This is to certify that the

dissertation entitled

MANAGEMENT STRATEGIES TO MINIMIZE NITRATE LEACHING IN SEED CORN PRODUCTION

presented by

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has been accepted towards fulfillment of the requirements for

Ph.D. degree in AGRICULTURE

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Date May 18, 1992

MANAGEMENT STRATEGIES TO MINIMIZE NITRATE LEACHING IN SEED CORN PRODUCTION

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

1992

ABSTRACT

MANAGEMENT STRATEGIES TO MINIMIZE NITRATE LEACHING IN SEED CORN PRODUCTION

By

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Increasing nitrate concentrations in groundwater in Southwest Michigan has caused the public to perceive the seed corn industry as a source of the problem. In response, growers are seeking alternative management strategies to reduce their nitrogen fertilizer applications. However, as growers apply less nitrogen fertilizer, they risk profit loss if they apply too little. little.

To help evaluate the dimensions of this problem, a simulation model called CERES-IM was developed to evaluate the impact of nitrogen management strategies on plant growth and nitrate leaching in seed corn production. Patterned after the CERES-Maize model, CERES-IM simulated the management operations unique to seed corn production, including the distinction between male and female plants, and field operations such as the detasseling of the female plants and the removal of the male plants.

CERES-IM was validated using results from a nitrogen fertilizer study conducted with hybrid maize. Not using the inbred maize options for these simulations, the yield and biomass values simulated compared well to the measured values. Also, the drainage and nitrate leaching values simulated compared well with values measured using drainage lysimeters.

CERES-IM was also compared with two years of data from a nitrogen fertilizer management study conducted with inbred maize. Using drainage lysimeters, nitrogen strategies were evaluated to determine their impact on yield and nitrate leaching. CERES-IM showed good comparisons with the measured biomass data. The mean squared-error of prediction was used to evaluate the predictive accuracy of the model. All values were less than 12.3% except for the stover biomass, which was consistently underestimated. The drainage data compared well for all the lysimeters. The nitrate leaching data also compared well, though there were some discrepancies during the first year.

Finally, various nitrogen management strategies, including a conventional strategies presently used by growers and a management strategy called plant response fertilization (PRF), were simulated using a continuous, multi-year simulation option. The basic premise of PRF is to apply nitrogen only when the plants experience a nitrogen deficiency. The amount of fertilizer applied is limited to the amount of nitrogen required to complete the plant's growth. After evaluating the strategies based on yield, nitrate leaching, and revenue, a split nitrogen application was the strategy of choice. Applying minimal nitrogen at planting and one additional application at cultivation (growth stage V6), the amount of nitrate leaching was minimal and the revenue and yield were among the highest of the 17 strategies evaluated. For the initial conditions used in these simulations, a strategy of applying 30 kg N ha^{-1} at planting with an additional application of 80 kg N ha^{-1} at cultivation time was optimal.

This work demonstrates the value of simulation to evaluate managements strategies to accomplish the dual goal of minimizing nitrate leaching and maximizing profit. It shows that valid models can assist growers and policy makers in making informed decisions and help educate the public on the effects of management schemes on plant growth and the environment.

Dedicated to Henry Miller, the late Dennis Cupp, and all farmers who participate in on-farm research with their local universities. Your efforts strengthen agricultural research and its impact on society.

ACKNOWLEDGEMENTS

I would like to thank of those who have supported me over the past years as I worked toward this goal. First and foremost is my deep gratitude to my advisor Dr. Joe T. Ritchie. In 1984, we began a professional career together at Michigan State University that has developed into a friendship of respect and love that will last forever.

Also, I would like to thank the other members of my graduate committee. Dr. Vincent Bralts, Agricultural Engineering, who gave me the opportunity to work in the Michigan Energy Conservation Program, an experience I won't soon forget. Also, Dr. Ted Loudon, Agricultural Engineering, with whom I have worked since my first day in 1984. My experiences with Dr. Loudon were the impetus that encouraged me to pursue a career in the Cooperative Extension Service. Finally, thanks to Fred Henningsen, Cooperative Extension Service, who taught me the fine art of balancing research with clientele needs. There will not be another Extension agent like Fred for many years to come.

I would also like to acknowledge the support of Pioneer Hi-Bred International, especially Steve Lupkes, John Lightner, and Richard Peterson. Their assistance, along with many support personnel, helped to make the seed corn management project a success.

I also want to express my gratitude to my colleagues of the Homer Nowlin Chair. The number of people is too numerous to name, but I need to mention a special thanks to Brian Baer, who has helped me with programming and has supported me throughout the years. Also, a very large thanks to Sharlene Rhines, who not only helped to edit this work, but has supported me through countless numbers of projects.

Finally, from the bottom of my heart, I thank my family. The support and love I received from you has been endless. A special thanks to my brother Bob, who has witnessed a transformation that began my first day on campus in 1978. I cannot thank you enough for your support over the years. You have been my advisor, my banker, and most importantly, my friend. Thanks!

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INTRODUCTION

Increasing public awareness of nitrate contamination of groundwater has caused agriculturalists to focus their attention on nitrogen recommendations and management strategies. At one time, farmers applied nitrogen fertilizer in sufficient amounts to prevent nitrogen stress throughout the plant's life cycle, regardless of plant uptake or leaching potential. Farmers viewed nitrogen fertilizer over-application as cheap insurance to guard against any nitrogen loss that might occur during the season. The relatively low cost of nitrogen fertilizer was one factor which lead to the practice of over-application (Ritchie, personnel communication). However, farmers are now becoming more keenly aware of the need for better nitrogen management and are seeking help from research and extension specialists for answers on how to improve nitrogen fertilizer application rates and timing to reduce the potential for leaching while maintaining a good profit from their crop yield.

The problem of nitrate contamination of groundwater in Michigan is pervasive. Exceptionally high nitrate concentrations in groundwater are found in three regions of the state. As shown in Figure 1, these areas are the Northwest, Central, and Southwest (Kittleson, 1987) regions. Orchard agriculture is prominent in the Northwest and is one of the largest cherry production regions in the world. The second area of concern is the Central region where potato is the major crop. Michigan ranks 10th in potato production in the U.S (Michigan Agricultural Statistics, 1989). The third area is the Southwest corner of the state where corn is the major crop grown. Soybean and dry bean production are also heavy in this region. Seed corn is also grown in this region with production acres increasing. Seed corn acreage has gone from near zero in 1950 to over 16,000 ha in 1990.

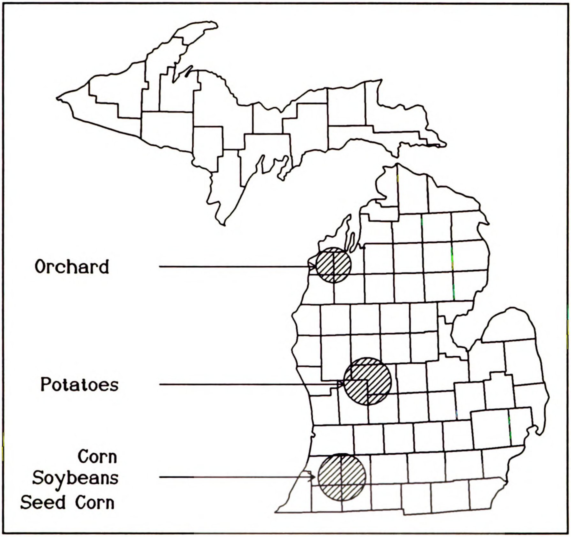

Figure 1. A map of Michigan showing the areas where high nitrate concentrations have been measured in groundwater samples.

All three of these regions have at least two common characteristics. First, each area is dominated by sandy loam and loamy sand soil types. The second is that all three areas have numerous acres of irrigated land. In the Northwest, the orchards are irrigated mostly by drip or trickle irrigation while in the Central and Southwest regions, center pivots and traveler or "Big Gun" type irrigation systems are mainly used. Because of the soils in these regions, irrigation has proven to be economical and in many cases, essential.

Though all of these regions are of concern to the general public, farmers in the Southwest region, seed corn growers in particular, have experienced pressure from the public to reduce the leaching of nitrates to the groundwater. In one instance, the EPA urged the town of Constantine, in the center of the seed corn production area, to install a $1.2 million de-ionizer in their water system to reduce the nitrate-N levels below the 10 ppm government health standard. Fortunately, a nearby well was located with a low nitrate-N concentration in the water. Mixing water from this well with water from the well with higher nitrate-N concentrations brought the water supply within the government standard.

Constantine is located in St. Joseph County, which contains the largest irrigated acreage of any county in Michigan; approximately 25,000 ha. It also contains the largest area of seed corn production, with approximately 14,000 ha planted each year.

The St. Joseph County area is dominated by outwash plains that are a result of deposits left by the glacial melt water in front of the ice. The major parent materials are glacial till, outwash deposits, alluvium, and organic material. Prairie soils that are considered part of the Great Prairies of the Midwest are also found in this area. Rivers flow throughout the region and there are numerous bogs and ponds. Lakes abound along the rivers, especially on the outwash plains. Groundwater is also plentiful in this area and irrigation wells range from 18 to 70 meters in depth.

Farming takes place primarily on the loamy sands and sandy loams which predominate this area. The sandy soil conditions, in conjunction with the ample supply of groundwater, make the area ideal for crop production while at the same time making it susceptible to groundwater contamination. As a result, nitrate levels in groundwater have increased during the past few years.

In a recent survey conducted in St. Joseph county, water from 2226 wells was tested for nitrate-N concentration, with 454 or about 20.5 % testing above 10 ppm nitrate-N (King, 1989). With increased public awareness and concern for environment quality, crop growers must begin to implement new management strategies that will minimize the impact on the environment.

When developing any management strategy, one must consider the crop type, soil type, and other components of the management system. The following is a brief description of the factors influencing the management strategy development.

Management System Components

Irrigation Considerations

Several factors influence irrigation water applications within Southwest Michigan. First there is the soil, with the potential extractable soil water (PESW) and the extractable soil water (ESW) being important variables. The PESW is the maximum amount of water the soil can hold that is available to, or extractable by, the plant. The ESW is the amount of plant extractable water in the soil at any given time. Farmers normally use the ESW to decide when to start their system, although this is not always the case and the PESW to determine how much water can be applied without overfilling the soil profile.

Farmers use a variety of information to help them decide when to irrigate. Some farmers use tensiometers to estimate the ESW. Tensiometer installation is fairly simple, but they do require some maintenance and often farmers find them too time consuming. Some experienced farmers determine when to irrigate by just feeling the soil or studying the crop. However, with the recent expansion of computer technology, combined with ever increasing input costs, more farmers are using computerized irrigation scheduling programs to help them decide when to irrigate and how much water to apply.

Most irrigation scheduling programs treat the soil like an empty glass. When a glass is filled it overflows if too much water is put in, thus wasting water. Soil too can hold only a certain amount of water and overflows if an excess is applied. Some scheduling programs estimate this overflow in terms of drainage, runoff, or surface water retention. Other programs just consider the excess water lost and unavailable to the plant. As plants begin to use the soil water, the ESW decreases. Once the ESW drops to a predetermined level, normally 40 - 60 percent of the PESW, an irrigation application is recommended.

Much work has been done on irrigation scheduling within St. Joseph County. A county-wide program using computerized irrigation scheduling in conjunction with irrigation system evaluations has been in operation within the county since 1980 with good success at helping farmers lower their inputs, conserve energy, and limit leaching. The program was developed by researchers at Michigan State University and has been refined over the years (Bralts et al., 1983; Algozin and Bralts, 1986; Shayya et al., 1990; Shayya and Bralts, 1992). Though this program has served as an excellent resource for scheduling irrigation water, it has never considered the effect an irrigation management strategy may have on nitrogen management. Many researchers recognize the importance of managing irrigation and nitrogen together. Watts and Martin (1981) showed nitrate leaching out of the rootzone was affected by the timing of the irrigation application and the amount of water applied. Other researchers reached similar conclusions (Watts and Hanks, 1978; Schepers et al., 1983; Smika, et al., 1977; Mielke et al., 1979). Considering irrigation and nitrogen management as separate components in the overall management system, each component affecting the other is imperative. For this reason, irrigation and nitrogen management must be given equal importance when developing management schemes that will limit potential leaching.

<u>Crop Considerations</u>

Crops such as soybeans or alfalfa require small amounts of nitrogen as compared to crops such as corn or potatoes. In this study, we are concerned with seed corn, also called inbred maize. At the start of a season, inbred maize appears similar to its offspring, hybrid corn. As the season continues, however, the inbred lines become quite unique.

The availability of information on inbred maize growth is limited. Seed companies have guarded their genetic lines closely, making detailed information unavailable to the general public. However, there are some basic, well know management strategies in use that require explanation.

First and foremost is the use of male and female plants. Normally, a grower will plant six or four rows of female (pollen receptor) plants and one or two rows of male (pollen donor) plants between them. This pattern is repeated throughout the field. The male plants and female plants are usually of two separate inbred lines and are often planted at different times to assure the male tassels are shedding pollen at the same time that the female silks are receptive to pollination. Additionally, young plants may be burned back to delay their development to assure synchronized pollination. This process is done using propane flamers and driving up and down the rows burning the tops of the male plants. This burn-back usually delays the plant's development by about 28 degree days (10 degrees C, base temperature). A major concern of seed corn growers is that both plants be at the proper growth stages when pollination takes places. A miscalculation of a few days can result in poor pollination and thus reduced yield and profit.

Another operation unique to seed corn management is the detasseling of the female plants. Before the female plant's tassels are exposed and shedding pollen, the tops of the plants are cut or pulled off. This prevents the female plants from shedding their pollen and assures that only the pollen from the male plants fertilize the silks from the female plants. The result is called a hybrid. Once pollination is completed, some seed companies require that the male plants be cut down, while others allow them to continue to grow.

Inbred plants are usually much smaller and yield less than hybrid plants. Once the female plants have been detasseled and the male plants cut out, one would be hard pressed to identify what is left in the field as maize. Average yields of irrigated inbred crops in the region range from as low as 1181 kg ha^{-1} to 6900 kg ha^{-1}. Irrigated hybrid crops yield an average of 10,000 kg ha^{-1}.

Farmers have often talked of the low vigor of the inbred plants. The inbreeds are considered more sensitive to stress from lack of water and/or nitrogen. Wych (1988) concurs with this, stating that in general, inbreeds have poorer rooting capabilities than hybrids, making them more vulnerable to nutrient and water deficiencies. Consequently, some farmers keep both water and nitrogen levels high throughout the plant's growth cycle. Wych, however, goes on to suggest that due to higher input costs combined with a decrease in commodity prices and an increasing concern for groundwater contamination, growers should apply nutrients only to maintain necessary fertility levels.

Soil Considerations

Soil type and its associated characteristics play a major role in any management strategy. The soils in Southwest Michigan are mostly loamy sands and sandy loams, with variations throughout the region. These soils have a low PESW and usually require irrigation to meet crop water needs, especially corn, during short term droughts. The soils also have a low nitrogen content, thus requiring farmers to apply nitrogen to their crops. Other factors such as soil pH, bulk density, organic matter content, etc. all impact the soil/nitrogen dynamics and should therefore be considered when developing a nitrogen management strategy.

Objectives

1. Develop a computer program that adequately simulates inbred maize growth and development as well as soil-plant interactions for water and nitrogen dynamics.

2. Perform field experiments to validate the simulation model.

3. Utilize the simulation model to evaluate the impact of several nitrogen management strategies on potential leaching in seed corn production.

LITERATURE REVIEW

Though seed corn is grown in nearly every region of the world, research work done on inbred growth and development is kept confidential. Competition between seed companies and a desire to assure that their genetic lines are not duplicated, has kept most of inbred maize research out of the scientific journals and unavailable to the public. Because of this, related research with similar crops must be investigated in order to formulate an understanding of seed corn management.

There has been much work in the area of nitrogen management with commercial hybrid corn. Researchers have studied the physiological aspects of nitrogen management including plant uptake of nitrogen, tissue concentrations, and the effects of nitrogen management on yield and biomass. Furthermore, work has been done on the environmental impact of nitrogen management. Research has been conducted studying the movement of nitrogen in the soil and the potential of nitrate contamination of groundwater resources.

The review of pertinent research will begin with a discussion on the management and unique field operations that take place in seed corn production. This will be followed by a discussion of related research performed with hybrid maize. Finally, maize growth simulation models will be reviewed to assist in the development of the inbred maize growth model.

Seed Corn Management

Growing Seed Corn

Plant densities normally range from 54,000 to 64,000 plants ha^{-1} (22,000 - 26,000 plants $acre^{-1}$) for inbred female plants, with the male plant population often exceeding that level (Wych, 1988). Planting patterns vary, but are normally 4:1 (four female rows to one male row), 4:2, 4:1:4:2, and 6:2. Other patterns such as solid female planting with interplanted males are used, but are not as common.

Split-date planting is used to assure that the male tassels shed pollen at the proper time for the female pollination. Planting dates are set by using a combination of days, heat units, and/or growth stages (Shoultz, 1985). Flaming or "burn back" is another technique used to retard plant development to assure good pollination. The plants are physically burned using lighted propane gas. This burning of the plant causes a short term severe stress that delays plant development by a day or two. This technique is normally only used on males, since it often leads to reduced yields of the burned plants (Fowler, 1967).

Detasseling

After planting, the next major field operation in the seed corn field is the detasseling of the female plants. This is done prior to silk emergence and pollen shed on the female plants. The tassels are removed either by hand or by mechanical detasselers. Hand removal is fairly efficient though often slow. Mechanical detasselers are quicker and more cost effective. Detasseling must be done with care to prevent unnecessary removal of plant leaf area. Hunter et al. (1973) showed that increased leaf removal decreased grain yield. The difference between the yield when only tassels were pulled as opposed to one, two, or three leaves was 1.5%, 4.9%, and 13.5%. This difference does vary somewhat with inbred and is dependent on the development of the plant, climatic conditions, operator skill, and other factors. Tests done by Pioneer Hi-Bred International, have shown little yield differences between hand pulled and mechanically detasseled fields (Lightner, Personal Communication). Detasseling of a field, whether done mechanically or by hand, is normally done twice, with 2 days to a week between operations. The second operation is performed due to uneven stands associated with inbred plants and to assure that all of the tassels of the female plants are removed.

Removal of the Male Plants

Once pollination has occurred, some companies destroy the male plants while others allow them to mature. Destruction of male plants is done by large "hi-boy" type machines that have rotary blades much like the old push type lawn movers. The blades do not simply cut the plants down, but rather cuts them into small pieces, leaving little possibility for survival. The removal of male plants serves two purposes. First, it assures that only the grain from the female plants are harvested. Secondly, it should reduce competition for nutrients and soil water for the female plants bordering the male plant rows, though there is no scientific evidence to support this theory (Wych, 1988).

Harvest

Harvesting of seed corn occurs just prior to physiological maturity, when grain weight has reached its maximum. Kernel moisture contents range from 30% to 38% (Knittle and Burris, 1985), with some variations among inbreeds (Carter and Poneleit, 1973). When planning harvest dates, most companies use the accumulation of heat units and/or black layer formation (Daynard and Duncan, 1969). Harvesting is planned mainly to avoid damage to the seed by freezing temperatures, mechanical harvesters (if the seed is too dry), insects, and/or diseases such as ear molds and stalk rots. Whole ears are harvested to minimize seed damage and to allow for individual ear inspection to assure proper seed quality.

Once the seed is harvested, it is normally taken to a drying depot and processed for storage. Most companies perform tests to assure quality and germination. The seed is conditioned and put into storage until the next season when it will be sold as hybrid corn seed.

Nitrogen Management and Scheduling

Research into the effect of nitrogen management strategies on the potential for nitrate leaching has increased as concerns about nitrate contamination of groundwater have grown. As previously mentioned, little work has been done with inbred maize varieties. However, nitrogen research in commercial hybrid production has been strong.

Much of the work on commercial hybrid corn has been done by predetermining a nitrogen strategy and then studying its effect on yield, plant growth, leaching, etc. Agricultural research on nitrates has been separated into two related areas. The first is nitrate within the plant's rootzone and plant uptake, and the other is nitrate movement beyond the rootzone and into groundwater.

Nitrate Movement Through the Rootzone and Plant Uptake

To develop a methodology for scheduling nitrogen, the dynamics of nitrogen within the rootzone must be studied. This includes not only nitrogen movement within the soil, but also plant uptake.

The driving force in nitrogen fertilizer management should be the plant demand or uptake. Legg et al. (1979) found that as the nitrogen fertilizer application rate increased, the amount of fertilizer nitrogen taken up by the plant also increased. However, the percentage of recovery of the fertilizer nitrogen decreased as the nitrogen fertilizer application rate increased. This indicates that as nitrogen fertilizer application rates are increased, plant efficiency in using the nitrogen fertilizer applied in season is decreased. Schepers et al. (1983) concurred with this conclusion, adding that the N uptake by maize often exceeded the fertilizer N applied. They concluded that the additional N must have come from some other source, such as mineralized soil nitrogen, nitrogen in the irrigation water, or residual fertilizer nitrogen in the soil. After further study, the researchers concluded that the mineralization of soil N was the major contributor of the additional N source and that from June through August, average daily N mineralized was 2.5 kg ha^{-1}. They estimated that the maize grown had a maximum daily N demand of 5.0 kg ha^{-1}. Therefore, even with this relatively high mineralization rate, some addition N would be required to meet maximum plant demand.

Watts and Martin (1981), found similar results. Using a simulation model they found that as nitrogen fertilizer amounts were increased, so did the plant's uptake of fertilizer N. The cost for this increased N uptake was an associated increase in nitrate leaching. This increase in nitrate leaching is what has caused great concern.

Leaching of Nitrates

The goal of a conservation minded farmer is to use a nitrogen application strategy that eliminates or at least minimizes nitrate leaching out of the plant rootzone while maintaining profit. Crop production on certain soils will always result in some nitrate leaching. This is especially true in coarse texture soils that have a high sand content. Watts and Martin (1981) used a nitrogen simulation model and predicted that it was impossible to completely eliminate nitrate leaching and still maintain present day production levels in the central Platte Valley of Nebraska. In their simulation, Watts and Martin used a fairly droughty soil, a Valentine very fine sand, which had an available water holding capacity of nine to 10 percent. Using two nitrogen rates (168 and 253 kg N ha^{-1}), corn production was simulated for this system. In addition, irrigation applications were simulated ranging from 0.75% to 1.67% replacement of the difference between evapotranspiration and rainfall every four days. The weather inputs included a below normal, normal, and above normal rainfall amount. The results of the study indicated that careful water management did not significantly reduce the loss of water through the soil profile, since most deep percolation occurred either before any irrigation was required or within days after a needed irrigation due to unforseen rainfall events. The researchers also stated that early season percolation could not be avoided on these sandy soils, even though seasonal rainfall was rarely enough to support crop production. Unfortunately, Watts and Martin simulated only the growing season (5/1 - 9/31). Their data show nitrate leaching amounts ranging from 30 to over 100 kg N ha^{-1}. Their simulation includes only N uptake data and no yield data. Attempts to limit nitrogen leaching may result in lower total biomass production, but that does not necessarily mean lower grain yields. These authors concluded that higher nitrogen rates do not necessarily impact leaching within the growing season rather, it is the following winter and spring leaching that is impacted by a season's nitrogen management.

In Minnesota, Timmons and Dylla (1979), conducted a similar study with hybrid corn production comparing irrigation amounts (2.5 and 5.1 cm per application), nitrogen fertilizer types (granular and liquid), and nitrogen fertilizer application timing (granular, preplant; liquid, four equal applications throughout the season through the irrigation system). The nitrogen amount applied was 225 kg N ha^{-1} and lysimeters where used to collect leachate at a depth of 122 cm. The results showed the 2.5 cm irrigation application and the 5.1 cm irrigation application increased nitrate leaching over the non-irrigated control by an average of 18% (70 kg N ha^{-1} to 82 kg N ha^{-1}) and 55% (70 kg N ha^{-1} to 108 kg N ha^{-1}). Again, these are within season leaching amounts only. The authors also concurred with Watts and Martin (1981) as to when the maximum percolation occurs. They cite an example in 1975 where 10.2 cm of percolation occurred before irrigation water was applied to the fertilizer treatments. This percolation accounted for 70% of the total within season nitrate leaching loss. Their study also included yield data which showed no significant yield difference between the irrigation amounts or fertilizer treatments, with the exception of the non-irrigated and non-fertilized treatments.

One element which causes much confusion in nitrate leaching research is the time span of the data collection or simulation. Seasonal leaching amounts may be minimal compared to those that occur between harvest and the next years planting, as previously mentioned by Watts and Martin (1981). Heavy autumn rain or deep winter snow followed by a spring thaw may cause excessive leaching in some regions. Schepers et al. (1983) found that mineralization of N was 312 $\pm$ 66 kg ha^{-1} during the 1980 growing season and 39.8 $\pm$ 9.0 kg ha^{-1} between the fall of 1980 and the spring of 1981. This mineralized N estimation was made from soil sampling and takes into account plant uptake. The study also shows how corn plants can utilize mineralized N for production and how farmers can reduce nitrogen fertilization applications. The result was an average decrease of 94 kg ha^{-1} of nitrogen fertilizer applied over an area of 3,000 ha. Harvest tests showed no significant reduction of grain yield. However, the within season mineralized N poses a threat for off season leaching. This is especially true if plants do not efficiently use mineralized N. Schepers and Martin (1983) simulated the leaching of nitrates in loamy sand soils in the sandhills of Nebraska. They estimated that 20% - 80% of the residual N in the soil on April 1 was leached out of the rootzone by June 15. This simulation was done over an 11-year period from 1973 to 1984. For fine sand soils, the percent leached increased to 60% - 100% .

The potential for leaching is a factor that often causes farmers to over apply nitrogen. Schepers (1988) stated that because of the fear of wet spring weather, many farmers consider fall and early spring applications of nitrogen. Even with preplant applications, many farmers over apply their nitrogen for fear that late spring and early summer rains will cause excessive nitrate leaching. This is especially true in the sub-humid and humid regions. Schepers notes that even though strong evidence exists that N recovery for corn is highest with sidedress applications (Anderson et al., 1982; Russelle et al., 1983), many farmers are fearful of wet weather causing delays in the timely applications of nitrogen.

Irrigation Management and Its Effect on Nitrogen Management

Because nitrate is a water soluble form of nitrogen, irrigation can have a significant impact on nitrogen fertilizer management. Too much irrigation water may cause excessive deep drainage, which in turn can carry nitrates out of the rootzone and down toward the groundwater. On the other hand, too little irrigation water can limit a plants's uptake of nitrogen causing water and nitrogen stress.

Much work has been done in evaluating irrigation strategies in respect to nitrogen management. Russelle et al. (1981) evaluated the effects of nitrogen and water management on maize yield by varying irrigation amount and application interval. Nitrogen uptake in the grain lowered with the heavier, less frequent irrigations (10 cm per application in 2 week intervals). Also, the recovery of fertilizer N from the soil was affected by the irrigation management, especially on the low sidedress applications of nitrogen (112 kg N ha^{-1}). As the irrigation water amount applied decreased and the application frequency increased, the fertilizer N recovered by the plant increased. This shows the importance of irrigation management especially at low or marginal nitrogen application rates. The lower and less frequent irrigations left more residual N in the upper soil profile and increased fertilizer use efficiencies.

Martin et al. (1982) found that irrigation management significantly impacted the nitrogen uptake by maize. The researchers used various nitrate-N concentrations in the irrigation water and a field calibrated simulation model to study the interaction of nitrogen and irrigation water in the Platte Valley region of Nebraska. They concluded that N uptake by maize was significantly influenced by the amount of irrigation water applied, and to a lesser extent by the nitrate-N concentration of that water. In addition, the plant's uptake efficiency of the fertilizer was also sensitive to irrigation water amounts applied.

The authors simulated for 4 nitrogen fertilizer application amounts, 0, 45, 135, and 225 kg ha^{-1}. The nitrogen applications were simulated with 45 kg N ha^{-1} applied at planting and the remainder of the nitrogen applied in a single side-dress application one month later. The irrigation amounts were simulated for "Irrigation Replacement Fractions (IRF)" ranging from 1 to 4. An IRF value of 1 represented an irrigation water application equal to the difference between evapotranspiration and the effective rainfall since the last irrigation (effectively refilling the soil profile). All irrigation applications were simulated on a 4 to 5 day frequency. The results of the simulation showed that for irrigation water with a nitrate-N concentration of 10 and 25 ppm, the fertilizer N uptake efficiency for IRF equal to 1 was always greater than 0.5, regardless of the nitrate-N concentration in the irrigation water or the nitrogen fertilizer applied. However, for IRF equal to 3 or 4, the fertilizer N uptake efficiency was never greater than 0.25, again without regard to nitrate-N concentrations or nitrogen fertilizer applied.

Maize Simulation Growth Models

Crop growth simulation models have been gaining acceptance as a viable research tool. These models usually integrate weather, soil, and management variables to simulate the growth and development of a particular crop. Crops that have been simulated include maize, soybeans, alfalfa, and cotton, to name a few. A partial list of published crop simulation models is in Table 1

(Jones and Ritchie, 1991). A simulation model for inbred maize does not exist at this time. However, hybrid maize simulation models that have gained acceptance could be adapted to inbred maize.

Though inbred maize does differ from hybrid maize, the basic structure and development of both crop types are the same. In 1980, Stapper and Arkin published a maize simulation model called CORNF (Stapper and Arkin, 1980). This model used a daily time step and simulated maize growth and development. The model also included a soil water component that allowed for estimations of ET, soil water content, drainage and runoff. This model does not include nitrogen subroutines that would allow for soil nitrogen content estimation and/or nitrate leaching. Also, the CORNF model does not simulate soil water below the wilting point or above field capacity. This could cause some problems during water stress periods or periods of excessive rainfall.

The CERES-Maize model is a daily time step model that simulates plant growth and development as well as soil water and soil nitrogen interactions. The first version was published in 1986 (Jones and Kiniry, 1986) and version 2.10 was released in 1989 (Ritchie et al., 1989). CERES-Maize is just one of a family of growth simulations models that are being developed through the USAID sponsored International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) program (Uehara, 1985). Other IBSNAT models include soybeans - SOYGRO (Wilkerson, 1983), peanuts - PNUTGRO (Boote et al., 1989), and wheat - CERES-Wheat (Ritchie and Otter, 1985).

Aside from the usual validation needed for model development, CERES-Maize has received much testing and use by researchers outside of the original development group. Hodges et al. (1987) illustrated the use of CERES-Maize in predicting regional yield estimations for the US Cornbelt. In this study, for the years 1982 (calibration year), 1983, 1984, and 1985, CERES-Maize production estimates were 92%, 97%, 98%, and 101%, of the figures reported by USDA in January, 1987. Piper and Weiss (1990) evaluated CERES-Maize for reduction in plant population and leaf area during the growing season. Their results showed that CERES-Maize gave good results except that it had difficulty predicting yields at high and low plant populations, though it

Table 1. Partial list of published crop growth simulation models taken from Jones and Ritchie, 1991.

Crop	Model Name	Reference
Alfalfa	ALSIM 1 (Level 2)	Fick (1981)
Barley	CERES-Barley	Ritchie et al (1989)
Cotton	GOSSYM	Baker et al. (1983)
Dry Bean	BEANGRO	Hoogenboom et al. (1989)
Maize	CERES-Maize V1.0 CERES-Maize V2.1	Jones and Kiniry (1986) Ritchie et. al (1989)
	CORNF	Stapper and Arkin (1985)
	VT-MAIZE	Newkirk et al. (1989)
Peanut	PNUTGRO	Boote et al. (1989)
Pearl Millet	CERES-Millet	Ritchie and Alagarswamy (1989)
Potato	SUBSTOR	Hodges et al. (1989)
Rice	CERES-Rice	Godwin et al. (1990)
Sorghum	SORGF	Arkin et al. (1976)
	CERES-Sorghum	Ritchie and Alagarswamy (1989)
Soybean	SOYGRO V5.00 SOYGRO V5.42	Wilkerson et al. (1983) Jones et al. (1989)
Wheat	CERES-Wheat V1.0 CERES-Wheat V1.0 (Nitrogen) CERES-Wheat V2.1	Ritchie and Otter (1985) Godwin and Vlek (1985) Godwin et al. (1989)
	TAMW	Maas and Arkin (1980)

did follow yield trends at the lower plant densities. CERES-Maize has also been used in the semi-arid tropics (Carberry et al., 1989) and as part of a newly developed light interception model (Hodges and Evans, 1990).

Work has also been done using CERES-Maize to aid in the economic analysis of irrigation strategies. Algozin et al. (1988) used the model to generate yield and irrigation water use information to perform an irrigation budget analysis for several irrigation strategies used in Michigan. Boggess and Ritchie (1988) used a similar approach for analyzing different irrigation regimes with respect to economics and risk aversion in humid regions. Their conclusion was that maximum profit is obtained when less irrigation water is used than needed to produce maximum yield. In other words, the extra cost associated with irrigating the crop to obtain maximum yield was greater than the increased revenue from the extra yield. Therefore, to obtain the highest amount of profit, maximum yields were not always obtained. Other works involving CERES-Maize with irrigation analysis include Martin et al. (1985) and Worman et al. (1988).

In one performance test, de Vos and Mallett (1987) compared CORNF and CERES-Maize. Though the authors did not find one model superior over the other, they did indicate that CERES-Maize predicted soil water patterns better than CORNF, although the inputs for CORNF were simpler than for CERES-Maize. In the final analysis, the authors concluded that, "CERES-Maize provided more realistic simulations, although its overall performance was not substantially better than that of CORNF."

A third maize model, VT-Maize (Newkirk et al., 1989) is a combination of separate published models. The developers took what they considered to be the best parts of several different simulations models and combined them into one maize model. The phenologic and physiologic development used was based on the CERES-Maize nitrogen version (Jones and Kiniry, 1986). The soil subsystem processes and interactions were based on the RHIZOS portion of the GOSSYM model (Baker, et al., 1983), while soil temperature is updated using the approach found in the EPIC model (Williams and Renard, 1985). Inputs for VT-Maize are similar to CERES-Maize for the phenological inputs. However, the soil inputs are much more detailed and difficult to obtain. Soil water and nitrogen distribution and interaction are based on a two-dimensional model, that is defined by a grid or cell matrix.

All three models have strong and weak points. The CORNF model does not contain the necessary elements for evaluating nitrogen management on yield and leaching. VT-Maize uses the same basic growth subroutines as CERES-Maize, but the soil water and soil nitrogen data are more detailed and whether this increased complexity results in a more precise prediction and/or simulation is not yet clear because the developers did not provide evidence though independent validation.

METHODOLOGY

OBJECTIVE 1: Development of an Inbred Maize Simulation Model

Though the production of inbred maize is different from that of hybrid maize, the growth and phenological development of both plants are similar. For this reason, it was decided that a presently used hybrid simulation model would be adapted for inbred growth. The model chosen was CERES-Maize because of its relatively wide use within the scientific community (Algozin et al., 1988; Boggess and Ritchie, 1988; Carberry et al. 1989; Hodges and Evans, 1990; Hodges, et al., 1987; Martin et al., 1985; Worman et al., 1988; and de Vos and Mallett, 1987) and the ease with which inputs are obtained. In addition, the CERES-Maize model has nitrogen components that will aid in developing of nitrogen fertilizer management schemes. The first step to reprogramming CERES-Maize for inbred maize is to calibrate/validate the model for hybrid maize grown within the region of interest.

Commercial Hybrid Maize Study

Though a validation of the CERES-Maize program was presented in Jones and Kiniry (1986), there was no validation on the program's ability to simulate soil nitrogen leaching. Since the leaching of nitrates is integral to the formulation of any nitrogen management scheme, it follows that this portion of the model requires further validation than that done by Jones and Kiniry.

In the summer of 1986, two drainage lysimeters were placed in a farmer's field near Mendon, Michigan. Both lysimeters were "disturbed" profile lysimeters. Installation began with an analysis of the soil and defining specific soil layers. Next, the soil was removed, layer by layer, and placed into individual piles. Then, once the lysimeter was lowered into the ground, the soil was placed back into the lysimeter, again layer by layer, and packed so as to best represent the soil in its original condition. The first lysimeter was placed under an existing center pivot irrigation system that the farmer used to irrigate hybrid maize. The other lysimeter was placed outside the area of the center pivot but within the same field as the first. The farmer controlled the water and nitrogen management of the lysimeter under the existing center pivot irrigation system (the conventional management practice - CMP) while researchers at MSU controlled the water and nitrogen management of the other (the research management practice - RMP). The data collected included soil water and soil nitrogen data as well as information on plant growth, phasic development, and yield. Also, the drainage volume was measured and samples were collected to analyze the drainage for nitrate concentration.

The lysimeters used in this experiment were 1.52 m wide, 1.22 m long, and 1.83 m deep (see Figures 2, 3, and 4). The corn was planted parallel with the 1.52 m width to assure that two rows of maize (at 76.2 cm spacings) would be planted over the lysimeters. The lysimeters were placed approximately 45.7 cm below the ground surface so that normal tillage operations could take place. The farmer was responsible for all tillage, planting, and pesticide applications for both plots. Both plots were treated exactly the same except for the irrigation water and nitrogen fertilizer applications (excluding the nitrogen in the starter fertilizer that was the same for both plots).

Drainage Sampling

Leachate sampling began in 1988. The sampling took place approximately every two weeks, or when the drainage volume warranted. The drainage was collected in polyethylene containers located under the lysimeter drainage pipe in the collection area. The drainage samples were analyzed for nitrate concentration. In 1989, a more sophisticated collection device was installed that allowed for the automatic collection of drainage samples. Using a datalogger, the

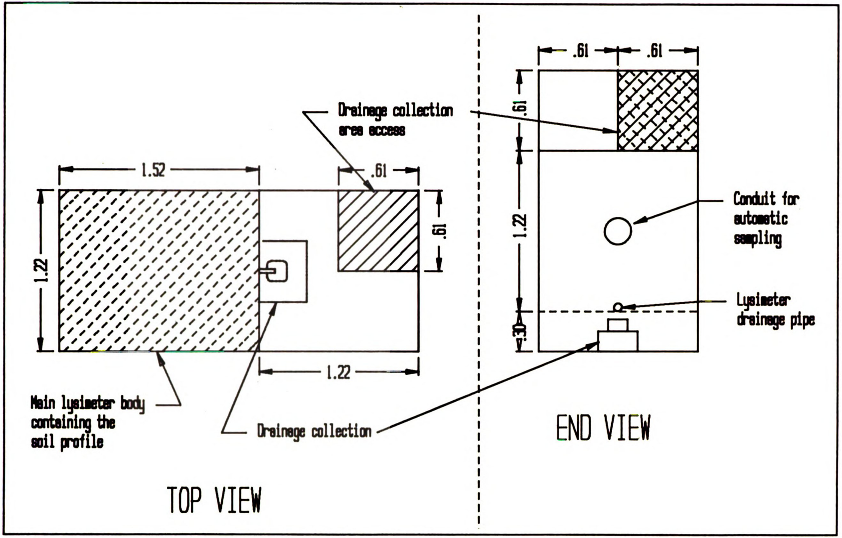

Figure 2. A schematic drawing of the top view and end view of one of the lysimeters used in the nitrogen management study in commercial hybrid maize production. All measurements are in meters. Mendon, MI.

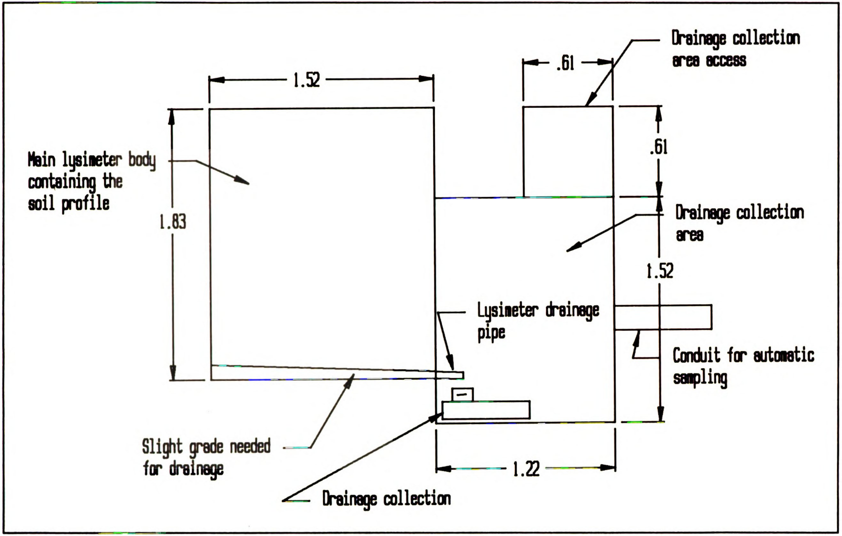

Figure 3. A schematic drawing of the side view of one of the lysimeters used in the nitrogen management study in commercial hybrid maize production. All measurements are in meters. Mendon, MI.

