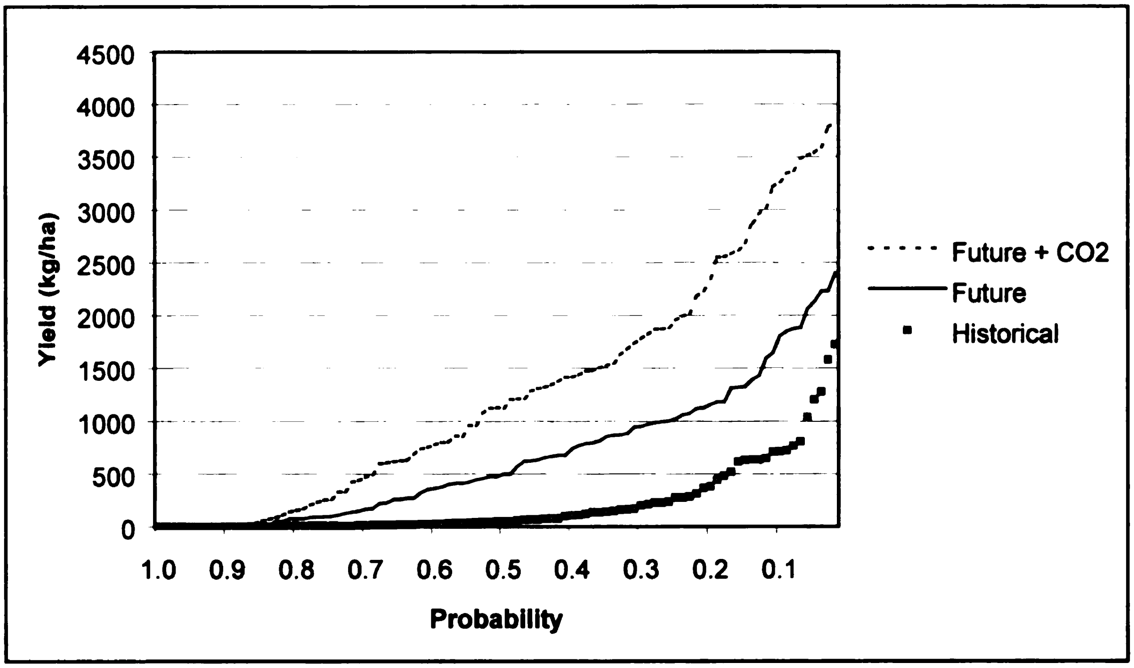

Figure 20a. Historical and future cumulative probability distributions of dryland soybean yields at Big Rapids for planting date July 15.

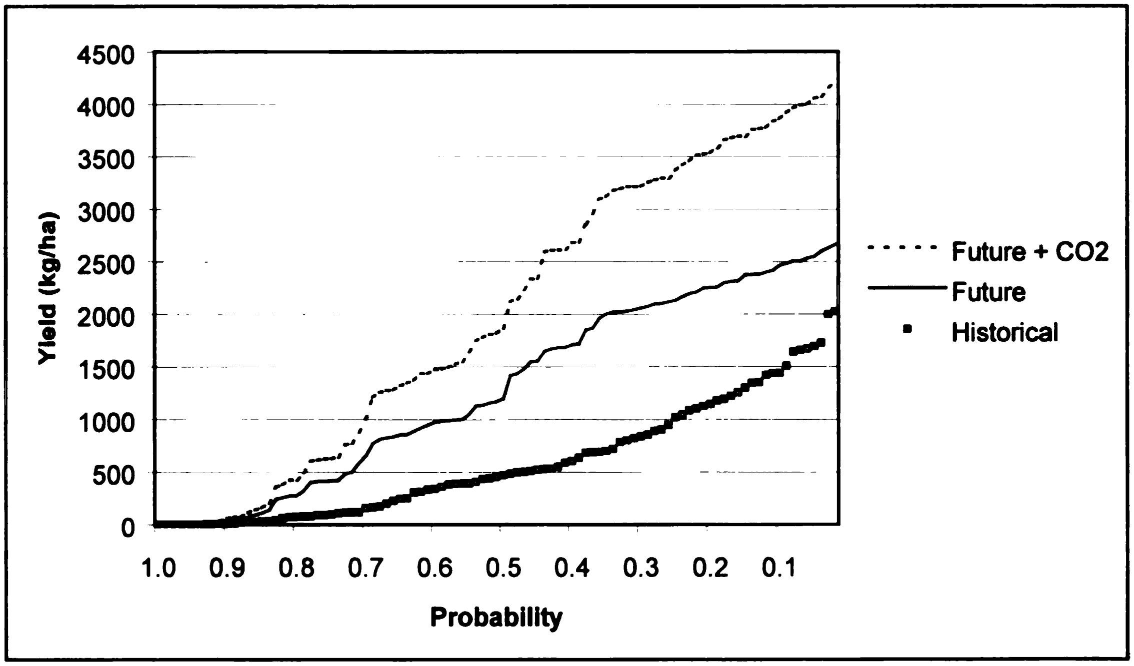

Figure 20b. Historical and future cumulative probability distributions of irrigated soybean yields at Big Rapids for planting date July 15.

reflects changing temperatures and precipitation amounts, and the yields increase over the historical simulations as a result.

Finally, time trends of yields in the future scenarios at Salem were plotted in Figures 21a and 21b. An evenly-weighted nine-year moving average was fitted to the distribution to illustrate decadal-scale trends. While the mean yields are greater in the CO_2-enriched scenario, the trends through time are similar. Both graphs reflect an overall upward trend through the next century, with a phase shift in mean yields occurring in mid-century. Periods of relatively low yields on the graphs correspond to periods of lower precipitation, including the 2040s.

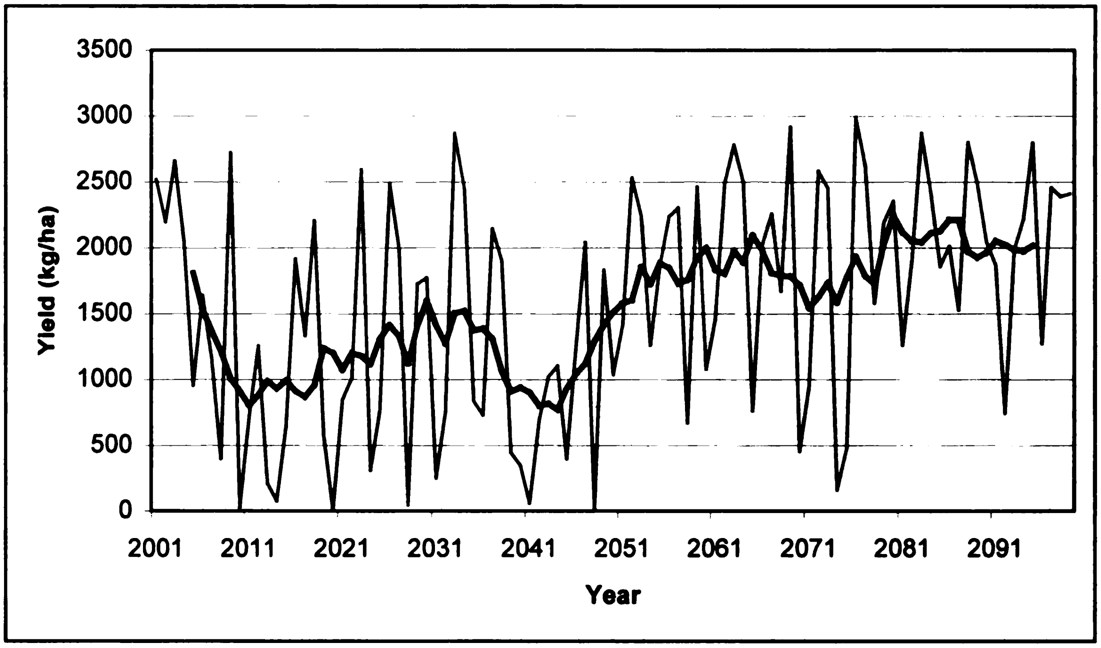

Figure 21a. Future simulated dryland soybean yields and nine-year moving average at Salem without CO_2 enrichment for the July 15 planting date (2001-2099).