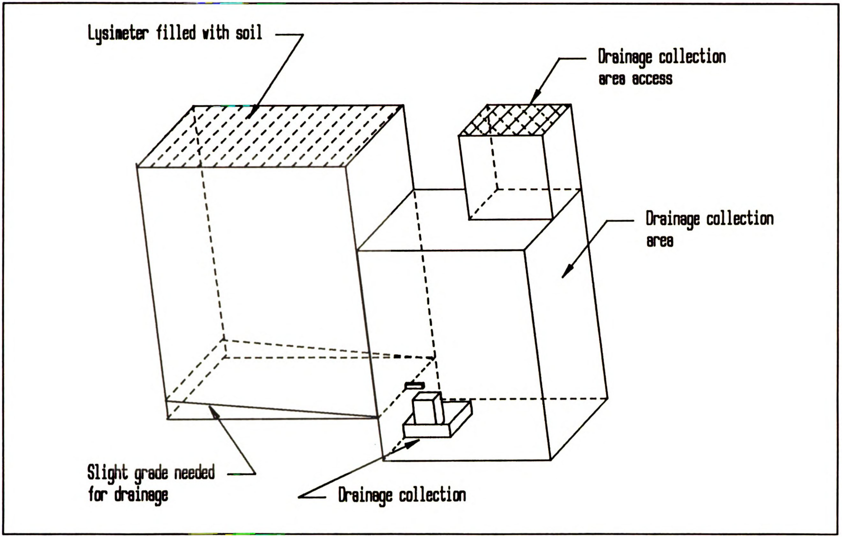

Figure 4. A schematic drawing of one of the lysimeters used in the nitrogen management study in commercial hybrid maize production. Mendon, MI.

volume of drainage was measured and a sample was taken whenever a 6 mm depth of water had drained.

Research Plot Irrigation System

The research plot, located at the end of the field, required its own irrigation system. Figure 5 shows a diagram of the irrigation system layout. A system was setup with four sprinklers at 9.14 m spacings, with the lysimeter in the center. The system employed the use of a Rainbird irrigation timer-controller that was connected to a solenoid valve located in the main line of the irrigation system. The controller was a 14-day timer, designed so that the user could chose the time to irrigate, the length of time the system was on and the day the system would turn on. The system was also equipped with an automatic device that shut the system down once a predetermined amount of rain had fallen. The rainfall was collected in a small calibrated bucket that was located on top of a spring activated switch connected to the controller. System reactivation occurred when the water in the bucket evaporated. To give more flexibility for controlling the irrigation events, the timer was rewired. First, both a "start" and a "stop" button were installed to turn the system on and off manually. Also, the system was altered so that if a sufficient rainfall amount had occurred to shut down the controller operation, the shut down would be irreversible, until the start button was pressed again. This avoided any over watering that might occur since the evaporation out of the bucket may not represent actual water loss from the research plot and could cause an irrigation event to occur before it was required.

Using the data gathered in 1988 and 1989, the CERES-Maize program was compared against field data. Comparisons are made with biomass and grain measurements in addition to nitrate leaching data recorded.

Development of CERES-IM

The changes required to simulate inbred growth dealt mainly with production events such as the detasseling of the female plants and removal of the male plants, and how these operations

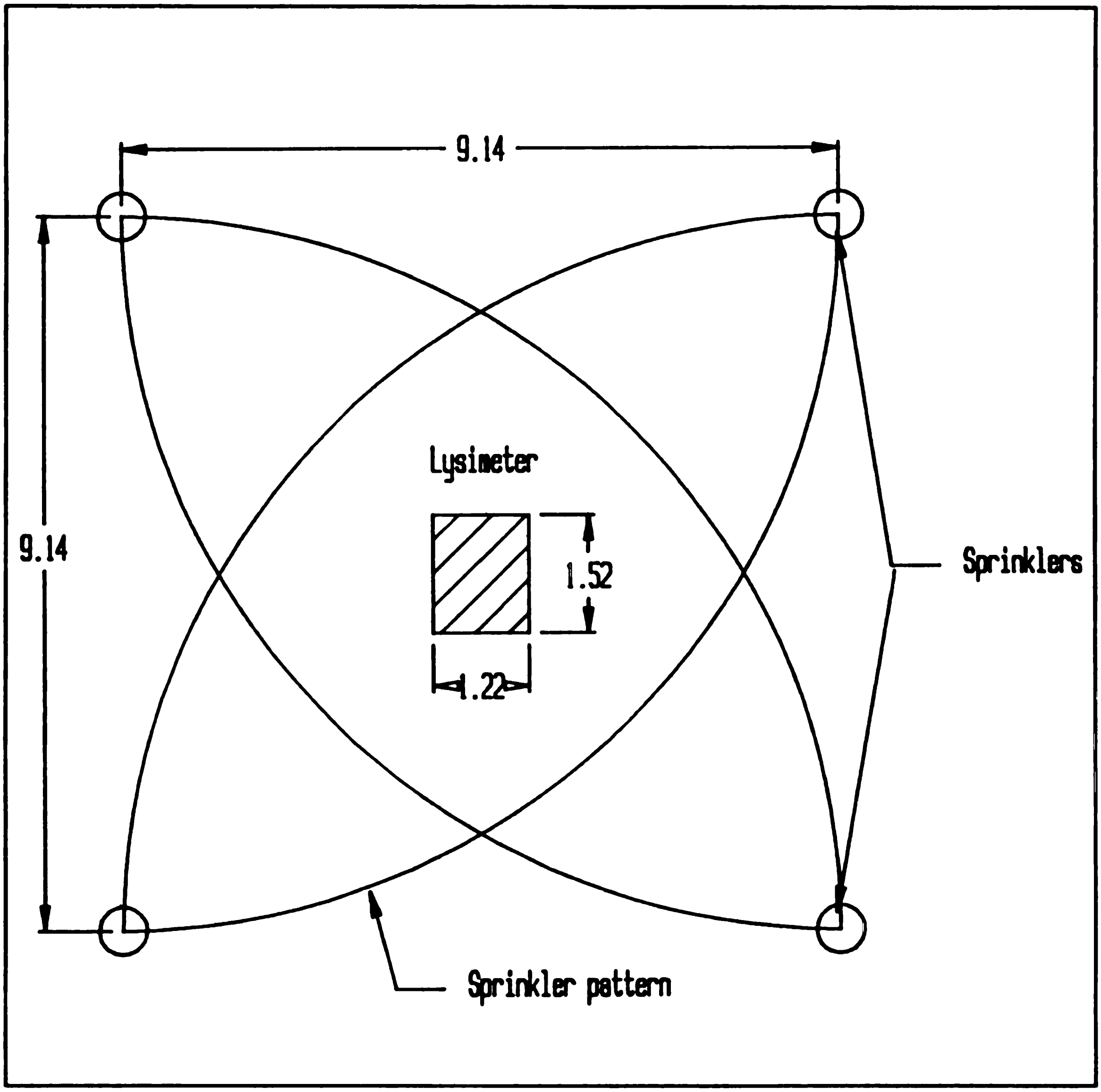

Figure 5. A schematic drawing of the irrigation system used on the RMP plot. The curved lines represent the radius of coverage of the four sprinklers. All measurements are in meters. Mendon, MI.

effect plant growth and development. The new model called CERES-IM (Inbred Maize) simulates inbred maize growth and development and allows for the necessary inputs relative to inbred production (male and female plants, detasseling, etc). Additionally, changes were made in the model in areas where shortcomings have been observed in past uses of CERES-Maize. Before discussing the changes made, a short summary of the present CERES-Maize structure is required.

Present CERES-Maize Input Structure

CERES-Maize presently has 9 input files (1 unused at the present time) in which all data required for a simulation can be entered. These files include information on soil water/nitrogen data, daily weather data, fertilization and irrigation data, management information (i.e., plant population, planting date, variety sown, etc.) and genetic parameter inputs. A description of these files can be found IBSNAT Technical Report 5, "Documentation for IBSNAT Crop Model Input & Output Files, Version 1.1: for the Decision Support System for Agrotechnology Transfer (DSSAT V.2.1)," (1990). The files are defined as follows:

File 1. Weather data - Daily solar radiation, max/min temperature, and rainfall.

File 2. Soil Data - Drained upper limit, lower limit, soil albedo, etc.

File 3. Unused at the present time

File 4. Soil Nitrogen Balance Parameters - Amount of the organic residue of previous crop, depth of incorporation, C:N ratio of residue, and dry weight of root residue of previous crop.

File 5. Soil Profile Initial Conditions - Water content, soil ammonium, soil nitrate, and soil pH, all by layer.

File 6. Irrigation Management Data - Date of irrigation and amount of water applied.

File 7. Fertilizer Management Data - Date of application, amount applied (actual N), depth of application, and type of fertilizer used.

File 8. Treatment Management Data - Sowing date, sowing depth, irrigation management (no irrigation, according to input (File 6), automatic irrigation, or water assumed non-limiting), nitrogen management (according to input (File 7) or nitrogen assumed non-limiting), irrigation system efficiency, depth of soil considered if irrigation is automatic, available soil moisture trigger used to automatically irrigate, phyllochron interval, and multi-year switch (indicates number of years of simulation).

File 9. Genetic Coefficient Data - Degree days from emergence to end of juvenile stage and from emergence to physiological maturity, photoperiod sensitivity, potential kernels per ear, and potential kernel growth rate.

In addition to these 9 input files, CERES-Maize also requires two other input files. One is named "WTH.DIR" and contains the names of the weather files that can be used in the simulation run. Any number of weather files can be listed. The other file is named "MZEXP.DIR" and contains the name of the eight input files previously listed plus the names of five output files (a description of the output files will be given later). The files are listed by experiment. Since an experiment can have several treatments, the input files themselves can be separated by treatment. Thus, the "MZEXP.DIR" file may contain 4 experiments, each having their own individual input and output file names. Within each of the 8 input files, experiments can be further separated into treatments. A more detailed description of the individual inputs within these files can be found in Jones and Kiniry (1986).

Restructuring of Input to Accommodate Male and Female Plants

Since male and female plants play different roles in seed corn production, there needed to be a method for identifying each within the input structure of CERES-IM. To keep changes to the input structure within the presently used CERES-Maize model, additional variable inputs were added to existing input files rather than completely restructuring the input format. Since the role of male or female is not necessarily dependent on genetic type, each treatment must be allowed to be either designated male or female. Therefore, the new parameters were placed within the treatment management input file (File 8).

The first additional input is ISEX. ISEX represents the role the treatment plays in the production of the seed corn. If ISEX equals 1, it is assumed to be a male plant. If ISEX equals 2, it is assumed to be a female plant. If there is no input for ISEX, the simulation is assumed to be for hybrid maize, and all inbred maize related changes are ignored.

The other two new inputs are IDET and IMCUT. IDET is the day-of-year (DOY) that detasseling occurred. IDET is used only if ISEX is equal to 2 (female). Even if a value exists for

IDET, detasseling is not simulated unless ISEX equals 2. If IDET equals 0, then detasseling is not simulated. Finally, if IDET is set equal to 999, then detasseling is automatically simulated within the program structure. A new subroutine, DETASS, was written to simulate the detasseling operation. A listing of the source code of the DETASS subroutine is in Appendix one.

Once detasseling has been simulated, a reduction in both leaf area and leaf weight is required. According to tassel samples taken in 1990, an average of 3 leaves per plant were removed during the detasseling operation. The average leaf weight loss compared to total plant biomass was 13.1 % (Table 2). However, the biomass samples taken for inbred 1 were taken 1 week after detasseling while the biomass sample taken for inbreeds 2 and 3 were taken on the same day of detasseling. This is reflected in the lower percentage of percent biomass loss for inbred 1 shown in Table 2. Therefore, averaging inbreeds 2 and 3, the average percent biomass loss due to detasseling is 14.05%. Therefore, once detasseling is simulated, leaf biomass is reduced by 14 % of the total plant biomass and leaf number is reduced by 3.

For automatic detasseling, tassel removal is assumed to take place just prior to silking, which is the norm for field situations. Early detasseling can cause excessive loss of leaves and lead to yield reduction while late detasseling can cause contamination of the cross breeding (Wych, 1988). Therefore, automatic detasseling is assumed to occur when 90% of its thermal time (TT) requirement to complete CERES-Maize phenological growth stage 3 (tassel initiation to end of leaf growth and silking). Though this may not always be the case, it does provide for the detasseling operation to take place before any pollination contamination would take place but not too early to cause excessive leaf loss.

The subroutine DETASS is called whenever the DOY is equal to the detasseling date (IDET) that was entered in File 8 or, if IDET is equal to 999, when the TT reaches 90% of the total TT required to complete stage 3. Once detasseling is simulated, a message is printed on the summary output file and to the screen, informing the user that on that day female detasseling was simulated.

Table 2. Average percent biomass loss due to female detasseling for all inbreeds. Constantine, MI, 1990.

Variety	Detasseled Biomass (kg ha^{-1})	Total Biomass# (kg ha^{-1})	% Biomass Loss
Inbred 1	413.3	3690.2	11.2
Inbred 2	443.9	3312.7	13.4
Inbred 3	515.3	3505.4	14.7

Biomass samples for inbred 1 were taken 1 week after detasseling. Biomass samples for inbreeds 2 and 3 were taken on the day of detasseling. The total biomass samples include the weight of the detasseled biomass.

The other new input in the treatment management file is IMCUT, the DOY the male plants are cut down. As with the females plants and the input IDET, IMCUT is ignored, regardless of its value if ISEX is not equal to 1 (male). However, if ISEX is equal to 1, then IMCUT is used to determine when the male plants are to be cut down. As with the female detasseling operation, if IMCUT is set equal to 999, automatic male plant removal is simulated. If IMCUT is equal to 0, the male plants are not removed. However, a value of 0 for IMCUT is invalid when simulating an entire seed corn field with male and female interactions. A new subroutine called MCUT was written to handle the simulation of the cutting out of the male plants. A listing of the FORTRAN code for the subroutine IMCUT is in Appendix one.

If ISEX is equal to 1 (indicating male plants), CERES-IM then determines if the removal of the male plants is to be simulated. If IMCUT equals 0, then the removal is not simulated and plant growth is simulated to physiological maturity. If IMCUT does not equal 0 (indicating that removal is to be simulated), then CERES-IM determines if the removal date is to calculated internally (IMCUT equal to 999) or if the removal is to simulated on the DOY entered (IMCUT equal to 1-366). If the removal is to be simulated on the day entered in the input file, CERES-IM checks to determine whether the DOY equals IMCUT. If it does, a message is sent to the summary output file and the screen informing the user that the removal of the males plants has been simulated and that the growth routines have been terminated. This termination of growth is accomplished by setting the plant growth stage to 6, physiological maturity. This terminates the growth portions of the model but allows the soil water and soil nitrogen routines to continue processing.

If IMCUT equals 999, the operation is simulated automatically. Male plants are removed mainly to protect the germplasm. Many companies feel that if the male plants are allowed to begin grain filling, their germplasm could be duplicated by other rival companies. Therefore, though the early removal of male plants may cause reduced yield due to poor pollination, late removal may cause anxiety for the seed companies. In the automatic removal of the male plants, it is assumed that the male plants are cut out when 35% of the required TT to complete grain filling has been reached. This may leave the males in the field too long for some growers, but is a good approximation and guarantees no loss of yield.

Another area of concern for inbred growth is the burning back of plants to delay development in order to extend the pollination period. This is done only on male plants and is rarely done on the entire male population. At most, only 50% of the male plants are burned back. Because of this, no reprogramming was done to account for this operation.

The male and female plants may vary in genetic type, plant population, and developmental stage as well as having separate field operations performed on them (ie, detasseling and removal). The interactions of these plants and how these interactions effect growth and soil water and soil nitrogen conditions must be accounted for. One consideration is the planting pattern used. Though most seed corn fields are planted in a pattern of four female rows per each male row (4:1), other patterns such as 4:2, 4:1:4:2, and 6:2 are used. In the new CERES-IM model, the ratio of female rows to male rows is a management input and is placed in the treatment management file, File 8. The input, called PRATIO (Planting RATIO) is a single real number that relates the ratio of female rows to male rows. Patterns such as 4:1 and 4:2 are entered as 4 or 2. Other patterns, such as the 4:1:4:2 are not allowed.

During the season, there is no interaction between the male and female plants. To run a simulation for a seed corn field, the user enters the treatment used for the female and male plants, making sure that all of the appropriate inputs relative to male and female plants are entered (i.e., ISEX, IDET, IMCUT, etc.). The model then makes two separate runs; one run for the female plants and one for the male plants. The male plant's simulation is run first. Using the inputs given, the simulation runs until the male plants are cut down. Once the removal of the male plants has been simulated, the model continues to run the soil water and soil nitrogen simulations for an additional 60 days. During this time, the daily soil water and soil nitrogen values, all by soil layer, are stored in a temporary file, to be used later at the end of the female plant's simulation.

After the male plant's simulation is completed, CERES-IM begins to simulate the female plants. Once the female plants have reached full maturity, the temporary file created by the male plant's run is read. When the DOY of the female plant's maturity equals the DOY in the male output file, the soil water and soil nitrogen contents of the two runs are combined. The combining of these data is accomplished by using PRATIO and weighing the appropriate values for soil water and soil nitrogen to produce combined values. These new soil water and nitrogen values are used for the remainder of the female simulation.

Present Structure of CERES-Maize Output Files

There are five output files in CERES-Maize. These files contain data on the growth and phenological development of the plant, including biomass accumulation, grain filling, and nitrogen uptake and concentration. Soil water and soil nitrogen data are also given. There is one output file that gives a year-end summary of the simulation, three component files that give data throughout the simulation, and a fifth file that is a short summary file used only during multi-year runs. All of these files are discussed in Technical Report 5, "Documentation for IBSNAT Crop Model Input and Output Files, Version 1.1", IBSNAT (1990). The following is a brief discussion of each file. An example of each of these output files is in Appendix two.

The first output file is the summary output. This file contains a summary of the input data and output data. Input data such as soil parameters, genetic parameters, experiment and treatment identifiers, and fertilizer and irrigation applications are all echoed in this file. Additionally, phenological data, such as end of juvenile stage and beginning of grain filling are given, with dates and TT, precipitation, and nitrogen uptake. Finally, the summary output file gives a comparison between observed and predicted data. This includes silking date and maturity date, kernel and yield data, biomass data, and nitrogen uptake and concentration data.

The component output data are separated into three files; the biomass, the soil water, and the nitrogen output files. Each of these files have the option to print output on a daily basis or at any daily frequency up to 99 days.

The biomass output file contains information on biomass accumulation, leaf number, LAI, root-stem-grain-leaf weights, rooting depth and root length volume for soil layers 1, 3 and 5. The default for writing to this output file is once every 7 days. However, the output interval can be changed.

The soil water output file contains information on the status of the soil water and the parameters that influence it. The data given include potential and actual evapotranspiration, plant evaporation, the soil water contents of soil layers 1 through 5, the profile soil water content, and maximum and minimum temperature, solar radiation, and precipitation.

The third component output file contains information on plant and soil nitrogen status. The data given include vegetative and grain nitrogen uptake, percent nitrogen in the above ground biomass, and nitrate concentrations for soil layers 1 through 5 and ammonium concentrations for soil layers 1 through 3.

The fifth output file is used only during multi-year runs. This output file contains summary data on nitrogen and water usage, biomass, yield, cumulative evapotranspiration, etc. This file is important for multi-year runs, since the other output files can become quite cumbersome and difficult to decipher when there are several years of data.

Together, the output files given by CERES-Maize provide users with opportunities to check predicted versus observed values for a host of plant and soil parameters. By changing the timing of the output, daily values for soil water, soil nitrogen, and plant biomass accumulation can be given, allowing for any number of comparisons throughout the simulation.

Restructuring of Output Files

Unlike the input file structure, the output file structure requires very few changes to accommodate inbred maize simulation. Some minor changes were made to the summary output file to allow for the new inputs such as ISEX and PRATIO to be printed out. Messages of when the female plants were detasseled and when the male plants were removed were also added. Additionally, when the male and female soil water and soil nitrogen parameters are combined at the end of the female growing season, a message to alert the user that this has taken place is also written to the summary output file. However, water drainage and nitrate leaching are not given within the present output file structure and are required to effectively evaluate nitrogen management strategies on potential groundwater contamination.

Though both water drainage and nitrate leaching are simulated within the model, these data are not written to any output file. A new output file, "OUTLCH.DAT" was created to give data on water drainage and nitrate leaching. This file uses the same output step used by the soil water output file. Therefore, if the user defines the frequency of output for the soil water file as once every 10 days, the drainage and leaching data are also written once every 10 days. These data can then be compared against observed data obtained through the use of the lysimeters.

New Leaf Area Relationship

In addition to the changes required to simulate inbred growth, changes were also made to some of the basic relationships in CERES-Maize. An area that has yielded inconsistencies between predicted and observed data is leaf area. This is especially true for the smaller leaves at the beginning of the season when CERES-Maize over-predicts leaf area (Ritchie, personal communication). This leaf area over prediction can cause errors in biomass accumulation and in evaporation from the plants and soil surface. A new aspect of the CERES-IM model is a new set of functions to describe leaf area growth.

Currently, CERES-Maize uses a series of discontinuous functions to simulate plant leaf area. These functions are separated based on leaf number and were fitted for the plant leaf area for leaves 1-3, 4-11, 12 to total leaf number (TLNO) minus three, and from TLNO minus three to the flag leaf, with leaf number as the independent variable. Muchow and Carberry (1989) described the use of functions based on leaf number that would describe the area of individual leaves, not total plant leaf area as in CERES-Maize. Using the leaf number break points of CERES-Maize, they developed new functions to describe the area of a leaf based on the leaf number. They also discussed the use of a single exponential function. Using the leaf number, area of the largest leaf, and leaf number of the largest leaf, they found the following function to best fit the data, with an R^2 value of 0.98:

$$Y = Y_o EXP(-0.0344(X - X_o)^2 + 0.000731(X - X_o)^3) \qquad [E1]$$

where Y is the area of the leaf (cm^2), Y_o is the area of the largest leaf (cm^2), X is the leaf number, and X_o is the number of the largest leaf. Though this function yielded a high R^2 value, it still had difficulty accurately describing the young, small leaves.

A function that does provide for small incremental increases at low values is the Gompertz function. Described by Richards (1959, 1969), the Gompertz function produces an asymmetric sigmoid curve that gives the small leaf area values when the plants are young. The

Gompertz function is described by:

$$A = A_o e^{-be^{-kt}} \qquad \text{[E2]}$$

where A represents the area of leaf t (cm^2), A_o is the area of the largest leaf (cm^2), and b and k are constants that regulate the spread of the curve and its position along the leaf number axis.

Though the Gompertz function has been used primarily in animal and population studies (Richards, 1969), it has begun to be used more in growth relationships of higher plants. Baker et al. (1975) applied the Gompertz equation to maize leaf area development and evaluated the influence of environmental conditions on the parameters of the function. More recently, Ritchie and Johnson (1990) proposed the use of the Gompertz function to predict leaf area index (LAI) for a variety of plants. Here, the Gompertz function is used to describe the leaf area of individual leaves, from the first leaf to the largest leaf.

To define the constants b and k, the equation must first be linearized. Substituting leaf number (LN) for the parameter t (equation [E2]), we get:

$$\log_e(\log_e(A/A_o) = \log_e b - k(LN) \qquad \text{[E3]}$$

When $\log_e(\log_e(A/A_o))$ is plotted against leaf number (LN), the resulting linear regression gives a line with a slope k and a Y-intercept $\log_e b$ that gives the constant b when exponentiated.

To determine these values, leaf area data gathered in Michigan was used. The data consisted of five hybrids grown on the MSU farms (Muchena and Ritchie, 1989) and data from two hybrids grown in St. Joseph County, Michigan, in 1986 and 1987. The hybrids used from the Muchena and Ritchie study included A632 x W117 (A632), B73 x Mo17 (B73), 883 z 045 (Z883), 882 z 105 (Z883) and X304C (X304). The two hybrids from St. Joseph County will be referred to as MI86 and MI87. The first step was to transform the leaf area data into its linear form by first taking the inverse of the areas, multiplying them by the area of the largest leaf, and then taking the $\log_e$ twice. Once this was accomplished, leaves greater than or equal to the largest leaf were deleted from the data set. Any extremely small values (less then 0.1) were also removed. This normally deleted the leaf just before the largest leaf. This was done to assure that these extremely small numbers did not dominate the regression fit, which is often the tendency when either inverse or $\log_e$ transformations are involved. The result is the regression analyses found in Figure 6. Though an R^2 of 0.936 was achieved with the regression, Figure 6 does show some scattering of the data. The next step was to formulate the actual Gompertz function.

Since the Gompertz is an asymmetric function, using individual maximum leaf area would cause under estimation of the largest leaf area. For example, the hybrid 882 z 105 had 27 leaves. Using the Gompertz with an A_0 value of the largest leaf would cause the function to asymptotically approach A_0 at leaf 27. Therefore, a value larger than the area of the largest leaf must be used. Since the largest area of all of the hybrid leaves is 896 cm^2, from hybrid 882 z 105, a value of 1000 was used for the variable A_0. The value of b is the exponential of the Y-intercept and the value of k is the slope. The regression analysis yields a Gompertz equation as follows:

$$A = 1000e^{-6.75\, e^{-0.211\, LN}} \qquad [E4]$$

Using equation [E4], the predicted leaf area can be plotted against leaf number along with the measured values for all of the hybrids. This is shown in Figure 7.

As seen in Figure 7, the Gompertz does a good job of fitting the data. However, once again the smaller leaves at the beginning of the season are all over estimated, due to the high value of b: -6.75. Additionally, one can see that the function does not adequately fit all of the data sets up to the maximum leaf area. This is due to the value of A_0: 1000.

To get a better fit, the value of b must be decreased. However, this can only be done by increasing A_0. Using the method of trial and error, a new A_0 value was determined: 1200. Using 1200 instead of the maximum area of the largest leaf, equation [E3] was recalculated. The new

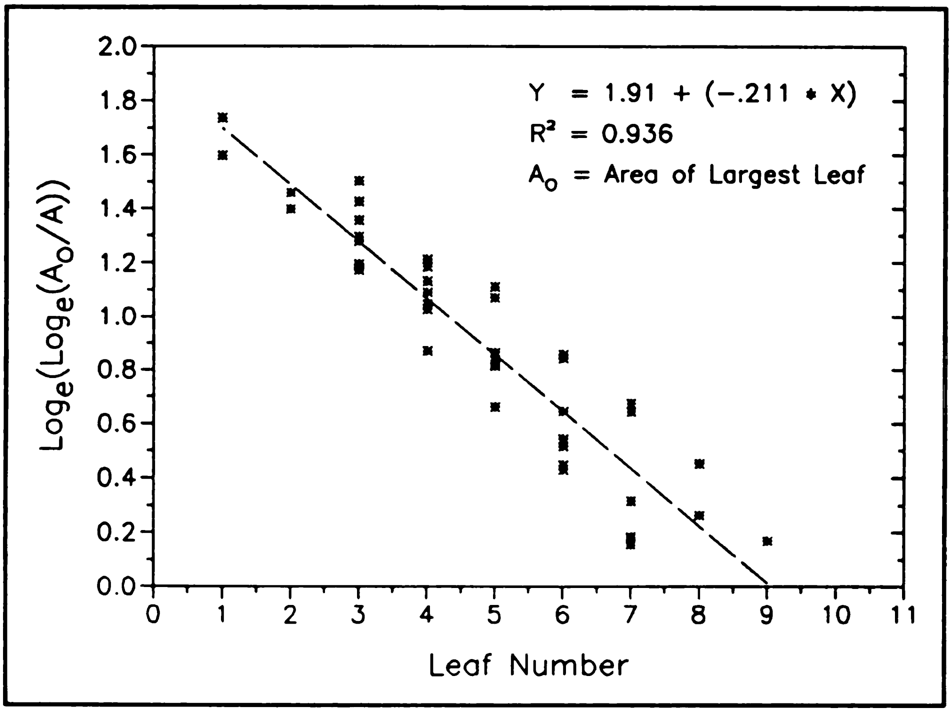

Figure 6. The regression analysis between the linearization of the Gompertz equation using the area of the largest leaf for A_0 and individual leaf number for the seven hybrids tested.

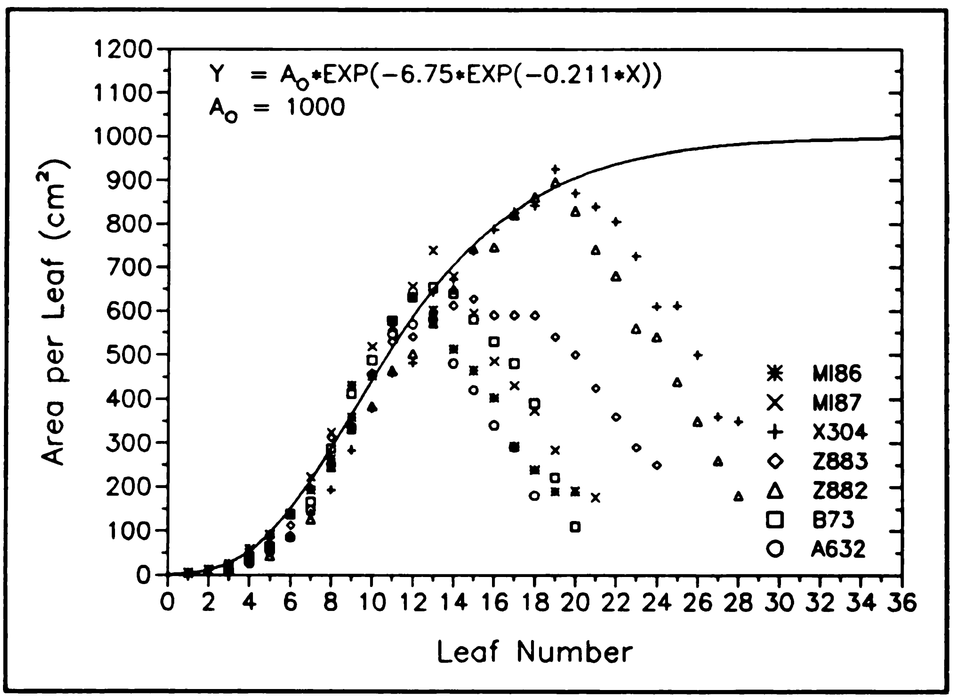

Figure 7. The area per leaf versus leaf number for the seven hybrid varieties tested. Also included is the Gompertz equation using a value of 1000 for A_0.

regression is shown in Figure 8. The resultant regression yields an R^2 value of 0.981 and the data are less scattered than that found in Figure 6 when A_o was equal to the area of the largest leaf. The value of the Y-intercept was increase to 2.01 while the slope remained fairly constant, decreasing only slightly.

Once again, taking the exponential of the Y-intercept, we get a new value for b: -8.08. The slope of the line, k, is -0.193. Using these values along with an A_o of 1200, we can rewrite equation [E4] as:

$$A = 1200e^{-8.08\, e^{-0.193\ LN}} \qquad \text{[E5]}$$

This new Gompertz function can then be plotted against leaf number along with the measured data for all of the hybrids as shown in Figure 9.

Figure 9 shows the new Gompertz more closely describes the leaf area for the smaller leaves. However, there is still some "noise" in the upper portion of the curve. This noise is most likely due to the larger leaf sizes. Large leaves appear on maize plants due to one of two conditions. The first is that the plant grows many leaves and therefore has more time to build up leaf area. The other is genetic. Some varieties simply grow larger leaves than others. Muchow and Carberry (1989), mentioned in their conclusions that there was clearly "A genotypic difference in the coefficients of the functions describing leaf growth" (referring to their coefficients Y_o, the area of the largest leaf and X_o, the leaf number of the largest leaf). To account for this genetic difference a new genetic parameter is required. To keep within the input format already present in CERES-Maize, a new genetic parameter was added, P6. P6 is a parameter that describes the leaf type of the variety. A value of 1.0 would indicate that the leaves are of average size. Values

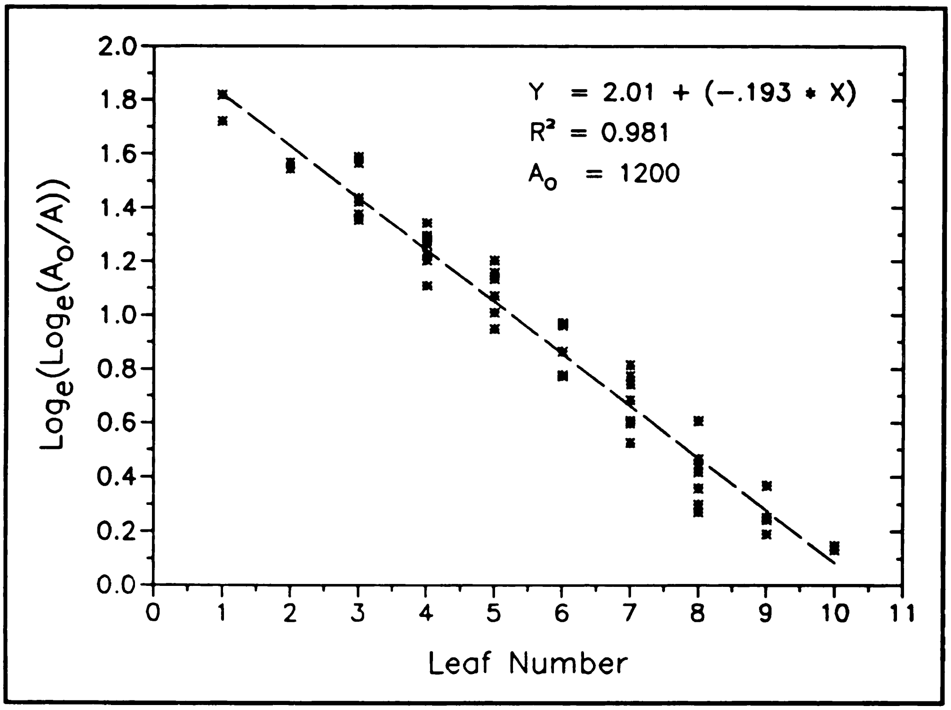

Figure 8. The regression analysis between the linearization of the Gompertz function using a value of 1200 for A_0 and individual leaf numbers for the seven hybrids tested.

of 1.2 or 0.8 would indicate either a large leaf type or a small leaf type. The parameter P6 was used as a multiplier and the new Gompertz reads:

$$A = 1200 P6 e^{-8.08 \, e^{-0.193 \, LN}} \qquad \text{[E6]}$$

Though the Gompertz function adequately describes the leaf area of the first leaf to the largest leaf, another equation is needed to describe the area of the remaining leaves. Figures 7 and 8 indicate that the remaining leaves show an almost linear decrease in size. Muchow and Carberry (1990), used a linear relationship to describe the area per leaf of the last four leaves of a grain sorghum plant. Therefore, in CERES-IM, a linear function was used to describe the area

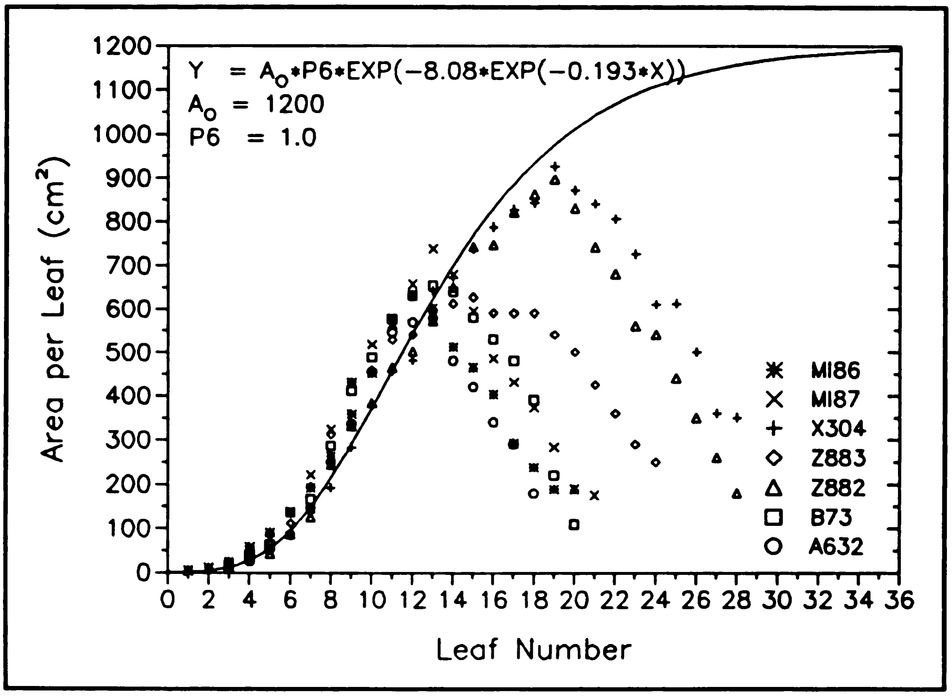

Figure 9. The area per leaf versus leaf number for the seven hybrid varieties analyzed. Also included is the Gompertz equation using a value of 1200 for A_0.

per leaf of all leaves after the largest leaf. Using the standard linear equation:

$$Y = aX + b \qquad \text{[E7]}$$

where Y is the area per leaf (cm^2), a is the slope of the line, b is the Y-intercept and X is the leaf number. Taking data from the largest leaf to the last leaf, linear equations were fitted for each individual hybrid. The regression analyses for the hybrids are graphically shown in three figures: Figure 10 contains data on the hybrids A632 and X304; Figure 11 contains data on hybrids B73 and Z883; and Figure 12 contains data on hybrids MI86, MI87, and Z882. The data were separate into the three figures based solely on appearance and ease of reading. Regression data for all 7 hybrids can also be found in Table 3.

As Table 3 shows, the slope of the linear equation is approximately similar for all of the hybrids, except 883 z 045. The reason for the difference is the hybrid's flattened curvature around

Table 3. Linear regression analysis for each individual hybrid for area per leaf for leaves from the largest leaf to the flag leaf.

Hybrid	Slope	R^2
A632 x W117	75.57	0.995
B73 x Mo17	77.71	0.962
882 z 105	79.56	0.998
883 z 105	43.50	0.963
X304C	67.51	0.984
MI87	74.20	0.995
MI86	62.21	0.989

the maximum leaf area. However, the other data shows fairly good agreement that would indicate a common slope. Therefore, using the slopes from the remaining six hybrids, a single slope for all hybrids was determined. This was done by averaging all of the slopes. The resulting linear equations is

$$Y = -72.80X + b \quad [E8]$$

where Y is the area of the leaf X (cm^2), b is the area of the largest leaf (obtained by the Gompertz equation), and -72.80 is the slope. This equation is used to predict the area of each leaf from the largest leaf plus 1 to the last leaf.

To obtain the parameter b, the area of the largest leaf is needed. To avoid additional inputs, the leaf number of the largest leaf is estimated and used in the Gompertz function to estimate the area of the largest leaf.

To obtain the leaf number of the largest leaf, a linear regression was performed on the data with total leaf number (TLNO) as the independent variable. Table 4 gives the TLNO and the leaf number of the largest leaf for each hybrid. As the Table 4 shows, the difference between the TLNO and the number of the largest leaf ranges from 5 (A632 x W117) to 10 (X304C). Because of its unusually low number, A632 was not used in the regression analysis. Again, using

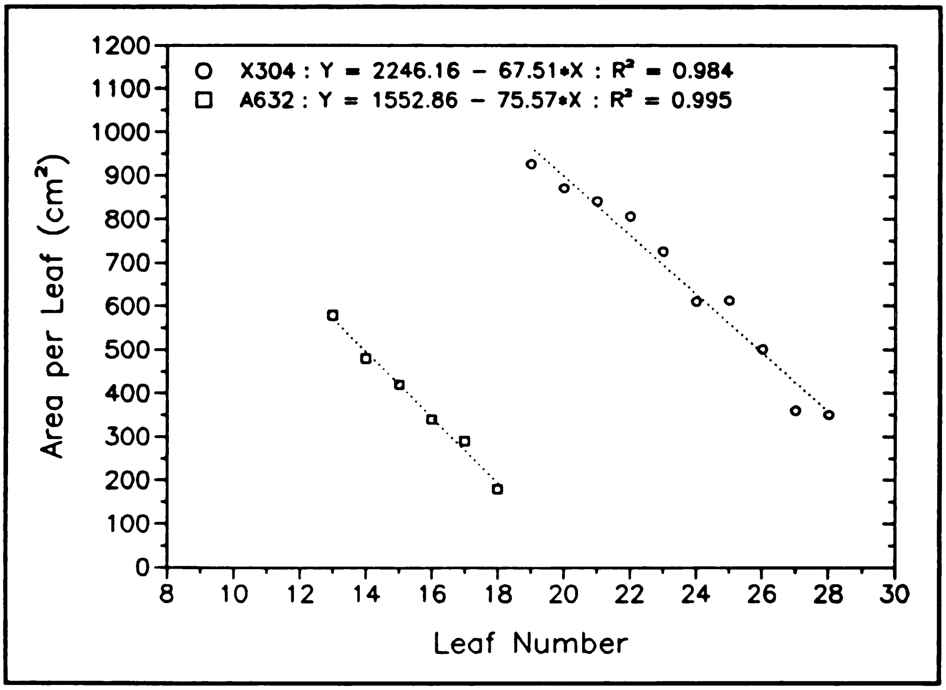

Figure 10. The regression lines for the area per leaf versus leaf number for leaves after the largest leaf for varieties A632 and X304.