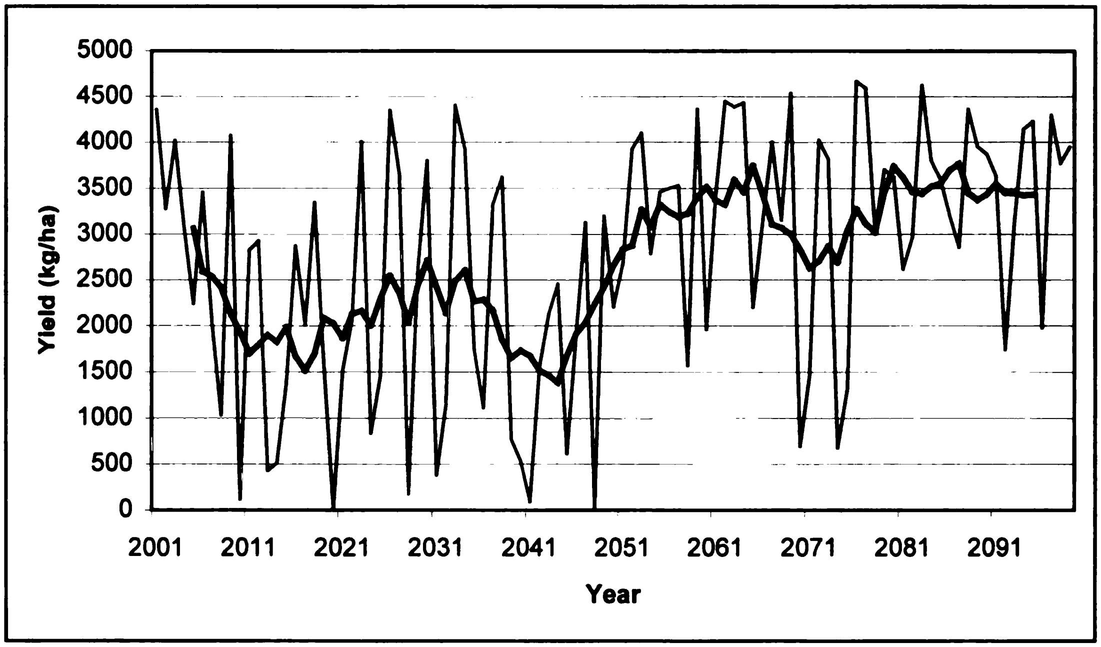

Figure 21b. Future simulated dryland soybean yields and nine-year moving average at Salem with CO_2 enrichment for the July 15 planting date (2001-2099).

For comparison, the same future simulated dryland soybean yield time series are given for Coldwater in Figures 22a and 22b. In general, the trends are similar to those at Salem. Yields decrease slightly in the first decade of the 21st century, but increase overall through the rest of the century.

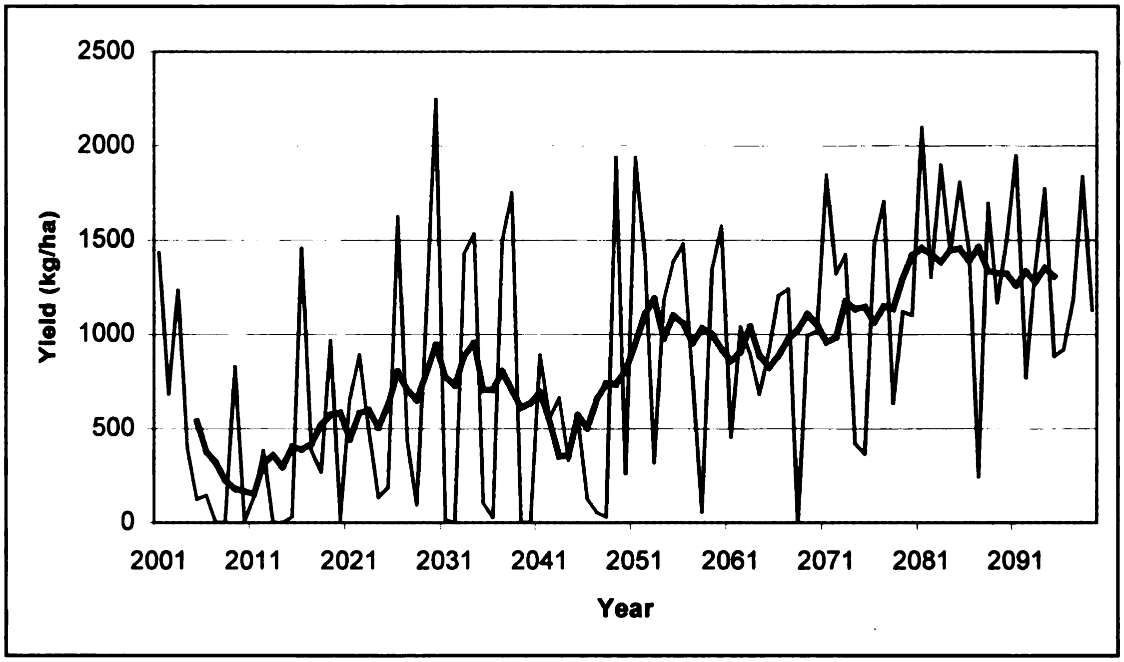

Figure 22a. Future simulated dryland soybean yields and nine-year moving average at Coldwater without CO_2 enrichment for the July 15 planting date (2001-2099).

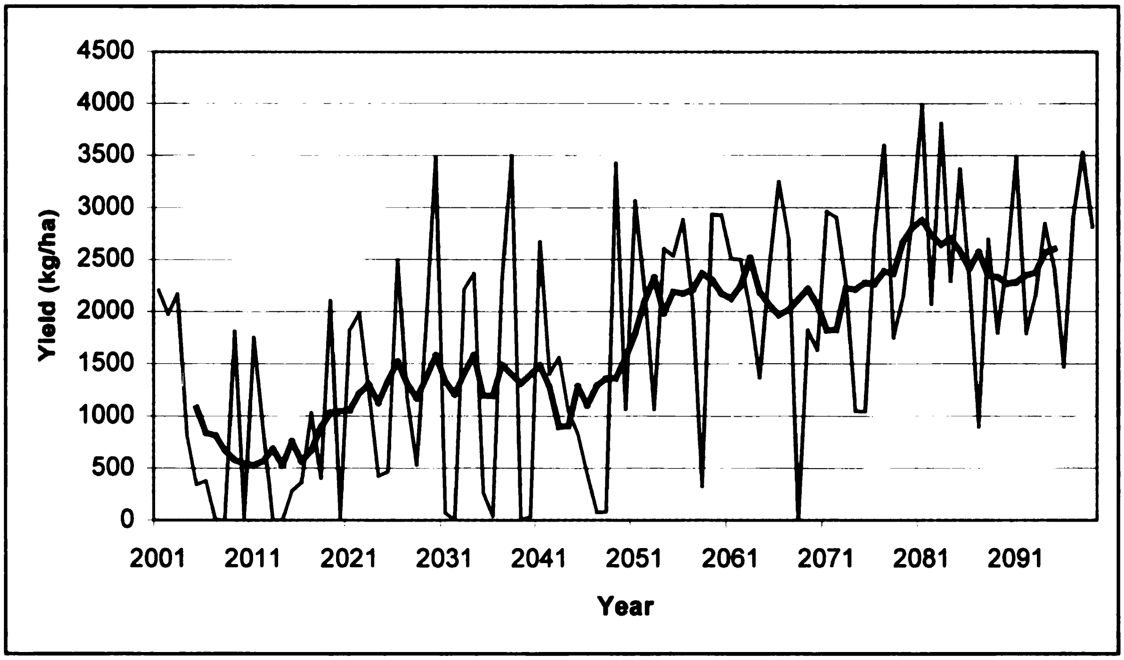

Figure 22b. Future simulated dryland soybean yields and nine-year moving average at Coldwater with CO_2 enrichment for the July 15 planting date (2001-2099).

Overall, the simulations with potential future climate appear to suggest an increased probability of successful double cropping in the region. For the six sites modeled, mean yields increased for all future scenarios vs. historical scenarios. Yields increased most with irrigation and when carbon dioxide enrichment was taken into account. The future yield potentials still reflected a north-south gradient, with overall yields greater at southern sites vs. those in the north.

Water stress in the future scenario was not as much of a limitation for sites in the Great Lakes region as it was in the historical scenario. Mean seasonal evapotranspiration totals increased for all future scenarios, especially for those including CO_2 enrichment. Future yield potential was enhanced by increasing ambient CO_2 levels. Frequency and amounts of irrigation required to eliminate water stress decreased for the future models, especially for higher concentrations of CO_2.

Chapter 4

CONCLUSIONS

Double cropping wheat and soybeans has been historically possible to some degree, according to research and simulations for the Great Lakes region. For model simulations at 18 sites throughout the region, later planting dates resulted in lower soybean yields than earlier planting dates and mean double-crop soybean yields and mean season length were positively correlated. The probability of attaining breakeven yields increased with earlier planting dates. Geographically, yield potential increased from north to south across the study area.

Soil moisture and precipitation are the most important climatological factors influencing double cropping in the Great Lakes region. In general, the Ohio Valley sites have higher mean seasonal precipitation and evapotranspiration than the Great Lakes sites. Soil moisture may also limit soybean emergence and growth due to high rates of wheat evapotranspiration and resulting depletion of subsoil moisture during grain-fill.