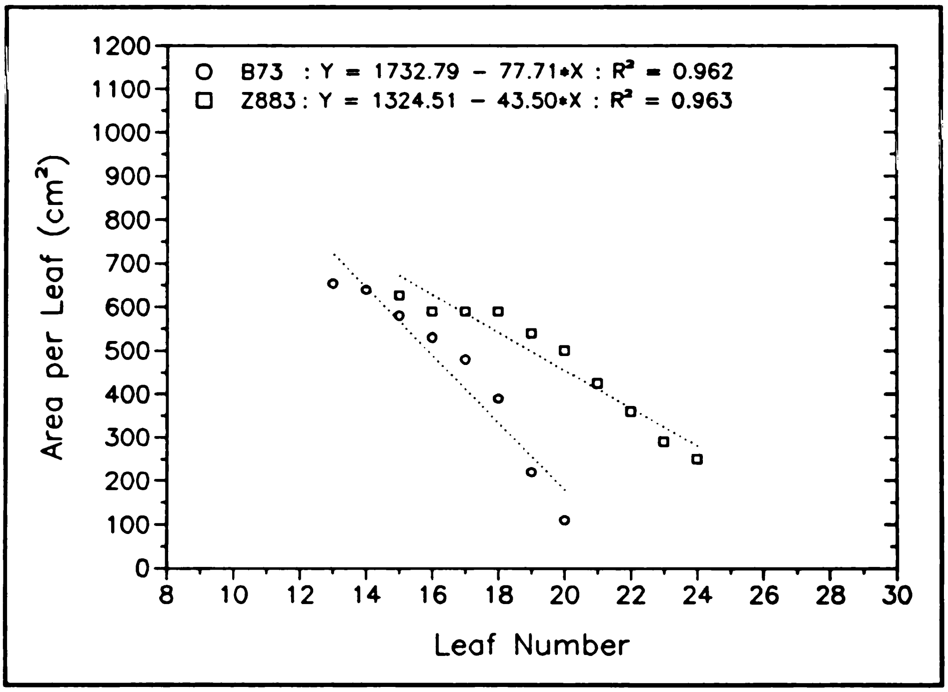

Figure 11. The regression lines for the area per leaf versus leaf number for leaves after the largest leaf for varieties B73 and Z883.

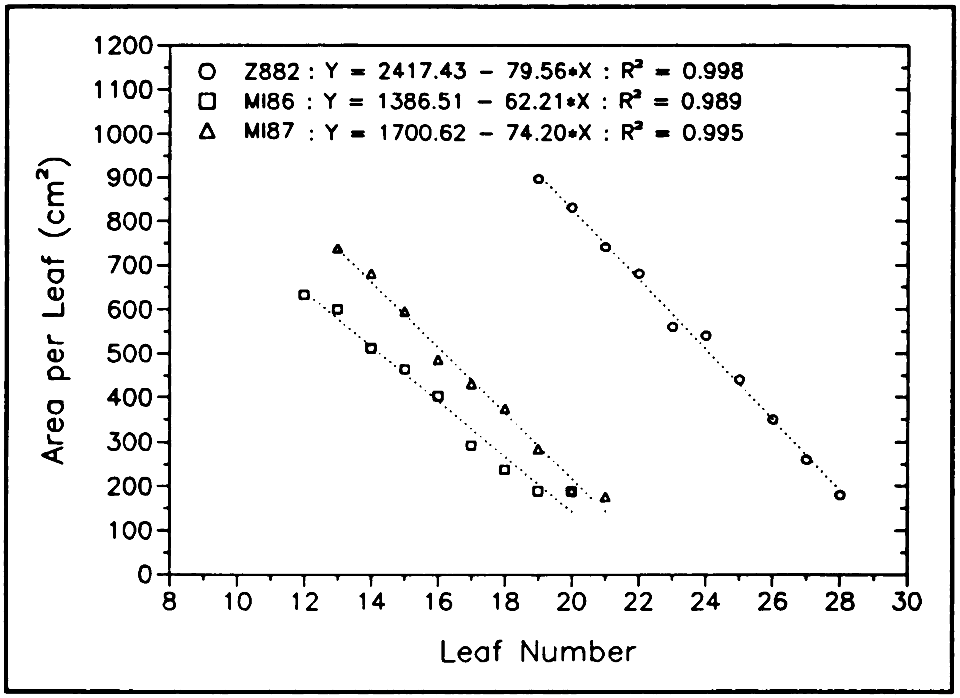

Figure 12. The regression lines for the area per leaf versus leaf number for leaves after the largest leaf for varieties MI86, MI87, and Z882.

the standard linear equation (equation [E6]), a regression analysis was performed (Figure 13). The resulting equation is:

$$Y = 0.796X - 3.53 \qquad \text{[E9]}$$

with Y equal to the leaf number of the largest leaf and X equal to the TLNO. From this equation, the leaf number of the largest leaf for each hybrid was determined. Table 5 gives a comparison between the actual leaf number of the largest leaf and the predicted one. As expected, the hybrid A632 x W117 shows the largest difference. This is due to its unusually high ratio of the leaf number of that largest leaf to the total leaf number.

Using the number of the largest leaf from equation [E8], in conjunction with the Gompertz Function (equation [E6]), the area of the largest leaf can be determined. Values of the new genetic parameter P6 were used in this calculation. Table 6 gives the actual and predicted

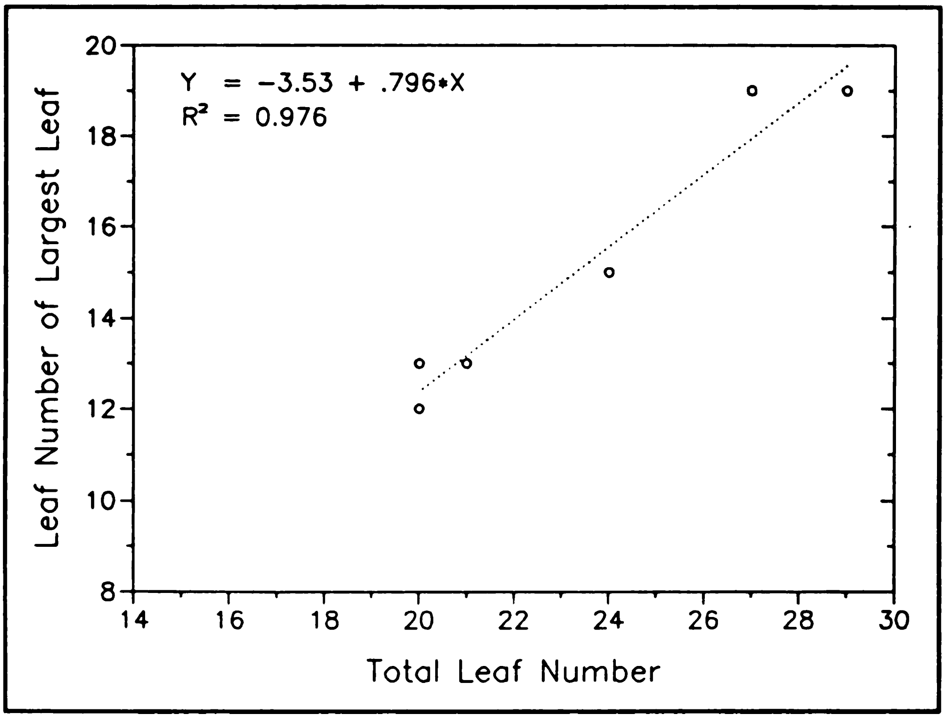

Figure 13. Regression line for the leaf number of the largest leaf and the total number of leaves for six of the hybrid varieties.

Table 4. Total number of leaves and the leaf number of the largest leaf for each hybrid.

Hybrid	Total Leaf Number	Number of Largest Leaf
A632 x W117	18	13
B73 x Mo17	20	13
883 z 045	24	15
882 z 105	27	19
X304C	29	19
MI87	21	13
MI86	20	12

Table 5. Measured and predicted values of the leaf number of the largest leaf for the hybrids.

Hybrid	Actual Number	Predicted Number	Difference
A632 x W117	13	10.8	- 2.2
B73 x Mo17	13	12.4	- 0.6
883 z 045	15	15.6	+ 0.6
882 z 105	19	18.7	- 0.3
X304C	19	18.7	- 0.3
MI87	13	13.2	+ 0.2
MI86	12	12.4	+ 0.4

Table 6. Measured and predicted leaf area (cm^2) of the largest leaf and the associated genetic parameter P6 for each hybrid.

Hybrid	P6	Actual Area (cm^2)	Predicted Area (cm^2)	Difference (cm^2)
A632 x W117	1.0	579	439.9	- 139.1
B73 x Mo17	1.1	654	631.0	- 23.0
883 z 045	1.1	627	921.9	+ 294.9
882 z 105	0.9	896	869.9	- 26.1
X304C	1.0	925	966.6	+ 41.6
MI87	1.2	737	764.2	+ 27.2
MI86	1.2	633	688.4	+ 55.9

area of the largest leaf for each hybrid. Most hybrids show good correlation except for A632 x W117 and hybrid 883 z 045.

Using the values of the area of the largest leaf obtained by the Gompertz function, the linear function can then be used to determine the area of the remaining leaves. Therefore, there now exists two equations which describe the area of a leaf, both based on leaf number. A regression was performed on all of the hybrids using both the Gompertz and the linear equation. The actual and simulated data for the area per leaf for all seven hybrids are shown in three figures: Figure 14 contains data on hybrids A632 and X304; Figure 15 contains data on hybrids

B73 and Z883; and Figure 16 contains data on hybrids MI86, MI87, and Z882. Also, Table 7 gives the R^2 values for each hybrid and for the Gompertz and linear portions of the curves. For the Gompertz equation, the R^2 values range from 0.984 for the 883 z 045 to 0.999 for hybrids 882 z 105, X304C and MI86. The low R^2 value for hybrid 883 z 045 is due mainly to the uncharacteristic "flat" top around the largest leaf. For the linear fit, R^2 values range from a low of 0.883 for hybrid A632 x W117 to a high a 0.999 for hybrid 883 z 045. The low R^2 value for hybrid A632 x W117 is clearly due to the large difference between actual and predicted largest leaf number. The measured value was leaf 13 while the predicted largest leaf number was 10.8. The

Table 7. Results of regression analysis performed between measured and predicted areas of leaves for both the Gompertz and linear functions.

Hybrid	Gompertz R^2	Linear R^2
A632 x W117	.998	.883
B73 x Mo17	.998	.992
883 z 045	.984	.997
882 z 105	.999	.999
X304C	.999	.998
MI87	.996	.998
MI86	.999	.998

others all show good agreement for both the Gompertz and the linear equations used, with R^2 values all above 0.99.

Two new subroutines were written for the new leaf area relationship. The first is LEAFAR (LEAF ARea). A listing of the subroutine is in Appendix one. LEAFAR is used twice in a single season run. It is used in the beginning of the simulation to fill an array with leaf number and plant leaf area, using the Gompertz and linear functions and summing the individual leaf areas. Since the program does not know what the final leaf number will actually be, a value of 22 leaves is used. Thus, before the season begins, the program first calculates the leaf number

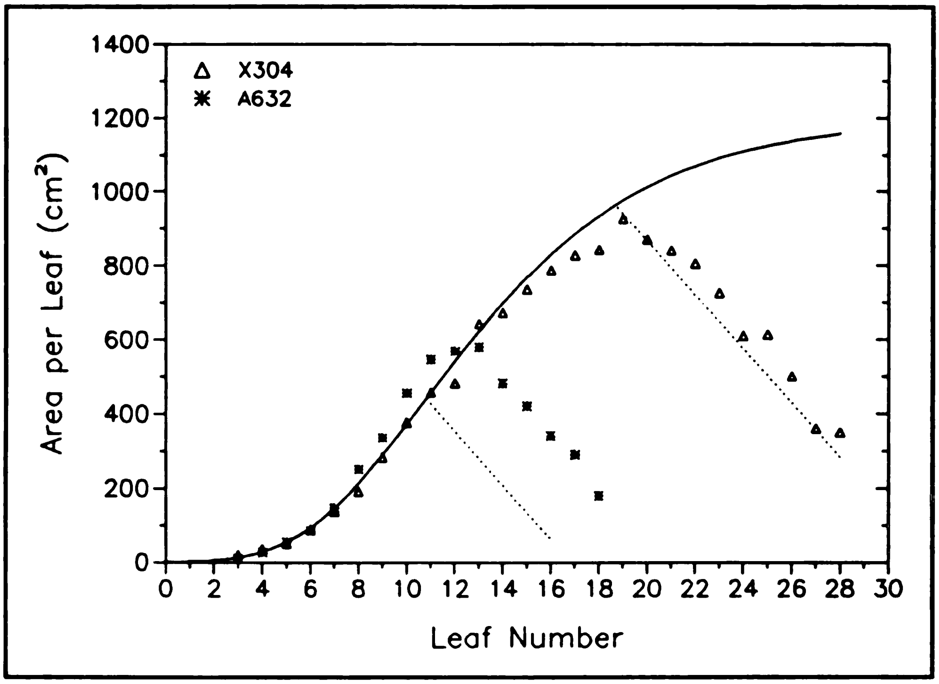

Figure 14. Measured values and predicted values using the Gompertz and linear equations of area per leaf for hybrids A632 and X304.

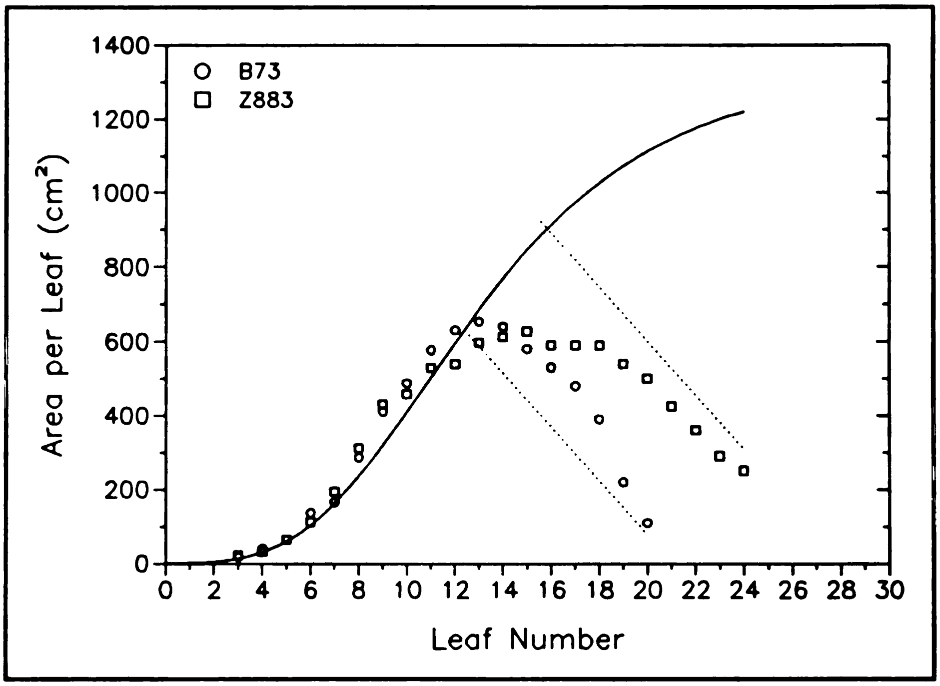

Figure 15. Measured values and predicted values using the Gompertz and linear equations of area per leaf for hybrids B73 and Z883.

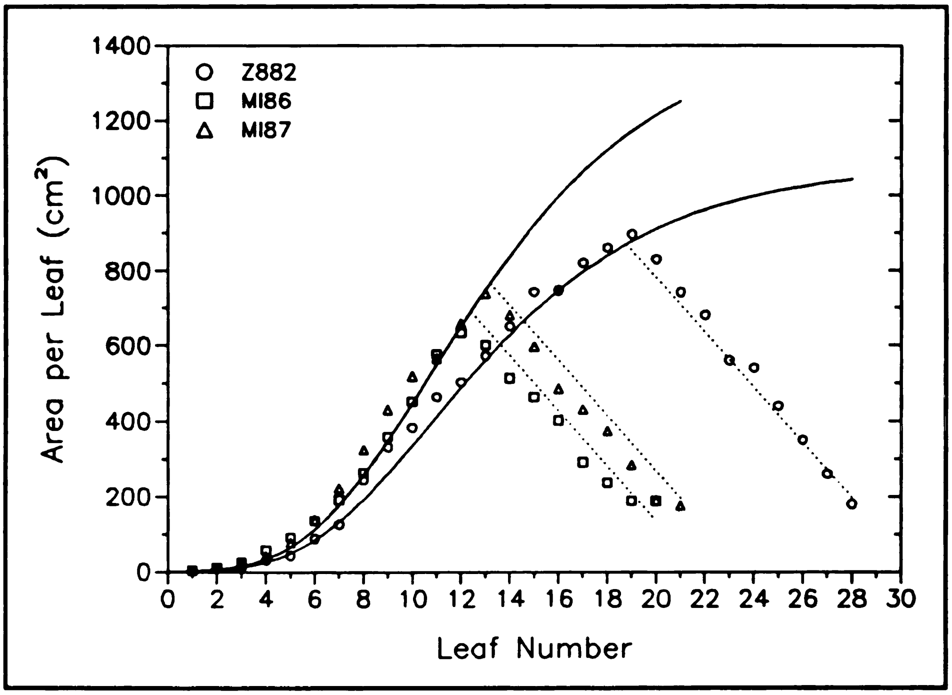

Figure 16. Measured values and predicted values using the Gompertz and linear equations of area per leaf for hybrids MI86, MI87, and Z882.

of the largest leaf, using equation [E9]. Then, using the Gompertz equation, equation [E6], the area of the first leaf to the largest leaf is calculated. Finally, using the linear equation, equation [E8], the remaining leaf areas are determined. All of the leaf areas are placed into an array and the values accumulated.

As the season progresses, CERES-Maize determines the total leaf number based on the genetic parameters entered and the accumulated TT. This occurs at tassel initiation. At this point, the leaf area array is recalculated as it was at the beginning of the season but with one exception. Instead of using the default value of 22 leaves for maximum leaf number, the program uses the calculated total leaf number. The result is a new array, with plant leaf area values based on the Gompertz function for leaves 1 through the largest leaf and the linear function for the remaining leaves. Though individual leaf areas have been determined, the next step is to calculate total plant leaf area.

When simulating leaf growth, CERES-Maize calculates leaf tip appearance. The variable XN represents the number of leaf tips and XN does not always come in whole numbers. While it is impossible to have 3.4 tips appearing, the variable XN is used only as a counter, based on degree days. When a sufficient amount of TT has occurred, the a new leaf appears. For example, if enough TT has accumulated for three leaves plus half the TT required for a fourth leaf, then XN would have the value of 3.5. To deal with these decimal numbers, an interpolation of the array is required.

A new subroutine was created to handle the interpolation of the leaf area array, LFINTER (LeaF INTERpolation). LFINTER uses a linear interpolation to approximate the potential plant leaf area growth. A listing of this subroutine is in Appendix one. Using the leaf tip number, XN, provided by CERES-Maize, LFINTER interpolates the plant leaf area growth by using the array set up in LEAFAR. The plant leaf area growth determined by the interpolation is actually a potential growth. This potential must be subjected to reduction due to nitrogen or water stress. In the present CERES-Maize program, this reduction is made by the following statement:

PLAG = PLAG * AMIN1(NDEF2,SWDF2)

where PLAG is the plant leaf area growth, AMIN1 is a FORTRAN function that returns a value equal to the minimum value of the variable list within the parentheses, in this case a nitrogen (NDEF2) and water (SWDF2) stress factor. These stress factors have values that range from 0.0 to 1.0, with 1 representing no stress and 0 representing maximum stress. This same procedure is used in the new leaf area model. Once the subroutine LFINTER has determined the potential leaf area growth, the actual leaf area growth is reduced if appropriate. Although the functions for relating individual leaf area show good correlation with measured leaf area, the area expansion rate must be determined with another function.

Muchow and Carberry (1989) used the number of fully expanded leaves in their equations as the independent variable when predicting total plant leaf area. Their function worked well when describing individual leaf areas, however it did not provide good agreement when predicting total plant leaf area. The reason for this was that their function did not account for expanding leaf area. Consider for example, when there are five fully expanded leaves, there will likely be an additional two or three leaves above leaf five that are expanding. They assumed that the leaf area at any given time in the development of leaves is equal to the area of the leaves fully expanded plus the area of the next two sequential leaves. This methodology was also applied to grain sorghum (Muchow and Carberry, 1990) with equally good results except that the fully expanded area of the next 1.6 leaves was assumed.

In the new CERES-IM, the independent variable is leaf tips, XN, not fully expanded leaves. When XN equals five, that does not represent five fully expanded leaves, and to use the leaf area data in the array that corresponds to five leaves would cause an overestimation of plant leaf area. In actuality, there are usually three to four leaves expanding at a time. For CERES-IM, it was determined that the expanding leaf area could be adequately approximated by assuming that the total leaf area was equal to the area of the fully expanded leaves for two leaves less than the leaf tip number.

Other Modifications

The ability to predict nitrogen stress and its effect on plant growth and yield is one area that is vital to this work. Though the present CERES-Maize model does contain a subroutine to determine nitrogen deficit factors, the approach used often gives erroneous nitrogen stress at relatively high nitrogen levels while the stress induced at low nitrogen levels is often not severe enough to adequately simulate field observations.

There are three nitrogen deficit factors used in the CERES-Maize model. All three of the factors are a function of NFAC, a variable that relates the actual plant nitrogen content with the minimum required for adequate growth. The variable NFAC is a 0 to 1 variable, with 1 indicating adequate nitrogen content and 0 representing maximum deficiency. The three nitrogen deficit factors follow the same logic, with a 0 to 1 range and with 1 being no nitrogen stress and a value of 0 indicating maximum nitrogen stress. The three are used to provide varying sensitivity values to different physiological process.

The first nitrogen factor is defined as NDEF1, which affects the photosynthesis of the plant and is used when calculating the plant's carbon assimilation. In its original form, this factor slowly decreases as the variable NFAC decreases in the form of:

```
IF(NFAC .GT. 0.5) THEN
        NDEF1 = NFAC * 0.4 + 0.6
ELSE
        NDEF1 = NFAC * 1.2 + 0.2
ENDIF
```

However, the decrease when NFAC is only slightly reduced has been found to be too severe and is also too slight when NFAC is greatly reduced. Following similar adjustments made in the CERES-Wheat model (Godwin et al., 1989) NDEF1 was redefined. The new code is:

```
IF(NFAC .LE. 0.45) THEN
        NDEF1 = NFAC * 2.0 + 0.1
ELSE
        NDEF1 = 1.0
ENDIF
```

This new formulation does not allow photosynthesis to be affected by nitrogen stress until NFAC is reduced to 0.45. At that point, the reduction is slightly more than the old code.

The second nitrogen deficit factor is NDEF2. This factor affects plant growth, namely leaf growth. In its original form, the relationship reads:

```
NDEF2 = NFAC * 0.95
```

In this relationship, the highest value NDEF2 can obtain is 0.95, indicating that a nitrogen stress was occurring regardless of the plant's nitrogen content. Whether this was an error in coding or a functional error, this relationship also required adjustment. Using the CERES-Wheat model as a basis, NDEF2 is defined as:

```
NDEF2 = NFAC * NFAC
```

This new formulation does not vary much from the old, but rather corrects the problem of always having a small nitrogen stress when there was adequate nitrogen.

The final nitrogen factor is NDEF3, which is used in the grain filling functions. In its present form, it reads:

```
IF(NFAC .LT. 0.8) THEN
      NDEF3 = 0.2 + NFAC
ELSE
      NDEF3 = 1.0
ENDIF
```

This relationship allows for the nitrogen deficit factor to remain at 1 until the plant nitrogen content becomes reduced significantly. Since this relationship follows logical deduction, it was not altered.

Another change that was made to the CERES-Maize model is the relationship between potential carbon assimilation (PCARB) and photosynthetically active radiation (PAR). The present formulation reads:

PCARB = 5.0 * PAR / PLANTS * (1. - AMAX1(Y1,Y2))

where PCARB is the potential carbon assimilation (per plant), PAR is the photosynthetically active radiation (MJ m^{-2} d^{-1}), PLANTS is the plant population (plants m^{-2}), and Y1 and Y2 are LAI factors related to row spacing that range from 0 to 1. AMAX1 is a FORTRAN function that returns a value equal to the maximum value of the variables listed within the parentheses. In the past, CERES-Maize has often over-estimated biomass accumulation, a result of the radiation use efficiency coefficient 5.0 used in this formulation (Ritchie, personal communication). Work done by Kiniry et al. (1989) showed that the mean value for this coefficient was closer to 3.5. However, their study only included above ground biomass accumulation and their coefficients ranged from a high of 4.5 to a low of 2.1, with the lower values representing extremely low plant populations. Therefore, taking into account that the Kiniry et al. study only observed above ground biomass and that the mean was 3.5, it was decided that the new coefficient should be more reasonably approximated by 4.5.

The final major change made to the CERES-Maize program was the method used for determining grain number. In its present form, the model determines grain number based on the average carbon assimilation rate from 50% silking to the beginning of grain filling. The formula reads:

PSKER = SUMP * 100 / IDURP * 3.4 / 5.0

GPPC = PSKER/7200

GPP = G2 * GPPC +50

where SUMP is the cumulative carbon assimilated during CERES-Maize phenological growth stage 4 (from silking to effective grain filling, g plant^{-1}), IDURP is the duration of stage 4 (d), PSKER is the average rate of carbon assimilation during stage 4 (g plant^{-1} d^{-1}), G2 is the potential number of grains per ear (entered as an input in File 9, the genetics file) and GPP is the predicted grains per plant. Additionally, the effect of nitrogen within the plant is taken into consideration and GPP is reduced if there is a nitrogen deficiency. The GPP formula presently used is based on work done by Edmeades and Daynard (1979). In their paper, the authors suggest a correlation between biomass accumulation rate just prior to anthesis and kernel number. This theory is well supported through the literature for a variety of cereal crops (maize - Hawkins and Cooper, 1981; Kiniry and Ritchie, 1985: wheat - Fischer and Maurer, 1976; Rawson and Bassa, 1979: millet - Ong and Squire, 1984: rice - Evans and DeDatta).

Problems have occurred with this relationship as the model has been used at many locations in the world. Using the rate of carbon assimilation rather than accumulated assimilation may cause some problems. Edmeades and Daynard (1979) found that carbon assimilation rate had a hyperbolic relationship with grain number. However, Hawkins and Cooper (1981) found the relationship to be linear in maize. To simplify this relationship, it was decided that the total carbon assimilated during stage 4 would be related to grain number. The new relationship reads:

GPP = ACCTOP ** G2

where ACCTOP is the accumulated above ground biomass during stage 4 and G2 is a new genetic parameter describing potential grain number per plant. This new G2 was determined by calibrating the hybrids and inbreeds used in the simulations.

Another change needed in the model for this work was the duration of the simulation. Normally, CERES-Maize simulates soil and plant dynamics from the first day of simulation (given in input File 8) until physiological maturity. However, with the use of male plants and the need to investigate drainage and leaching both before and after the growing season, an alteration was made. The model still begins simulation on the day entered in File 8, however the model continues to simulate soil water and soil nitrogen dynamics until the end of the weather data. In doing this, weather files can be arranged such that the simulation takes place from the beginning of one growing season until the beginning of the next growing season. This allows drainage and leaching dynamics to be simulated throughout the entire year.

Once the change was made to the model to allow for year round simulation, changes needed to be made to allow for snowfall. When snowfall occurs, the amount of precipitation, in rainfall equivalent, is entered in the weather file. In its present form, CERES-Maize reads the rainfall data and begins to simulate the distribution of the rainfall through the soil profile. However, since the rain is in reality snow, it is not available for distribution to the soil profile until it melts. Though CERES-Maize had no routines available to handle snowfall, CERES-Wheat did. The subroutine SNOW was added to CERES-IM and allows for the accumulation of snow and, if temperatures warrant, the melting of snow. Determination of both snowfall and snow melt are based on maximum temperature. A listing of the subroutine is in Appendix one.

Other changes to the model were made as deemed necessary, though no basic functional changes were made except for those mentioned above. Error traps were placed where appropriate and input/output changes were made where required.

OBJECTIVE 2. Perform field experiments to validate the simulation model.

<u>Inbred Calibration/Validation</u>

In 1988, researchers at Michigan State University, in cooperation with Pioneer Hi-Bred International, Inc., began a study to investigate alternative nitrogen management strategies for seed corn production. Conducted in Constantine, Michigan, the study was designed to aid local seed corn growers in managing their nitrogen applications. The effect of various nitrogen management strategies on nitrate leaching and the growth and yield of inbred maize were subjects of study. Four nitrogen treatments were used with three inbred varieties. Drainage lysimeters were installed to determine the impact of nitrogen applications on the leaching of nitrates from below the rootzone.

Lysimeter Installation and Drainage Sampling Systems

During fall of 1988, five drainage lysimeters were installed: four were "disturbed" while the fifth was an undisturbed monolith. The dimensions of the lysimeters were 0.91 m by 3.81 m by 1.83 m deep (see Figures 17, 18, and 19), and they were placed approximately 45.7 cm below the soil surface to allow normal field operations to take place. The disturbed lysimeters were installed using the same method described earlier in the hybrid drainage study. The one undisturbed lysimeter was installed by first cutting a soil monolith out of a barrow site in the field, placing the lysimeter walls around it, sliding a plate of steel under it, and then lifting the containerized soil with a crane. The lysimeter, with the monolith inside, was then turned over and the bottom of the lysimeter was welded on. Finally, the soil was excavated where the lysimeter would finally rest and the entire lysimeter, with the monolith still intact, was again inverted and placed in the ground.

A sampling system was installed in June 1989. Modified tipping buckets from rain gauge sensors were chosen to measure the flow from the lysimeters because they could easily be interfaced with a datalogger. Tipping bucket assemblies (Sierra Misco) were attached to an aluminum mounting plate. The mounting plate was bolted to the top of a 38 liter polyethylene reservoir. The lysimeter soil drainage water passed through a 1.27 cm diameter pipe in the lysimeter wall, located at the lowest point. The drainage water was then funneled to the tipping bucket assembly. The water dumped by the tipping buckets was then funneled to the reservoir. A PVC pipe was fed through the aluminum mounting plate to the bottom of the reservoir and connected to the suction side of a 12-volt diaphragm pump (Flojet) using a flexible hose. The

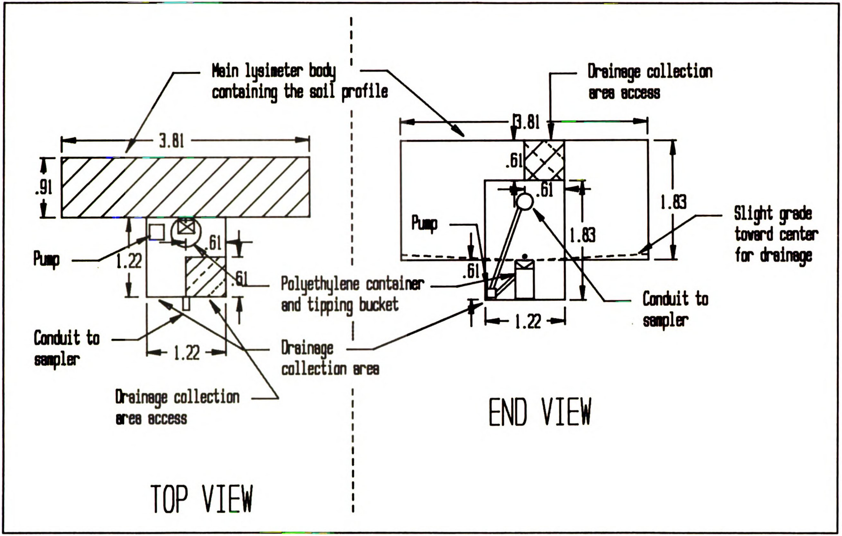

Figure 17. A schematic drawing of the top view and end view of one of the lysimeters used in the nitrogen management study in seed corn production. All measurements are in meters. Constantine, MI.

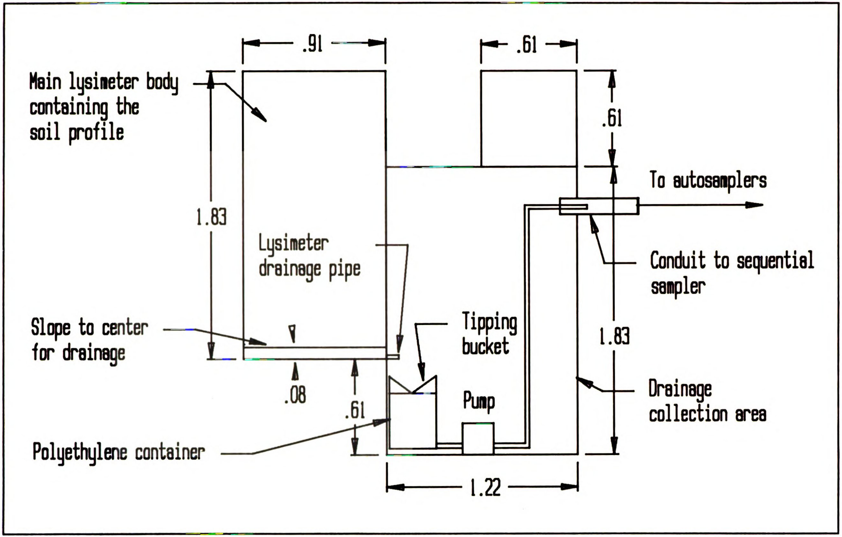

Figure 18. A schematic drawing of the side view of one of the lysimeters used in the nitrogen management study in seed corn production. All measurements are in meters. Constantine, MI.

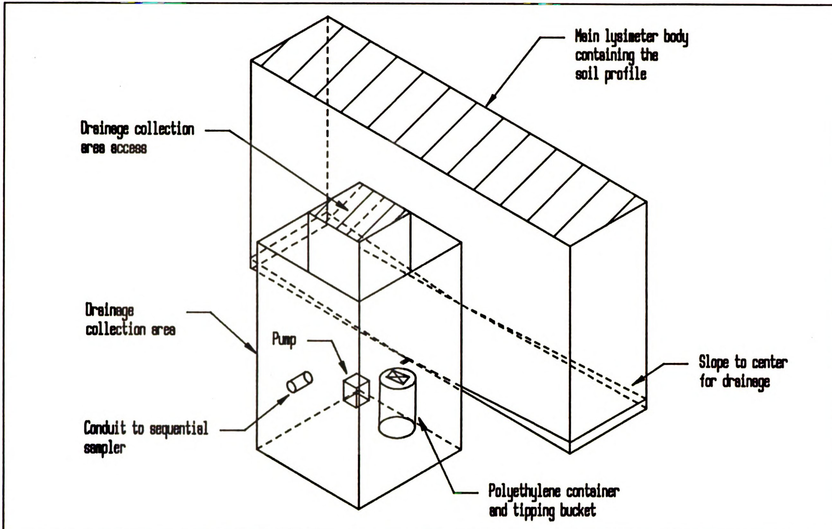

Figure 19. A schematic drawing of one of the lysimeters used in the nitrogen management study in seed corn production. All measurements are in meters. Constantine, MI.

pressure side of the pump was connected to a 1.27 cm diameter PVC pipe leading to a sequential sampler located outside the plot, approximately 12 m from the lysimeter. The PVC pipe and cabling between the collection area and the sampler box ran through a 7.62 cm diameter conduit buried underground at the time of the lysimeter installation.

The sequential sampler was contained in a waterproof wood box (see Figures 20 and 21). The wood box was beneath the soil surface so the box lid was just above the soil surface. A solenoid valve (Spraying Systems) was used to divert a portion of the accumulated drainage water contained in the lysimeter reservoir during the pumping stage to obtain a sample for chemical analysis. The solenoid valve was placed above the sequential sampler and the diverted water funneled through a small PVC pipe (1.27 cm diam.) connected to a rotating pipe. The diverted water flowed through the pipe by gravity into a 500 ml wide mouth polyethylene sample bottle. The pipe was rotated by a 12-volt gearmotor (Grainger) when the sampling cycle was completed. The major components of the sequential sampler included a 12-volt gearmotor, a roller micro-switch, and a 14-tooth sprocket. The 14-tooth sprocket allowed the sequential sampler to collect 14 samples before the sample bottles required emptying. The sprocket was directly connected to the gearmotor shaft. The micro-switch and sprocket combination stopped the gearmotor so the rotating pipe was exactly over the next empty sample bottle.

The electronic control system consisted of a Campbell Scientific CR10 micro-datalogger interfaced with a Campbell Scientific SDM-SW8A Switch Closure Module and SDM-CD16 Control Port Expansion Module, placed in a separate waterproof box outside of the plot area and next to a weather station. The SDM-SW8A increased the number of pulse channels available on the CR10 for measuring multiple tipping bucket sampler pulses. The SDM-CD16 allowed the datalogger control of remotely powered electrical devices through the use of 12-volt relays controlling the current going to the 12-volt components (the pumps, the valves, and the gearmotors). Power was supplied to the components via a 12-volt battery placed in the datalogger box and in each sequential sampler box. The batteries were connected in parallel and were

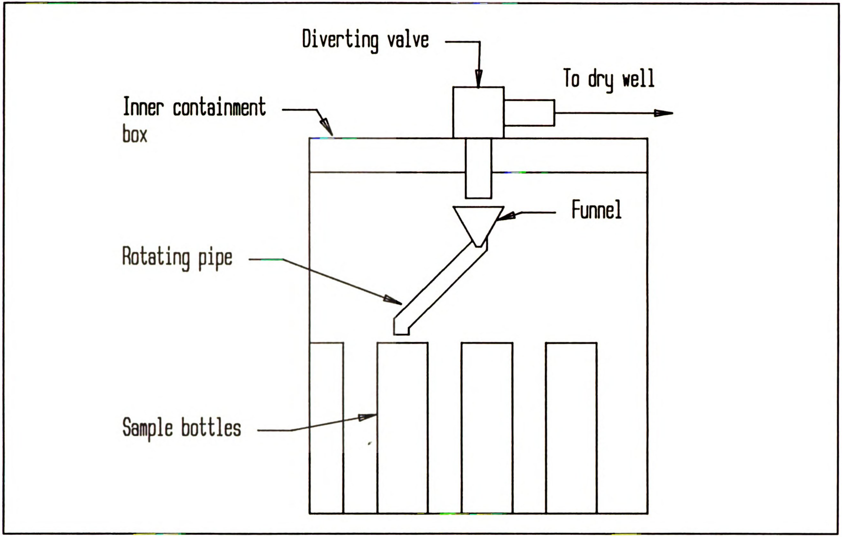

Figure 20. A side view of the sequential sampler used to sample the drainage water from the lysimeters used in the nitrogen management study for seed corn production. Constantine, MI.

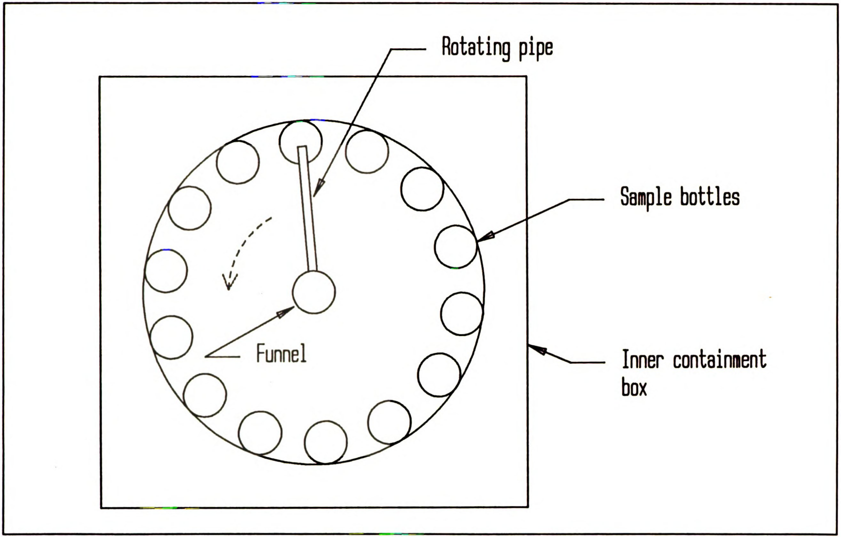

Figure 21. A top view of the sequential sampler used to sample the drainage water from the lysimeters used in the nitrogen management study for seed corn production. Constantine, MI.

charged by a battery charger connected when the voltage became low. The use of the 12-volt system ensured continuous sampler and datalogger operation in case of AC failure.