Even when moisture is non-limiting, the probability of reaching breakeven yields is still greater for sites in the southern portion of the study area, likely an impact of limited growing season length on the secondary soybean crop.

Increasing yields through time are evident in time series plots of historical yield simulations, especially in the past 50 years. Climate change, particularly

Increasing yields through time are evident in time series plots of historical yield simulations, especially in the past 50 years. Climate change, particularly with increasing levels of atmospheric CO_2, longer growing seasons, warmer temperatures, and increasing precipitation, may help to boost yields in the future. Time series plots of simulated double-crop soybean yields from the future HadCM2 scenario indicate a significant increase in yields by the end of the 21st century.

The results of this model analysis should be tested and proven in the field before widespread adoption of double cropping occurs. Given both crop model and general circulation model limitations, this is just one in a range of possible scenarios that might occur in a future climate. This study explores one possible farm-level adaptation to climate change. It does not include the effects of fertility, pest, or disease problems that may occur or develop in the future. It also does not factor in any technological advances that may occur, such as seed genetics, new management techniques, or advances in tillage, planting, and harvesting equipment.

Model limitations are the major constraint to this sort of analysis. Some research and development for the DSSAT model suite that might be useful to this analysis would include the implementation of relay intercropping simulations.

The DSSAT model does have some inherent limitations. Currently, DSSAT is capable of handling only one crop at a time, meaning that soybeans cannot be planted into standing wheat in a simulation, making it impossible to simulate relay intercropping. Only standard double cropping practices can currently be modeled using DSSAT, with the proper adjustments to the sequential experiment files.

Future research might include other general circulation models, particularly those with transient CO_2 scenarios, to further assess potential impacts of changing climate and ambient carbon dioxide levels on crop production.

APPENDICES

APPENDIX A

DSSAT INPUT FILE SAMPLES

Weather (*.WTH) File Sample: Coldwater, Michigan, 1901

```
*WEATHER DATA : Coldwater, MI

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  COMI   41.950  -85.000  1000   9.1  13.4 -99.0 -99.0
@DATE  SRAD  TMAX  TMIN  RAIN
01001   3.7  -5.6 -15.0   0.0
01002   2.3  -5.6 -16.7   0.0
01003   5.2  -5.0 -19.4   0.0
01004   2.4   1.1  -9.4   0.0
01005   3.9   0.0 -10.6   0.0
01006   5.6   3.9  -8.9   0.0
01007   2.1   2.2  -1.1   3.6
01008   2.1   9.4  -1.7   2.5
01009   2.1   6.1  -3.9   5.1
01010   2.1   4.4  -2.2  22.9
01011   2.1   0.6  -1.7  10.2
01012   6.4   0.0  -3.3   0.0
01013   8.5   1.1 -11.1   0.0
01014   2.2   1.7  -3.3   5.1
01015   9.5   5.6  -3.3   0.0
01016   8.2   5.6  -2.2   0.0
01017   7.1  -1.7  -8.9   0.0
01018   8.9  -6.7 -10.0   0.0
01019   2.3  -5.6 -17.8   5.1
01020   4.8  10.6 -12.2   0.0
01021   6.1   7.2  -1.1   0.0
01022  10.6   1.7  -3.9   0.0
01023  11.8   1.7  -3.3   0.0
01024   2.4   2.2  -6.1   2.5
01025   7.5  -2.2  -7.8   0.0
01026   2.4  -3.9 -11.1   8.9
01027  10.6  -0.6  -4.4   0.0
01028   9.2  -3.3  -8.3   0.0
01029   8.9  -5.6 -12.8   0.0
01030   2.8  -4.4 -10.0   2.5
01031   3.6  -5.6 -17.2   2.5
01032  10.2  -7.2 -12.8   0.0
01033   9.7  -3.3 -17.8   0.0
01034   2.7  -2.8  -6.1  15.2
01035   2.7  -1.7  -8.3   3.8
01036  10.5  -5.6 -10.0   0.0
01037   9.9  -7.2 -15.6   0.0
01038  13.8  -5.0 -17.2   0.0
01039   9.0  -5.6 -17.8   0.0
01040   6.8  -5.6 -11.1  12.7
01041   7.2  -5.0 -18.3   0.0 …
```

Soil File Sample: Catlin Silty Clay Loam, Ottawa, IL.

```
*SOILS

*MS00910002  SCS    SICLL   114 FINE-SILTY MIXED MESIC TYPIC ARGIUDOLL
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 OTTAWA      USA           41.320   88.920 MOLLISOL
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
 BN     0.13  10.8  0.40    76  1.00  1.00 IB001 IB001 IB001
@  SLB SLMH   SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI
SLCF  SLNI  SLHW  SLHB  SCEC
    28 AP    0.189 0.329 0.388  1.00 -99.0  1.50  2.90  34.5  63.0 -
99.0   -99   5.9 -99.0  25.4
    41 AB    0.203 0.341 0.387  0.75 -99.0  1.50  1.72  37.5  60.6 -
99.0   -99   5.6 -99.0  24.2
    66 BT    0.193 0.332 0.387  0.50 -99.0  1.47  0.67  35.4  62.2 -
99.0   -99   5.2 -99.0  22.7
   104 BT    0.056 0.200 0.389  0.35 -99.0  1.50  0.40  25.5  71.1 -
99.0   -99   5.8 -99.0  15.6
   114 BC    0.178 0.307 0.399  0.35 -99.0  1.30  0.24  32.6  47.3
3.0   -99   7.4 -99.0  10.0
```

Sequential file sample: Coldwater, Michigan, historical irrigated simulation for planting date 1 June.

```
*EXP.DETAILS: COMI2004SQ COLDWATER 1900S PDAT=01JUN   IRR

*TREATMENTS                        -------------FACTOR LEVELS----------
--
@N R O C TNAME.................. CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 soybean                  1  1  0  1  1  1  0  0  0  0  0  1  1
 1 2 1 0 wheat                    2  1  0  2  2  0  0  0  0  0  0  2  2

*CULTIVARS
@C CR INGENO CNAME
 1 SB 990001 M GROUP   1
 2 WH 990003 WINTER-US

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX   SLDP
ID_SOIL
 1 COMI     COMI     -99.0     0 IB000     0     0 00000 -99     150
MS00000001
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN
.FLWR .SLAS
 1         0.00000         0.00000      0.00               0.0     0
0.0   0.0

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP
ICRID
 1    SB  1001   100     0  1.00  1.00 180.0  1000  0.80  0.00   100
15
@C  ICBL  SH2O  SNH4  SNO3
 1    20 0.201   1.0   1.3
 1    28 0.233   1.0   1.1
 1    71 0.224   1.0   1.1
 1   152 0.223   1.0   1.1
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP
ICRID
 2       01001     0     0  1.00  1.00 -99.0     0  0.00  0.00   100
15
@C  ICBL  SH2O  SNH4  SNO3
 2    10 0.338   1.0   4.5
 2    23 0.340   1.0   4.9
 2    43 0.340   0.5   1.4
 2    69 0.315   0.5   0.8
 2    89 0.304   0.5   1.0
 2   114 0.338   0.5   1.1
 2   152 0.408   0.5   1.4

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE
PENV  PLPH  SPRL
 1  1152   -99  50.0  50.0     S     R    38     0   4.0   -99   -99 -
99.0 -99.0   0.0
```

```
 2 01280   -99 300.0 300.0     S     R    10     0   4.0   -99   -99 -
99.0 -99.0   0.0

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT
 1  1.00    30    50   100 GS000 IR001    10

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC
 1  1354                   100.0   0.0
 2 02151                   100.0   0.0

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE             96     1     S  1001  1157 COLDWATER SB IRR
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     N     N     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO
 1 ME              M     M     E     R     S     C     R
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     A     N     N     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT
DIOUT  LONG CHOUT OPOUT
 1 OU              N     Y     Y    30     Y     N     Y     N     N
N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          01152 01196     1    99     5    40     2
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 IB001 IR004    25  0.75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 IB001 IB001
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 01360   100     0

@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 2 GE             95     1     S  1001  1157 COLDWATER WH  IRR
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 2 OP              Y     N     N     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO
 2 ME              M     M     E     R     S     C     R
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 2 MA              A     A     N     N     R
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT
DIOUT  LONG CHOUT OPOUT
 2 OU              N     Y     Y    30     Y     N     Y     N     N
N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 2 PL           1275  1360     1    99     5    40     2
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 2 IR             30    50   100 IB001 IR004    25  0.75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
```

```
 2 NI              30    50    25 IB001 IB001
@N RESIDUES     RIPCN RTIME RIDEP
 2 RE             100     1    20
@N HARVEST      HFRST HLAST HPCNP HPCNR
 2 HA               0 02195   100     0
```

APPENDIX B

DSSAT OUTPUT FILE SAMPLES

*GROWTH ASPECTS OUTPUT FILE

```
*RUN   1         : soybean
 MODEL           : CRGRO980 - SOYBEAN
 EXPERIMENT      : ALMI2004 SB    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1    : soybean

 CROP            : SOYBEAN        CULTIVAR : M GROUP   1      -
MATURITY GROUP 1
 STARTING DATE   : JAN  1 1901
 PLANTING DATE   : JUN  1 1901    PLANTS/m2 : 50.0     ROW SPACING :
38.cm
 WEATHER         : ALMI   1901
 SOIL            : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C  : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
.0kg/ha
 WATER BALANCE   : AUTOMATIC IRRIGATION - REFILL PROFILE
 IRRIGATION      : AUTOMATIC - PLANTING -> MATURITY [ SOIL DEPTH:30.00m
50.%]
 NITROGEN BAL.   : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER    :
 RESIDUE/MANURE  :
 ENVIRONM. OPT.  : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
.00
                   RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
ET :R
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :A  FERT :N  RESIDUE:N  HARVEST:M
WTH:M

@DATE   CDAY  L#SD  GSTD  LAID  LWAD  SWAD  GWAD  RWAD  CWAD  G#AD
GWGD  HIAD  PWAD  P#AD  WSPD  WSGD  NSTD  EWSD  LN%D  SH%D  HIPD  PWDD
PWTD  SLAD  CHTD  CWID  NWAD  RDPD  RL1D  RL2D  RL3D  RL4D  RL5D  RL6D
RL7D  RL8D  RL9D  RL10  CDAD  LDAD  SDAD
  1152     0   0.0     0  0.00     0     0     0     0     0     0
0.0 0.000     0     0 0.000 0.000 0.000 0.000  0.00  0.00  0.00     0
0 192.9  0.00  0.00   0.0  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00     0     0     0
  1181    29   3.8     0  0.51   166    74     0   191   239     0
0.0 0.000     0     0 0.000 0.000 0.000 0.000  5.31  0.00  0.00     0
0 310.9  0.21  0.20   0.0  0.62  0.30  0.38  0.35  0.17  0.08  0.00
0.00  0.00  0.00  0.00     5     3     2
  1211    59  11.6     5  4.13  1599  1731     0  1106  3749     0
0.0 0.000   419   680 0.000 0.000 0.000 0.000  5.17  0.00  0.11     0
419 258.3  0.68  0.38   0.0  1.23  1.11  1.45  1.38  0.96  0.73  0.41
0.14  0.00  0.00  0.00   158   100    58
```

```
  1241    89  14.8     5  2.83  1125  1564  2912   799  7073  2232
130.5 0.412  4384  1015 0.000 0.000 0.000 0.000  3.17 66.43  0.62     0
4384 251.3  0.88  0.38   0.0  1.43  0.81  1.05  1.01  0.70  0.53  0.31
0.13  0.02  0.00  0.00  1154   370   215
  1259   107  14.8     8  0.17    67   925  3916   654  6288  2232
175.4 0.623  5296  1015 0.000 0.000 0.000 0.000  2.19 73.94  0.84     0
5296 258.4  0.88  0.38   0.0  1.50  0.65  0.87  0.83  0.58  0.44  0.26
0.11  0.01  0.00  0.00  2707  1354   785


*RUN   2         : wheat
 MODEL           : GECER980 - WHEAT
 EXPERIMENT      : ALMI2004 WH    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1    : wheat

 CROP            : WHEAT          CULTIVAR : WINTER-US         -
 STARTING DATE   : JAN  1 1901
 PLANTING DATE   : OCT 27 1901    PLANTS/m2 :300.0     ROW SPACING :
10.cm
 WEATHER         : ALMI   1901
 SOIL            : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C  : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
.0kg/ha
 WATER BALANCE   : RAINFED
 IRRIGATION      : NOT IRRIGATED
 NITROGEN BAL.   : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER    :
 RESIDUE/MANURE  :
 ENVIRONM. OPT.  : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
.00
                   RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
.00
 SIMULATION OPT  : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
ET :R
 MANAGEMENT OPT  : PLANTING:A  IRRIG   :N  FERT :N  RESIDUE:N  HARVEST:R
WTH:M

!YR    Days   Leaf  Grow                 Dry Weight             Grain
Kern.          Pod       Phot. Grow       Leaf  Shell  Spec     Canopy
Root  ³                 Root Length Density                     ³
! and  after  Num  Stage  LAI   Leaf  Stem Grain  Root  Crop   per
wght   HI   Wgt.   No.    Water     Nit.  Nit   -ing  Leaf  Hght  Brdth
Depth ³                 cm3/cm3  of soil                        ³
!  DOY plant                    ³<--------- kg/Ha --------->³  m2    mg
Kg/Ha        ³<Stress (0-1)>³   %      %   Area   m     m          m
³<--------------------------------------------------------->³
@DATE   CDAY  L#SD  GSTD  LAID  LWAD  SWAD  GWAD  RWAD  CWAD  G#AD
GWGD  HIAD  EWAD  E#AD  WSPD  WSGD  NSTD  LN%D  SH%D  SLAD  CHTD  CWID
EWSD  RDPD  RL1D  RL2D  RL3D  RL4D  RL5D  RL6D  RL7D  RL8D  RL9D  RL10
  1283     0    .0     0   .00     0     0     0     0     0     0
.0  .000     0     0  .000  .000  .000   .00   .00    .0   .00   .00
.000   .04   .00   .00   .00   .00   .00   .00   .00   .00   .00   .00
  1290     7    .0     0   .00     0     0     0     0     0     0
.0  .000     0     0  .000  .000  .000   .00   .00    .0   .00   .00
.000   .09   .00   .00   .00   .00   .00   .00   .00   .00   .00   .00
```

```
  1320    37   3.0     1   .21   137     0     0    69   137     0
.0  .000     0     0  .000  .000  .000   .00   .00 152.7   .00   .00
.000   .28   .39   .47   .23   .00   .00   .00   .00   .00   .00   .00
  1350    67   4.0     1   .23   159     0     0   109   159     0
.0  .000     0     0  .000  .000  .000   .00   .00 142.5   .00   .00
.000   .32   .62   .70   .46   .01   .00   .00   .00   .00   .00   .00
  2015    97   4.0     1   .02   154     0     0    99   167     0
.0  .000     0     0  .000  .000  .000   .00   .00  10.2   .00   .00
.000   .33   .56   .63   .43   .01   .00   .00   .00   .00   .00   .00
  2045   127   4.0     1   .02   154     0     0    99   167     0
.0  .000     0     0  .000  .000  .000   .00   .00  10.2   .00   .00
.000   .33   .51   .57   .39   .01   .00   .00   .00   .00   .00   .00
  2075   157   5.0     1   .12   226     0     0   112   226     0
.0  .000     0     0  .000  .000  .000   .00   .00  53.9   .00   .00
.000   .43   .51   .60   .45   .06   .00   .00   .00   .00   .00   .00
  2105   187   7.0     1  1.36  1106     0     0   742  1106     0
.0  .000     0     0  .000  .000  .000   .00   .00 123.3   .00   .00
.000   .61  1.62  2.95  2.72  1.75  1.00   .00   .00   .00   .00   .00
  2135   217  12.0     2  5.13  5685  1117     0  1933  6802     0
.0  .000     0     0  .000  .000  .000   .00   .00  90.2   .00   .00
.000   .91  3.54  4.00  4.00  4.00  3.16   .73   .00   .00   .00   .00
  2151   233  12.0     4  4.68  5928  5057     0  2272 10985     0
.0  .000     0     0  .000  .000  .000   .00   .00  78.9   .00   .00
.000  1.10  4.00  4.00  4.00  4.00  3.64  1.19   .19   .00   .00   .00
```