The objectives for the water sampling system were to record the hourly flow of water draining from the lysimeters and to sample a portion of that water after some predetermined volume has been obtained. The sampling cycle began when a certain volume had accumulated in the lysimeter reservoir as determined by the number of tipping bucket pulses. The volume to take a sample can easily be changed by a simple entry in the datalogger program. Once a predetermined number of tips have occurred, the datalogger program entered into a programming loop. Once in this loop, the program directed the SDM-CD16 to ground the pump relay control circuit that operated the pump and began pumping out the sample. The sample was then pumped through the PVC pipe buried under the plot, through the diverting valve and into a dry well next to the sequential sampler box. After 1 minute (used to expel any water left in the line from the previous sample) the SDM-CD16 grounded the relay controlling the diverting valve. The valve was opened for eight seconds to allow a sample to be taken. The pump continued to run for an additional six minutes to pump any remaining sample into the dry well. Once the pump turned off, the relay controlling the gearmotor was grounded for four seconds. That began to rotate the diverting pipe. The gearmotor relay remained closed until a shaft connected to the diverting pipe rotated a sufficient amount to allow the roller micro-switch to be closed by a sprocket tooth. The gearmotor operation was then controlled by the micro-switch. When the roller was in the valley of the sprocket, the micro-switch was opened, stopping the gearmotor and leaving the diverting pipe aligned with the next sample bottle. This cycle was repeated for each lysimeter, but only one sampling cycle could occur at any one time. After the sampling cycle, the time the sample was taken, the sample number, and the total volume the sample represented was written to the final output storage in the datalogger.

Experimental Design and Plot Layout

The plots were planted parallel to the .91 m dimension of the lysimeters so that an entire block (four female rows with 1 male row, 76.2 cm spacing) could be planted within the lysimeter area. The male rows were planted in the center of the lysimeter area with two rows of females on either side. The entire plot dimensions were 5.24 m by 7.62 m, with eight rows of females and two rows of males. Figure 22 shows a detailed plot plan. All normal seed corn production field operations were performed on the plants, i.e., detasseling and male removal.

Three inbreeds were used in this experiment, with four nitrogen treatments. The inbreeds used were an early maturity (inbred 1), a mid-season maturity (inbred 2), and a late season maturity (inbred 3) variety. Each treatment was replicated four times. The lysimeters were all planted with inbred 2.

Plant Growth, Development and Yield Measurements

The plant growth measurements included total above ground plant biomass and were taken four times throughout the season. Each sample was analyzed for total nitrogen, including the grain and cob. Developmental factors such as shedding dates for the males and silking dates for the females were also noted. Harvest data included ear counts, stalk counts, barren plants, plants with double ears, ear length and grain yield.

Soil - Nitrogen Data

Soil samples were taken to evaluate the soil's nitrate and ammonium contents. Samples were taken at the beginning of each season to establish initial conditions. Also, samples were taken just prior to detasseling and then again towards the end of the season. Sampling depths were determined by examining the nitrogen analysis of the previous sample, and were changed accordingly. Soil samples were also taken before the lysimeters were installed and analyzed for percent organic matter, sand, silt, and clay.

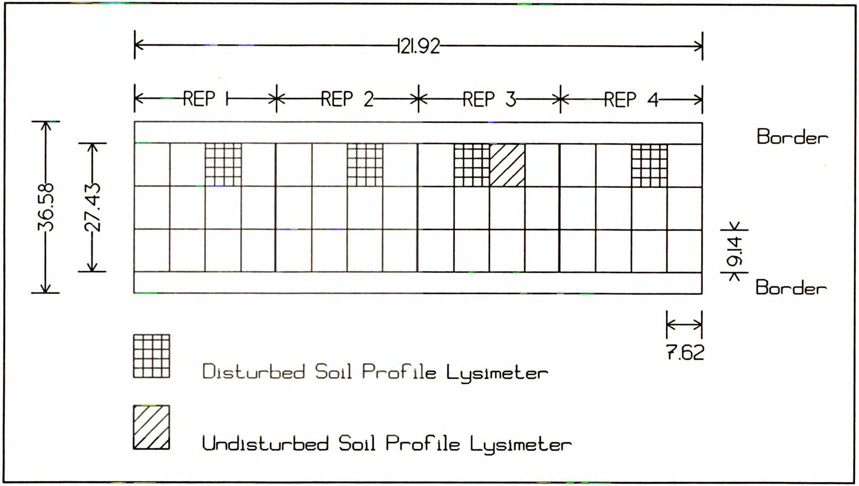

Figure 22. A diagram of the plot layout used in the nitrogen management in seed corn production study. Constantine, MI.

Irrigation and Nitrogen Application

The irrigation water applications for this study were scheduled using the "Micro-Scheduler" computer program as described by Shayya et al. (1990). The program uses crop curves developed for specific areas in Michigan. Though no crop curve exists for inbred maize, the curve for hybrid maize has been used for irrigation scheduling on inbred fields with good results. This curve was used for scheduling the irrigation of this study.

Nitrogen applications were separated into four treatments. These treatments are listed in Table 8. Treatment 1, 180 kg N ha^{-1} preplant, was considered to be a typical treatment used by many growers in the area.

Treatment 2, the research management strategy (RMP), used a new concept of Plant Response Fertilization (PRF). The basic premise of PRF is to allow the plants to indicate the need for nitrogen by showing signs of nitrogen deficiency. In 1989, the first year of the study, 30 kg N ha^{-1} was applied preplant to assure adequate early plant growth. Then, an observed color difference was used as a factor to determine if any additional nitrogen was required. In the second season, 1990, the 30 kg N ha^{-1} preplant was not applied and more scientific approaches were used to detect a nitrogen deficiency. One method employed the use of a multispectral radiometer (MSR). The MSR allows for near simultaneous inputs of signals representing incident as well as reflected irradiation. This enabled measurements to be taken from the crop canopies when sun angles or sunlight conditions were less than ideal. Positioning the radiometer over the crop canopies, measurements were taken at three wavelengths, 450 nm, 650 nm and 800 nm. The 450 nm is the red region and the 650 nm is the blue region. These two regions comprise the reflectance of the green color within the plant. The 800 nm represents the infrared and gives an indication of plant biomass. Readings obtained from the MSR were in percent reflectance. The more reflectance that occurred, the greener the plant leaves (in the case of the 450 and 650 nm wavelengths) or the more plant biomass there was (in the case of the 800 nm wavelength). The radiometer was positioned approximately 1 meter above the crop canopy centered on the row.

Table 8. Nitrogen treatments for 1989 and 1990, inbred nitrogen management study, Constantine, Michigan.

Treatment	Nitrogen Treatment* (kg ha^{-1}) 1989	Nitrogen Treatment* (kg ha^{-1}) 1990
1	180 - preplant	180 - preplant
2	30 - preplant 50 - PRF	40 - PRF (1)$ 0 - PRF (2&3)$
3	30 - preplant 60 - sidedress	30 - preplant 60 - sidedress
4	30 - preplant 150 - sidedress	0 treatment

* Preplant applications were applied at planting and sidedress applications were applied between the 6-8 collared leaf stage.

$ PRF treatment for inbred 1 was 40 kg N ha^{-1} and the PRF treatment for inbreeds 2 and 3 was 0 nitrogen added.

Readings were taken on one replication of PRF plots and on one replication of the 180 kg N ha^{-1} preplant plots (considered to be nitrogen non-limiting) for each inbred. Eight readings were taken for each inbred and treatment, giving a total of 48 readings taken at a time. Plant height measurements were also taken to detect any reduction in plant growth due to a nitrogen deficiency.

Treatment 3 was a split application of 90 kg N ha^{-1} with 30 kg N ha^{-1} applied preplant and an additional 60 kg N ha^{-1} applied sidedress. Treatment 4 was a split of 180 kg N ha^{-1}, with 30 kg N ha^{-1} applied at planting and an additional 150 kg N ha^{-1} applied sidedress. However, due to the small differences measured in yield between all of the treatments in 1989, it was decided that this treatment would be changed for 1990. The new treatment 4 was a 0 kg N ha^{-1} to provide a baseline from which to analyze the nitrogen effect of the other three treatments. All preplant applications were made at planting and sidedress applications were applied between the 6-8 leaf collared stage.

OBJECTIVE 3. Use the simulation model to evaluate the impact of several nitrogen managements strategies on potential leaching in seed corn production.

With the completion of CERES-IM, attention then was focused on evaluating the impact of nitrogen management strategies on the leaching of nitrates and crop yield. To achieve this goal, an automatic fertilization subroutine was written into the CERES-IM programming. However, before discussing nitrogen scheduling, a brief overview of how CERES-IM simulates soil nitrogen dynamics is required.

CERES-IM Nitrogen Simulations

The simulation of nitrogen dynamics performed by the CERES-IM model is the same as simulated in the CERES-Maize model, with the exception of the change mentioned earlier in this section (i.e. adjustment of the nitrogen deficit factors) and the new auto-fertilization routine. Godwin and Jones (1991) give a detailed description of the nitrogen simulations used in the CERES-N model, the same routines used in the CERES-Maize and CERES-Wheat models. The following is a brief description of the nitrogen simulations found in CERES-IM.

CERES-IM simulates soil nitrogen dynamics on a daily basis if the nitrogen switch is turned on. If the nitrogen switch is turned off, nitrogen is assumed non-limiting. The switch is an input in the treatment management file, File 8. All nitrogen transformations are simulated within the subroutine NTRANS. Within NTRANS, the subroutine is divided into four parts: 1) fertilizer incorporation (if nitrogen was added to the soil on that day); 2) mineralization; 3) nitrification; 4) denitrification. A flow chart of the soil nitrogen dynamics is shown in Figure 23.

If the nitrogen switch is turned on, the model simulates soil nitrogen dynamics for the entire length of the weather data provided. Before the crop is planted, only the soil dynamics are simulated but once the crop begins to grow, plant and soil nitrogen dynamics are simulated. When the crop reaches physiological maturity, only soil dynamics are simulated. To better

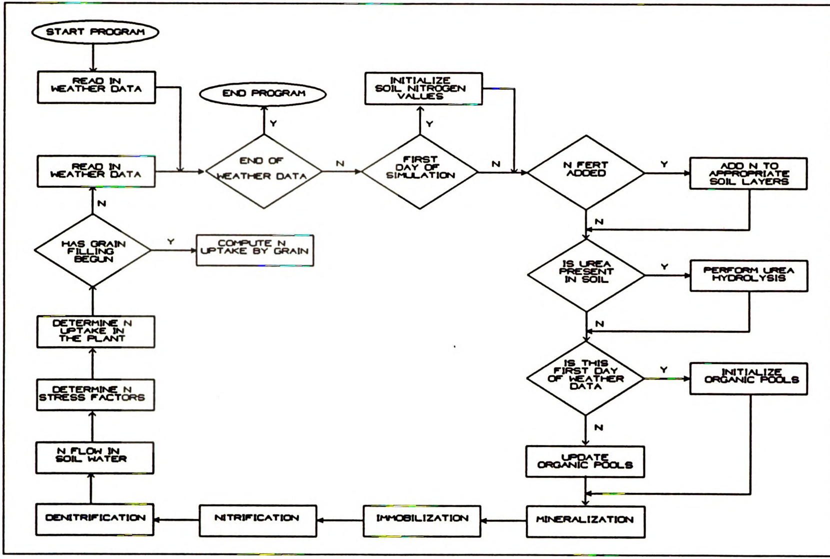

Figure 23. A flow diagram of the sequence of nitrogen simulations in the CERES-Maize model, V2.1.

understand how nitrogen dynamics are simulated, a short step-by-step procedural explanation follows.

The first step in simulating the nitrogen dynamics is to read in the soil nitrogen input data. This includes data from File 4, soil nitrogen balance parameters. These include any above ground organic residue left from the previous crop and the depth of incorporation of that residue, the carbon:nitrogen (C:N) ratio of the residue, and the dry weight of any root residue from the previous crop. Initial soil nitrogen data are read from File 5, soil profile initial conditions. From this file the program reads the initial amount of water, nitrate (NO_3^-), ammonium (NH_4^+), and the pH of each soil layer. Finally, the program reads in the fertilizer data stored in File 7. This data includes that day of application, the amount of nitrogen applied, the depth of incorporation, and the type of fertilizer used. Once the data have been read, the model initializes the soil nitrogen parameters.

Not all of the required soil nitrogen parameters are entered as inputs, so CERES-IM performs a few initial calculations to obtain values for the various nitrogen pools and sinks within the soil. For example, values of the amount of fresh organic matter and the associated nitrogen content must be determined. Once all of the initial conditions have been calculated, the model can begin its simulation.

The first step in the simulation is to check whether fertilizer was added on the day of simulation. If no fertilizer was added, normal soil nitrogen dynamics are simulated. However, if nitrogen was added, it must be incorporated into the soil according to the inputs given.

In adding nitrogen from a fertilizer application to the soil, CERES-IM first determines to which soil layer that the nitrogen is to be added to and the amount and type of nitrogen added. CERES-IM allows for the use of 12 types of fertilizer. A list of these can be found in Table 9. Within this list, four forms of nitrogen are defined; ammonium, ammonia, nitrate, or urea. Depending on the composition of the fertilizer, varying amounts of each form is added to the soil. For fertilizer types 2, 6, 7, and 11, the model simply adds the correct amount of ammonium to the

Table 9. List of fertilizer types and their codes used in the CERES-Maize simulation model.

CERES-Maize Input Code	Fertilizer Type
1	Ammonium Nitrate
2	Ammonium Sulphate
3	Ammonium Nitrate-Sulphate
4	Anhydrous Ammonia
5	Urea
6	Diammonium Phosphate
7	Monoammonium Phosphate
8	Calcium Nitrate
9	Aqua Ammonia
10	Urea Ammonium Nitrate
11	Calcium Ammonium Nitrate
17	Potassium Nitrate

appropriate soil layer. For types 4 and 9, which are ammonia based, the conversion to ammonium is assumed to be instantaneous. All of the nitrogen is assumed to be in the ionic form, and is added to the appropriate soil layer as ammonium. For fertilizer types 1 and 3, both ammonium and nitrate are added to the appropriate soil layer. The composition of the fertilizer nitrogen is assumed to be 50% ammonium and 50% nitrate. For fertilizer type 10, ammonium, nitrate and urea is added. The composition of this fertilizer nitrogen is assumed to be 25% ammonium, 25% nitrate, and 50% urea. Finally, for fertilizer type 5, only urea is added.

The next step is to perform soil nitrogen dynamics. First, if any urea was added, the model begins to simulate urea hydrolysis. Hydrolysis of urea is a chemical reaction by which the urea is converted to ammonia, NH_3 and then to ammonium, NH_4^+.

Then the model simulates mineralization. Mineralization is the process by which organic nitrogen is converted to mineral nitrogen. Also, the immobilization of nitrogen, a process by which mineral nitrogen is converted to organic nitrogen, is simulated. This makes the nitrogen unavailable for plant uptake, thus the term immobilization.

The next step is to simulate the conversion of ammonium to nitrate. Referred to as nitrification, this process involves two steps. First, ammonium is converted to nitrite, NO_2^-, and then the nitrite is converted to nitrate. CERES-IM assumes a constant rate for the reaction. The actual amount of ammonium that is converted into nitrate is based on this rate along with soil temperature and soil water content. Finally, denitrification is simulated. This process is a chemical reduction of nitrate to dinitrogen, N_2, or nitrogen gas. The gas then escapes through the soil and is lost to the atmosphere.

Once all of the soil dynamics have been simulated, the model simulates nitrogen movement due to water movement. The model simulates the redistribution of soil nitrogen attributed to the redistribution of soil water. Soil water concentrations are calculated and the appropriate amounts of nitrogen are distributed among the soil layers. Any soil water that drains from the last layer is considered to be drainage and the amount of both water and nitrogen loss is recorded.

After the soil nitrogen has been simulated, nitrogen uptake by the plants must be simulated. In CERES-IM, this is a three step process. First, nitrogen deficit factors must be determined to simulate any effect of nitrogen stress on plant growth for the day of simulation. Then, plant biomass accumulation is simulated. Finally, based on the new plant biomass, soil nitrogen is removed from the soil and translocated in the plant. This process is repeated for every day of the growth cycle.

The nitrogen cycle is a series of chemical reactions and interactions within the soil environment. Many factors, including soil water content, pH, C:N ratios, temperature, and organic carbon content play a role in how fast certain reactions take place and how much and what form the soil nitrogen is in. Additionally, the translocation of nitrogen from the soil to the plants, and within the plants themselves, create problems in modelling. CERES-IM uses empirical formulas to simulate these nitrogen interactions.

Evaluation of Nitrogen Management Strategies

Most present day nitrogen management strategies rely on yield goals to determine the amount of nitrogen fertilizer to be applied. Some work has been done in testing soils for nitrogen content and relating the results to the expected amount of nitrogen required for good crop growth. Blackmer, et al. (1989), showed fair correlation between late spring soil tests and corn yields in Iowa. However, these tests cannot fully account for the soil's ability to mineralize organic nitrogen. This mineralized pool of nitrogen is what must be utilized to its fullest to limit nitrate leaching. One alternative to traditional methods of estimating plant nitrogen requirements is the method mentioned earlier, Plant Response Fertilization. By watching the plants for signs to determine when a nitrogen deficiency exists, nitrogen can be applied only when needed, thus taking full advantage of the mineral nitrogen pool within the soil. To test the feasibility of such a strategy, new code was written for CERES-IM that evaluates the plant's nitrogen content in relationship to the minimum required for adequate growth. Once the plant's nitrogen content falls below this critical level, nitrogen must be added to the soil.

The auto-fertilizer routine uses the nitrogen deficit factor NFAC. As mentioned earlier, NFAC is a 0 to 1 variable that relates the actual nitrogen concentration of the plant to the minimum required for adequate growth. A value of 1.0 for NFAC indicates no nitrogen stress and a value of 0.2 is maximum nitrogen stress. The threshold value of NFAC chosen to trigger a nitrogen fertilizer application is 0.90. This value was chosen because preliminary simulations showed no significant increase in grain yield when nitrogen fertilizer was applied prior to this value. Once NFAC is less than or equal to 0.90, the model simulates the addition of nitrogen fertilizer to the soil.

Using CERES-IM in conjunction with simulated weather, nitrogen strategies in seed corn production were evaluated for their impact on yield, leaching, and revenue. The simulated weather used was compiled using real weather data and a weather estimation program called WGEN (Richardson, 1984). Sixty years of weather data were simulated for this exercise. The weather data generated included the 4 inputs required by CERES-IM, i.e., daily solar radiation, maximum temperature, minimum temperature, and precipitation. This site chosen for the simulation was the center of St. Joseph county, Michigan.

The soil inputs used were taken from the hybrid study used for the hybrid calibration done earlier. These data were chosen because they represented a soil in production. The soil data from the inbred study were from a newly cultivated field, and did not necessarily represent normal field conditions. The variety chosen for these simulation was inbred 1 from the inbred analysis performed earlier. Inbred one was chosen because it was best simulated by the CERES-IM program.

Reprogramming of CERES-IM to Accommodate Multi-year Simulations

In addition to the auto-fertilization routine that was written, CERES-IM required other changes in the code in order to simulate 60 years of production. The simulations for the hybrid and inbred calibrations performed earlier were on a yearly basis. The inputs required for initial conditions were entered for each year of simulation. However, in the 60 year simulation, it was decided that the model should be continuous, each year depending on the previous year's biomass production and nitrogen uptake. In order to accommodate this, a few changes were required.

The obvious change was to reprogram the model to run continuously without reading input files at the beginning of each simulation. Additionally, the residue inputs for each year, except for year one, were the residue left by the previous years's crop. The inputs for year one were read in through the traditional input files. However, for the remaining 59 years, the residue simulated by CERES-IM was entered as the inputs for the fresh organic matter for the following year.

Nitrogen Strategies Evaluated

The possibility of nitrogen management strategies that can be evaluated are endless. To keep the amount of data within a quantifiable amount, only 14 strategies were chosen. These strategies are listed in Table 10.

Table 10. Nitrogen management strategies simulated by CERES-IM for a 60 year period.

Strategy Number	Description
1	Zero nitrogen added
2	180 kg N ha^{-1} applied at planting
3	180 kg N ha^{-1} sidedressed (30 kg N at planting and an additional 150 kg N at V6)
4	90 kg N ha^{-1} sidedressed (30 kg N at planting and an additional 60 kg N at V6)
5	30/30 PRF - If less than 30 kg N are required then 30 kg N will be applied (time < silking)
6	30/30 PRF - If less than 30 kg N are required then 30 kg N will be applied (time < grain fill)
7	30/0 PRF - If less than 30 kg N are required then no nitrogen will be applied (time < silking)
8	30/0 PRF - If less than 30 kg N are required then no nitrogen will be applied (time < grain fill)
9	15/15 PRF - If less than 15 kg N are required then 30 kg N will be applied (time < silking)
10	15/15 PRF - If less than 15 kg N are required then 30 kg N will be applied (time < grain fill)
11	15/0 PRF - If less than 15 kg N are required then no nitrogen will be applied (time < silking)
12	15/0 PRF - If less than 15 kg N are required then no nitrogen will be applied (time < grain fill)
13	PRF - The exact amount of nitrogen required is applied (time < silking)
14	PRF - The exact amount of nitrogen required is applied (time < grain fill)

The nitrogen strategies used in the inbred study were all evaluated. This included a zero nitrogen fertilizer, a 180 kg N ha^{-1} applied at planting (180 pp), 180 kg N ha^{-1} sidedressed (180 sd) with 30 kg N ha^{-1} at applied planting and an additional 150 kg N ha^{-1} applied at growth stage V6, a 90 kg N ha^{-1} sidedressed (90 sd) with 30 kg N ha^{-1} at applied planting and an additional 60 kg N ha^{-1} applied at growth stage V6, and a PRF (Auto N) treatment. The PRF treatment was accomplished by using the nitrogen factor NFAC as an indicator of nitrogen stress.

The PRF strategies evaluated used the auto-fertilization routine mentioned earlier. Once nitrogen stress was detected, CERES-IM used a nitrogen uptake curve developed from the inbred study to make a determination of the required amount of nitrogen needed by the plant to complete its growth without nitrogen stress. A nitrogen application of this required amount was then simulated. An irrigation water application of 7 mm was also simulated on the day of a nitrogen fertilizer application. The irrigation application was made to assure that the nitrogen penetrated the soil surface, since all nitrogen applications were assumed to be sprayed on in the form of urea-ammonium nitrate (28% N). However, if sufficient rainfall occurred the day of a nitrogen fertilizer application, then no irrigation was applied.

It was decided that if a nitrogen stress occurred earlier than the end of the juvenile stage, that a base amount of 50 kg N ha^{-1} would be applied. This was done based on previous experience that any nitrogen stress that occurred early in the plants growth would require a substantial amount of nitrogen. This would also indicate that the of mineralization would not be very high. The intent of PRF is to make use of the mineralized nitrogen to its fullest extent. Also, the fertilizer amounts needed late in the PRF strategy may be small, too small for practical consideration. Therefore, four additional strategies were added.

Using the PRF methodology just mentioned, four more strategies were evaluated that contained the same assumption that early fertilizer applications would be set to 50 kg N ha^{-1}. However, instead of adding what was required by the plant in the later stages, it was decided that two threshold values would be used. One threshold value was set at 15 kg N ha^{-1}. If, after the end of the juvenile stage, the amount of nitrogen required was less than 15 kg N ha^{-1}, then 15 kg N ha^{-1} would be added. The 15 kg was considered to be the lowest practical amount of nitrogen fertilizer to apply. Additionally, a strategy was setup that if less than 15 kg ha^{-1} of nitrogen was required, then no nitrogen fertilizer would be added. This allowed for a comparison of whether the 15 kg threshold had any real impact. Also, a threshold of 30 kg N ha^{-1} was also chosen for evaluation. Both strategies that were used with the 15 kg threshold were used with the 30 kg threshold.

Finally, there was the timing of the late application with respect to plant growth stage. Late applications of nitrogen fertilizer often have little effect on grain yield because the nitrogen does not have time to be available for plant uptake before grain filling is started. To evaluate this, each of the PRF strategies, including the 15 and 30 kg threshold strategies and the PRF-Auto N strategy, were simulated with two different growth stage related restrictions. One restriction was that if a nitrogen stress was detected after silking, no nitrogen fertilizer would be applied. The second restriction was that if nitrogen stress was detected after the beginning of grain filling, no nitrogen would be added. Growers would generally agree with the second limit of not apply nitrogen after the beginning of grain filling. The addition of nitrogen after silking is done, though this strategy is not used widely. With the addition of these conditional strategies, the total number of strategies simulated was 14 (see Table 10).

All of these strategies were evaluated for their impact on grain yield and nitrate leaching. Yearly data on irrigation and nitrogen fertilizer applications were also written to an output file to allow for further assessment of these strategies.

RESULTS AND DISCUSSION

Commercial Hybrid Maize

The data used for the hybrid validation/calibration in this research was part of a five year project to study the effects of irrigation and nitrogen fertilizer application management on hybrid corn production and nitrate leaching below the rootzone. Drainage lysimeters were installed in 1986 and were used to measure the leaching at a depth of 2.29 m. The years used for this validation were 1988 and 1989.

The two drainage lysimeters were installed in a farmer's field in St. Joseph County, MI. One lysimeter was located under an existing center pivot irrigation system and the farmer managed the nitrogen fertilizer and irrigation water applications to the plot. This treatment is referred to as the conventional management practice (CMP). The other lysimeter was located in the same field but outside of the area irrigated by the center pivot. This lysimeter was under the management of the researchers at MSU and the treatment used is referred to as the research management practice (RMP). Both lysimeters received the same management in terms of tillage, planting, and pesticide control. However, the irrigation and nitrogen management schemes differed greatly.

Input Data

The input data for the simulation runs includes weather data, soils data, genetic data, and management data. These data make up the eight input files required by CERES-IM. The following is a brief discussion of the input files.

Weather Data

Weather data were collected on site using a LICOR weather station. The station consisted of a LICOR LI-1200 minimum data set recorder, a LICOR LI-200SA pyranometer sensor, a LICOR 1000-07 instrument enclosure with an air temperature sensor, and a Sierra Misco tipping bucket rain gauge. The weather data were recorded on a daily basis and included solar radiation, maximum and minimum temperature, and rainfall. During the winter months, the solar and temperature data were used from the weather station on site, but the precipitation data were taken from a nearby weather station that recorded snowfall. A listing of the weather data used for the simulation runs is in Appendix three.

Soil Nitrogen Balance Parameters

To simulate nitrogen dynamics, CERES-IM requires information on the addition of fresh organic matter such as the amount of residue from the previous crop and the depth of incorporation. Also, the C:N ratio of the residue is required. Finally, the root residue from the previous crop is needed. The plots used in this study were both in commercial hybrid maize production for several years before 1988. For the 1988 simulation, the C:N ratio and amount of residue was estimated based on the grain yield from the previous year. The depth of incorporation was based on the tillage depth in the spring of 1988. In 1989, the data from the previous year's harvest were used and root residue was again estimated. Input File 4 (soil nitrogen balance parameters) was created with these data. All of the residue data used for the simulations are in Appendix C.

Soils Data

The soils data were collected at the beginning of each season before fertilizer was applied. In 1987, soil samples were taken and the bulk density of each plot was determined. These numbers were used in the 1988 and 1989 simulation runs. On April 15, 1988, three soil samples were taken from each plot in increments of 15, 15, 30, 60, and 30 cm to a depth of 150 cm. The samples were analyzed for nitrate and ammonium content. The measured values from one sample, from the RMP plot, were discarded because of its unexplainably high value.

In 1989, on April 11, four samples from each plot were taken and analyzed for nitrate-N and ammonium-N concentrations. The soil layers were separated as in 1988. Additionally, the organic carbon percentage of the soil and the soil pH were measured for each soil layer. The organic carbon and pH data were used in the 1988 simulations as well as in 1989 because they do not vary greatly from year to year and no measurements were taken in 1988.

There was large variation in the measured NO_3^- and NH_4^+ contents among the soil samples taken. Tables 11 and 12 gives the average values used and the standard deviation (SD) associated with those measured values for the soil nitrogen components for the CMP and the RMP plots for 1988. The 1989 data for the CMP and RMP plots are found in Tables 13 and 14. All four tables show the difficulty in establishing good initial conditions for soil nitrogen. The soil water inputs, i.e., drained upper limit, lower limit, saturation, were estimated based on soil survey data and the sand, silt, and clay content of the soil. All of these data were used to create input File 5 (soil profile initial conditions).

Irrigation and Nitrogen Applications

The irrigation input file was created by using a combination of measured values and farmer records. The farmer supplied a schedule of when an irrigation took place and the amount of water applied on the CMP plot. Researchers also kept a record of when irrigation water was applied and for how long the system ran on the RMP plot. These data were compared against data recorded by wedge type and tipping bucket rain gauges located in the fields near the lysimeters. Using the three pieces of data, the amount of irrigation water applied and when that water was applied was determined.

The nitrogen fertilizer application dates and amounts for the CMP plot were supplied by the farmer. The preplant applications were made by knifing anhydrous ammonium into the soil at a depth of 25 cm. The nitrogen applied at planting was in the form of diammonium phosphate

Table 11. Averages of the measured soil nitrogen values and the associated standard deviations for the CMP plot from samples taken on April 15, 1988. Mendon, MI.

DEPTH (cm)	Nitrate-N (ppm)		Ammonium-N (ppm)	
	AVE	SD	AVE	SD
0-15	.905	.429	3.99	1.93
15-30	.743	.323	0.831	0.393
30-60	.516	.205	0.805	0.317
60-120	.634	.012	0.780	0.425
120-150	.475	.060	0.600	0.201

Table 12. Averages of the measured soil nitrogen values and the associated standard deviations for the RMP plot from samples taken on April 15, 1988. Mendon, MI.

DEPTH (cm)	Nitrate-N (ppm)		Ammonium-N (ppm)	
	AVE	SD	AVE	SD
0-15	.905	.005	2.29	.845
15-30	.57	.11	1.12	.690
30-60	.545	.175	1.94	.105
60-120	.305	.105	0.67	.115
120-150	.535	.015	0.77	.265

Table 13. Averages of the measured soil nitrogen values and the associated standard deviations for the CMP plot from samples taken on April 11, 1989. Mendon, MI.

DEPTH (cm)	Nitrate-N (ppm)		Ammonium-N (ppm)		Organic Carbon (%)		Soil pH	
	AVE	SD	AVE	SD	AVE	SD	AVE	SD
0-15	1.19	.895	2.31	.120	.780	.080	7.45	.250
15-30	.810	.180	1.92	.605	.725	.185	6.70	.100
30-60	1.11	.530	2.61	.720	.370	.090	5.70	.200
60-120	1.11	.078	1.39	.890	.375	.115	6.45	.050
120-150	1.81	.125	1.57	.225	.320	.020	7.45	.950

Table 14. Averages of the measured soil nitrogen values and the associated standard deviations for the RMP plot from samples taken on April 11, 1989. Mendon, MI.

DEPTH (cm)	Nitrate-N (ppm)		Ammonium-N (ppm)		Organic Carbon (%)		Soil pH	
	AVE	SD	AVE	SD	AVE	SD	AVE	SD
0-15	.225	.225	1.99	.330	.600	.001	5.75	.250
15-30	.285	.285	1.56	.410	.660	.050	5.60	.200
30-60	.570	.120	1.43	.335	.365	.045	5.65	.150
60-120	.495	.025	0.47	.465	.190	.010	6.10	.500
120-150	.390	.090	0.22	.215	.205	.085	7.25	.145

(DAP) and was sidedressed with the other fertilizers added at the time. The RMP also received the DAP application at planting. All additional nitrogen added to the RMP plot was in the form of ammonium nitrate and applied by hand.

In 1988, the CMP plot received 210 kg N ha^{-1}: 200 kg N ha^{-1} preplant as anhydrous ammonium and 10 kg N ha^{-1} at planting as DAP. The RMP plot received a total of 130 kg N ha^{-1}: 10 kg N ha^{-1} at planting as DAP and then 2 additional applications of 40 kg N ha^{-1} and 80 kg N ha^{-1} as ammonium nitrate. Additionally, the CMP plot received 347 mm of irrigation water while the RMP plot received only 267 mm.

In 1989, the nitrogen applied to the CMP plot was the same as in previous year, with 200 kg N ha^{-1} applied preplant as anhydrous ammonium and 10 kg N ha^{-1} applied at planting as DAP. The RMP plot received the 10 kg N ha^{-1} at planting and then an additional 113.1 kg N ha^{-1} as ammonium nitrate split into 3 applications of 30, 35.6 and 47.5 kg N ha^{-1}. The total irrigation water applied to the CMP plot was 131 mm and the RMP plot received 49 mm of irrigation water. The input data for the irrigation water applications (File 6) and the nitrogen fertilizer applications (File 7) are in Appendix three.

Management Input Data

The management data required to run CERES-IM are easily obtainable if good field records are kept. In this study, the grower was given a form to fill out after each field operation. Phone calls were made to him to verify the data. The plant population data used for the simulation runs were measured after emergence because CERES-IM requires the plant population, not the planting population. Often the planting population is higher than the actual field population because 100 percent germination does not occur. In 1988, both plots had a plant population of 6.8 m^{-2}. However, in 1989, wet weather and mechanical problems caused a late planting for the study and the plant population was not as homogenous. Planting normally takes place by the first week in May, but this year planting was delayed until May 20. The plant populations for 1989 were 8.3 m^{-2} for the RMP plot and 7.3 m^{-2} for the CMP plot. The difference in plant populations was due to poor plant germination on the CMP plot.

Genetic Coefficient Information

The genetics coefficients for the hybrid used in this study were created for CERES-IM by using data from previous years and data from other experiments within the state using the same or a similar hybrid type. In CERES-IM however, the potential grain number has been changed to a grain number factor. This parameter was developed by using the 1988 data and adjusting the value to match the CMP plot harvest data. The same value was then used for the RMP treatment in 1988 and both the CMP and RMP treatments in 1989. The new leaf area parameter was determined in the same way, again using the 1988 CMP plot for calibration.

Simulated Versus Measured

The comparisons made between CERES-IM simulated values and those measured in the field for this study include year end plant biomass and yield data, soil water drainage and nitrate loss below the plant rootzone. In the CMP and RMP treatments, for 1988 and 1989, no replications were made. However, some measurements were made on several plants within the plot areas.

Both plots were approximately 8 m X 10 m. In both years, harvest data were collected by harvesting approximately 2.1 m^2 (2.63 m of a row with 0.80 m spacing). Over an area of approximately 80 m^2, each treatment was split into 36 sub-plots, with grain data collected on all. Additionally, four sub-plots were chosen at random and total above ground biomass samples taken. The plant nitrogen data were obtained by using biomass and grain samples from two of the four sub-plots to determine total above ground biomass. As with the soil analysis, some variation existed in the measured data. Table 15 gives the averages and the SDs for the yield and stover for the CMP and RMP plots for 1988 and 1989.

Table 15. Yield and stover data measured for the CMP and RMP plots for 1988 and 1989. Mendon, MI.

Plot	Yield (kg ha^{-1})				Stover (kg ha^{-1})			
	1988		1989		1988		1989	
	AVE	SD	AVE	SD	AVE	SD	AVE	SD
CMP	10848	1170	11095	1667	9370	620.45	10546	834.24
RMP	9396	1410	10882	1579	8920	595.32	7853	811.82

Plant Biomass and Yield Data

The weather during the 1988 growing season was not typical. There was widespread drought throughout much of the U.S., causing crop damage and yield losses. Fortunately, both plots in this study were irrigated.

As seen in Table 16, there was good agreement between the measured values and those simulated by CERES-IM for the CMP plot for 1988. The grain yield and kernel data showed excellent agreement. There was a discrepancy in the amount of stover produced and the grain nitrogen content. However, the overall nitrogen uptake data compared well. For the RMP plot, Table 17, the comparisons were good for all of the data. Yield, kernel, and nitrogen data showed good agreement between the measured and simulated values.

The 1989 season saw a return to more traditional weather patterns. Again, using the data collected, the input files for CERES-IM were created. A comparison of the year end yield and biomass data are given in Tables 18 and 19, for the CMP plot and the RMP plot.

Results of the simulation for the CMP plot for 1989 again showed good agreement with the measured values (Table 18). The yield and kernel data comparisons showed well. As in 1988, CERES-IM simulated the percent nitrogen content higher than that measured resulting in the grain nitrogen uptake being overestimated as well. However, the simulated total nitrogen uptake again compared well with the measured values.

Table 16. A comparison of several parameters between CERES-IM simulated values and measured values for the CMP treatment. Mendon, MI, 1988.

Parameter	CERES-IM	Measured	Difference
Silking Date	201	200	+ 1
Grain Yield (kg ha^{-1})	10112	10848	- 6.8 %
Kernel Weight (g)	0.279	0.286	- 2.4 %
Grains m^{-2}	3063	3279	- 6.6 %
Grains ear^{-1}	452	484	- 6.6 %
Maximum LAI	4.63	5.06	- 8.5 %
Biomass (kg ha^{-1})	19700	18762	+ 4.5 %
Stover (kg ha^{-1})	11155	9370	+19.0 %
Grain Nitrogen %	1.71	1.39	+23.0 %
Tot N Uptake (kg ha^{-1})	219.7	208.7	+ 5.3 %
Stover N Uptk (kg ha^{-1})	73.2	78.2	- 6.4 %
Grain N Uptk (kg ha^{-1})	146.5	130.5	+12.3 %

Table 17. A comparison of several parameters between CERES-IM simulated values and measured values for the RMP treatment. Mendon, MI, 1988.

Parameter	CERES-IM	Measured	Difference
Silking Date	201	202	-1
Grain Yield (kg ha^{-1})	10014	9396	+ 6.5 %
Kernel Weight (g)	0.279	0.259	- 7.7 %
Grains m^{-2}	3033	3139	- 3.3 %
Grains ear^{-1}	447	463	- 3.5 %
Maximum LAI	4.26	3.81	+11.8 %
Biomass (kg ha^{-1})	15884	17055	- 6.9 %
Stover (kg ha^{-1})	7423	8920	-16.8 %
Grain Nitrogen %	1.54	1.39	+ 9.7 %
Tot N Uptake (kg ha^{-1})	163.5	148.8	+ 9.9 %
Stover N Uptk (kg ha^{-1})	33.4	35.7	+ 6.4 %
Grain N Uptk (kg ha^{-1})	130.1	113.1	+15.0 %

Table 18. A comparison of several parameters between CERES-IM simulated values and measured values for the CMP treatment. Mendon, MI, 1989.

Parameter	CERES-IM	Measured	Difference
Silking Date	215	216	- 1
Grain Yield (kg ha^{-1})	10714	11095	- 3.4 %
Kernel Weight (g)	0.251	0.262	- 4.2 %
Grains m^{-2}	3605	3585	+ 0.6 %
Grains ear^{-1}	495	491	+ 0.8 %
Maximum LAI	4.84	4.33	+11.8 %
Biomass (kg ha^{-1})	18969	19993	- 5.1 %
Stover (kg ha^{-1})	9916	10546	- 6.0 %
Grain Nitrogen %	1.65	1.40	+17.9 %
Tot N Uptake (kg ha^{-1})	212.7	194.0	+ 9.6 %
Stover N Uptk (kg $ha^{-1)}$	63.0	63.4	- 0.6 %
Grain N Uptk (kg $ha^{-1)}$	149.7	131.3	+ 14.0 %

Table 19. A comparison of several parameters between CERES-IM simulated values and those measured in the RMP treatment. Mendon, MI, 1989.

Parameter	CERES-IM	Measured	Difference
Silking Date	214	214	0
Grain Yield (kg ha^{-1})	10073	10882	- 7.4 %
Kernel Weight (g)	0.263	0.239	+10.0 %
Grains m^{-2}	3238	3843	-15.7 %
Grains ear^{-1}	391	463	-15.6 %
Maximum LAI	5.08	4.18	+21.5 %
Biomass (kg ha^{-1})	16500	17048	- 3.2 %
Stover (kg ha^{-1})	7989	7853	+ 1.7 %
Grain Nitrogen %	1.36	1.26	+ 7.9 %
Tot N Uptake (kg ha^{-1})	148.9	155.2	- 4.1 %
Stover N Uptk (kg $ha^{-1)}$	33.0	39.3	-16.0 %
Grain N Uptk (kg $ha^{-1)}$	115.9	115.9	- 0.0 %

The simulation for the RMP plot for 1989 also showed good agreement with the measured yield and nitrogen components (Table 19). However, individual kernel data was under predicted by the simulation.

Another area of interest in these simulations was the leaf area index (LAI). With the introduction of a new leaf area formulation, analyzing how well CERES-IM described the leaf area of the plants in the treatments is appropriate. Throughout the growing season 15 plants were measured four times in 1988 and five times during the 1989 season.

In 1988, CERES-IM showed good agreement in simulating LAI for both the CMP and the RMP treatments, Figures 24 and 25. Figure 24 shows the LAI simulated by CERES-IM and the measured values and the associated SDs for the plants in the CMP treatment. CERES-IM simulated LAI well for the first two measurements but underestimated LAI for the third and fourth measurement. This resulted in an underestimation of the maximum LAI, as shown previously in Table 16. In the RMP treatment, Figure 25, CERES-IM again did a good job of simulating LAI. However, CERES-IM under-predicted LAI during the early vegetative phase. This may be due to the water stress that was imposed on the plants in the RMP plot. This stress may have caused some variations in individual plant growth.

In 1989, CERES-IM showed good agreement with the measured LAI, Figures 26 and 27. In the CMP treatment, Figure 26, CERES-IM showed close agreement with the LAI measured. In the RMP treatment, Figure 27, CERES-IM showed good agreement with a slight underestimation during the middle of the vegetative growth stage similar to that seen in 1988, Figure 25.

The results shown here illustrate the ability of the model to simulate the biomass and nitrogen components of hybrid maize. Though some deviations exist, the overall results compare well giving validity to the model's phasic and developmental capabilities. However, since this study involves nitrate leaching, a comparison of those values is also warranted.

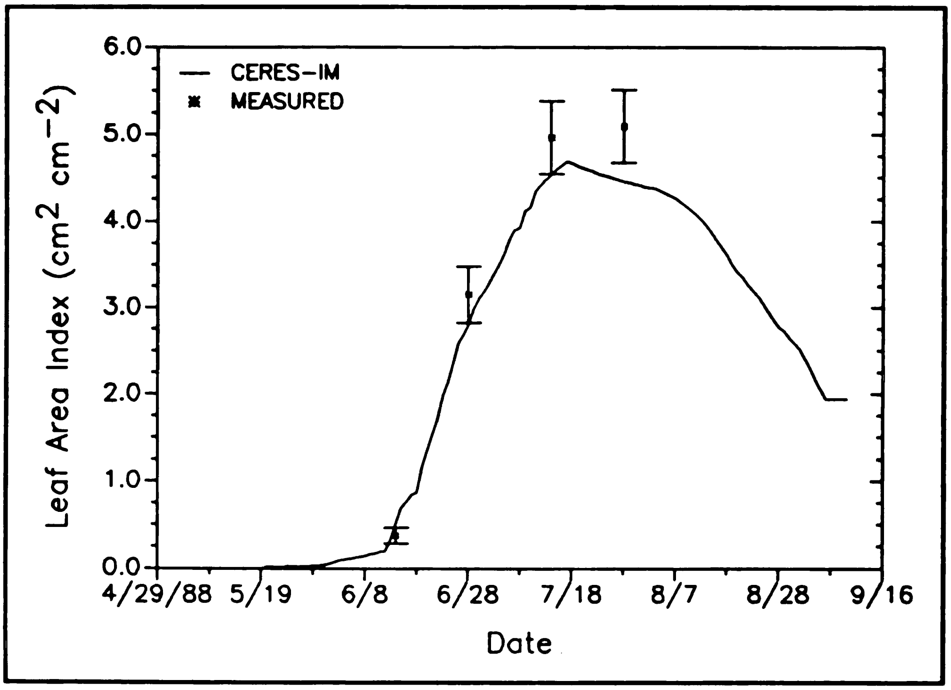

Figure 24. Measured and CERES-IM simulated leaf area index values for the CMP treatment for 1988. Mendon, MI.

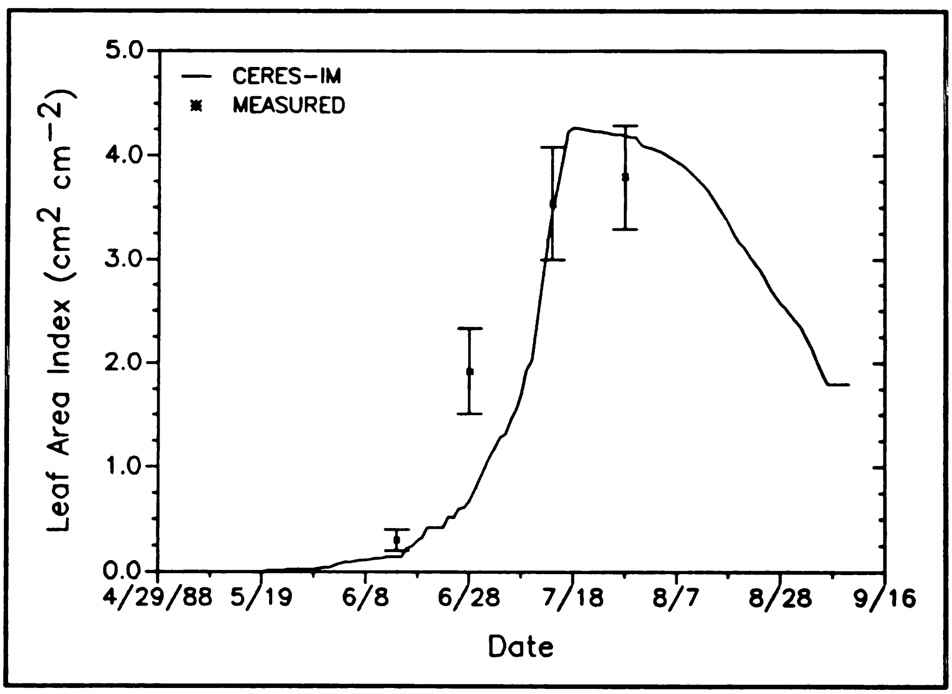

Figure 25. Measured and CERES-IM simulated LAI values for the RMP treatment for 1988. Mendon, MI.

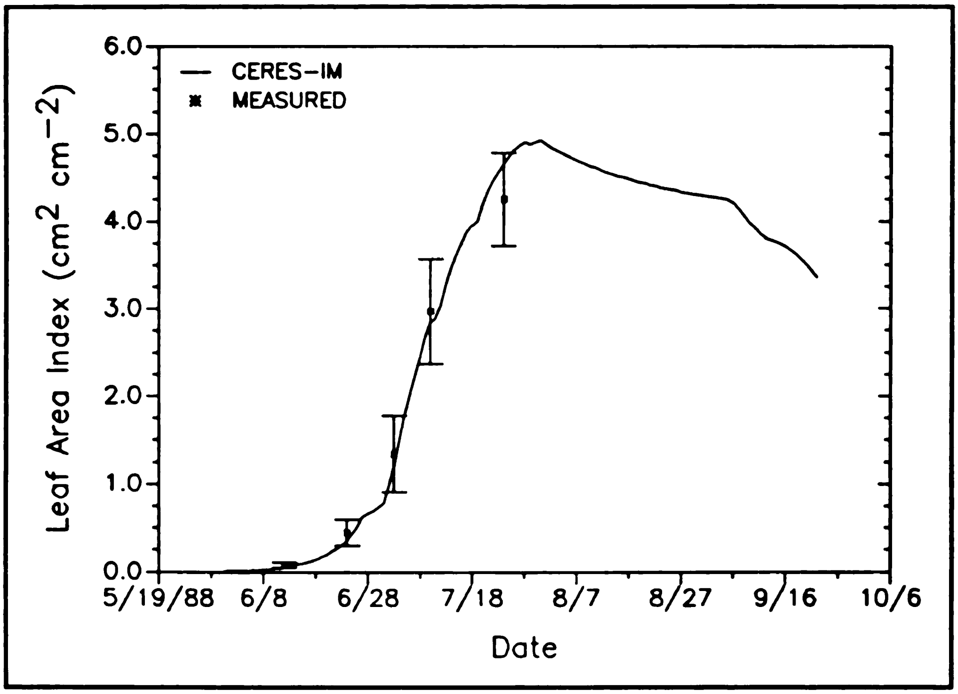

Figure 26. Measured and CERES-IM simulated leaf area index values for the CMP treatment for 1989. Mendon, MI.

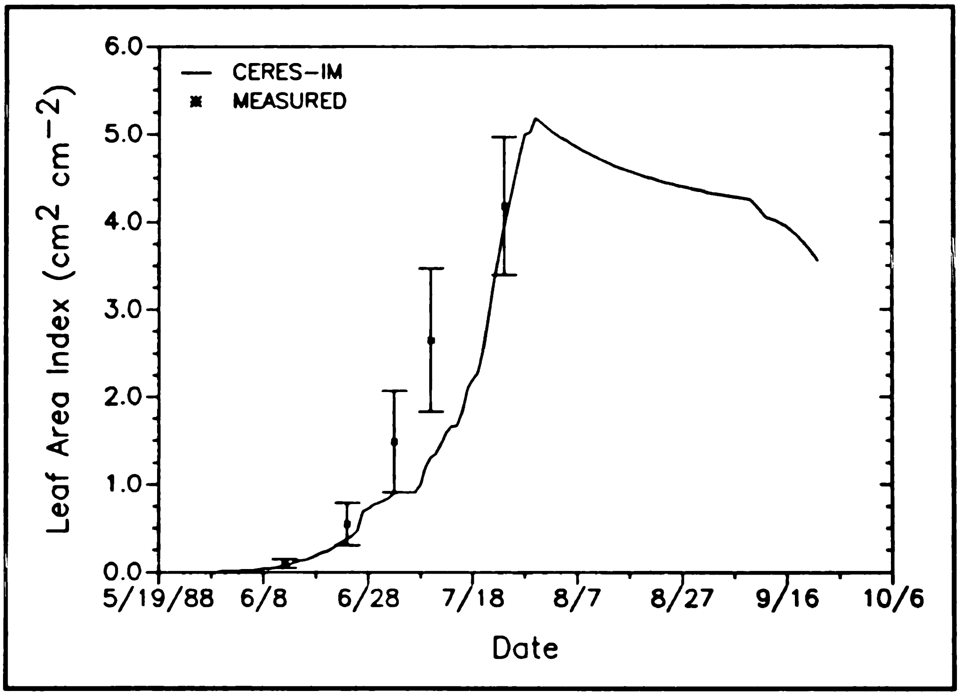

Figure 27. Measured and CERES-IM simulated leaf area index values for RMP treatment for 1989. Mendon, MI.

Drainage and Nitrate Leaching

Nitrate leaching was measured in both plots using non-weighing lysimeters. Samples were taken approximately every two weeks, or as warranted by drainage events. Drainage amounts were measured and samples were analyzed for nitrate-N concentrations. Although the lysimeters were installed in 1986, the drainage data were not collected and studied intensively until 1988.

Collection of the drainage data for the 1988 season began on April 10th. With the onset of the summer drought, the drainage from the RMP lysimeter was low compared to the CMP lysimeter. At summer's end, heavy autumn rain caused excessive drainage. Relatively high drainage amounts were recorded over most of the winter, except for periods of extreme cold when the soil would freeze. The CERES-IM model was run for the entire length of the drainage record, from April 10, 1988 to April 10, 1989. Figures 28 and 29 show the drainage amount for the CMP and RMP lysimeters along with the CERES-IM simulated values and the precipitation. As seen in Figures 28 and 29, CERES-IM performed well in simulating soil water drainage. Though the timing of the drainage events do not always coincide, CERES-IM did a good job of mimicking the general curve described by the measured data.

The measured nitrate accumulated for the drainage water sampled from the CMP and the RMP lysimeters for 1988 is shown in Figures 30 and 31, along with the CERES-IM simulated values and the precipitation. Figure 30, the CMP lysimeter, shows one set of measured data and two CERES-IM runs. The first CERES-IM run is that with the original fertilizer input of 200 kg N ha^{-1} applied preplant in the form of anhydrous ammonium. This curve underestimates nitrate loss by more than 50%. After discussions with the farmer, it was concluded that an over-application of nitrogen was possible and highly likely. Also, because the drainage component compared so well, it was decided that a new fertilizer input would be used and CERES-IM was rerun to test the hypothesis that in 1988, the amount of fertilizer applied as anhydrous ammonium was greater than 200 kg N ha^{-1} reported by the farmer. A value of 300 kg N ha^{-1} was used and the result is the second CERES-IM line shown in Figure 30. At 300 kg N ha^{-1}, CERES-IM

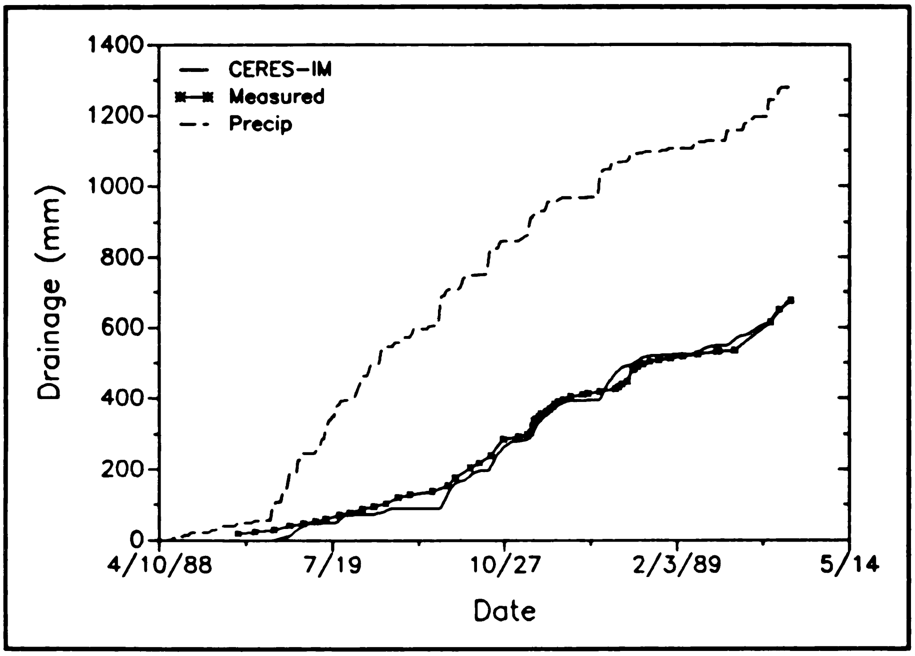

Figure 28. Measured and CERES-IM simulated drainage for the CMP lysimeter for 1988-89. Precipitation is also shown. Mendon, MI.

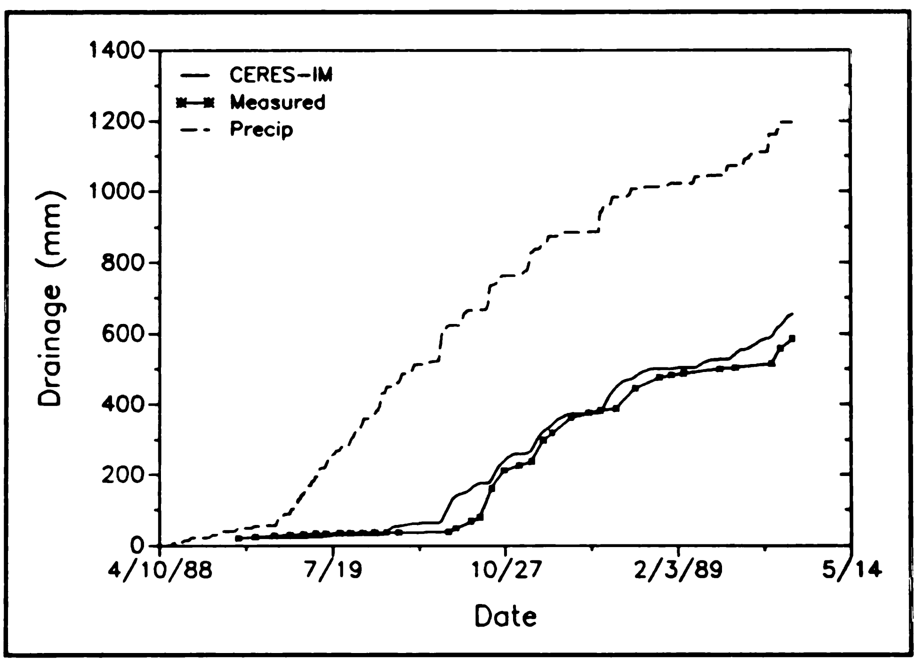

Figure 29. Measured and CERES-IM simulated drainage values for the RMP lysimeter for 1988-89. Precipitation is also shown. Mendon, MI.

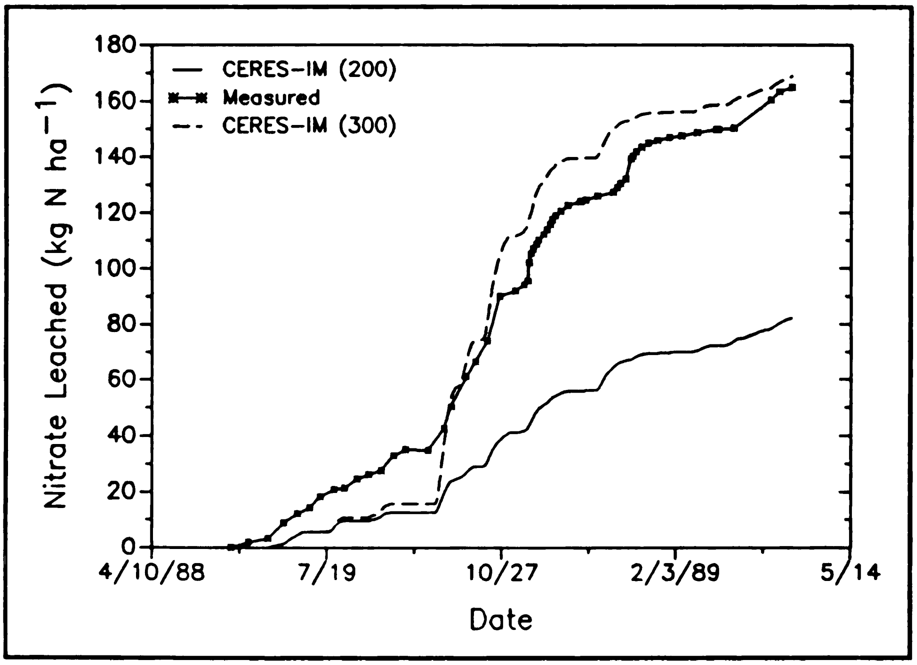

Figure 30. Measured and CERES-IM simulated (for both 200 and 300 kg N ha^{-1} pp) nitrate leaching values for the CMP lysimeter for 1988-89. Mendon, MI.

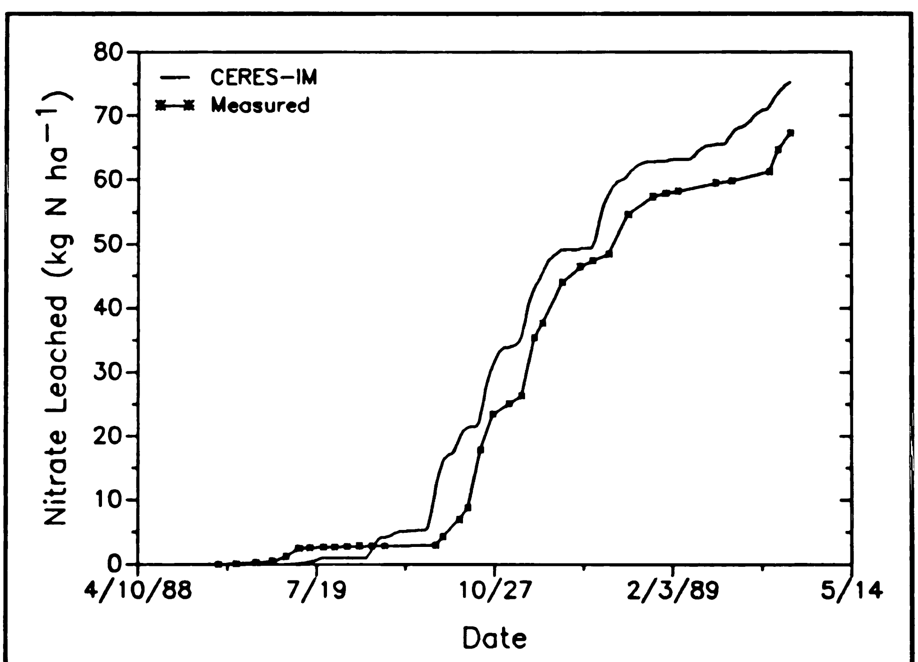

Figure 31. Measured and CERES-IM simulated nitrate leaching values for the RMP lysimeter for 1988-89. Mendon, MI.

showed excellent agreement with the measured values. Additionally, the phasic and developmental outputs that were shown in Table 16 changed little. Table 20 shows the comparison between the measured values and CERES-IM with a fertilizer input of 300 kg N ha^{-1} instead of the 200 kg N ha^{-1} as reported by the farmer. As seen in Table 20, the stover nitrogen uptake is increased slightly by 6.7 kg N ha^{-1} and the grain nitrogen content increased by 0.02% causing an increase in the grain nitrogen uptake of 0.3 kg N ha^{-1}. All of the other values remained the same. Figure 30, however, shows excellent agreement between the measured values and those simulated by CERES-IM when the 300 kg ha^{-1} input is used.

The RMP nitrate results are shown in Figure 31. Here, CERES-IM showed a bias throughout most of the simulation period. This may be due to the difficulty in determining the day to begin accumulation of the drainage values simulated by CERES-IM should begin. In the measured data, there seemed to be more lag time between rainfall and drainage than is simulated

Table 20. A comparison of several parameters between CERES-IM simulated (using 300 kg N ha^{-1} input) and measured values. Mendon, MI, 1988.

Parameter	CERES-IM	Measured	Difference
Silking Date	201	200	+ 1
Grain Yield (kg ha^{-1})	10112	10848	- 6.8 %
Kernel Weight (g)	0.279	0.286	- 2.4 %
Grains m^{-2}	3063	3279	- 6.6 %
Grains ear^{-1}	452	484	- 6.6 %
Maximum LAI	4.63	5.06	- 8.5 %
Biomass (kg ha^{-1})	19728	18762	+ 5.1 %
Stover (kg ha^{-1})	11183	9370	+19.3 %
Grain Nitrogen %	1.73	1.39	+24.5 %
Tot N Uptake (kg ha^{-1})	227.4	208.7	+ 8.9 %
Stover N Uptk (kg $ha^{-1)}$	79.9	78.2	+ 2.2 %
Grain N Uptk (kg $ha^{-1)}$	147.5	130.5	+13.0 %

by CERES-IM. However, even with this bias, CERES-IM simulated the measured accumulated nitrate leaching loss well showing the pulses and plateaus measured in the field.

In 1989, the drainage comparisons between the measured and the CERES-IM simulated values (Figures 32 and 34) again showed good agreement for the CMP and RMP lysimeters. As in 1988, there were discrepancies between the measured and simulated values as to when drainage occurred. This is especially true for the RMP lysimeter, Figure 33, during the winter months. However, the total drainage amounts for both lysimeters compared well.

The nitrate leaching data measured in the CMP and RMP lysimeters and those values simulated by CERES-IM for 1989 are shown in Figures 34 and 35. In both cases, CERES-IM slightly overestimated the total amount of nitrate leached by approximately 10 kg N ha^{-1}. Figure 34, the CMP lysimeter, shows that CERES-IM overestimated the nitrate loss throughout the simulation period. CERES-IM showed more nitrate loss occurring during the summer and less during the fall than that measured. However, by the end of the simulation period, the total nitrate loss compared well.

Figure 35 shows the simulated and the measured nitrate leached for the RMP lysimeter. CERES-IM slightly underestimated nitrate loss through most of the growing season and into autumn. However, both the measured and the simulated curves show a sharp increase during the winter months and the values of the measured and predicted total nitrate loss again compared well.

These results have shown that CERES-IM can reasonably simulate drainage and nitrate leaching in hybrid maize production. Discrepancies between the measured and simulated values of when drainage actually occurs does not seem to have a large impact on the models ability to simulate nitrate leaching. The next step is to compare CERES-IM with inbred maize in seed corn production.

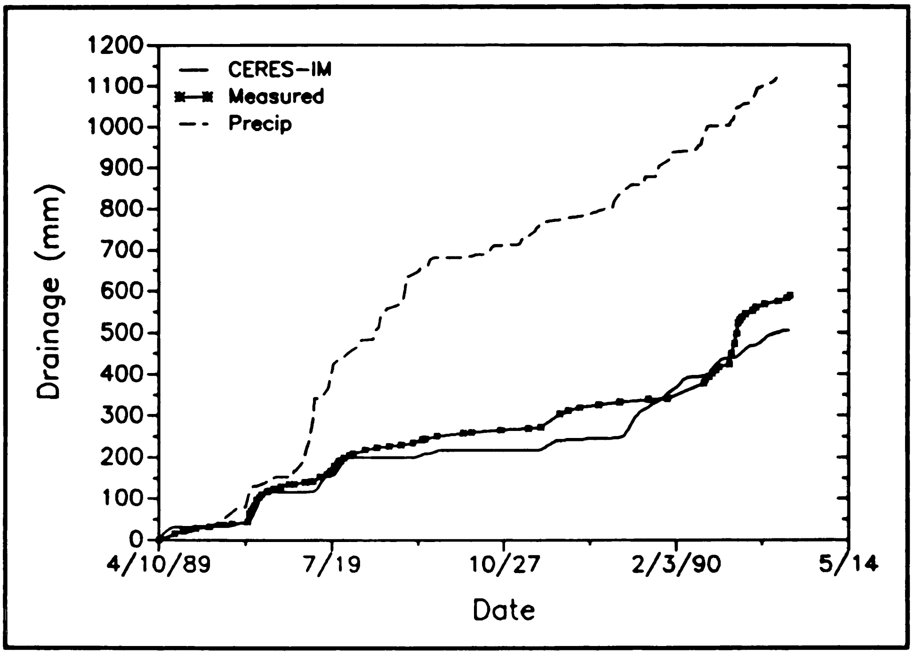

Figure 32. Measured and CERES-IM simulated drainage values for the CMP lysimeter for 1989-90. Precipitation is also shown. Mendon, MI.

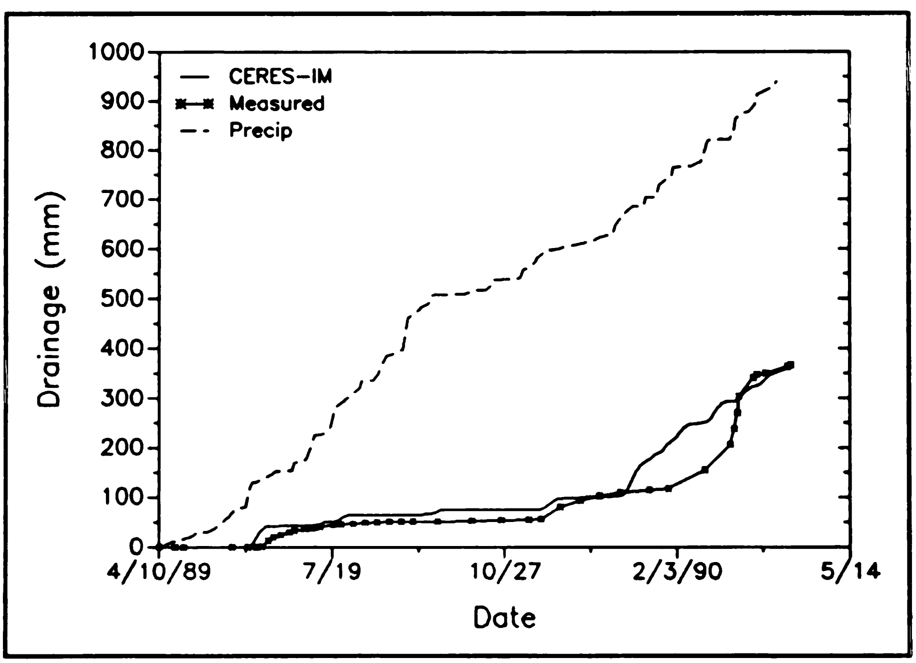

Figure 33. Measured and CERES-IM simulated drainage values for the RMP lysimeter for 1989-90. Precipitation is also shown. Mendon, MI.

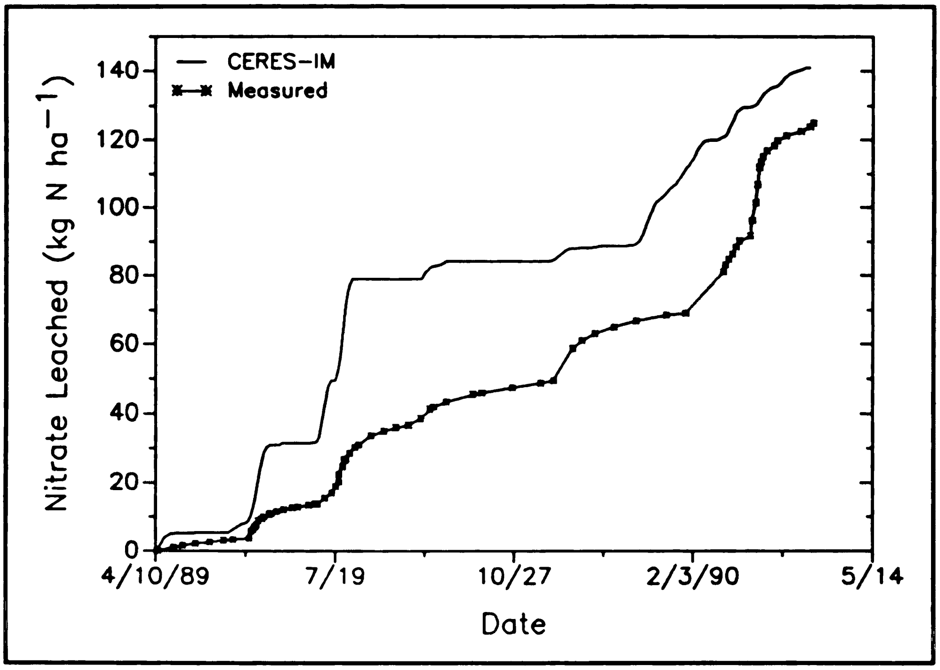

Figure 34. Measured and CERES-IM simulated nitrate leaching values for the CMP lysimeter for 1989-90. Mendon, MI.

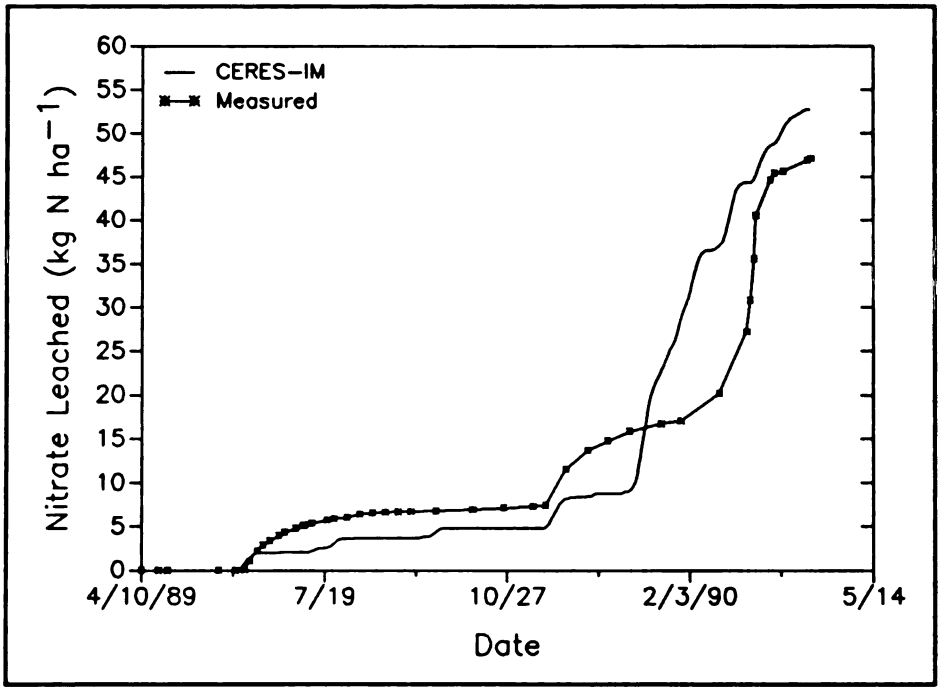

Figure 35. Measured and CERES-IM simulated nitrate leaching values for the RMP lysimeter for 1989-90. Mendon, MI.

Inbred Maize

The inbred phase of this research was part of a joint research project between Michigan State University and Pioneer Hi-Bred, Int., Inc. Begun in 1988, the project's focus was to evaluate the impact of nitrogen fertilizer application management on grain yield and the leaching of nitrate below the rootzone in seed corn production. Using drainage lysimeters, soil-water drainage was measured at a depth of 2.29 m below the surface and analyzed for nitrate content. Using three inbred varieties, the nitrogen fertilizer treatments evaluated ranged from a conventional strategy of 180 kg N ha^{-1} applied at planting to 90 kg N ha^{-1} sidedressed to no nitrogen fertilizer added. Using the data collected, input files for the CERES-IM simulation model were created and simulation runs were made for each inbred and treatment for both 1989 and 1990.

Plant Response Fertilization

As previously mentioned, one treatment for the inbred study was a research nitrogen management treatment called plant response fertilization, or PRF. The basic premise of PRF is to develop a methodology that once a nitrogen stress is detected, only the required amount of nitrogen needed to sustain the plants until physiological maturity is applied. During the first season, 1989, 30 kg N ha^{-1} were applied at planting for this treatment. This was done to assure adequate plant growth, since there were no records of yield or growth for this field. Additionally, 50 kg N ha^{-1} were applied later that season because of a color change observed by the researchers. The plants in the PRF treatment appeared lighter green in their leaf color than the plants in the other treatments. In the second year, a more scientific approach was used.

In 1990, two methods were used to determine nitrogen stress in the plant. One was comparing the height of well fertilized plants with the height of the plants in the PRF treatment. Also, a multi-spectrum radiometer (MSR) was used to measure the reflectance of the plants. Again, the reflectance of the plants in the PRF treatment was compared with well fertilized plants. Using multiple light ranges, the MSR can measure the reflectance in the blue and red ranges of light, allowing for a determination of the "greenness" of the plant. The theory was that plants experiencing nitrogen stress would be less green than non-stressed plants. Unfortunately, it was discovered that this methodology did not work well with the inbred plants. There was a problem with incomplete ground cover. Due to the relatively low plant populations (5.5 pl m^{-2}), the reflectance of the soil surface was often measured and caused erroneous readings. The onset of nitrogen stress often begins with a yellowing of the bottom leaves, which are often shielded from the MRS by the upper leaves of the plants. In the end, it was the plant height measurements that best determined nitrogen stress. In only inbred 1 was a stress detected. Using nitrogen uptake data from the previous year, a determination was made on the amount of nitrogen the plants required to complete their growth. On July 23, an additional 40 kg N ha^{-1} was applied to the PRF treatment plots with inbred 1. The other inbreeds never showed any significant difference in plant height comparisons with the 180 kg ha^{-1} treatment.

Input Data

The input data required to simulate inbred maize are similar to that for hybrid maize. The same 8 input files are used and the information within the files is the same except for the few additional parameters required for inbred simulation, i.e., male/female plant designation, detasseling date, etc. The following is a brief discussion on how the information required for these inputs files was obtained.

Weather Data

The weather data for this study were collected on site using a Campbell Scientific 1200 weather station. The station included a CR10 datalogger that was programmed to record hourly data. The instruments used to collect the weather data included a LI200S LICOR pyranometer (solar radiation), a LI-207 temperature and relative humidity probe (maximum and minimum air temperature), and a Weathertronics 0.01 in. tipping bucket rain gage (rainfall). Other meteorological measurements taken included relative humidity and wind speed and direction. Also, the CR10 was used in conjunction with other peripherals to control the drainage sampling system for the five lysimeters. Weather data were collected year round. During the winter months, precipitation data were obtained from a nearby weather station that recorded snowfall. A listing of the weather data is in Appendix D.

Soil Nitrogen Balance Parameters

Information on the incorporation of fresh organic matter into the soil profile is required by the CERES-IM program. These data include organic residue of previous crop, depth of incorporation, C:N ratio of organic residue, and root residue of previous crop. In 1989, estimates for these values were made based on observations made at the time of the installation of the lysimeters. Also, a new input was added in to allow for the user to enter the C:N ratio of the root residue. This was done because CERES-IM assumes the C:N ratio for the roots to be 40, a common value used for maize roots. Because the plot area was an old alfalfa field, with some alfalfa and pasture grasses growing, the C:N ratio of the roots was probably lower. The new input allowed for the C:N ratio of the root residue to be entered.

In 1990, data from the previous years crop were used as the inputs for these parameters in conjunction with the inputs used for 1989. The crop residue entered was the stover biomass from 1989. For the root residue, it was assumed that one-third of the root residue from the crop in 1988 was still present in 1990. All of the residue data used in the 1989 and 1990 simulations are listed in Appendix D.

Soils Data

To obtained the necessary inputs for soil nitrate and ammonium initial conditions, soil samples were collected at the beginning of each season. Data for organic carbon, bulk density, and pH were taken when the lysimeters were installed and used for both the 1989 and 1990 simulations.

In 1989, soil samples were taken from each lysimeter area. The sampling consisted of 2 samples for every 15 centimeters of depth, down to a depth of 120 cm. Each sample was comprised of 4 sub samples that were mixed together. The measured ppm values for nitrate-N and ammonium-N and the related standard deviations (SD) are found in Table 21. The data shows considerable variation.

In 1990, the soil sampling was simplified and the soil was analyzed every 25 centimeters down to a depth of 200 cm. Single samples, comprised of 10 sub-samples were analyzed for the top 75 cm on two treatments (180pp and 90s). The other two treatments (PRF and 0) had four samples analyzed, each comprised of 4 sub-samples, for the top 75 cm. Additionally, only 2 treatments (PRF and 0) were sampled beyond the 75 cm depth. Two samples were taken down to a depth of 200 cm, each comprised of four sub-samples. This new soil sampling procedure was done due to the time and cost of analysis for soil samples and because deep soil analysis yielded very little difference between treatments in 1989. The averages and SDs of the measured concentration of nitrate-N and ammonium-N for the 1990 soil analysis are shown in Tables 22 and 23. The data from 0-75 cm for each treatment is in Table 22. Table 23 contains the soil nitrogen values from 75 - 200 cm that were used for all treatments in 1990.

The soil water parameters used for the simulation were estimated based on soil survey data and mechanical analysis of the soil. All of the soil input data used for the simulations are listed in Appendix D. This information was used to create the soil profile initial conditions (soil-water and bulk density - input File 2; soil nitrogen and soil pH - input File 5).

Irrigation and Nitrogen Applications

The irrigation applications were measured using wedge type rain gages. Four gages were placed around each lysimeter and measurements were taken after each irrigation event. All nitrogen applications were done by hand except for the nitrogen applied at planting, which was applied mechanically. The amount of irrigation water applied (File 6) and the nitrogen fertilizer applied (File 7) for each treatment are listed in Appendix four.

Table 21. Averages and the associated standard deviations (SD) for measurements taken for nitrate-N and ammonium-N concentration in the soil for the four treatments from samples taken on May 4, 1989. Constantine, MI.

DEPTH (cm)	Soil Nitrogen Values for Each Treatment							
	180 pp Average (SD)		PRF Average (SD)		90 s Average (SD)		180 s Average (SD)	
	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)
15	13.77 (.73)	2.25 (.61)	9.99 (.95)	8.89 (2.2)	10.64 (.07)	1.89 (.80)	11.01 (.70)	3.55 (.20)
30	4.75 (.99)	1.68 (.23)	3.52 (.23)	2.73 (.51)	5.07 (.52)	2.36 (.84)	3.45 (.14)	1.08 (0.0)
45	3.09 (.32)	0.37 (.06)	2.49 (.23)	2.52 (.56)	2.71 (.27)	3.23 (1.4)	2.13 (.03)	2.67 (1.1)
60	2.08 (.03)	3.96 (3.2)	1.32 (.11)	2.21 (.68)	1.57 (.62)	2.33 (.38)	1.81 (.03)	2.45 (1.1)
75	1.68 (.21)	2.68 (2.0)	0.98 (.11)	4.14 (.58)	0.89 (.11)	4.20 (2.2)	0.79 (.11)	4.29 (.54)
90	1.07 (.11)	3.17 (3.0)	1.11 (.03)	1.71 (.18)	0.80 (.27)	1.35 (2.6)	0.49 (.05)	0.99 (.05)
105	0.76 (.11)	3.88 (9.2)	0.81 (.08)	1.47 (.08)	0.90 (.03)	3.25 (.16)	0.98 (.26)	5.03 (3.7)
120	0.52 (.03)	6.18 (2.5)	0.63 (.34)	1.66 (.34)	0.54 (.12)	1.72 (3.0)	0.44 (0.0)	1.78 (.03)

Table 22. Averages and the associated standard deviations (SD) for measurements taken for nitrate-N and ammonium-N concentration in the soil (0-75 cm depth) for the four treatments from samples taken on April 25, 1990. Constantine, MI.