*SIMULATION OVERVIEW FILE

```
*RUN   1          : soybean
 MODEL            : CRGRO980 - SOYBEAN
 EXPERIMENT       : ALMI2004 SB    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1     : soybean

 CROP             : SOYBEAN        CULTIVAR : M GROUP   1       -
      MATURITY GROUP 1
 STARTING DATE    : JAN  1 1901
 PLANTING DATE    : JUN  1 1901    PLANTS/m2 : 50.0     ROW SPACING :
      38.cm
 WEATHER          : ALMI   1901
 SOIL             : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C   : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
      .0kg/ha
 WATER BALANCE    : AUTOMATIC IRRIGATION - REFILL PROFILE
 IRRIGATION       : AUTOMATIC - PLANTING -> MATURITY [ SOIL DEPTH:30.00m
      50.%]
 NITROGEN BAL.    : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER     :
 RESIDUE/MANURE   :
 ENVIRONM. OPT.   : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
      .00
                    RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
      .00
 SIMULATION OPT   : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
      ET :R
 MANAGEMENT OPT   : PLANTING:R  IRRIG   :A  FERT :N  RESIDUE:N  HARVEST:M
      WTH:M

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

    SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3
      NH4    ORG
   DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS
      C
    cm   cm3/cm3    cm3/cm3    cm3/cm3        g/cm3         ugN/g
      ugN/g     %
-----------------------------------------------------------------------
      ---------
   0-  5  .111  .233  .366  .122  .233    .50   1.41   6.30   4.50
      .50   1.23
   5- 15  .111  .233  .366  .122  .233    .50   1.41   6.30   4.50
      .50   1.23
  15- 30  .186  .305  .380  .119  .305    .48   1.38   6.50   2.89
      .50    .77
  30- 45  .244  .363  .411  .119  .363    .35   1.38   7.24   1.94
      .50    .51
  45- 60  .216  .336  .399  .121  .336    .28   1.36   7.73   1.67
      .50    .44
  60- 90  .191  .317  .386  .126  .317    .20   1.33   8.10   1.40
      .50    .35
  90-120  .191  .317  .386  .126  .317    .20   1.33   8.10   1.40
      .50    .35
```

```
120-136  .191  .317  .386  .126  .317    .20   1.33   8.10   1.40
     .50    .35
136-152  .191  .317  .386  .126  .317    .20   1.33   8.10   1.40
     .50    .35

TOT-152  28.9  47.7  58.8  18.8  47.7  <--cm   -  kg/ha-->     .0
     .0      0
SOIL ALBEDO    :  .13       EVAPORATION LIMIT : 9.40        MIN.
     FACTOR  : 1.00
RUNOFF CURVE # :84.00       DRAINAGE RATE     :  .20        FERT.
     FACTOR : 1.00

SOYBEAN    CULTIVAR :990001-M GROUP   1        ECOTYPE :SB0101-
     MATURITY GROUP 1
CSDVAR :13.84  PPSEN  :  .20  EMG-FLW:17.00  FLW-FSD:13.00  FSD-PHM
     :32.00
WTPSD  : .190  SDPDVR : 2.20  SDFDUR :23.00  PODDUR :10.00  XFRUIT  :
     1.00


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.  1    soybean

   DATE CROP GROWTH   BIOMASS  LAI  LEAF   ET  RAIN IRRIG SWATER CROP
      N  STRESS
        AGE  STAGE     kg/ha        NUM.  mm    mm    mm     mm   kg/ha
      %  H2O  N
-----------------------------------------------------------------------
      ---------
  1 JAN    0 Start Sim      0  0.00  0.0    0     0     0    188    0
      0.00.000.00
  1 JUN    0 Sowing         0  0.00  0.0  123   199     0    176    0
      0.00.000.00
 12 JUN   11 Emergence     26  0.04  0.1  128   200     0    172    1
      5.20.000.09
 12 JUN   11 End Juven.    26  0.04  0.1  128   200     0    172    1
      5.20.000.09
 20 JUN   19 Unifoliate    45  0.08  1.1  142   216     0    174    2
      4.80.000.46
 21 JUN   20 Flower Ind    54  0.11  1.3  143   216     0    173    3
      4.70.000.00
 11 JUL   40 First Flwr  1025  1.83  6.5  234   267    47    163   43
      4.20.000.00
 20 JUL   49 First Pod   2203  3.30  8.9  287   281    73    142   87
      3.90.000.00
 30 JUL   59 First Seed  3749  4.13 11.6  346   327   121    151  137
      3.70.000.00
 13 AUG   73 End Pod     5393  3.70 14.1  412   327   170    122  190
      3.50.000.00
 19 AUG   79 End Msnode  6058  3.34 14.8  447   327   197    107  217
      3.60.000.00
 19 AUG   79 End Leaf    6058  3.34 14.8  447   327   197    107  217
      3.60.000.00
  4 SEP   95 Phys. Mat   7492  2.64 14.8  515   363   245    108  290
      3.90.000.00
```

```
 16 SEP  107 Harv. Mat   6288  0.17 14.8  558   390   295   124  278
      4.40.000.00
 16 SEP  107 Harvest     6288  0.17 14.8  558   390   295   124  278
      4.40.000.00


*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                          PREDICTED     MEASURED
      --------                          ---------     --------
      Anthesis Date (dap)                  40            -99
      First Pod (dap)                      49            -99
      First Seed (dap)                     59            -99
      Physiological Maturity (dap)         95            -99
      Pod Yield (kg/ha;dry)              5296            -99
      Seed Yield (kg/ha;dry)             3916            -99
      Shelling Percentage (%)           73.94            -99
      Weight Per Seed (g;dry)           0.175            -99
      Seed Number (Seed/m2)              2232            -99
      Seeds/Pod                          2.20            -99
      Maximum LAI (m2/m2)                4.14            -99
      Biomass (kg/ha) at Anthesis        1025            -99
      Biomass (kg/ha) at Harvest Mat.    6288            -99
      Stalk (kg/ha) at Harvest Mat.       925            -99
      Harvest Index (kg/kg)             0.623            -99
      Final Leaf Number (Main Stem)     14.83            -99
      Canopy Height (m)                  0.88            -99
      Seed N (kg N/ha)                    253            -99
      Biomass N (kg N/ha)                 278            -99
      Stalk N (kg N/ha)                     6            -99
      Seed N (%)                         6.47            -99
      Seed Lipid (%)                    19.25            -99


*ENVIRONMENTAL AND STRESS FACTORS

------------------------------------ENVIRONMENT-----------------STRESS-
      ---------
 |--DEVELOPMENT PHASE--|-TIME-|-------WEATHER--------| |---WATER--| |-
      NITROGEN-|
                         DURA TEMP  TEMP  SOLAR PHOTOP PHOTO GROWTH
      PHOTO GROWTH
                         TION  MAX   MIN    RAD  [day] SYNTH
      SYNTH
                         days   oC    oC  MJ/m2   hr
-----------------------------------------------------------------------
      ---------
 Emergence -First Flower  29  30.36  17.46 23.17  15.00 0.000 0.000
      0.000 0.128
 First Flower-First Seed  19  32.04  18.92 24.64  14.60 0.000 0.000
      0.000 0.000
 First Seed - Phys. Mat.  36  27.48  14.15 21.35  13.58 0.000 0.000
      0.120 0.000
 Emergence  - Phys. Mat.  84  29.51  16.37 22.72  14.30 0.000 0.000
      0.052 0.044
```

```
                                                            (0.0 = Minimum
     Stress
                                                             1.0 = Maximum
     Stress)

 SOYBEAN     YIELD :      3916 kg/ha     [DRY WEIGHT]


*RUN   2          : wheat
 MODEL            : GECER980 - WHEAT
 EXPERIMENT       : ALMI2004 WH    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1     : wheat

 CROP             : WHEAT          CULTIVAR : WINTER-US         -
 STARTING DATE    : JAN  1 1901
 PLANTING DATE    : OCT 27 1901    PLANTS/m2 :300.0     ROW SPACING :
     10.cm
 WEATHER          : ALMI   1901
 SOIL             : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C   : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
     .0kg/ha
 WATER BALANCE    : RAINFED
 IRRIGATION       : NOT IRRIGATED
 NITROGEN BAL.    : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER     :
 RESIDUE/MANURE   :
 ENVIRONM. OPT.   : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
     .00
                    RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
     .00
 SIMULATION OPT   : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
     ET :R
 MANAGEMENT OPT   : PLANTING:A  IRRIG   :N  FERT :N  RESIDUE:N  HARVEST:R
     WTH:M

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

    SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3
     NH4    ORG
   DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS
     C
    cm   cm3/cm3    cm3/cm3    cm3/cm3         g/cm3         ugN/g
     ugN/g     %
-----------------------------------------------------------------------
     ---------
   0-  5  .111  .233  .366  .122  .338    .50   1.41   6.30   4.50
     1.00   1.23
   5- 15  .111  .233  .366  .122  .339    .50   1.41   6.30   4.70
     1.00   1.23
  15- 30  .186  .305  .380  .119  .340    .48   1.38   6.50   3.27
     .77    .77
  30- 45  .244  .363  .411  .119  .337    .35   1.38   7.24   1.32
     .50    .51
  45- 60  .216  .336  .399  .121  .315    .28   1.36   7.73    .80
     .50    .44
```

```
 60- 90  .191  .317  .386  .126  .308    .20   1.33   8.10    .94
     .50    .35
 90-120  .191  .317  .386  .126  .352    .20   1.33   8.10   1.16
     .50    .35
120-136  .191  .317  .386  .126  .408    .20   1.33   8.10   1.40
     .50    .35
136-152  .191  .317  .386  .126  .408    .20   1.33   8.10   1.40
     .50    .35

TOT-152  28.9  47.7  58.8  18.8  52.8  <--cm   -  kg/ha-->     .0
     .0     0
SOIL ALBEDO    :  .13       EVAPORATION LIMIT : 9.40        MIN.
     FACTOR  : 1.00
RUNOFF CURVE # :84.00       DRAINAGE RATE     :  .20        FERT.
     FACTOR : 1.00

WHEAT      CULTIVAR :990003-WINTER-US          ECOTYPE :      -
P1V    :6.000000  P1D    :2.500000  P5     :   -5.00
G1     :    5.000  G2     :    1.200  G3     :   1.400  PHINT  :  80.000


*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.  2    wheat

   DATE CROP GROWTH   BIOMASS  LAI  LEAF   ET  RAIN IRRIG SWATER CROP
     N  STRESS
        AGE  STAGE     kg/ha          NUM.  mm   mm    mm    mm   kg/ha
     %  H2O  N
-----------------------------------------------------------------------
     ---------
 17 SEP    0 Start Sim      0   .00   .0    3     0     0  122    0
     .0 .00 .00
 10 OCT    0 Sowing         0   .00   .0   18    22     0  127    0
     .0 .00 .00
 10 OCT    0 Emergence      0   .00   .0   18    22     0  127    0
     .0 .00 .00
 11 OCT    1 Germinate      0   .00   .0   21    22     0  125    0
     .0 .00 .00
 24 OCT   14 Emergence     37   .01  2.0   40    80     0  151    0
     .0 .00 .00
 28 APR  200 Term Spklt  3291  3.78  9.0  247   337     0  147    0
     .0 .00 .00
 19 MAY  221 End Veg     7781  4.93 12.0  329   447     0  157    0
     .0 .00 .00
 31 MAY  233 End Ear Gr 10985  4.68 12.0  390   468     0  114    0
     .0 .00 .00
 31 MAY  233 Harvest    10985  4.68 12.0  390   468     0  114    0
     .0 .00 .00


*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                        PREDICTED     MEASURED
      --------                        ---------     --------
      FLOWERING DATE (dap)               -99           -99
      PHYSIOL. MATURITY (dap)            -99           -99
```

```
      GRAIN YIELD (kg/ha;dry)                0          -99
      WT. PER GRAIN (g;dry)              .0000          -99
      GRAIN NUMBER (GRAIN/m2)                0          -99
      GRAINS/EAR                            .0          -99
      MAXIMUM LAI (m2/m2)                 4.96          -99
      BIOMASS (kg/ha) AT ANTHESIS        10985          -99
      BIOMASS N (kg N/ha) AT ANTHESIS        0          -99
      BIOMASS (kg/ha) AT HARVEST MAT.    10985          -99
      STALK (kg/ha) AT HARVEST MAT.          0          -99
      HARVEST INDEX (kg/kg)               .000          -99
      FINAL LEAF NUMBER                  12.00          -99
      GRAIN N (kg N/ha)                      0          -99
      BIOMASS N (kg N/ha)                    0          -99
      STALK N (kg N/ha)                      0          -99
      SEED N (%)                           .00          -99


*ENVIRONMENTAL AND STRESS FACTORS

------------------------------------ENVIRONMENT-----------------STRESS-
      ---------
 |--DEVELOPMENT PHASE--|-TIME-|-------WEATHER--------| |---WATER--| |-
      NITROGEN-|
                         DURA TEMP  TEMP  SOLAR PHOTOP PHOTO GROWTH
      PHOTO GROWTH
                         TION  MAX   MIN    RAD  [day] SYNTH
      SYNTH
                         days   øC    øC   MJ/m2   hr
-----------------------------------------------------------------------
      ---------
 Emergence - Term Spiklt 186   5.46  -4.93 10.17  10.45  .000  .000
      .000  .000
 End Veg-Beg Ear Growth   21  20.61   6.85 20.97  14.10  .000  .000
      .000  .000
 Begin Ear-End Ear Grwth  12  24.88  11.26 24.49  14.65  .000  .000
      .000  .000
 End Ear Grth-Beg Grn Fi   1  26.70  12.20 24.00  14.82  .000  .000
      .000  .000
 Linear Grain Fill Phase   0    .00    .00   .00    .00  .000  .000
      .000  .000

                                                       (0.0 = Minimum
      Stress
                                                        1.0 = Maximum
      Stress)

       WHEAT     YIELD :       0 kg/ha    [DRY WEIGHT ]
```

*SUMMARY : ALMI2004SQ ALLEGAN 1900S WH-SB PDAT=01JUN

IRR

```
!IDENTIFIERS.............................
      DATES........................ DRY
      WEIGHTS..................................
      WATER..................................
      NITROGEN.................................... ORGANIC MATTER...
      PHOSPHORUS............
@RP TN ROC CR TNAM                FNAM      SDAT  PDAT  ADAT  MDAT
      HDAT  DWAP  CWAM  HWAM  HWAH  BWAH  HWUM  H#AM  H#UM  IR#M  IRCM
      PRCM  ETCM  ROCM  DRCM  SWXM  NI#M  NICM  NFXM  NUCM  NLCM  NIAM
      CNAM  GNAM  RECM  ONAM  OCAM  PO#M  POCM  CPAM  SPAM
   1  1 110 SB soybean            ALMI      1001  1152  1192  1247
      1259   119  6288  3916  3916     0   175  2232  2.20    12   295
      390   558    37    79   124     0     0     0     0     0     0
      278   253     0     0     0     0     0     0     0
   2  1 210 WH wheat              ALMI      1260  1283   -99   -99
      2151    85 10985     0     0     0     0     0     0     0     0
      468   390    50    37   114     0     0     0     0     0     0
      0     0     0     0     0     0     0     0     0
   3  1 110 SB soybean            ALMI      2152  2152  2199  2256
      2268   119  5951  3412  3412     0   145  2347  2.20    12   292
      339   503    33     0   138     0     0     0     0     0     0
      254   225     0     0     0     0     0     0     0
   4  1 210 WH wheat              ALMI      2269  2275  3151   -99
      3151    85 10917     0     0     0     0     0     0     0     0
      565   394    75   180    54     0     0     0     0     0     0
      0     0     0     0     0     0     0     0     0
   5  1 110 SB soybean            ALMI      3152  3152  3202  3260
      3272   119  5652  3261  3261     0   159  2046  2.20    11   272
      403   441    83     0   137     0     0     0     0     0     0
      233   209     0     0     0     0     0     0     0
   6  1 210 WH wheat              ALMI      3273  3275   -99   -99
      4151    85  6866     0     0     0     0     0     0     0     0
      396   308    30   113    82     0     0     0     0     0     0
      0     0     0     0     0     0     0     0     0
   7  1 110 SB soybean            ALMI      4152  4152  4196  4252
      4264   119  6029  3603  3603     0   163  2215  2.20    17   429
      223   466    33     0   127     0     0     0     0     0     0
      259   233     0     0     0     0     0     0     0
   8  1 210 WH wheat              ALMI      4265  4275   -99   -99
      5151    85 10858     0     0     0     0     0     0     0     0
      567   409    96    66   124     0     0     0     0     0     0
      0     0     0     0     0     0     0     0     0
   9  1 110 SB soybean            ALMI      5152  5152  5196  5251
      5263   119  6146  3842  3842     0   161  2382  2.20     9   231
      324   458    40     0   123     0     0     0     0     0     0
      272   248     0     0     0     0     0     0     0
  10  1 210 WH wheat              ALMI      5264  5284   -99   -99
      6151    85  8046     0     0     0     0     0     0     0     0
      461   357    35   101    91     0     0     0     0     0     0
      0     0     0     0     0     0     0     0     0
```