DEPTH (cm)	Soil Nitrogen Values for Each Treatment							
	180 pp Average		PRF Average (SD)		90 s Average		0 Average (SD)	
	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)	NH_4^+ (ppm)
25	4.9	2.5	4.1 (.52)	2.4 (.85)	4.1	2.1	3.5 (.44)	2.1 (.46)
50	4.3	2.0	2.1 (.39)	1.8 (.19)	2.5	1.3	2.6 (.15)	1.1 (.37)
75	3.0	1.3	1.4 (.37)	1.2 (.64)	1.9	1.8	1.3 (.30)	1.0 (.29)

Table 23. Average and the associated standard deviation for mineral soil nitrogen measurements from samples taken on April 25, 1990. Constantine, MI.

DEPTH (cm)	Soil Nitrogen Values for All Treatments Average (SD)			
	NO_3^- (ppm)		NH_4^+ (ppm)	
100	0.86	(.30)	0.59	(.10)
125	0.82	(.11)	0.53	(.11)
150	1.12	(.34)	0.50	(.07)
175	1.41	(.46)	0.66	(.29)
200	1.67	(.60)	0.65	(.29)

Management Input Data

Management information and field operation records were well kept by personnel at the site. Dates of planting, detasseling, and the removal of the male plants were all recorded. Additionally, field notes were taken as to the condition of the plots throughout the season. Plant populations were obtained by planting at a high rate and then thinning the plots to the desired population of 5.5 pl m^{-2}. All of the management information used to create the management input files (File 8), is listed in Appendix four.

Genetic Coefficients

Since no previous data existed concerning the phasic development of the inbred lines, the genetic coefficients needed to be established. Using data gathered from treatment 1 in 1989 (180 kg N ha^{-1} at planting), the genetic coefficients were adjusted to give reasonable results. This was done for each of the inbreeds. The same genetic coefficients were then used for the rest of the treatments in 1989 and all the treatments in 1990. The listing of the genetic parameters used to create the genetic input file (File 9) is in Appendix four.

Simulated versus Measured

There was variation in the biomass and yield measurements taken in the inbred study. The year end data used for comparison with the values simulated by CERES-IM are a result of two separate sampling procedures. The yield data given are part of a harvest sampling taken at physiological maturity. The data values used for comparison are averages of eight samples, two samples from each replication within a treatment. The samples were about 1/1235 of a hectare (1/500 of an acre) in size. From this data set, kernel weight, kernel number, and grain yield were determined.

The stover and nitrogen data were obtained from a biomass sampling that took place four times throughout the season. Six plants from each replication were removed and dry weight and nitrogen contents were determined. The biomass samples were divided in leaf and stem, cob, and grain. These samples were taken at growth stage V6, silking, 50 % grain filling, and at physiological maturity. These samples were not part of the harvest sample previously mentioned. The stover and cob weights measured in these biomass samples were added to the grain yield data from the harvest sample to obtain above ground biomass. Additionally, the nitrogen concentrations obtained for the grain in the last biomass sample was used for grain N (%) comparisons. In turn, this grain N (%) was multiplied by the grain data from the harvest sample to obtain grain N uptake. Finally, the percent nitrogen in the cob and in the stover (leaves and stems) was averaged (weighted) to obtain the stover N percentage. Again, this in turn was multiplied by the total stover and cob weight to obtain a value for the nitrogen uptake by the stover.

The averages and the associated SDs for the key parameters of the simulation (i.e., grain yield, kernel number, stover, % N grain, % N stover) for 1989 and 1990, taken at physiological maturity, are shown in Tables 24 and 25. These average values are used later to compare against CERES-IM simulated values.

Taking the data from Tables 24 and 25, a third table, Table 26 was created that gives the coefficient of variation (CV) for the various parameters analyzed. The CV is the standard

Table 24. Averages and the associated standard deviations (SD) for yield, biomass, and plant nitrogen measurements taken at physiological maturity for 1989. Constantine, MI.

Treatment	Inbred 1 Average - (SD)				Inbred 2 Average - (SD)				Inbred 3 Average - (SD)			
Parameter	180pp	PRF	90s	180s	180pp	PRF	90s	180s	180pp	PRF	90s	180s
Yield (kg ha^{-1})	6551	6747	6699	6582	6047	6229	6096	5990	5500	5689	5789	5514
	(418.9)	(116.0)	(375.5)	(289.4)	(288.1)	(221.9)	(512.7)	(850.7)	(247.8)	(485.7)	(499.7)	(538.7)
Kernel Wt. (g)	.233	.232	.230	.233	.257	.255	.251	.252	.214	.243	.240	.242
	(.006)	(.011)	(.003)	(.009)	(.006)	(.004)	(.017)	(.008)	(.006)	(.007)	(.005)	(.007)
Stover (kg ha^{-1})	4903	4607	4389	4393	7398	6714	7074	6568	6129	6659	7402	6175
	(475.3)	(992.4)	(707.1)	(439.8)	(793.6)	(366.0)	(1206)	(1081)	(584.8)	(825.2)	(2099)	(883.4)
% Nitrogen Grain	1.63	1.53	1.45	1.55	1.61	1.55	1.60	1.58	1.49	1.49	1.48	1.53
	(0.17)	(0.12)	(0.15)	(0.06)	(0.13)	(0.09)	(0.10)	(0.06)	(0.12)	(0.03)	(0.15)	(0.07)
% Nitrogen Stover	0.88	0.78	0.75	0.79	0.97	1.12	1.02	1.06	0.98	1.00	0.84	1.13
	(0.12)	(0.07)	(0.10)	(0.12)	(0.15)	(0.06)	(0.09)	(0.25)	(0.15)	(0.18)	(0.12)	(0.17)

Table 25. Averages and the associated standard deviations (SD) for yield, biomass, and plant nitrogen measurements taken at physiological maturity for 1990. Constantine, MI.

Treatment	Inbred 1 Average - (SD)				Inbred 2 Average - (SD)				Inbred 3 Average - (SD)			
Parameter	180pp	PRF	90s	0	180pp	PRF	90s	0	180pp	PRF	90s	0
Yield ($kg\ ha^{-1}$)	5443	4992	5197	5226	5185	5494	5422	5363	3454	3972	4321	4126
	(514.0)	(381.6)	(502.1)	(370.2)	(728.0)	(407.7)	(542.0)	(261.1)	(346.6)	(356.0)	(504.5)	(294.4)
Kernel Wt. (g)	.201	.196	.201	.204	.262	.262	.249	.257	.244	.234	.229	.244
	(.009)	(.021)	(.014)	(.013)	(.016)	(.014)	(.006)	(.009)	(.008)	(.009)	(.005)	(.018)
Stover ($kg\ ha^{-1}$)	6715	5545	6092	5107	8496	9052	8794	7953	6573	7611	7313	6868
	(763.1)	(628.7)	(778.2)	(471.0)	(865.6)	(680.3)	(459.9)	(1035)	(1077)	(431.4)	(319.2)	(725.7)
% Nitrogen Grain	1.69	1.53	1.74	1.53	1.64	1.53	1.83	1.46	1.63	1.48	1.48	1.56
	(0.12)	(0.25)	(.13)	(0.11)	(0.15)	(0.18)	(0.09)	(0.13)	(0.20)	(0.04)	(0.21)	(0.16)
% Nitrogen Stover	1.08	1.20	1.05	1.15	1.23	1.07	1.03	1.12	0.90	0.88	1.21	1.08
	(0.17)	(0.55)	(0.27)	(0.24)	(0.08)	(0.20)	(0.32)	(0.35)	(0.04)	(0.04)	(0.35)	(0.45)

Table 26. Coefficient of variation expressed as a percentage for yield, biomass, and plant nitrogen measurements taken at physiological maturity for 1989 and 1990. Constantine, MI.

Parameter	Inbred 1 CV		Inbred 2 CV		Inbred 3 CV		Average	
	1989	1990	1989	1990	1989	1990	1989	1990
Yield (kg ha^{-1})	4.51	8.46	7.73	9.08	7.86	10.06	6.70	9.20
Kernel Wt. (g)	3.12	7.39	3.46	4.34	2.67	4.17	3.08	5.30
Stover (kg ha^{-1})	14.34	11.17	12.42	8.99	16.15	9.25	14.30	9.80
% Nitrogen Grain	8.12	9.52	5.98	8.68	6.19	9.85	6.76	8.32
% Nitrogen Stover	12.78	27.04	13.31	21.88	15.37	19.90	13.82	22.94

deviation divided by the average and multiplied by 100. The CVs of the measured data for each inbred and treatment for 1989 and 1990 are shown in table 26.

The data from 1989 in Table 26, show that the variation in grain yield is fairly small, with the CVs averaging 6.70 %. The lowest CV was inbred 1, PRF treatment, with a CV of 1.7 %. The highest was inbred 2, 180s treatment, with a CV of slightly over 14.2 %. The kernel weight data all looked good and showed little variation. The stover data, however, showed quite of variation within replications with an average CV of 13.82 % (Table 26).

Tables 24, 25, and 26 also contain data for the percent nitrogen in the grain and in the stover. This follows a similar patter to the yield and stover data. The average CV of the percent nitrogen in the grain was 6.70 %. However, the CV increased in the percent nitrogen in the stover to 13.9%.

The CVs of the measured values for the 1990 season followed the same trends as seen in 1989 (Table 26). However, the CVs increased in 1990 for each parameter except stover. The reason for the increase in CVs is not known, except that the low nitrogen treatments may have caused some sporadic nitrogen stress which caused some increases in the variability of the inbreeds growth. However, there is no statistical data to support this theory. The decrease in the CVs of the measured stover from 1989 to 1990 may have been due to late biomass sampling in 1989. In 1989, the last biomass samples was taken until a few weeks after physiological maturity. This late sampling may have caused non-uniformity in stover amount due to loss of leaves from wind or rain.

Plant and Biomass Data

Overall, the comparisons between CERES-IM simulated values and those measured in the field showed good agreement. The simulated values versus the measured values for the grain yield, kernel weight, grains per plant, and stover yield (at physiological maturity) are shown in Figures 36 through 39. The nitrogen related biomass data, which includes information on percent nitrogen in the grain, nitrogen uptake by the grain, percent nitrogen in the stover, and nitrogen uptake by the stover (at physiological maturity) are shown in Figures 40 through 43.

Because of the large quantity of data involved in the inbred validation, a simple comparison of simulated and measured values like that used in the hybrid demonstration shown early, would lead to cumbersome tables with results difficult to quantify. Traditionally, model evaluation has been done by testing the hypothesis that the regression line of simulated versus observed values has a slope of 1 and passes through the origin (Carter, 1986). However, this approach does not directly relate the predictive accuracy of the model. One commonly used term to describe the measure of predictive accuracy is the mean squared error of prediction (MSEP) (Wallach and Goffinet, 1989). The MSEP is a statistical term that represents an average weighted difference between observed and simulated data. Muchow and Carberry, 1990, used the MSEP to evaluate their mathematical models which described phenology and leaf-area development in tropical grain sorghum. The MSEP, also called the root mean squared deviation, is defined as:

$$MSEP = [\,(\Sigma (O-P)^2)\,/\,n\,]^{0.5}$$

Where O is the observed value, P is the predicted, or simulated value, and n is the number of paired values. In Figures 36 through 43 the data points are shown with the 1:1 line (solid) and the traditional regression line (dashed). Also shown is the regression line formula and the associated R^2 value. Additionally, the MSEP values for the components compared are given in Table 27.

The grain and biomass data are shown in Figures 36 through 39. The grain yield comparisons (Figure 36) showed good agreement between the simulated and measured values. The regression analysis yielded a regression line with a slope of 1.08 and an R^2 value of .656. Additionally, the y-intercept was -549, indicating that CERES-IM has a bias to underestimate yield. However, further study of figure 36 shows that it is the data from inbred 2 and 3 for 1990

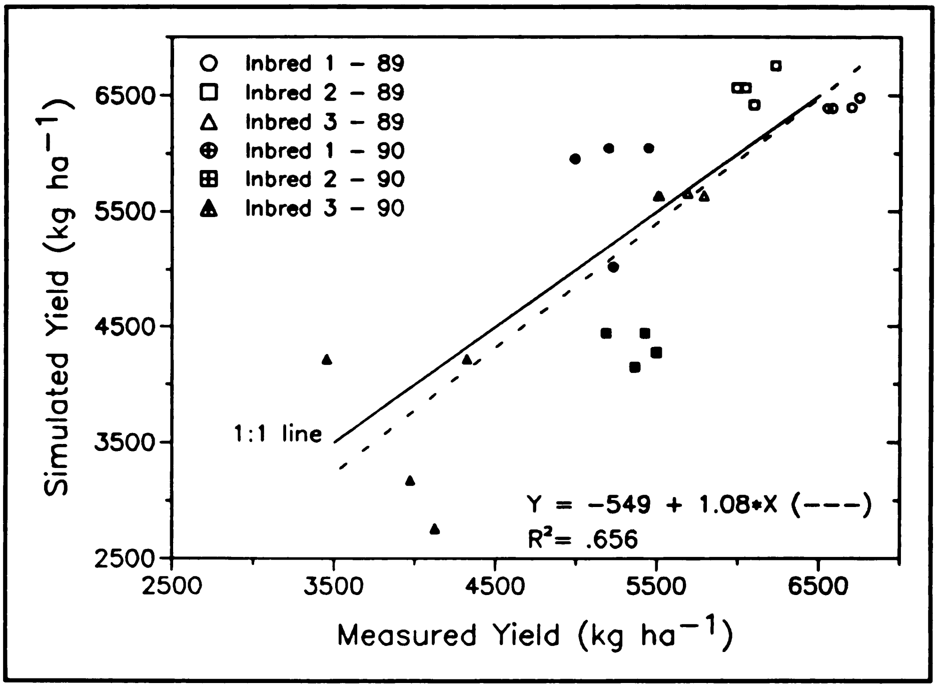

Figure 36. CERES-IM simulated versus measured grain yield for the three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

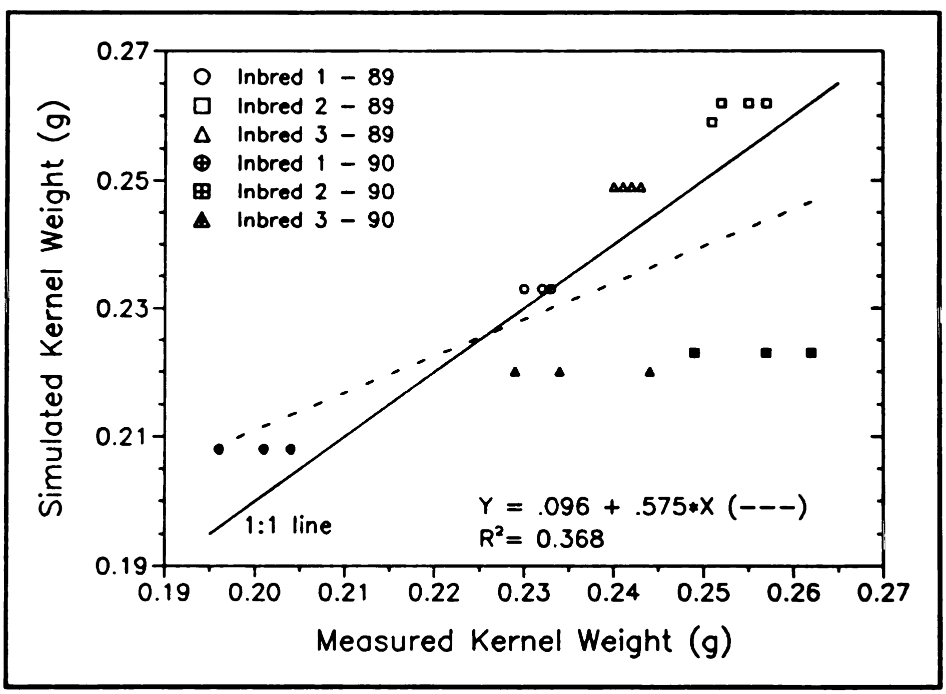

Figure 37. CERES-IM simulated and measured kernel weight for the three inbreeds for the four treatments for 1989 and 1990. Constantine, MI.

Table 27. Values of the MSEP for CERES-IM simulated versus measured values for plant and biomass data collected for the 3 inbred varieties. Constantine, MI, 1989 and 1990.

PARAMETER	INBRED 1		INBRED 2		INBRED 3		TOTAL (% of Measured)*
	1989	1990	1989	1990	1989	1990	
Yield (kg ha^{-1})	237	715	493	1059	118	880	673 (12.3%)
Kernel Wt. (g)	.002	.0086	.008	.035	.008	.019	0.017 (7.2%)
Grains $Plant^{-1}$	19.10	42.36	20.27	28.76	14.09	64.13	35.99 (9.4%)
Stover (kg ha^{-1})	275	441	683	1924	678	915	978 (16.7%)
N% Grain	.128	.156	.110	.071	.203	.170	0.146 (9.3%)
N Grn (kg ha^{-1})	4.40	13.65	12.11	14.85	15.52	15.21	13.20 (18.2%)
N% Stover	.268	.607	.470	.505	.398	.296	0.440 (45.3%)
N Stvr (kg ha^{-1})	12.69	36.04	35.94	52.65	27.54	23.36	33.73 (57.6%)

* Numbers in parenthesis are the MSEP value divided by the measured value.

that are the main causes of the low y-intercept and R^2 value. The MSEP values given in Table 27 confirm this. However, the overall MSEP shows a good predictive accuracy, with a value of 673 kg ha^{-1}, or 12.3%.

In comparing simulated kernel weight with measured values (Figure 37), CERES-IM often simulated the same number of kernels regardless of the treatment. This follows the logic of the program since the simulation runs did not show any evidence of significant water or nitrogen stress, regardless of the treatment. The data points show a horizontal spread for all of the inbreeds for 1989 and 1990. Also, inbred 2 and again to a lesser degree, inbred 3 in 1990 show the poorest comparisons. Table 27 shows good predictive accuracy for kernel weight simulation. The MSEP value for all inbred and treatment combinations for 1989 and 1990 was 0.017 g, or 7.2%. This is a good example of how the traditional statistical analysis does not provide a clear indication of predictive accuracy of the model.

When grains per plant were compared between simulated and measured values (Figure 38) the highest R^2 value was obtained: 0.797. This coincides with the low MSEP values found in

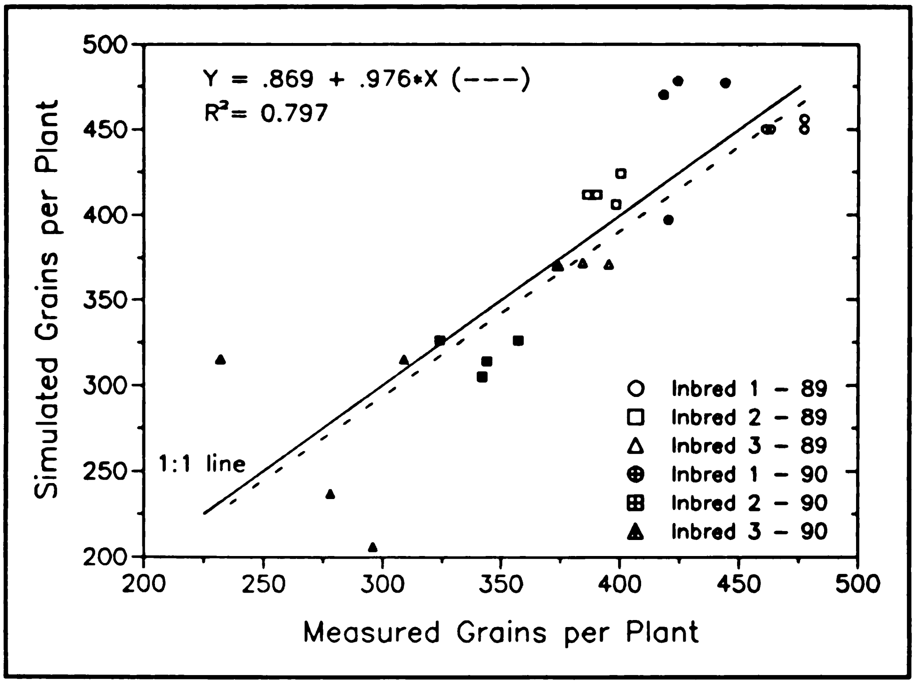

Figure 38. CERES-IM versus measured grains per plant for the three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

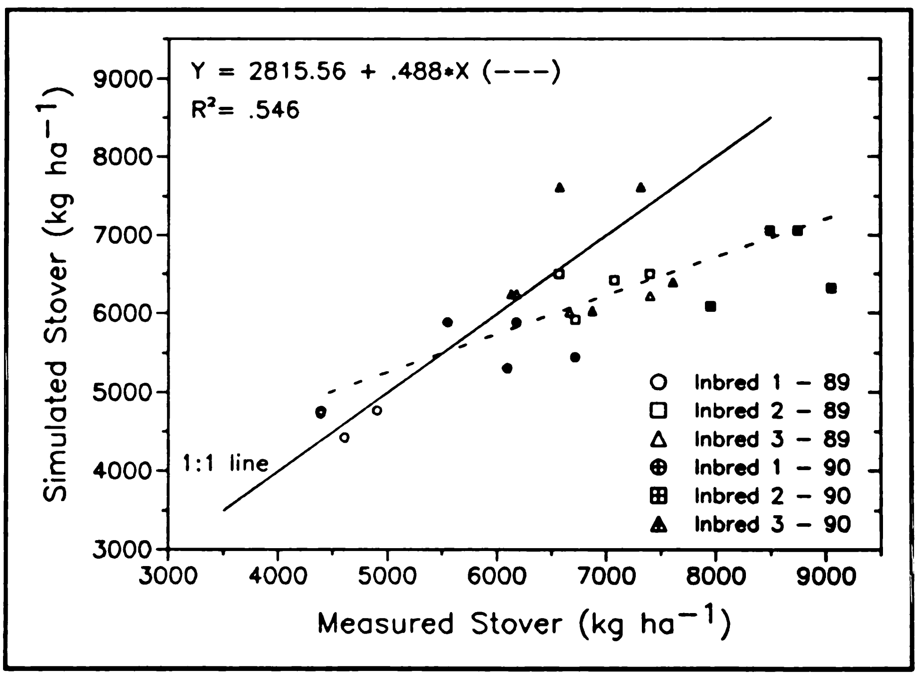

Figure 39. CERES-IM versus measured stover yield for the three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

Table 27. There is some discrepancy with inbred 3 in 1990, but the remainder of the data compared well.

The last of the biomass related comparisons made was the stover (Figure 39). Though a relatively low R^2 value was obtained from the regression analysis (0.546), Figure 39 does show a fair correlation. As in previous comparisons, data from inbred 2 in 1990 showed the poorest comparison. This is confirmed by the high MSEP value in Table 27. If the data for inbred 2, 1990, was removed from the analysis, the new R^2 value would be only .608. The MSEP value would be reduced from 978 kg ha^{-1} (16.7%) to 634 kg ha^{-1} (10.8%).

The nitrogen related plant data are graphically shown in Figures 40 through 43. The MSEP values are also given in Table 27. The percent nitrogen in the grain and related nitrogen uptake by the grain are shown in Figures 40 and 41. A comparison of the percent nitrogen in the grain showed a seemingly poor correlation with a R^2 value of only 0.135 because of the low range of values. However, the MSEP data in Table 27 indicates good predictive accuracy. In the simulation of nitrogen dynamics in CERES-IM, the maximum percent nitrogen that can be obtained in the grain is 1.70 percent. Given that no stress occurs and there is ample nitrogen for grain filling, the model will normally simulate a grain nitrogen content approximating 1.70%. The almost horizontal regression line in Figure 40 illustrates this. However, the MSEP given in Table 27 for percent nitrogen in the grain shows an error of less than 10% for the 3 inbreeds over the 2 year period. This is another example of how R^2 values can be misleading in evaluating model performance.

In the comparison of nitrogen uptake by the grain (Figure 41), the data compared well. The R^2 and MSEP values are reasonable and the regression line formula indicates a good comparison.

Figures 42 and 43 contain information on the nitrogen in the stover. For both the percent nitrogen in the stover (Figure 42) and the nitrogen uptake by the stover (Figure 43) CERES-IM underestimated as compared to the measured values. The values for the measured percent nitrogen range from 0.75 to 1.3 percent. However, CERES-IM simulated values range

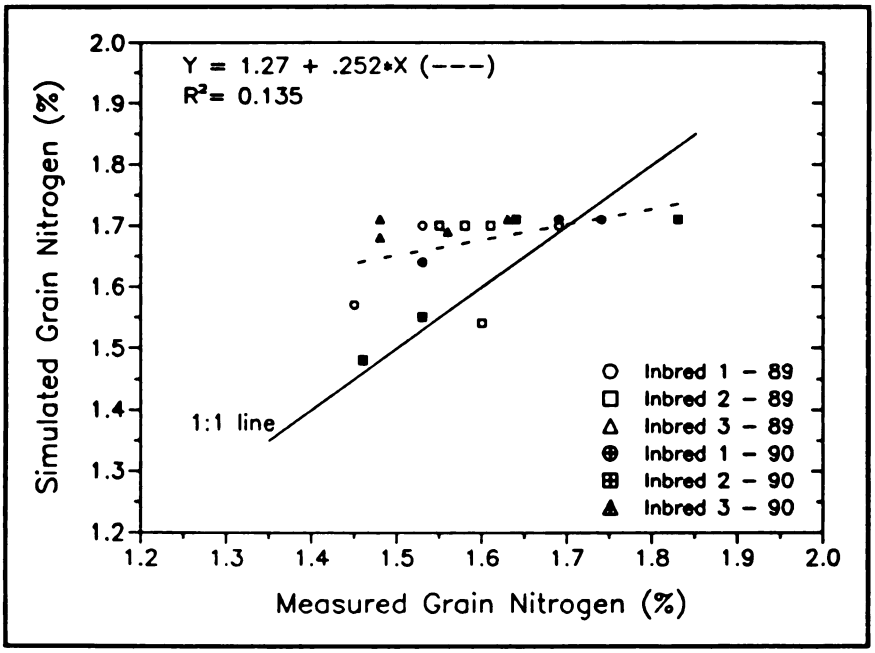

Figure 40. CERES-IM versus measured percent nitrogen in the grain for three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

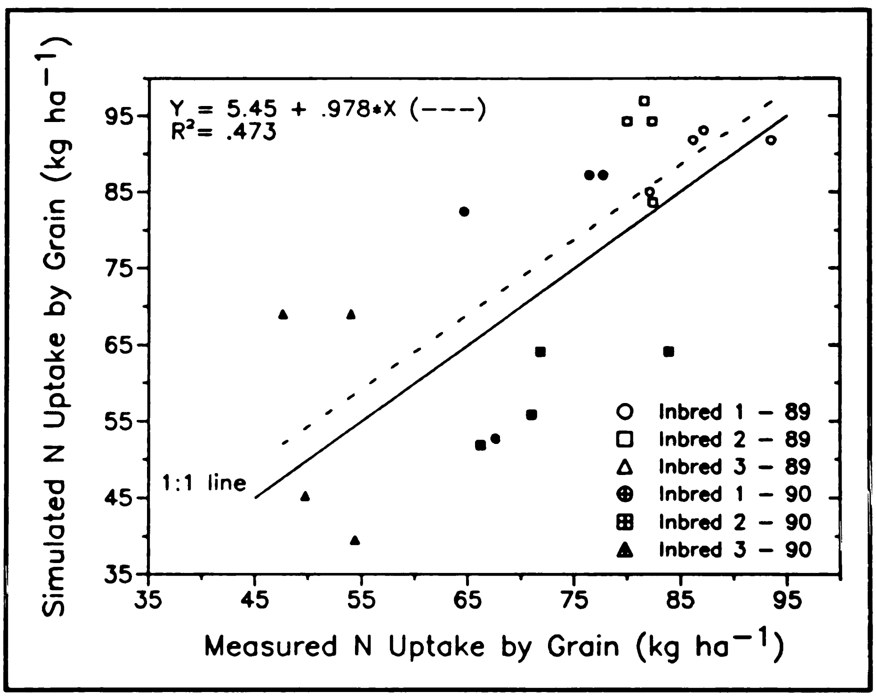

Figure 41. CERES-IM versus measured nitrogen uptake by the grain for the three inbreeds and the four treatments for ·1989 and 1990. Constantine, MI.

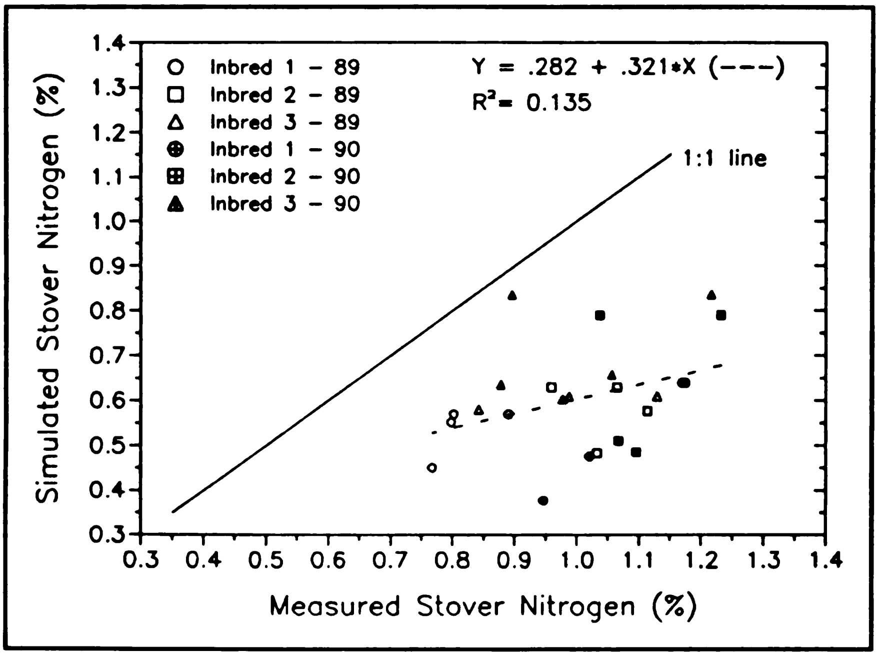

Figure 42. CERES-IM versus measured percent nitrogen in the stover for the three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

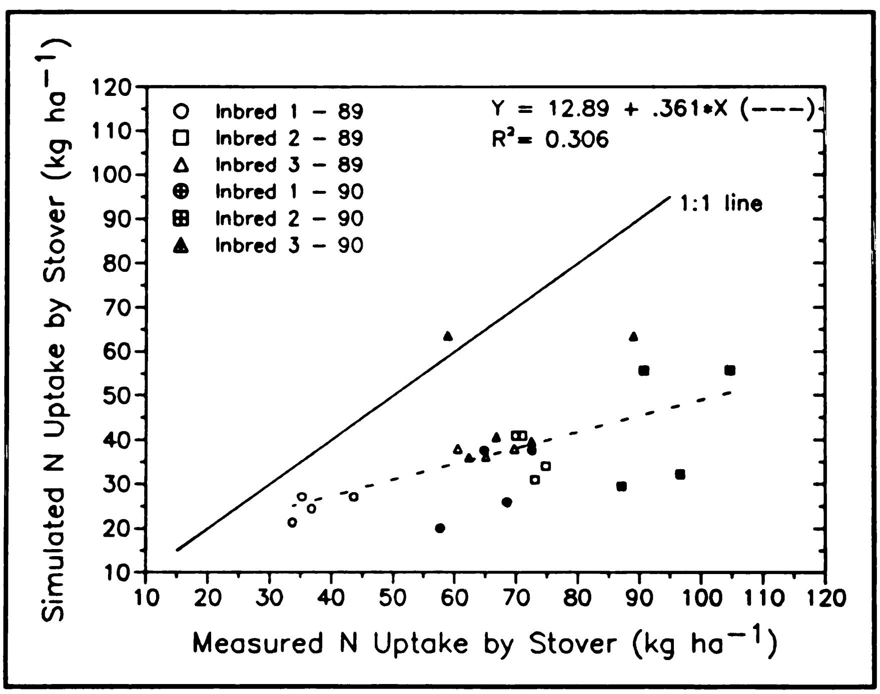

Figure 43. CERES-IM versus measured nitrogen uptake by the stover for the three inbreeds and the four treatments for 1989 and 1990. Constantine, MI.

from 0.35 to 0.85 percent. This seems to indicate that CERES-IM allowed the nitrogen content of the stover to fall too low and perhaps did not allow for enough nitrogen uptake to be simulated. There was also some question as to the cob nitrogen content. Though CERES-IM simulates the growth of the ear, it does not simulate the nitrogen in the ear independently of the other plant components. The measured data used for comparison of the stover nitrogen includes the nitrogen in the cob. This may explain the underestimation by CERES-IM. The discrepancy in the nitrogen uptake by the stover followed a similar pattern.

Another comparison made was above ground biomass accumulation during the growing season. As mentioned earlier, biomass samples were taken four times during the growing season. Because of the large number of comparisons, only inbred 2 will be discussed in depth. Inbred 2 was chosen because it showed the best and worst comparisons for above ground biomass and is the inbred that was grown on the lysimeter plots. However, all of the MSEP values for all of the inbreeds are in Table 28.

The MSEP values for the biomass were larger in 1990 than in 1989, except for inbred 3, sample 2 (Table 28). The largest increases came from inbred 2 and inbred 3. It is difficult to determine the exact causes of these increases. One definite factor is the zero nitrogen treatments in which CERES-IM underestimated grain and stover yields. Other factors such as amount of biomass removed by detasseling may have contributed. CERES-IM simulated values and those measured for above ground biomass for inbred 2, treatments 1 through 4, for 1989, are shown in Figures 44 through 47. For all four treatments, there was excellent agreement between CERES-IM and the measured values.

The comparison between modelled and measured above ground biomass for 1990 are shown in Figures 48 through 51. All four figures show a similar pattern: CERES-IM either simulated well or slightly overestimated above ground biomass accumulation through to the third sampling. Biomass accumulation for the fourth sample is underestimated by CERES-IM for all treatments.

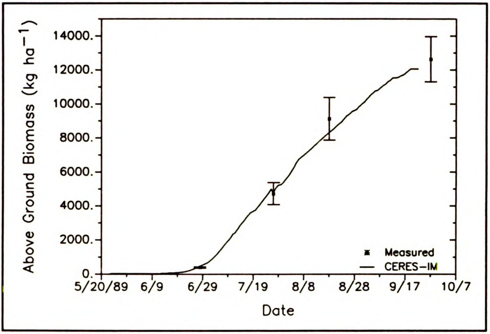

Figure 44. CERES-IM and measured above ground biomass values for inbred 2, treatment 1 (180pp). Constantine, MI, 1989.

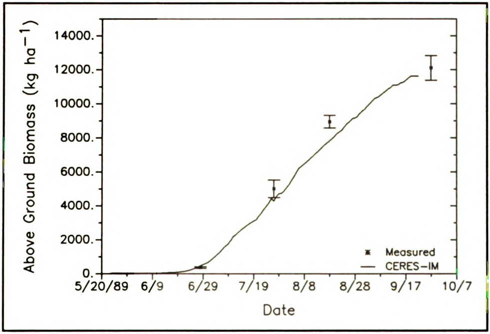

Figure 45. CERES-IM and measured above ground biomass values for inbred 2, treatment 2 (PRF - 80 kg N ha^{-1}). Constantine, MI, 1989.

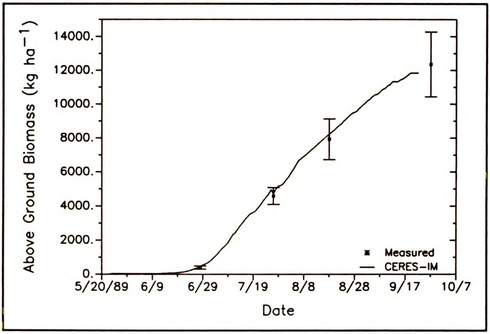

Figure 46. CERES-IM and measured above ground biomass values for inbred 2, treatment 3 (90s). Constantine, MI, 1989.

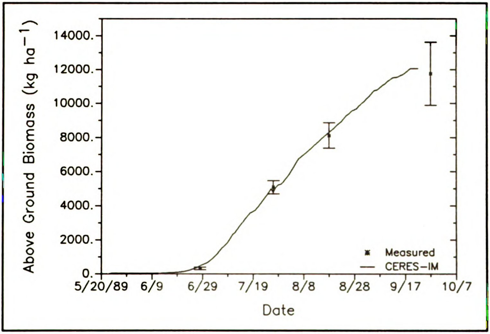

Figure 47. CERES-IM and measured above ground biomass values for inbred 2, treatment 4 (180s). Constantine, MI, 1989.

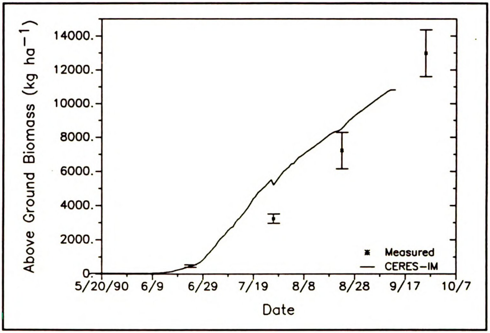

Figure 48. CERES-IM and measured above ground biomass values for inbred 2, treatment 1 (180pp). Constantine, MI, 1990.

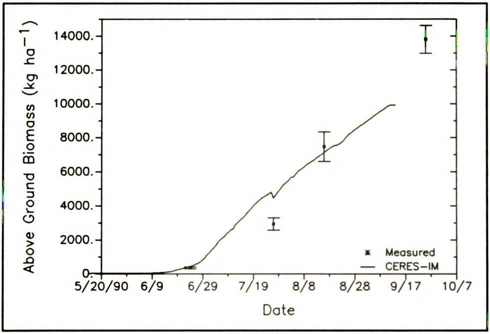

Figure 49. CERES-IM and measured above ground biomass values for inbred 2, treatment 2 (PRF - 0 kg N ha^{-1}). Constantine, MI, 1990.

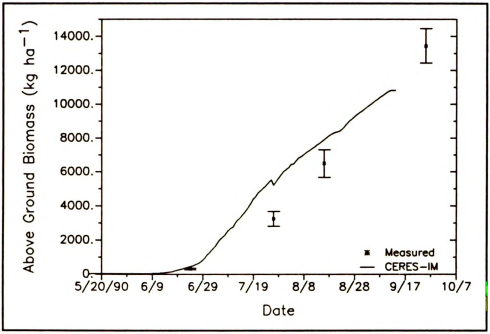

Figure 50. CERES-IM and measured above ground biomass values for inbred 2, treatment 3 (90s). Constantine, MI, 1990.

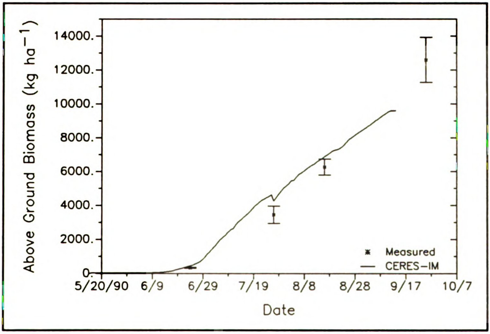

Figure 51. CERES-IM and measured above ground biomass values for inbred 2, treatment 4 (0 kg N ha^{-1}). Constantine, MI, 1990.

Table 28. MSEP values (kg ha^{-1}) of CERES-IM simulated values for above ground biomass for the 3 inbreeds, for all treatments, for 1989 and 1990. Constantine, MI.

Sampling* Date	MSEP FOR ABOVE GROUND BIOMASS (kg ha^{-1})						AVERAGE
	INBRED 1		INBRED 2		INBRED 3		
	1989	1990	1989	1990	1989	1990	
1	144	376	125	358	50	254	249
2	943	1278	428	1631	1064	1008	1119
3	794	878	712	1039	957	1555	986
4	350	425	479	2989	828	1643	1463

* Sampling dates for all inbreeds for 1989 were 1) June 28; 2) July 27; 3) August 18; and 4) September 27. Sampling dates for 1990 for inbred 1 were 1) June 24; 2) July 27; 3) August 16; and 4) September 12. Sampling dates for inbreeds 2 and 3 for 1990 were 1) June 24; 2) July 27; 3) August 23; and 4) September 25.

The final comparison made between simulated and measured values was leaf area index (LAI). LAI measurements were taken in 1989 only. All three inbreeds were measured using 15 plants from the 180 kg pp treatment (treatment 1). The comparisons of CERES-IM simulated and measured LAI values are shown in Figures 52 through 54. There was excellent agreement between CERES-IM simulated and measured LAI values. As seen in Figure 52, CERES-IM adequately simulated LAI for most of the season, though there is some discrepancy just after detasseling. The other two inbred, Figures 53 and 54, show excellent agreement throughout the season.

Drainage and Leaching Data

The lysimeter plots in this study were all planted with inbred 2. There were 5 drainage lysimeters installed: four with disturbed soil profiles and one with an undisturbed soil profile. There were four treatments and the undisturbed lysimeter was used as a replicate for one of the treatments. To keep the data consist with lysimeter type, only the undisturbed lysimeters were evaluated with the CERES-IM simulated data. Table 29 shows the lysimeter number and the nitrogen treatment used for 1989 and 1990. The undisturbed lysimeter was lysimeter number 3.

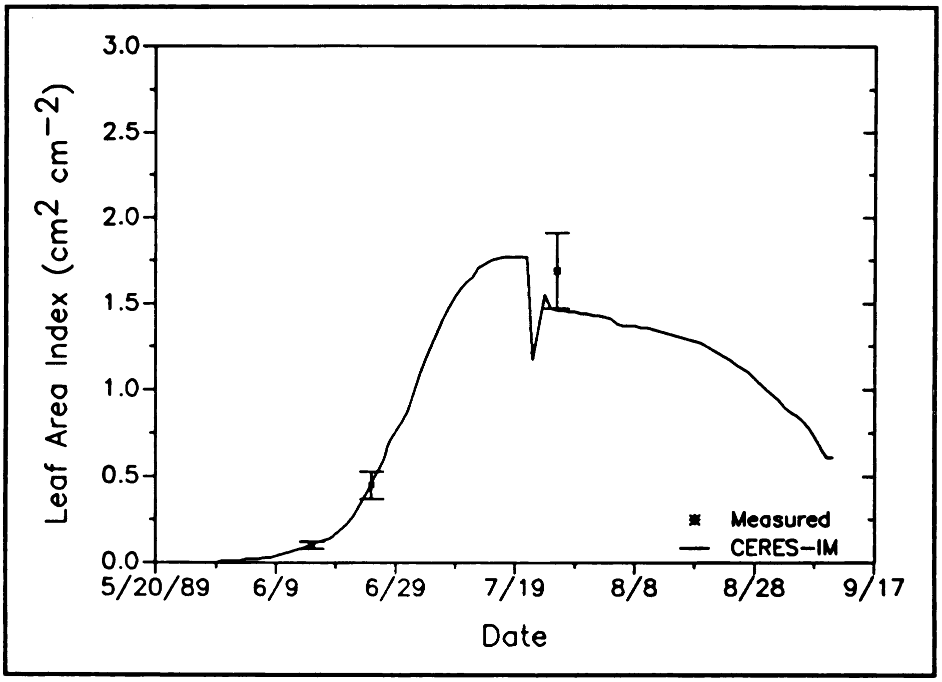

Figure 52. CERES-IM and measured LAI values for inbred 1, treatment 1 (180pp). Constantine, MI, 1989.

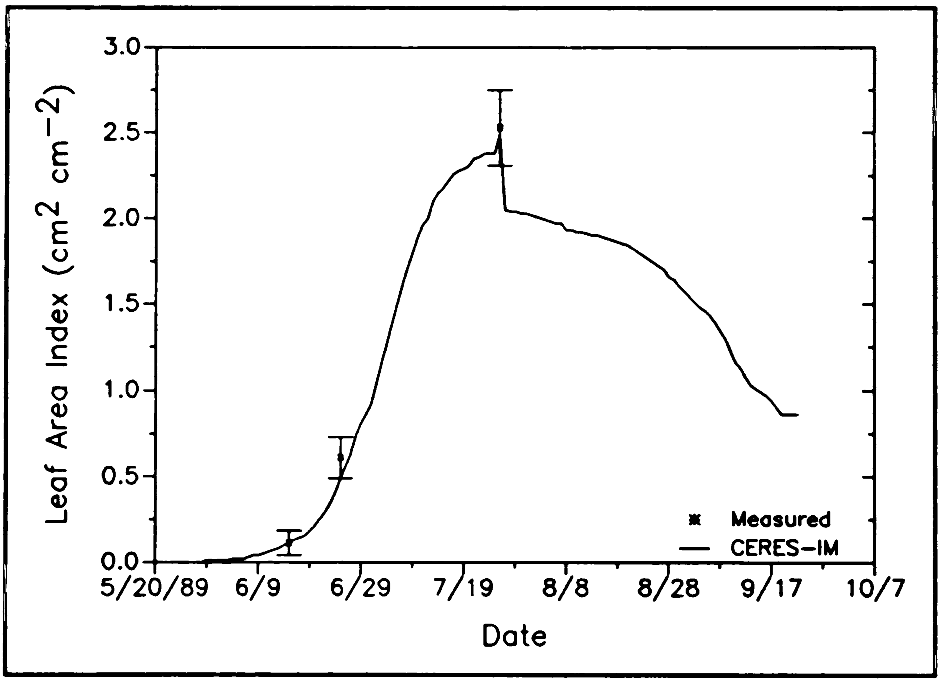

Figure 53. CERES-IM and measured LAI values for inbred 2, treatment 1 (180pp). Constantine, MI, 1989.

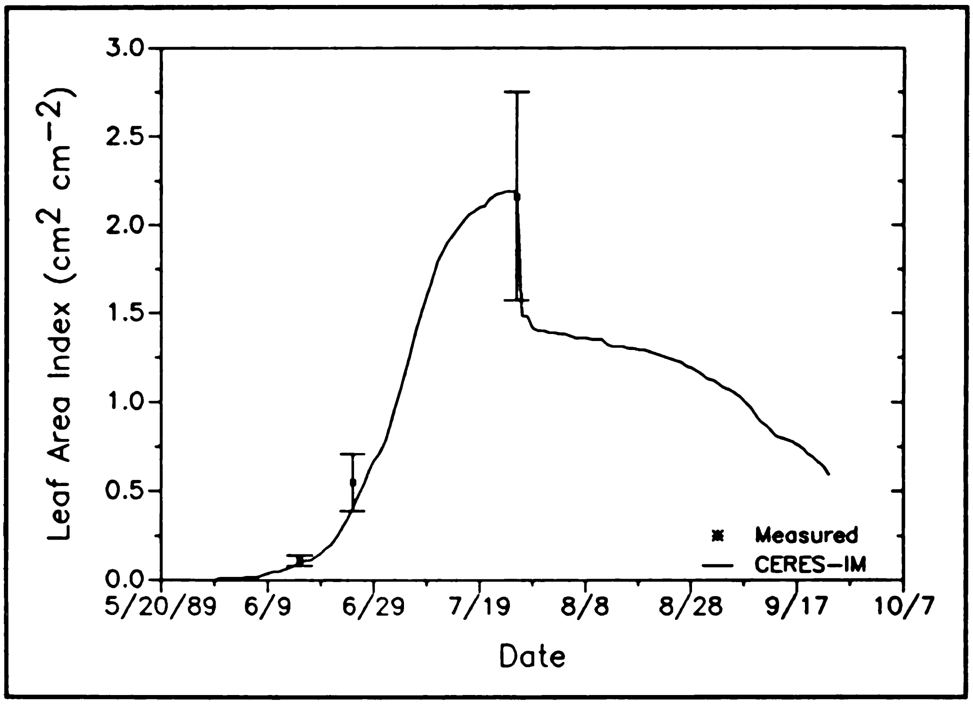

Figure 54. CERES-IM and measured LAI values for inbred 3, treatment 1 (180pp). Constantine, MI, 1989.

Table 29. List of the lysimeters and the nitrogen treatments used for 1989 and 1990. Constantine, MI

LYSIMETER (Trt n#)	TREATMENT (kg N ha^{-1})	
	1989	1990
1 (3)	90 split	90 split
2 (2)	80 PRF	0 PRF
4 (4)	180 split	0
5 (1)	180 preplant	180 preplant

Comparisons between the measured and simulated drainage data showed excellent results for both years of the study. The drainage data for 1989 is shown in Figures 55 through 58. For all four lysimeters, CERES-IM did a good job of following the flow of drainage water throughout the year, though there was some discrepancy at the beginning of the season. One explanation for this is the lag time for drainage to occur. Measurements taken have shown a lag time between

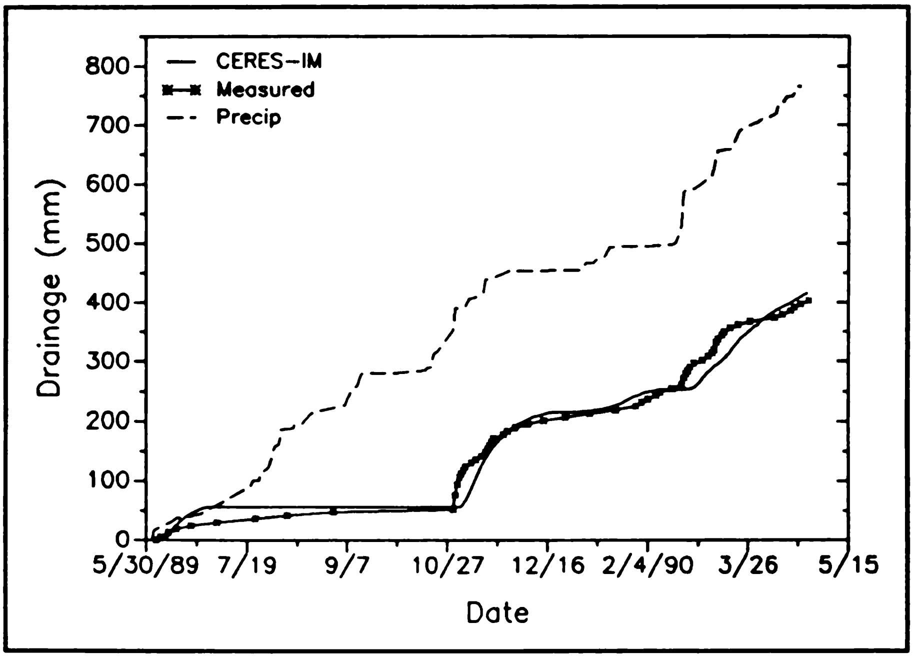

Figure 55. CERES-IM and measured drainage values for lysimeter 1, treatment 3 (90s). Precipitation is also shown. Constantine, MI, 1989.

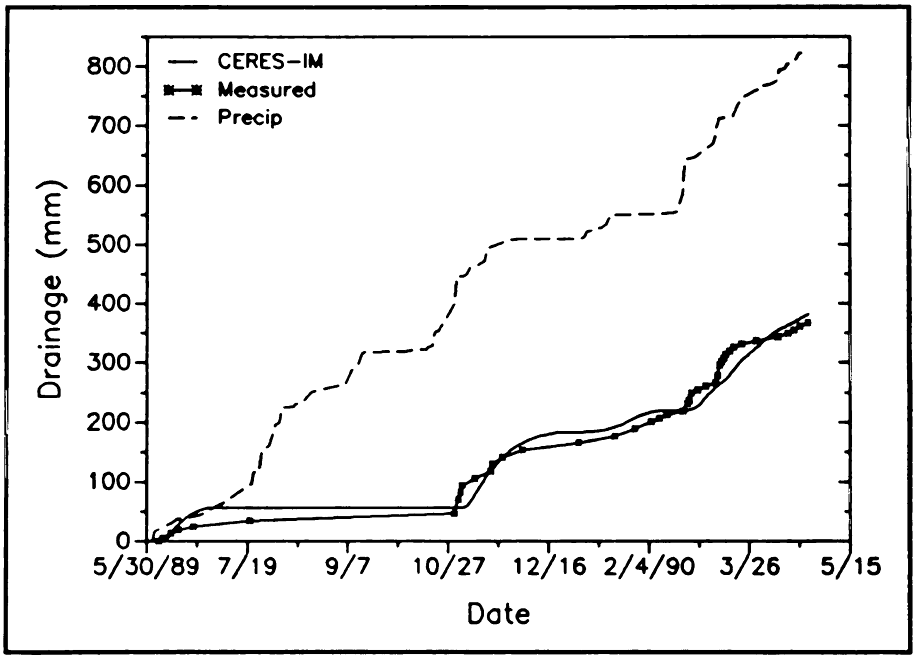

Figure 56. CERES-IM and measured drainage values for lysimeter 2, treatment 2 (PRF - 0 kg N ha^{-1}). Precipitation is also shown. Constantine, MI, 1989.

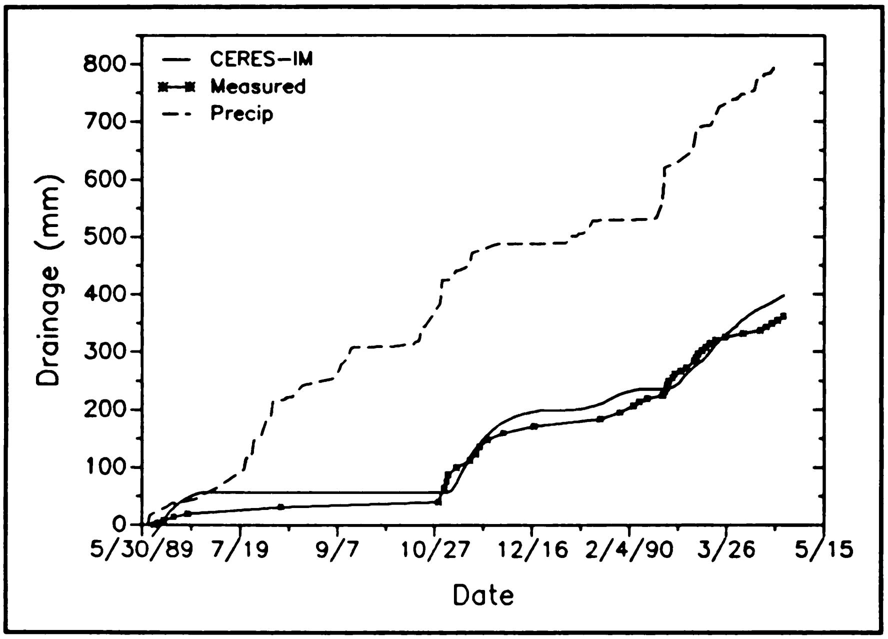

Figure 57. CERES-IM and measured drainage values for lysimeter 4, treatment 4 (180s). Precipitation is also shown. Constantine, MI, 1989.

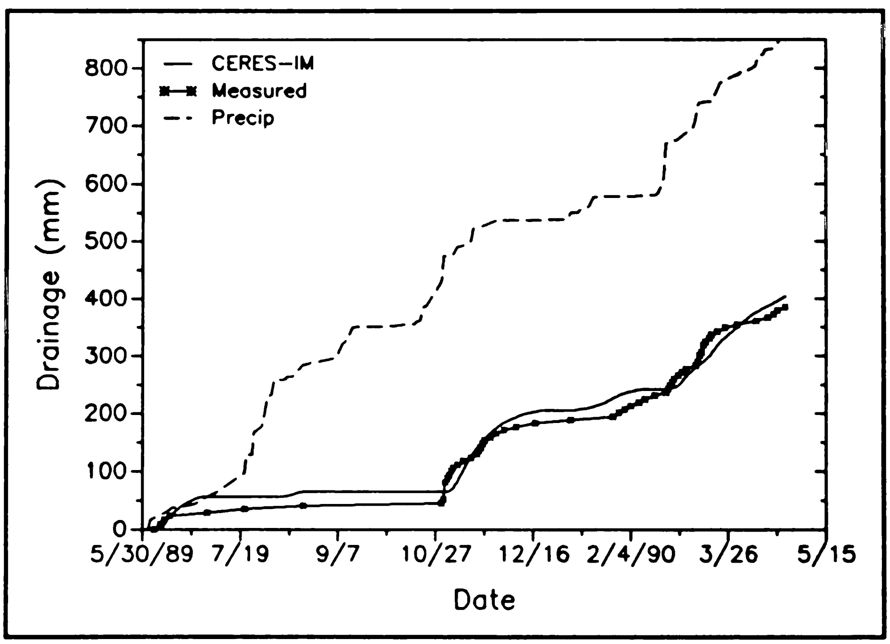

Figure 58. CERES-IM and measured drainage values for lysimeter 5, treatment 1 (180pp). Precipitation is also shown. Constantine, MI, 1989.

precipitation events and the drainage that these events cause. CERES-IM cannot adequately simulate this lag time because the bottom of the lysimeter causes a time delay in the outflow. However, most of the data showed good agreement.

The nitrate leaching data for 1989 did not compare as well as the drainage data. The comparison between CERES-IM and the measured values for nitrate leaching are shown in Figures 59 through 62. CERES-IM did a good job of simulating the nitrate leached for lysimeters 1 (90s) and 2 (PRF-80 kg N ha^{-1}), though the timing of when the nitrate leached does differ between the measured and simulated values (Figures 59 and 60). However, for lysimeters 4 (180s) and 5 (180pp), CERES-IM overestimated the nitrate leached by a factor of almost two (Figures 61 and 62). As seen in all four figures, there was a large increase in the nitrate leaching at the end of October. The reason for this was that a large irrigation was added to the lysimeters.

Following the summer of 1989, in which almost no drainage occurred, a large amount of irrigation water was applied to the plots to test the lysimeters and to assure there were no leaks in the system. The amount of irrigation water applied ranged from 250 mm to 350 mm. The irrigations took place over a 2-day period and applications were split between the two days. Fortunately, the application of the irrigation water showed no leaks in the systems. However, the large amount of drainage that occurred may have caused difficulties in simulating the nitrate leached. The large discrepancy between the simulated and measured values of nitrate leaching may have been caused by macropore flow. Macropore flow is water that flows through the macropores of the soil, coming in contact with little of the soil particles and leaching out minimal amounts of chemicals. If macropores were present in the lysimeters 4 (180s) and 5 (180pp), this could account for the discrepancies. Also, it should be noted that the measured amounts of nitrate leached from the lysimeters was not proportionate to the nitrogen fertilizer applications made.

The lysimeter with the largest amount of nitrate leaching was lysimeter 1, which received a nitrogen fertilizer application of 90 kg N ha^{-1} and leached a total of 90 kg N ha^{-1}. Lysimeter 5 received 180 kg N ha^{-1} of nitrogen fertilizer and leached about 80 kg N ha^{-1}. Lysimeters 2 and 4

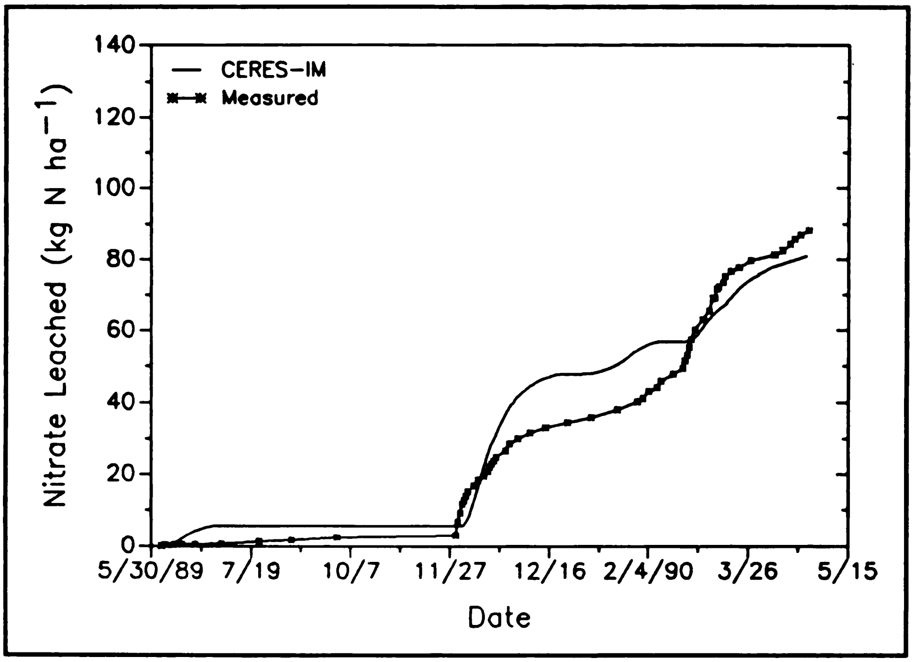

Figure 59. CERES-IM and measured nitrate leaching values for lysimeter 1, treatment 3 (90s). Constantine, MI, 1989.

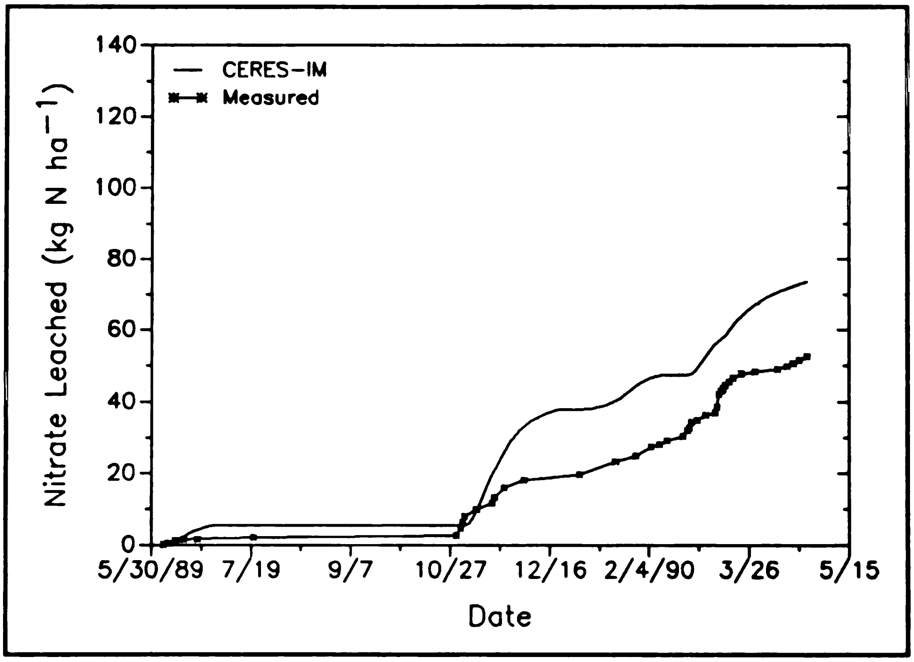

Figure 60. CERES-IM and measured nitrate leaching values for lysimeter 2, treatment 2 (PRF - 80 kg N ha^{-1}). Constantine, MI, 1989.

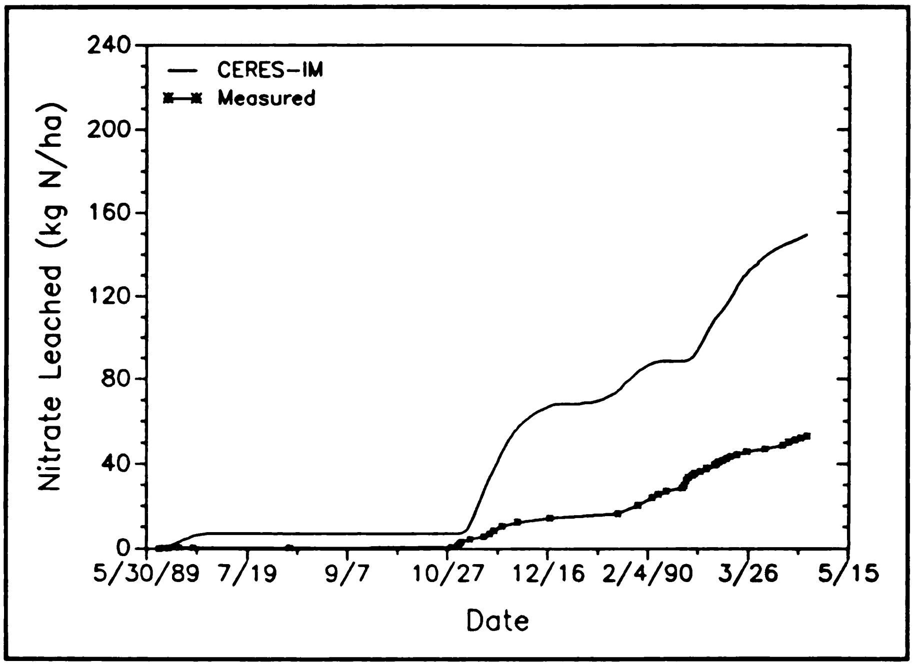

Figure 61. CERES-IM and measured nitrate leaching values for lysimeter 4, treatment 4 (180s). Constantine, MI, 1989.

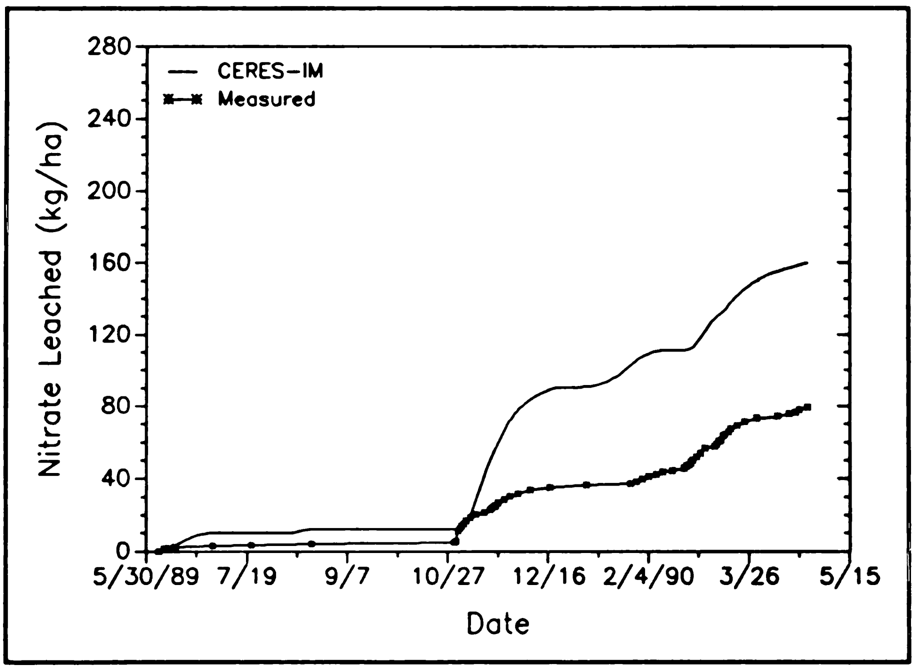

Figure 62. CERES-IM and measured nitrate leaching values for lysimeter 5, treatment 1 (180pp). Constantine, MI, 1989.

both leached about 55 kg N ha^{-1}. However, lysimeter 2 received only 80 kg N ha^{-1} while lysimeter 4 received 180 kg N ha^{-1}. The nitrate leaching simulated by CERES-IM follows the expected pattern with lysimeter 4 and 5, the 180 kg N ha^{-1} treatments, leaching about the same nitrate (160 kg N ha^{-1}) and lysimeters 1 and 2, which received 90 kg N ha^{-1} and 80 kg N ha^{-1}, leaching about same amount of nitrate (80 kg N ha^{-1}). Since the simulated data of CERES-IM follows logic concerning nitrogen added and nitrate leached, it seems to indicate that there were interactions which took place that CERES-IM could not account for or that the initial state was not properly described.

In the second year of the study, CERES-IM continued to show good ability to simulate the soil-water drainage from the lysimeters. The measured and simulated drainage values for the four lysimeters for 1990 are shown in Figures 63 through 66. Once again, some discrepancies occurred between the timing of the drainage, but overall, CERES-IM followed the drainage patterns measured.

The nitrate leaching data for 1990 is shown in Figures 67 through 70. All four lysimeters showed good agreement between CERES-IM simulated and measured values. All of the lysimeters showed a slight increase in loss during the early summer and then a leveling off of nitrate loss during the growing season. This is partly due to the plants using soil nitrogen and the low drainage that occurred during the season. Likewise, the graphs show the increase in nitrate leaching that occurred after the growing season, during the fall and early winter months. One graph of interest is that for lysimeter 5, the 180pp treatment (Figure 66). The nitrate loss for the lysimeter followed a similar pattern to that shown by the other lysimeters for most of the year. However, toward the end of the year, the nitrate loss sharply increased. This is probably due to the nitrogen fertilizer treatments over the last two years (180 kg N ha^{-1} applied each year). CERES-IM simulated this loss well, though the total nitrate loss was slightly overestimated.

The data presented here have shown that CERES-IM can adequately simulate inbred maize yield and development. Additionally, CERES-IM can simulate drainage through the soil profile and the nitrate loss associated with the drainage. The next step was to use CERES-IM

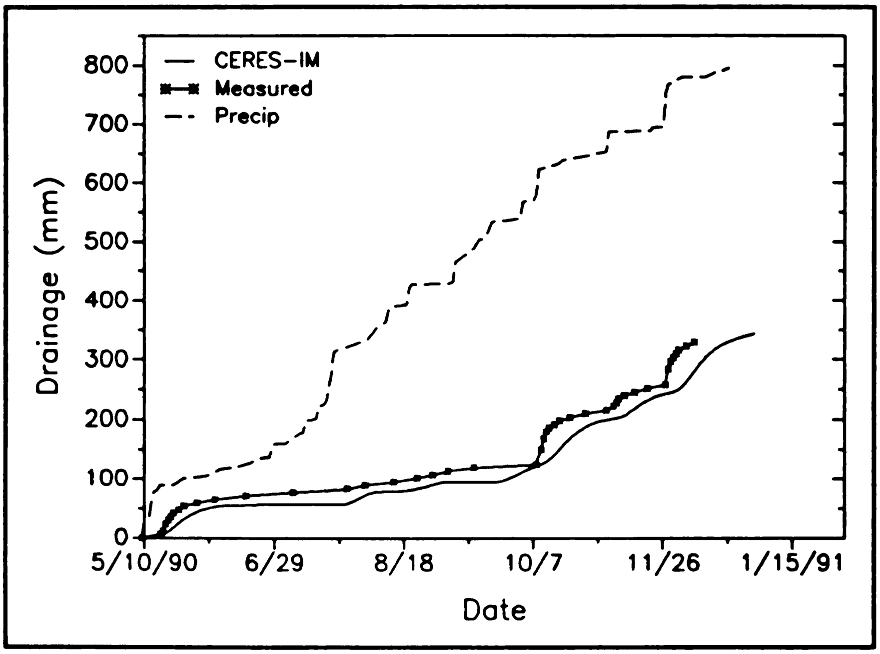

Figure 63. CERES-IM and measured drainage values for lysimeter 1, treatment 3 (90s). Also shown is the precipitation. Constantine, MI, 1990.

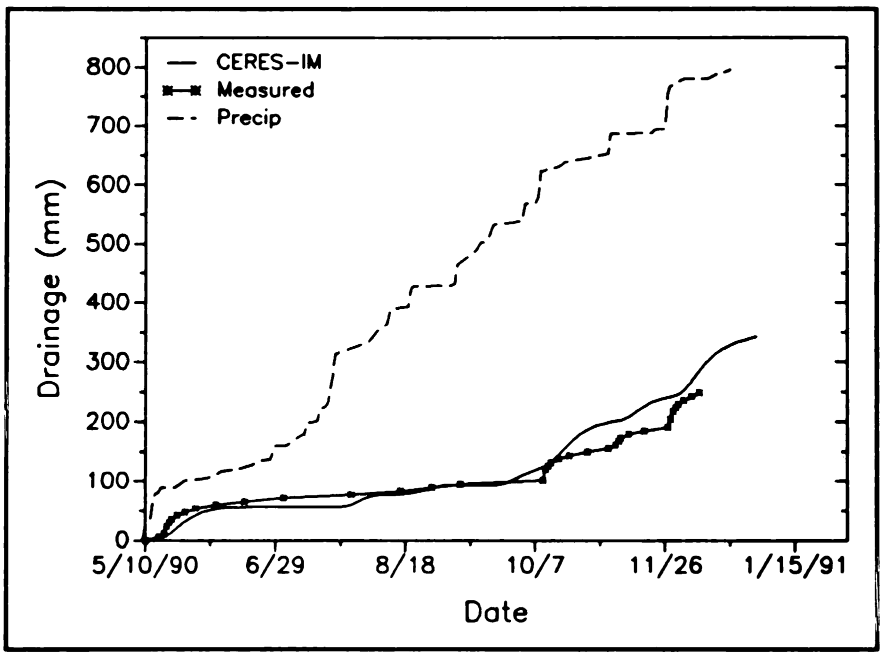

Figure 64. CERES-IM and measured drainage values for lysimeter 2, treatment 2 (PRF - 0 kg N ha^{-1}). Precipitation is also shown. Constantine, MI, 1990.

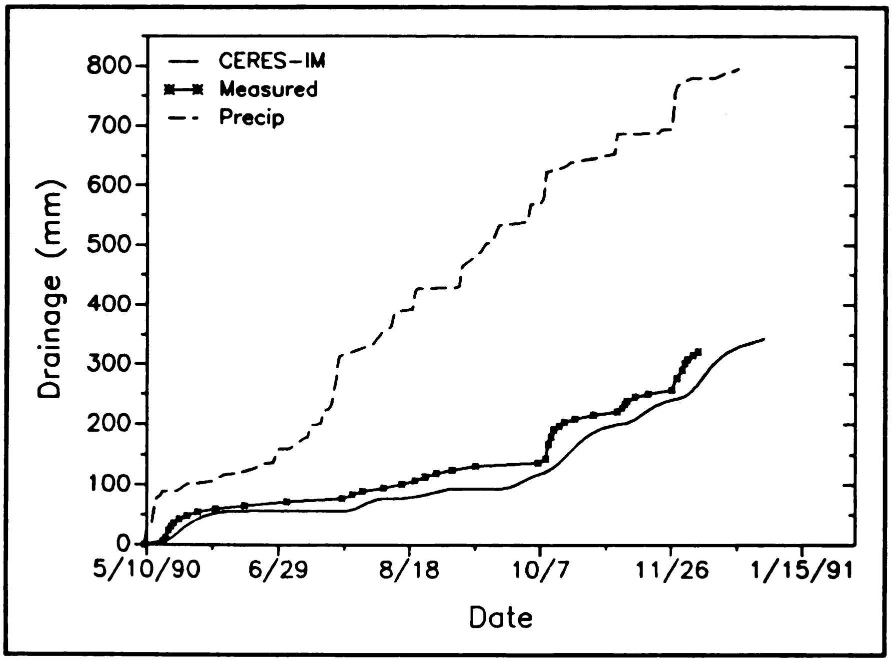

Figure 65. CERES-IM and measured drainage values for lysimeter 4, treatment 4 (0 kg N ha^{-1}). Precipitation is also shown. Constantine, MI, 1990.

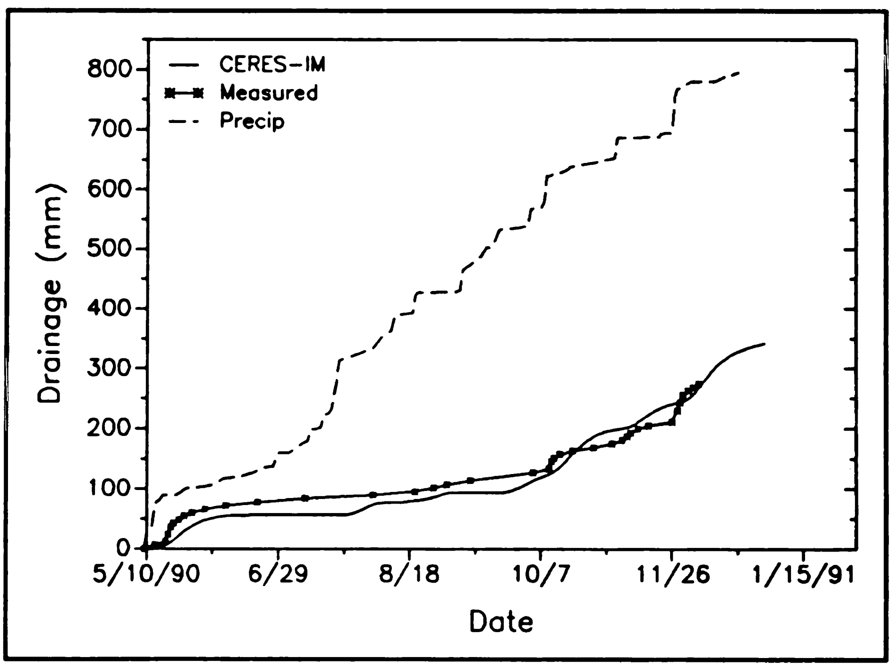

Figure 66. CERES-IM and measured drainage values for lysimeter 5, treatment 1 (180pp). Precipitation is also shown. Constantine, MI, 1990.

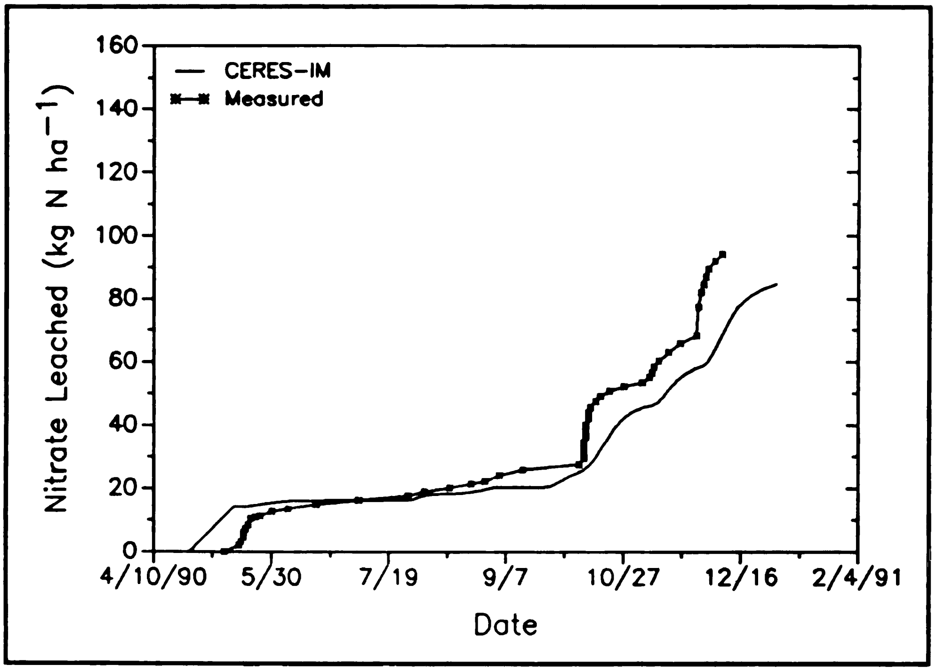

Figure 67. CERES-IM and measured nitrate leaching values for lysimeter 1, treatment 3 (90s). Constantine, MI, 1989.

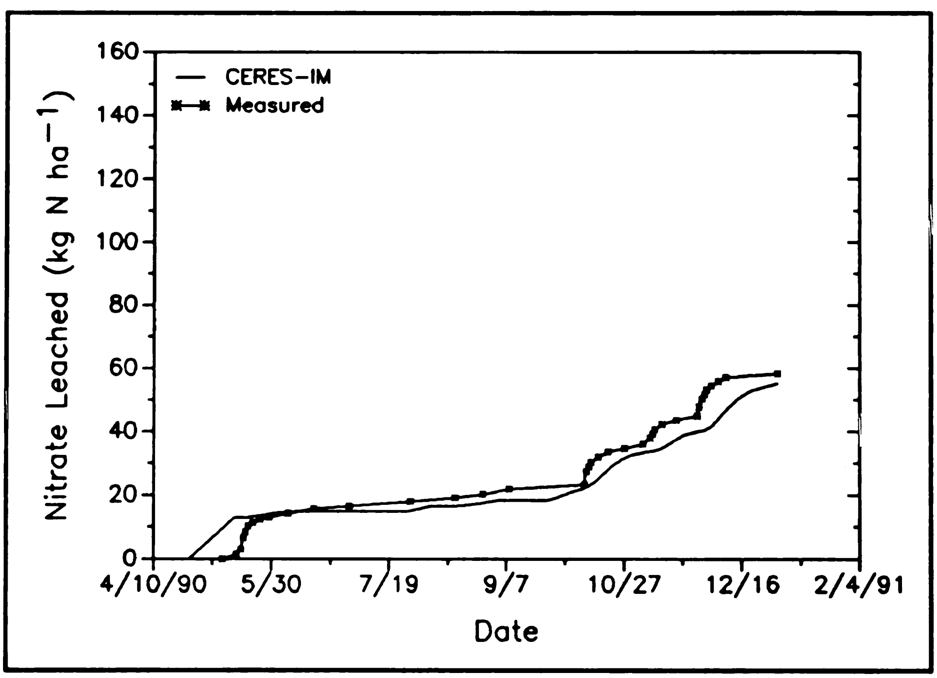

Figure 68. CERES-IM and measured nitrate leaching values for lysimeter 2, treatment 2 (PRF - 0 kg N ha^{-1}). Constantine, MI, 1990.