*WATER BALANCE OUTPUT FILE

```
*RUN   1         : soybean
 MODEL           : CRGRO980 - SOYBEAN
 EXPERIMENT      : ALMI2004 SB    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1    : soybean

 CROP            : SOYBEAN        CULTIVAR : M GROUP   1      -
      MATURITY GROUP 1
 STARTING DATE   : JAN  1 1901
 PLANTING DATE   : JUN  1 1901    PLANTS/m2 : 50.0     ROW SPACING :
      38.cm
 WEATHER         : ALMI   1901
 SOIL            : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C  : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
      .0kg/ha
 WATER BALANCE   : AUTOMATIC IRRIGATION - REFILL PROFILE
 IRRIGATION      : AUTOMATIC - PLANTING -> MATURITY [ SOIL DEPTH:30.00m
      50.%]
 NITROGEN BAL.   : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER    :
 RESIDUE/MANURE  :
 ENVIRONM. OPT.  : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
      .00
                   RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
      .00
 SIMULATION OPT  : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
      ET :R
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :A  FERT :N  RESIDUE:N  HARVEST:M
      WTH:M

@DATE   CDAY  EPAA  ETAA  EOAA  SWXD  ROFC  DRNC  PREC  IRRC  SRAA
      TMXA  TMNA  DAYD  ESAA  EPAC  ESAC  ETAC  IR#C  DTWT  SW1D  SW2D
      SW3D  SW4D  SW5D  SW6D  SW7D  SW8D  SW9D  SW10  TS1D  TS2D  TS3D
      TS4D  TS5D  TS6D  TS7D  TS8D  TS9D  TS10
  1001     0  0.00  0.04  0.04 187.9   0.0     0     0     0   2.0  -
       3.9 -10.6  9.01  0.04   0.0   0.0   0.0     0   152 0.232 0.233
```

```
    0.305 0.363 0.336 0.317 0.317 0.317 0.317 0.000  -5.9  -3.6  -0.3
    2.8   5.0   7.1   8.5   8.9   9.0   0.0
1031     0  0.00  0.36  0.36 187.9   0.3    11    22     0   6.1
    0.4  -8.0  9.76  0.36   0.0  10.9  10.9     0   152 0.222 0.230
    0.308 0.366 0.336 0.317 0.317 0.317 0.317 0.000  -4.3  -2.6   0.0
    2.6   4.7   6.8   8.3   8.9   9.1   0.0
1061     0  0.00  0.21  0.21 192.7   0.3    11    34     0   7.6  -
    3.6 -13.4 11.03  0.21   0.0  17.1  17.1     0   152 0.310 0.242
    0.304 0.365 0.336 0.317 0.317 0.317 0.317 0.000  -3.1  -1.9   0.0
    2.1   4.0   6.1   7.9   8.6   8.9   0.0
1091     0  0.00  1.38  1.39 189.3   9.2    77   147     0  14.3
    4.4  -4.4 12.47  1.38   0.0  58.6  58.6     0   152 0.153 0.237
    0.312 0.368 0.340 0.320 0.320 0.320 0.320 0.000   2.4   2.6   3.1
    4.1   5.1   6.5   7.9   8.5   8.8   0.0
1121     0  0.00  1.11  3.49 179.0   9.3    79   171     0  18.8
    14.3   1.6 13.83  1.11   0.0  91.8  91.8     0   152 0.096 0.201
    0.295 0.361 0.338 0.320 0.320 0.320 0.320 0.000  24.0  21.2  17.7
    14.7  12.8  11.2  10.3  10.0   9.9   0.0
1151     0  0.00  1.01  5.21 176.8   9.3    79   199     0  25.1
    19.4   7.4 14.82  1.01   0.0 122.2 122.2     0   152 0.133 0.190
    0.285 0.356 0.334 0.320 0.320 0.320 0.320 0.000  14.3  13.0  11.2
    9.8   9.0   8.5   8.5   8.7   8.9   0.0
1152     0  0.00  0.51  4.91 176.3   9.3    79   199     0  26.5
    16.1   1.1 14.84  0.51   0.0 122.7 122.7     0   152 0.127 0.189
    0.285 0.356 0.334 0.320 0.320 0.320 0.320 0.000  14.5  13.2  11.4
    9.9   9.1   8.5   8.5   8.7   8.9   0.0
1181    29  0.42  1.73  5.70 169.1   9.9    79   243     0  23.6
    27.8  14.5 15.02  1.31  12.3 160.6 172.9     0   152 0.126 0.200
    0.255 0.339 0.328 0.318 0.320 0.320 0.320 0.000  30.4  27.3  22.8
    18.7  15.7  12.8  10.8  10.1   9.8   0.0
1211    59  3.85  5.76  5.97 151.4  29.1    79   327   121  24.5
    31.6  18.6 14.33  1.91 127.7 218.0 345.7     5   152 0.307 0.245
    0.279 0.315 0.267 0.256 0.308 0.319 0.320 0.000  27.8  25.4  21.8
    18.3  15.6  12.8  10.7  10.0   9.7   0.0
1241    89  3.88  4.96  4.96 110.4  33.2    79   363   222  22.5
    27.5  14.7 13.08  1.08 244.2 250.3 494.5     9   152 0.122 0.203
    0.263 0.309 0.256 0.236 0.263 0.306 0.315 0.000  26.5  24.6  21.7
    18.7  16.2  13.4  11.1  10.2   9.8   0.0
```

```
 1259   107  1.75  3.55  3.59 124.5  37.3    79   390   295  16.6
     24.8  11.8 12.23  1.80 275.7 282.8 558.5    12   152 0.127 0.274
     0.304 0.339 0.257 0.234 0.258 0.300 0.310 0.000  20.3  19.4  17.9
     16.1  14.5  12.5  10.7   9.9   9.6   0.0


*RUN   2          : wheat
 MODEL            : GECER980 - WHEAT
 EXPERIMENT       : ALMI2004 WH    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1     : wheat

 CROP             : WHEAT          CULTIVAR : WINTER-US        -
 STARTING DATE    : JAN  1 1901
 PLANTING DATE    : OCT 27 1901    PLANTS/m2 :300.0     ROW SPACING :
     10.cm
 WEATHER          : ALMI   1901
 SOIL             : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C   : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
     .0kg/ha
 WATER BALANCE    : RAINFED
 IRRIGATION       : NOT IRRIGATED
 NITROGEN BAL.    : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER     :
 RESIDUE/MANURE   :
 ENVIRONM. OPT.   : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
     .00
                    RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
     .00
 SIMULATION OPT   : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
     ET :R
 MANAGEMENT OPT   : PLANTING:A  IRRIG   :N  FERT :N  RESIDUE:N  HARVEST:R
     WTH:M

!YR     Days  Daily Evapotran.  PESW      Cumulative         Ave
     Temp. Temp  Day   Day   Cumu. Evap.        No.
     Soil water in Layer                                      Soil
     Temperature in Layer
```

```
! and   after Plant Total Pot.      RunOff Drain Prcip Irr   Sol   Max
     Min   Len   Soil Plant Soil  Total   of          1     2     3
     4     5     6     7     8     9    10     1     2     3     4
     5     6     7     8     9    10
!  DOY  Plant ³<---- mm ---->³   mm  ³<--------mm--------->³MJ/m2   C
     C     hr   Evap ³<------mm----->³   irr      ³<----------------
     ------- cm3/cm3 ----------------------->³ ³<--------------------
     ----- C ------------------------->³
@DATE   CDAY  EPAA  ETAA  EOAA  SWXD  ROFC  DRNC  PREC  IRRC  SRAA
     TMXA  TMNA  DAYD  ESAA  EPAC  ESAC  ETAC  IR#C  DTWT  SW1D  SW2D
     SW3D  SW4D  SW5D  SW6D  SW7D  SW8D  SW9D  SW10  TS1D  TS2D  TS3D
     TS4D  TS5D  TS6D  TS7D  TS8D  TS9D  TS10
  1260     0   .00  2.65  3.27 121.8    .0     0     0     0  17.2
     15.6   4.4 12.18  2.65    .0   2.7   2.7     0   152  .086  .259
     .304  .343  .257  .234  .258  .300  .310  .000  19.4  18.6  17.3
     15.7  14.2  12.3  10.6   9.9   9.6    .0
  1283     0   .00   .68  3.05 127.4    .3     0    22     0  14.7
     20.6   7.0 11.08   .68    .0  18.4  18.4     0   152  .208  .246
     .298  .338  .273  .236  .261  .296  .305  .000  17.8  17.4  16.6
     15.4  14.2  12.6  11.0  10.2   9.8    .0
  1290     7   .00  1.47  1.47 162.7  13.1     0    80     0   7.8
     13.9   5.4 10.76  1.47    .0  28.7  28.7     0   152  .234  .295
     .338  .379  .335  .262  .262  .295  .303  .000   9.6  10.3  11.1
     11.4  11.3  10.8  10.0   9.6   9.4    .0
  1320    37   .08   .99  1.52 164.5  13.3     0   112     0   8.8
     13.4   1.2  9.55   .91   2.4  56.0  58.3     0   152  .259  .248
     .305  .363  .336  .300  .270  .292  .298  .000   4.0   5.4   7.2
     8.6   9.4   9.9   9.8   9.5   9.4    .0
  1350    67   .06   .62   .62 204.7  23.2     0   180     0   6.5
     3.5  -5.0  8.96   .56   4.1  72.7  76.9     0   152  .297  .301
     .343  .374  .339  .317  .317  .317  .310  .000  -1.9    .0   2.7
     5.1   6.8   8.3   9.1   9.2   9.2    .0
  2015    97   .00   .38   .38 182.6  23.2    18   188     0   6.2
     .2  -9.1  9.27   .38   4.3  84.0  88.3     0   152  .165  .207
     .301  .365  .339  .319  .317  .317  .317  .000  -1.8   -.2   2.2
     4.5   6.2   7.9   8.9   9.2   9.3    .0
  2045   127   .00   .22   .22 180.5  23.2    18   192     0   7.2  -
     2.4 -11.2 10.31   .22   4.3  90.5  94.8     0   152  .180  .204
```

```
! and   after Plant Total Pot.       RunOff Drain Prcip Irr    Sol   Max
      Min    Len    Soil Plant Soil   Total    of          1      2      3
      4      5      6      7      8      9     10      1      2      3      4
      5      6      7      8      9     10
!  DOY  Plant ³<---- mm ---->³    mm  ³<--------mm--------->³MJ/m2    C
      C       hr    Evap ³<------mm----->³    irr        ³<----------------
      ------- cm3/cm3 ----------------------->³ ³<----------------------
      ----- C -------------------------->³
@DATE   CDAY  EPAA  ETAA  EOAA  SWXD  ROFC  DRNC  PREC  IRRC  SRAA
      TMXA  TMNA  DAYD  ESAA  EPAC  ESAC  ETAC  IR#C  DTWT  SW1D  SW2D
      SW3D  SW4D  SW5D  SW6D  SW7D  SW8D  SW9D  SW10  TS1D  TS2D  TS3D
      TS4D  TS5D  TS6D  TS7D  TS8D  TS9D  TS10
  1260     0   .00  2.65  3.27 121.8    .0     0     0     0  17.2
      15.6   4.4 12.18  2.65    .0   2.7   2.7     0   152  .086  .259
      .304  .343  .257  .234  .258  .300  .310  .000  19.4  18.6  17.3
      15.7  14.2  12.3  10.6   9.9   9.6    .0
  1283     0   .00   .68  3.05 127.4    .3     0    22     0  14.7
      20.6   7.0 11.08   .68    .0  18.4  18.4     0   152  .208  .246
      .298  .338  .273  .236  .261  .296  .305  .000  17.8  17.4  16.6
      15.4  14.2  12.6  11.0  10.2   9.8    .0
  1290     7   .00  1.47  1.47 162.7  13.1     0    80     0   7.8
      13.9   5.4 10.76  1.47    .0  28.7  28.7     0   152  .234  .295
      .338  .379  .335  .262  .262  .295  .303  .000   9.6  10.3  11.1
      11.4  11.3  10.8  10.0   9.6   9.4    .0
  1320    37   .08   .99  1.52 164.5  13.3     0   112     0   8.8
      13.4   1.2  9.55   .91   2.4  56.0  58.3     0   152  .259  .248
      .305  .363  .336  .300  .270  .292  .298  .000   4.0   5.4   7.2
       8.6   9.4   9.9   9.8   9.5   9.4    .0
  1350    67   .06   .62   .62 204.7  23.2     0   180     0   6.5
       3.5  -5.0  8.96   .56   4.1  72.7  76.9     0   152  .297  .301
      .343  .374  .339  .317  .317  .317  .310  .000  -1.9    .0   2.7
       5.1   6.8   8.3   9.1   9.2   9.2    .0
  2015    97   .00   .38   .38 182.6  23.2    18   188     0   6.2
       .2     1          .38   4.3  84.0  88.3     0   152  .165  .20
                        .319     7  .317  .317  .000  -1.8   -.2
                         8.9         9.3    .0
                  2                 23.2    18   192     0
                         .22         0.5  94.8     0   152
```

```
     .292  .359  .337  .319  .317  .317  .317  .000  -3.7  -2.3    .0
     2.4   4.4   6.5   8.2   8.8   9.0    .0
2075   157   .04  1.21  1.40 191.9  27.1    32   257     0  11.7
     5.3  -6.1 11.70  1.18   5.4 125.8 131.2     0   152  .214  .257
     .311  .366  .339  .319  .317  .317  .317  .000   7.8   7.4   7.1
     7.3   7.7   8.4   9.1   9.4   9.4    .0
2105   187   .74  2.23  2.47 167.2  28.0    37   306     0  16.3
     10.2  -1.5 13.13  1.49  27.6 170.5 198.1     0   152  .078  .185
     .274  .343  .327  .320  .317  .317  .317  .000   8.3   7.6   7.0
     6.8   7.0   7.6   8.4   8.9   9.1    .0
2135   217  3.22  3.68  3.80 167.1  49.1    37   437     0  20.7
     19.2   5.5 14.36   .45 124.4 184.2 308.5     0   152  .293  .306
     .308  .313  .255  .280  .314  .317  .317  .000  16.1  14.5  12.4
     10.7   9.7   9.0   9.0   9.1   9.2    .0
2151   233  4.46  5.12  5.12 114.4  50.4    37   468     0  24.7
     25.2  11.2 14.82   .66 195.7 194.7 390.4     0   152  .135  .160
     .226  .284  .248  .246  .307  .315  .317  .000  20.9  18.7  15.7
     13.2  11.5  10.1   9.4   9.3   9.3    .0
```

*WATER BALANCE SUMMARY FILE

```
*RUN   1         : soybean
 MODEL           : CRGRO980 - SOYBEAN
 EXPERIMENT      : ALMI2004 SB    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
 TREATMENT  1    : soybean

 CROP            : SOYBEAN        CULTIVAR : M GROUP   1      -
      MATURITY GROUP 1
 STARTING DATE   : JAN  1 1901
 PLANTING DATE   : JUN  1 1901    PLANTS/m2 : 50.0     ROW SPACING :
      38.cm
 WEATHER         : ALMI   1901
 SOIL            : MS00890001     TEXTURE : lo    - BLOUNT
 SOIL INITIAL C  : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
      .0kg/ha
 WATER BALANCE   : AUTOMATIC IRRIGATION - REFILL PROFILE
 IRRIGATION      : AUTOMATIC - PLANTING -> MATURITY [ SOIL DEPTH:30.00m
      50.%]
 NITROGEN BAL.   : NOT SIMULATED ; NO N-STRESS
 N-FERTILIZER    :
 RESIDUE/MANURE  :
 ENVIRONM. OPT.  : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
      .00
                   RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
      .00
 SIMULATION OPT  : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
      ET :R
 MANAGEMENT OPT  : PLANTING:R  IRRIG   :A  FERT :N  RESIDUE:N  HARVEST:M
      WTH:M


     WATER BALANCE PARAMETERS
     ========================          --mm--

     Soil H20 (start) on day   1001      477.19
     Soil H20 (final) on day   1259      413.73
     Irrigation                          295.22
     Effective Irrigation                221.42
     Irrigation Lost                      73.81
     Precipitation                       389.70
     Drainage                             78.76
     Runoff                               37.35
     Soil Evaporation                    282.79
     Transpiration                       275.68
     Evapotranspiration                  558.48
     Potential ET                        882.50


     Final Balance                       0.0001


*RUN   2         : wheat
 MODEL           : GECER980 - WHEAT
```

```
EXPERIMENT      : ALMI2004 WH    ALLEGAN  1900S WH-SB PDAT=01JUN  IRR
TREATMENT  1    : wheat

CROP            : WHEAT          CULTIVAR : WINTER-US        -
STARTING DATE   : JAN  1 1901
PLANTING DATE   : OCT 27 1901    PLANTS/m2 :300.0     ROW SPACING :
     10.cm
WEATHER         : ALMI   1901
SOIL            : MS00890001     TEXTURE : lo    - BLOUNT
SOIL INITIAL C  : DEPTH:152cm EXTR. H2O:188.1mm  NO3:   .0kg/ha  NH4:
     .0kg/ha
WATER BALANCE   : RAINFED
IRRIGATION      : NOT IRRIGATED
NITROGEN BAL.   : NOT SIMULATED ; NO N-STRESS
N-FERTILIZER    :
RESIDUE/MANURE  :
ENVIRONM. OPT.  : DAYL=     .00  SRAD=     .00  TMAX=     .00  TMIN=
     .00
                  RAIN=     .00  CO2 = R330.00  DEW =     .00  WIND=
     .00
SIMULATION OPT  : WATER   :Y  NITROGEN:N  N-FIX:N  PESTS  :N  PHOTO  :C
     ET :R
MANAGEMENT OPT  : PLANTING:A  IRRIG   :N  FERT :N  RESIDUE:N  HARVEST:R
     WTH:M


    WATER BALANCE PARAMETERS
    ========================          --mm--

    Soil H20 (start) on day   1260      413.73
    Soil H20 (final) on day   2151      403.63
    Irrigation                             .00
    Effective Irrigation                   .00
    Irrigation Lost                        .00
    Precipitation                       467.50
    Drainage                             36.76
    Runoff                               50.40
    Soil Evaporation                    194.75
    Transpiration                       195.68
    Evapotranspiration                  390.43
    Potential ET                        478.06


    Final Balance                        .0001
```

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