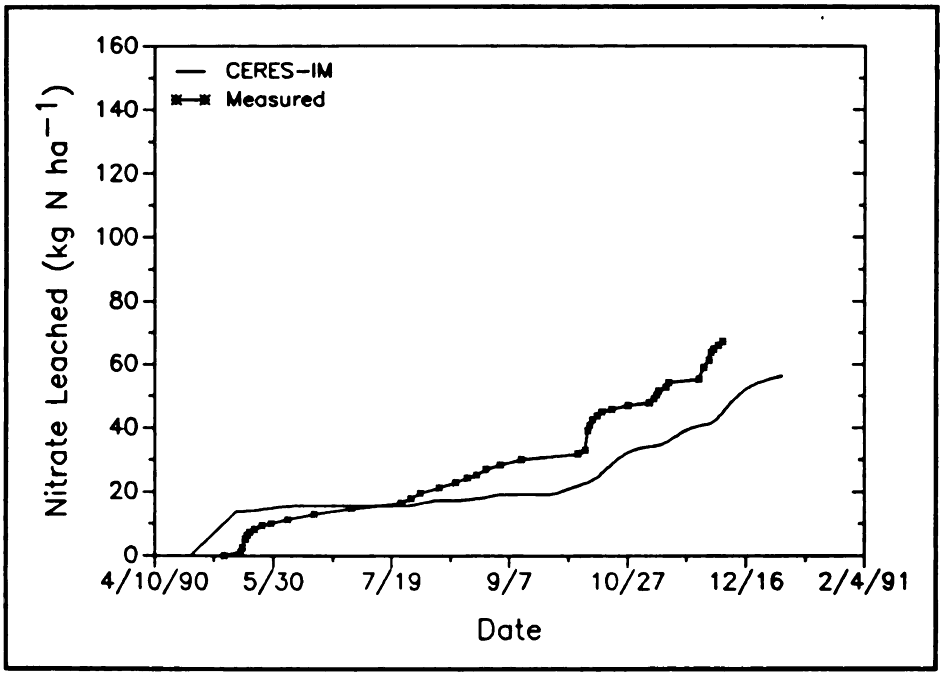

Figure 69. CERES-IM and measured nitrate leaching values for lysimeter 4, treatment 4 (0 kg N ha^{-1}). Constantine, MI, 1990.

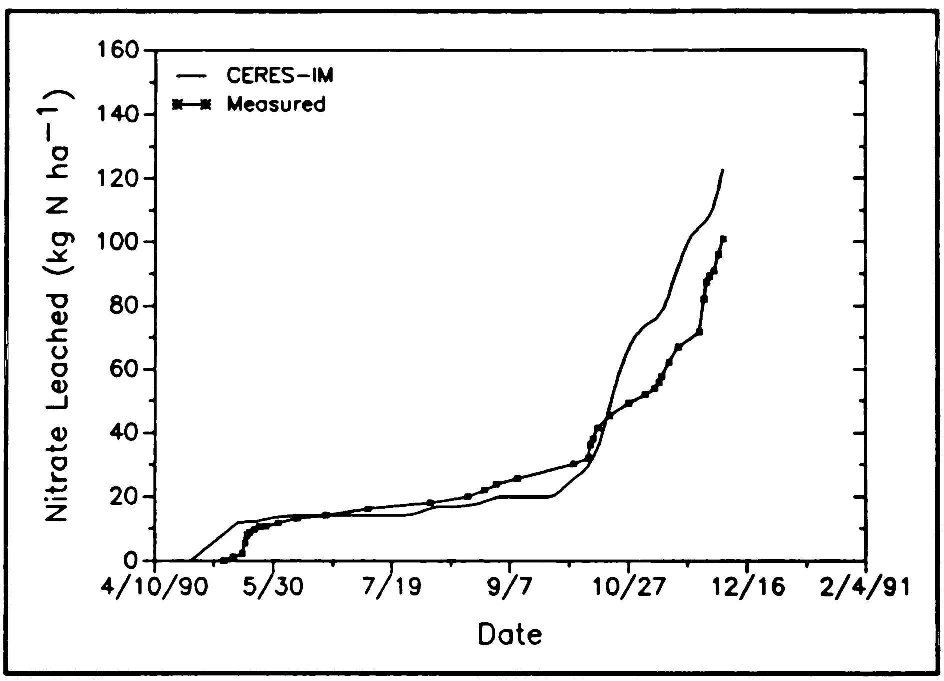

Figure 70. CERES-IM and measured nitrate leaching values for lysimeter 5, treatment 1 (180pp). Constantine, MI, 1990.

investigate the possible effects of various nitrogen management schemes on grain yield and nitrate leaching. To do this, several years of simulated weather data were used and some additional reprogramming of the model was performed.

Evaluation of Nitrogen Management Strategies

The nitrogen management strategies were evaluated over a 60 year time period. The data were examined in 30 year intervals to determine if the first 30 years was significantly different than the last 30 years. However, the data showed no significant differences for any of the strategies. Additionally, differences in the PRF strategies with regards to the plant stage limitation set were also minimal, except for the 30 kg N ha^{-1} threshold value. Therefore, the strategy that limited nitrogen fertilizer application after grain filling were deleted from the analysis for the PRF-Auto N , the PRF-15/15, and the PRF-15/0 strategies. The analyses for the PRF-30/30 and the PRF-30/0 included the growth stage limitations as an example.

The average yield for the 60 year period for the strategies evaluated are presented in Figure 71. The zero nitrogen strategy had the lowest average yield, as expected. The two 180 kg N ha^{-1} strategies yielded the highest, with an average of 5758 kg ha^{-1}. The next highest yielding strategies were the two PRF-30/30 strategies and followed by the PRF-15/15 and the PRF-Auto N. The lowest average yields, besides the zero nitrogen strategy, were produced by the two PRF-30/0 strategies. This would indicate that if 30 kg of nitrogen is required, some nitrogen should be added. The data from the PRF-15/0 suggest that the threshold value should be somewhere between 15 and 30 kg N.

In conjunction with average grain yield, it is also important to know the variation of the yields from year to year. Often, the strategy that yields the highest average grain yield is not the most stable strategy. However, in this case it was. Table 30 contains data on the CVs of the grain yields for the 11 strategies presented in Figure 71. The strategy with the lowest CV was the 180 pp strategy. The highest was, as expected, the zero nitrogen treatment. The two PRF-30/0 strategies also showed relatively high variation. The remainder of the strategies had

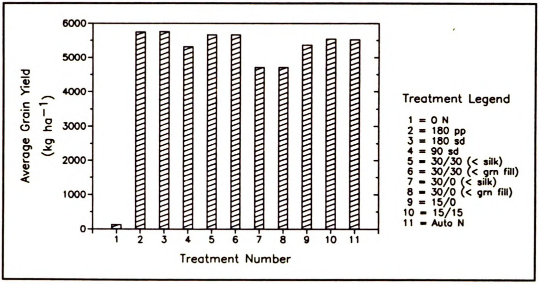

Figure 71. Average grain yield for the 11 strategies evaluated for the 60-year continuous simulation.

Table 30. Coefficient of variation expressed as a percentage for grain yields for a 60 years CERES-IM simulation run.

Strategy	Coefficient of Variation
Zero N	182.60
180 pp	15.78
180 sd	16.26
90 sd	19.71
30/30 (< silk)	16.54
30/30 (< grn fill)	16.83
30/0 (< silk)	29.69
30/0 (< grn fill)	29.69
15/0	19.27
15/15	17.09
Auto N	17.29

relatively the same variation, with CVs ranging from 16.29 to 19.71. The highest of these was the 90 sd strategy.

All of the strategies evaluated had the same inputs and initial conditions except for the nitrogen management. For some strategies, the amount of nitrogen fertilizer applied was fixed (i.e., 180 pp, 180 sd, 90 sd). For the PRF strategies, the amount of nitrogen fertilizer applied varied depending on the threshold value used. The average amount of nitrogen fertilizer added for each strategy is shown in Figure 72. The strategies of most interest are the PRF strategies.

The PRF-30/30 strategies show a slight increase between the silking day restriction and the grain fill restriction. This increase was also seen in the PRF-15/15 (only silking day restriction shown). The two PRF-30/0 strategies applied the same amount of nitrogen, but less than either PRF-30/30 strategy. This trend was also seen in the PRF-15/0 strategies (only silking day restriction shown).

Leaching amounts are presented in Figure 73. These data follow a somewhat expected trend with the two 180 kg N ha^{-1} strategies leaching the most nitrate with an average of approximately 111 kg N ha^{-1} yr^{-1}. Also, the zero nitrogen strategy yielded the lowest leaching average, with about 50 kg N ha^{-1} leaching annually. One strategy that also produced relatively low leaching amounts was the 90 kg N ha^{-1} sidedress. The leaching amount from this strategy was slightly lower than the two PRF-30/0 strategies while the yield was significantly higher. However, the yields from the other PRF treatments were slightly higher than the 90 sd. This may indicate that the 90 sd strategy, which is fairly straight forward and easy to manage, is comparable to the more manage intensive PRF strategies.

A final evaluation made of these nitrogen strategies was a simple economic analysis. Since only the nitrogen fertilizer applications and irrigation water applications were the only inputs that varied among strategies, only the costs associated with these two inputs were

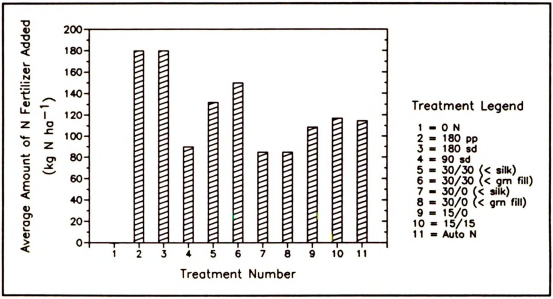

Figure 72. Average annual amount of nitrogen fertilizer added for the 11 strategies evaluated for the 60-year continuous simulation.

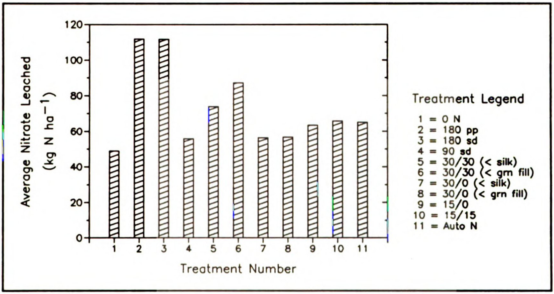

Figure 73. Average annual nitrate leaching for the 11 strategies evaluated for the 60-year continuous simulation.

considered. Thus, the fixed production costs are not subtracted. The formula used to compute the average revenue is:

$$REV = YLD * 0.108 -((NIT * 0.40) + (NFERT * 12.00) + (AMIRR * 0.14))$$

where REV is the revenue ($\$ ha^{-1}$), YLD is the grain yield ($kg\ ha^{-1}$), NIT is the amount of nitrogen fertilizer added ($kg\ N\ ha^{-1}$), NFERT is the number of nitrogen fertilizer applications made (applications yr^{-1}), and AMIRR is the amount of irrigation water applied (mm). The constants used are based on cost incurred in the inbred study discussed earlier.

The revenue values from the 11 strategies evaluated are shown in Figure 74. Once again, the zero nitrogen strategy had the lowest amount, with a revenue of only \$14.12 ha^{-1}. The 180 pp strategy yielded the highest average revenue, \$529.30 ha^{-1}. The lowest revenue, besides the zero N strategy, was obtained with the two PRF-30/0 strategies. The remainder of the strategies varied from about \$498 ha^{-1} to \$518 ha^{-1}. Also, it should be noted that the 90 sd strategy again ranked high as it did in the yield data. Only the 180 pp, the 180 sd, and one of the PRF-30/30 strategies yielded more revenue. With the low leaching amount shown earlier, the 90 sd strategy must be considered as the viable strategy of this evaluation in terms of revenue, minimal leaching, and management required.

Another alterative method to evaluating these strategies is to plot the revenue data against the leaching data, as shown in Figure 75. With revenue on the y-axis and leaching on the x-axis, the most optimal strategy in terms of revenue would be the data point closest to the top of the graph. However, the most optimal strategy in terms of nitrate leaching is the data point furthest to the left of the graph. Unfortunately, the most optimal point in terms of revenue is also the least optimal point in terms of leaching. The 180 pp strategy yielded the largest revenue and the largest annual nitrate leaching. The converse is true for the most optimal strategy in terms of leaching. The zero nitrogen strategy yielded the lowest nitrate leaching but also yielded the lowest revenue. Therefore, the point of compromise must lie between these two strategies. In Figure 75, this is the point that lies furthest to the top and furthest to the left, which is the 90 sd strategy.

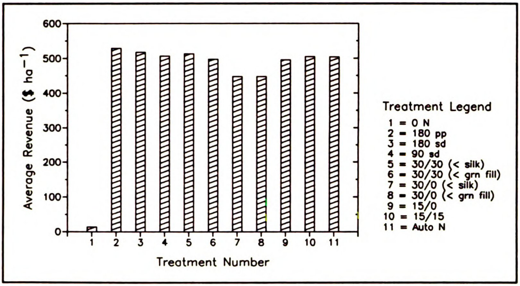

Figure 74. Average annual revenue for the 11 strategies evaluated for the 60-year continuous simulation.

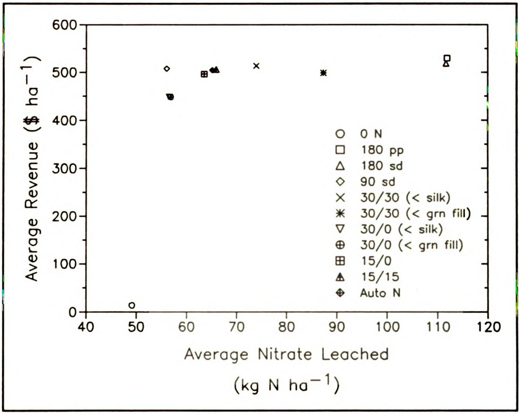

Figure 75. Average annual revenue and annual nitrate leaching for the 11 strategies evaluated for the 60-year continuous simulation.

Once again, the 90 sd strategy must be considered as a viable strategy to minimize nitrate leaching while maintaining a profitable yield.

To investigate a possible improvement on the 90 sd strategy, additional sidedress strategies were simulated. These strategies include a 100, 110, 120, 130, 140, and 150 kg N ha^{-1}. In each case, 30 kg N ha^{-1} was applied at planting and the remainder of the nitrogen was applied at V6, the same time the second application of the 90 sd was made. This was done to determine if there existed an amount between the 90 sd and the 180 pp strategy that yielded the same or greater revenue than the 180 pp strategy but still minimized the nitrate leached.

The yield data for the different sidedress strategies is shown in Figure 76. The yields steadily increased as the amount of nitrogen fertilizer added increased until about 130 kg N ha^{-1}. At this point, the yield differences between the strategies became extremely small. The CVs for the yields are shown given in Table 31. The nitrate leaching data are shown in Figure 77. The amount of nitrate leached increased as the amount of nitrogen fertilizer applied increased.

The data on the revenue for the strategies are shown in Figure 78. The revenue graph followed more closely the yield data shown in Figure 76. However, as the amount of nitrogen applied increased past 130 kg N ha^{-1}, the amount of revenue actually decreased. This is because the extra profit from the increase in yield cannot pay for the extra cost in nitrogen fertilizer.

Finally, the revenue data versus the leaching data are shown in Figure 79. The data points formed an arc within the graph, with the 130 kg N ha^{-1} at the top. Though the 130 sd strategy does provide for about \$27 ha^{-1} more in revenue over the 90 sd strategy, it also leaches an additional 22 kg N ha^{-1} of nitrate. A possible optimal strategy taken from a path along the curve where the curvature is the greatest at about the 110 sd treatment. Note that compared to the 90 sd treatment, the 110 sd treatment gives 263 kg ha^{-1} more yield and \$9.65 ha^{-1} more revenue, with only about 4 more kg N ha^{-1} leaching.

As previously mentioned, the PRF-30/30 strategy yielded a slightly higher revenue than the 90 sd strategy, but with some additional nitrate leaching. The 110 sd strategy also yielded a slightly higher average revenue than the 90 sd strategy, but with only a minimal increase in

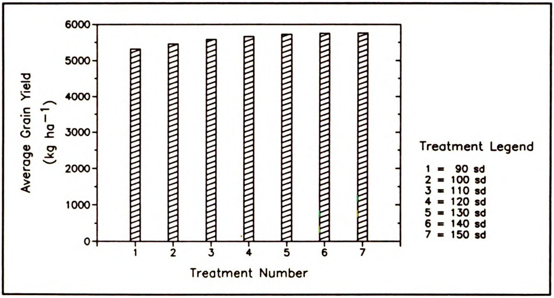

Figure 76. Average grain yield for the seven sidedressed strategies evaluated for the 60-year continuous simulation.

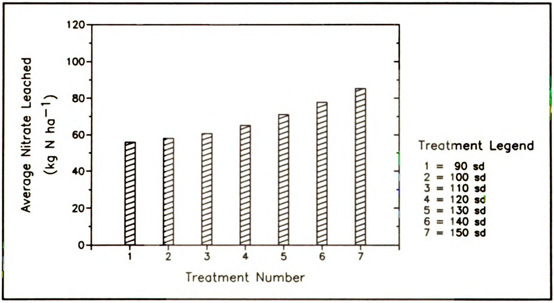

Figure 77. Average annual nitrate leaching for the seven sidedressed strategies evaluated for the 60-year continuous simulation.

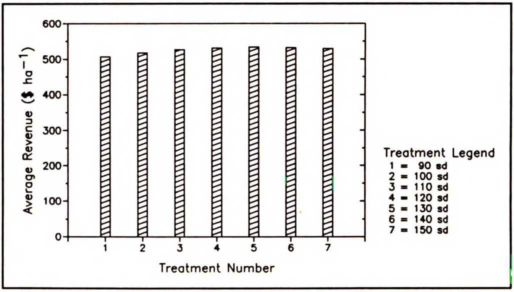

Figure 78. Average annual revenue for the seven sidedressed strategies evaluated for the 60-year continuous simulation.

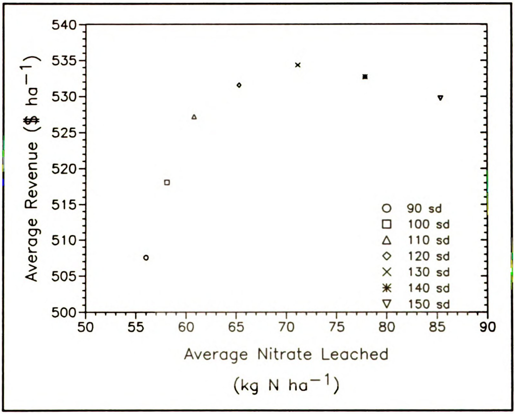

Figure 79. Average annual revenue and nitrate leaching for the seven sidedressed strategies evaluated for the 60-year continuous simulation.

nitrate leaching. To help compare these strategies, the annual revenues for the 60 year period were sorted and plotted as cumulative probabilities in Figure 80. As seen in Figure 80, all of the strategies obtained approximately the same revenue at 100% cumulative probability. As the cumulative probability decreases, the curve of 90 sd strategy begins to diverge from the other two curves. This shows the increase in variability in the 90 sd strategy. It also shows that the 110 sd and the PRF-30/30 strategies have virtually the same probability of revenue. The strategy that should be chosen in Figure 80 is the strategy that lies furthest to the right. However, since the 110 sd and the PRF-30/30 strategy cannot be distinguished from each other, either of these strategies can be chosen based on cumulative probability. However, based on revenue, leaching, and management required, the 110 sd strategy would be the strategy of choice.

Table 31. Coefficient of variation expressed as a percentage for grain yields for a 60 years CERES-IM simulation run.

Strategy	Coefficient of Variation
90 sd	19.71
100 sd	18.88
110 sd	18.27
120 sd	17.70
130 sd	16.71
140 sd	16.29
150 sd	16.07

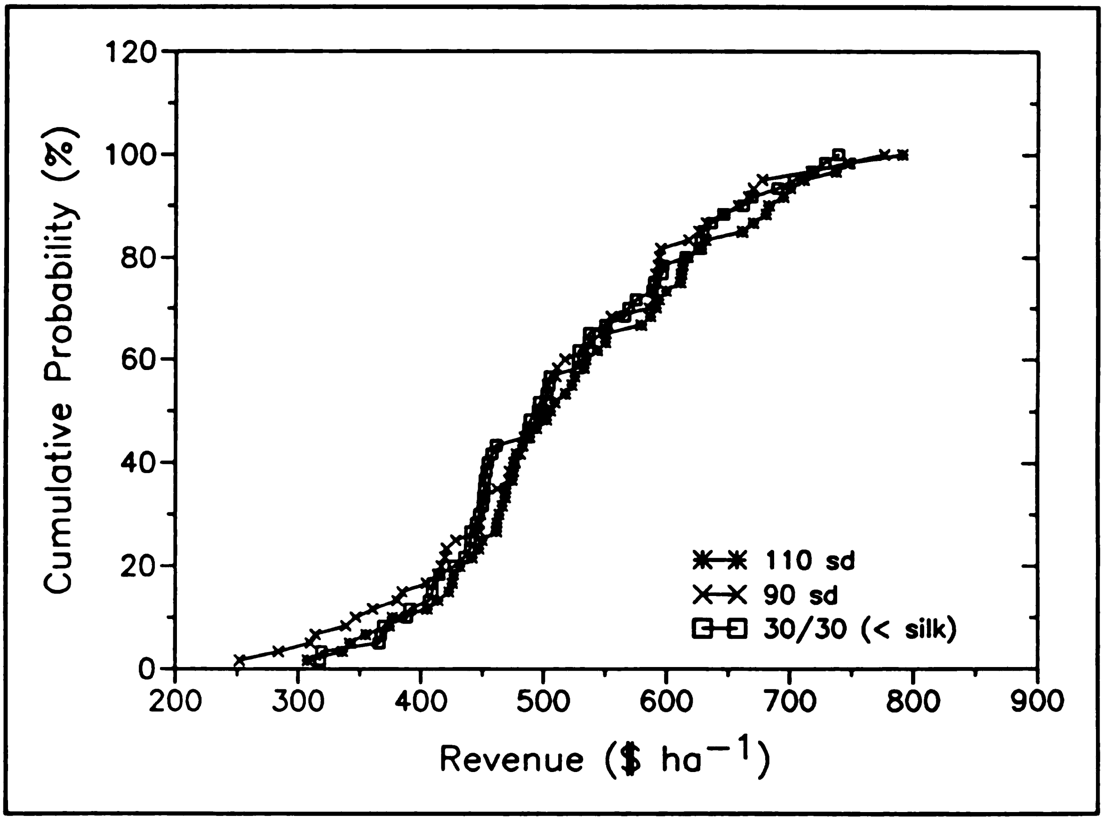

Figure 80. Cumulative probability of the annual revenue for selected strategies for the 60-year continuous simulation.

SUMMARY AND CONCLUSIONS

Objective 1: Develop a computer program that adequately simulates inbred maize growth and development as well as soil-plant interactions for water and nitrogen dynamics.

The CERES-IM model developed for this study has shown a good ability to simulate inbred growth and development. Using the CERES-Maize model as a basis has allowed for the development of a model that can actually simulate both inbred and hybrid maize.

In order to simulate inbred maize growth and development, CERES-Maize was first reprogrammed to simulate the unique field operations of seed corn production such as detasseling, the removal of the male plants, and the designation and interaction of male and female plants. The removal of the male plants was easily handled by changing code to end plant growth on the date of removal. The detasseling routine required more integration with other components of the model but the change was not drastic. The interaction of the male and female plants did, however, pose several questions.

In seed corn production, the male plants are grown only to provide the necessary pollen needed to pollinate the female plants. The actual yield of the male plants is of no concern to most growers, though some companies allow the growers to harvest the male rows and sell the grain. A decision needed to be made whether or not to simulate the growth and development of the male plants. After much discussion, it was decided that growth of the male plants be simulated to take into account any soil nitrogen effect the male plants might have. Further study of the interaction between the male and female plants should be made. The methodology used in CERES-IM is simplistic but may be all that is necessary. However, if the male inbred is drastically different from the female inbred, the interaction between the plants may be of more importance.

One of the major changes to the CERES-IM model was the incorporation of a new leaf area relationship. Integrating individual leaf growth with plant leaf area gives the model more flexibility. For instance, the detasseling routine could be rewritten to allow for the specific loss of the biomass of the last three leaves at the time of detasseling. In its present form, CERES-IM reduces biomass based on a percentage of total above ground biomass. A more precise reduction may help to avoid the problems of biomass simulation as seen in the inbred comparisons shown earlier.

The refining of the nitrogen deficit factors should continue as more is learned about the effects of stress on inbred maize growth and development. Most growers of seed corn agree that the inbred varieties are less tolerant of water and nitrogen stress, though little has been done to prove this. Work done is this area would help to clarify this suspicion and also help to refine the model's ability to simulate the effects of water and nitrogen stress on inbred maize, if appropriate.

All of the other changes made to either accommodate seed corn production or to improve the empirical formulas of CERES-Maize to work well. The new CERES-IM model should be considered a first version from which to make improvements. It can be use to simulate hybrid or inbred maize, single season or continuous, multiple years. These new options give the model flexibility in its usefulness. In the future, work should continue to refine and simplify the code. Also, user interfaces need to be improved to keep the model user friendly.

Objective 2: To perform field experiments to validate the simulation model.

The validation of CERES-IM was presented in two phases. First, data from a hybrid study were used to help validate the models ability to simulate nitrate leaching. This hybrid study was done in a field that was under cultivation for many years. This helped to provide historical data on crop yield and management. Also, the lysimeters had been in placed for a few years before intensive data collecting began. Waiting a few years after the lysimeters were installed before collecting the data minimized the impact of any soil disturbances caused by the installation.

For these two reasons, data from the hybrid study compared fairly well with values simulated by CERES-IM.

Though "on-farm" research is normally more applicable than research conducted in greenhouses or on small research plots, problems can occur when working with growers. The problem experienced with the nitrogen application in the hybrid study in 1988 are not uncommon. However, good communication and trust between the researcher and the farmer can usually minimize these errors. It is imperative that the participating farmer understand that though it is important to apply the correct amount, it is just as important to know how much was applied, even if the amount was incorrect.

The inbred validation phase of this study was key to the development of CERES-IM. The data collected over the two year period was designed to aid in the development of the model as well as to determine the impact of nitrogen management in seed corn production. Of all the data collected, the soils data proved to be the most difficult to quantify.

The soil nitrate and ammonium data collected throughout the inbred study have shown inconsistencies with large variations between samples. At the time of the installation of the lysimeters, measurements were taken to determine soil organic matter content and soil pH. Due to the disturbance caused by the installation of the lysimeters, these measurements probably should have been taken yearly, at least for the first few years.

The amount of nitrate in the soil is dependent on a number of factors including microbial activity, mineralization, and denitrification. Sampling the soil within the lysimeters would cause sink holes to develop which would cause errors in the amount of drainage water and its nitrate content. However, sampling around the lysimeters must also be limited because the plot area is not infinitely large and after several years of research, the soil samples collected would not represent the actual soil conditions in the plot area. With these two limitation, soil sampling procedures have been chosen to limit sampling size and number while still trying to maintain some sense of accuracy. Unfortunately, Michigan soils are not homogenous and limiting sample size or number can introduce large errors. However, the sampling procedure used is probably the most optimal given the limitations of this study. In future years, as in the past, the soil sampling procedures should be reviewed yearly and changes should be made when appropriate. The investments of time, money, and people in this project are large and this study will undoubtedly continue for several more years.

The comparisons between CERES-IM and the inbred data showed a good correlation for most of the parameters studied. The yield and kernel data compared well as did the grain nitrogen. The stover data, however, did not compare as well. One problem is that there is no mechanism in CERES-IM to take into account the biomass production and nitrogen uptake by the cob. By most measures, cob data is inconsequential when compared to the stover or grain. However, this seemingly small amount becomes a more integral component when simulating inbred maize. The overall plant size is smaller than in hybrid maize, making cob biomass a larger contributor to the overall above ground biomass. Changes should be made to separate cob biomass accumulation from the stover in CERES-IM.

The stover nitrogen data showed the poorest comparison of all the components. CERES-IM consistently underestimated the percent nitrogen in the stover. This in turn gave a poor comparison for the nitrogen uptake by the stover. However, there is large variation in the measured values as seen in Table 23. According to researchers at Pioneer Hi-Bred Int., this is not uncommon. Inbred maize normally shows large variations in both yield and biomass. Often, the detasseling operation is performed two or three times on a single field because plant height is irregular and some tassels are not removed with just one pass. This is especially true for when the tassels are removed mechanically. With this inherent variation, it is difficult to determine the sources of error in the simulation. At the present, stover samples are taken with leaves and stems mixed together. It may be useful if these were separated since CERES-IM simulates the growth of these two components separately. Also, it may be useful for CERES-IM to be reprogrammed to simulate nitrogen uptake by the leaves and stems separately. In its present form, CERES-IM only simulates stover nitrogen uptake.

Another area that requires more investigation is the detasseling operation and its effect on yield and biomass production. Presently, CERES-IM uses a percent reduction in biomass loss to simulate the loss of leaves due to detasseling. A more precise method may be to use the new leaf area model to follow the biomass accumulation by individual leaves. Also, more work needs to be done in the impact of detasseling on carbon assimilation, if any. Undoubtedly, the assimilation of carbon will be reduced by the loss of leaf area. However, detasseling may cause a shock to the entire plant system causing a temporary reduction the assimilation rate. Work should also continue on the effects of timeliness of the detasseling operation on grain yield. Late detasseling is rarely practiced since one of the companies major goals is to assure the quality of their seed. However, if the female plants are detasseled too early how and to what degree will this impact yield?

Future research should also focus on the impact of the male plants on nitrate leaching. Work done within St. Joseph county has shown that minimal amounts of nitrogen fertilizer can be applied to the male plants without causing a reduction in female yield. Data from Pioneer Hi-Bred Intl. confirm this, showing that a moderate nitrogen stress does not effect the quantity or quality of the male pollen. However, steps should be taken to assure that the nitrogen stress is not too severe to cause a delay in phasic development which can cause poor pollination. If male plants can be given limited amounts of nitrogen fertilizer, this should reduce the amount of nitrate leaching. Work can be done both in the field and using CERES-IM to try to study the impact of this strategy. With male plants accounting for 20% - 25% of the entire field, the potential impact on reducing nitrate leaching may be great.

As work continues at the lysimeter site and at other research sites, CERES-IM should be reprogrammed and refined. The model presented here will act as a base for others to work from. Like the original CERES-Maize V1.0, CERES-IM will continually be challenged and, if appropriate, changed. With the concern for environmental integrity, companies like Pioneer Hi-Bred Intl. are becoming more keenly aware of responsibility to help provide their growers with the most up-to-date information possible. Models such as CERES-IM can help demonstrate the effects of management strategies on grain yield and nitrate leaching. Combined with other information, growers will be able to make more informed decisions about which management strategy best fits their overall farm management scheme.

Objective 3: Utilize the simulation model to evaluate the impact of several nitrogen management strategies on potential leaching in seed corn production.

The evaluation of the management strategies in this section provided some interesting information but provided even more stimulating questions. The PRF threshold values of 15 kg and 30 kg were more or less arbitrarily selected. Results showed that the 30 kg value was too high since the PRF-30/0 strategies showed a significant decrease in yield as compared to the PRF-30/30 strategies. Also, the 15 kg value may be too low, though it is difficult to determine because no yield loss was observed between the PRF-15/0 and the PRF-15/15 strategies. Additional simulations could be made to determine a proper threshold value.

The simulations evaluated in this study seemed to indicate that the sidedress strategy was as good if not better than any PRF strategy. In terms of leaching, the 90 sd strategy did leach less than any PRF strategy. However, all of the PRF strategies yielded higher, except for the PRF-30/0 strategy. Only one PRF strategy, PRF-30/30 (with the silking day limitation) produced a higher revenue.

Continued analysis of the sidedress strategy lead to the discovery that the 90 sd strategy was still not the most optimal, but that perhaps a strategy between 110 - 120 sd will probably yield the highest revenue while keeping nitrate leaching to a relatively low amount. However, other factors must be considered.

First and most importantly is the initial conditions of the field in question. Given the initial conditions used in this study the 90 sd seems to produce the most reasonable revenue with the minimal amount of leaching. However, the 110 sd strategy could produce an extra \$20.00 ha^{-1} over the 90 sd strategy while leaching only about 4 kg N ha^{-1} more. Additionally, the CV for the yield of the 90 sd strategy was 19.71 and only 18.27 for the 110 sd strategy. Furthermore, the CV for the yield of the PRF-30/30 (<silk) was only 16.54. If a grower was concerned about yield stability, then the PRF strategy should be chosen. However, the success of the sidedress strategy presented here has also been recorded by a recent PRF study with a seed corn grower in St. Joseph county.

In 1990, a field study was conducted to test the applicability of a PRF strategy on a field scale. Using the MSR and the plant height measurements described earlier, an eight hectare field was fertilized according to a PRF strategy similar to the PRF- Auto N strategy evaluated earlier. The farmer asked to participate in the study had been a seed corn grower for Pioneer Hi-Bred Intl. for several years and had always produced high yields. Additionally, this particular farmer had done his own nitrogen fertilizer tests and his annual nitrogen fertilizer application was one of the lowest in the county.

The farmer's basic nitrogen management scheme was to apply a nominal amount of nitrogen fertilizer at planting time. Then, a second application would be applied at cultivation time, approximately growth stage V6-V8. A few years ago, he was applying a total of 180 kg N ha^{-1} and wanted to find out if he could lower the amount of nitrogen fertilizer without yield loss. Each year he would set aside a small portion of his field and apply 10 kg of nitrogen less and then compare the yields. It was not until he was down to 110 kg N ha^{-1} that a yield decrease was found. Therefore, his new strategy is to apply about 10-30 kg N ha^{-1} at planting and the remainder at cultivation for a total of 120 kg N ha^{-1}. Yield records at Pioneer hi-Bred Intl. have shown his average yields to be always above the county average and among some of the top in the county.

In the PRF study, the farmer applied 24 kg N ha^{-1} at planting and then an additional 90 kg N ha^{-1} at cultivation to all of his fields except the eight hectares under the PRF strategy. Using plant height as an indicator of stress, a nitrogen deficiency was detected in the plants in the PRF field. Unfortunately, heavy rains over the next few days caused a delay in the nitrogen application. When the yield results came in, the farmers strategy had yielded about 0.064 kg ha^{-1} (4 bu ac^{-1}) more than the PRF strategy. Though this amount is small, the formulas used by the seed companies to compensate the farmers for the expected lower yields of the inbreeds make this a significant difference. In this study, using a simple economic analysis similar to that used with the 60 years analyses, the farmer made an additional \$60 ha^{-1}. If the PRF fertilizer application could have applied in a more timely manner, this difference may not have existed. However, it is interesting to see that the evaluations of the various nitrogen management strategies performed earlier confirm the results of the farmers own "on-farm" nitrogen management tests.

Data from the literature as well as that recorded in Michigan suggest that a zero nitrate leaching strategy is non-obtainable in most inbred maize fields using present management strategies. The zero nitrogen fertilizer strategy simulated here indicates that at best, this soil under inbred maize production will leach and average of 50 kg N ha^{-1}. Perhaps if the initial conditions were changed or if the biomass at the end of a season were removed instead of plowed into the soil, then the total organic N content of the soil could be reduced to a level which might approach a zero nitrate leaching level. Models such as CERES-Maize and CERES-IM could be reprogrammed to look at the possible strategies that might accomplish this goal. However, it seems impossible that maize can be grown without some minimal amount of nitrate leaching. There was likely some nitrate leaching before the land was cultivated.

The question then becomes, are seed corn growers applying too much nitrogen fertilizer? A 1990 survey of seed corn growers in St. Joseph county indicated the answer is yes. According to the survey, growers applied an average of 180 kg N ha^{-1} to their seed corn fields. Data from the study presented here suggests that this is too much. However, the variability data also presented here show that the growers are following are strategy of low variability, not necessarily high revenue. Since farmers are traditionally a risk adverse group, this over application of nitrogen fertilizer is not unexpected. If farmers were to lower their nitrogen fertilizer inputs to help limit nitrate leaching losses, they would be accepting a greater risks. The question now becomes who should bear the burden of this risk?

The use of models such as CERES-IM help to show gaps in our knowledge base as well as help to answer some "what if" questions. With the power of personal computers increasing almost daily, growth simulation models will gain more common use within the agricultural community. Models such as CERES-IM can help to educate and inform agricultural and non-agricultural clientele regarding the effects of management schemes on plant growth and the environment. Hopefully, the data provided by models such as these can help farmers and policy makers make more informed decisions.

APPENDICES

APPENDIX A

APPENDIX A

A listing of the subroutine DETASS, that simulates the detasseling of the female plants.

```
      SUBROUTINE DETASS
C
C
C     ********** DETASSELING SUBROUTINE ********************************
C
C     Version  2.1S:
C
C     By:  E. Martin
C     January, 1991
C     Called by:   GROSUB Program
C
      include 'maiz1.blk'
      include 'maiz2.blk'
      include 'maiz4.blk'
      include 'comibs.blk'

C     REDUCE LEAF NUMBER AND PLA DUE TO LOSS OF PLA
C
C     IF ISTAGE LE TO 3, THEN LOSS OF BIOMASS DUE TO DETASSELING IS
C     APPROXIMATELY 14.0% OF THE TOTAL PLANT BIOMASS
C
C     REDUCE LEAF NUMBER BY 3
C
         IF (ISTAGE .LE. 3) THEN
            LN = LN-3
            LFWT= LFWT -((LFWT+STMWT)*.14)
            PLA= PLA-((LFWT*.14)**.8*267)
               CALL CALDAT
            IF (IPHOUT) THEN
               write (*,100)ND,Month
               write (NOUT1,100)ND,Month
            ENDIF
            IDET = DOY
            idett = 1
            RETURN
         ELSE
C
C     IF ISTAGE IS GREATER THAN 3, THEN LOSS OF BIOMASS DUE TO
C     DETASSELING IS APPROXIMATELY 10.5% OF THE TOTAL BIOMASS
C
C     LEAF LOSS REMAINS AT 3
C
```

APPENDIX A

A listing of the subroutine DETASS (cont.)

```
C
            LN = LN-3
            LFWT = LFWT -((LFWT+STMWT)*.105)
            PLA = PLA-((LFWT*.105)**.8*267)
                CALL CALDAT
            IF (IPHOUT) THEN
               write (*,100)ND,Month
               write (NOUT1,100)ND,Month
            ENDIF
            IDET = DOY
            idett = 1
            RETURN
         ENDIF
 100  FORMAT(1X,I2,1X,A3,'       FEMALE PLANTS DETASSELED',)
      END
```

A listing of the subroutine MCUT that simulates the removal of the male plants

```
      SUBROUTINE MCUT
C
C     ********* SUBROUTINE TO DETERMINE MALE PLANT REMOVAL *************
C
C     Version   2.01S
C
C     Added for CERES-IM
C
C     Written by: E. Martin
C                 February 12, 1991
C
C     Called by Phenol
C
      include 'maiz1.blk'
      include 'maiz2.blk'
      include 'comibs.blk'

      CALL CALDAT
C
      IF (IPHOUT) THEN
           WRITE(*,100)ND,MONTH
           WRITE(NOUT1,100)ND,MONTH
      ENDIF
      ISTAGE = 6
      IMCUT=DOY
      RETURN
  100 FORMAT(1X,I2,1X,A3,'       GROWTH TERMINATED DUE TO',/,'
     +    REMOVAL OF MALE PLANTS.')
      END
```

APPENDIX A

A listing of the subroutine LEAFAR that simulates the growth of plant leaf area. This subroutine fills the array used to predict leaf area.

```
      SUBROUTINE LEAFAR
C
C     ********* SUBROUTINE TO DETERMINE LEAF AREA GROWTH *************
C
C     Version   2.01S
C
C     Added for CERES-IM
C
C     Written by: E. Martin and J. T. Ritchie
C                 May 1991
C
C     Called by STAGE1  STAGE2  STAGE3  STAGE4  GROSUB
C

      include 'maiz2.blk'
      include 'maiz3.blk'
      include 'maiz4.blk'
      include 'ed.blk'
C
      TAREA=0.0
C
C     **** Calculate Area of Largest Leaf
C
      armax = 1200 * P6 * (EXP(-8.08*EXP(-0.193*xmaxlf)))
C
C     Calculate the Area of Individual Leaves
C
      DO 100 I=1,TLNO
      if (i .le. xmaxlf) then
C     ****  GOMPERTZ  ****
          PLA1 = 1200 * P6 * (EXP(-8.08*EXP(-0.193*I)))
      else
C     ****  LINEAR  ****
          PLA1 = armax - 72.80*(i-xmaxlf)
      ENDIF
C
C     Total Up the Areas and Store them in an Array
C
      TAREA=TAREA+PLA1
        AREALF(I) = TAREA
 100  CONTINUE
      RETURN
      END
```

APPENDIX A

A listing of the subroutine LFINTER that simulates the growth of leaf area. This subroutine is used to read the array already filled by the subroutine LEAFAR.

```
      SUBROUTINE LFINTER
C
C     ********* SUBROUTINE TO DETERMINE LEAF AREA GROWTH *************
C
C     Version   2.01S
C
C     Added for CERES-IM
C
C     Written by: E. Martin and J. T. Ritchie  May 1991
C
C     Called by STAGE1  STAGE2  STAGE3  STAGE4  GROSUB
C
      include 'maiz1.blk'
      include 'maiz2.blk'
      include 'maiz3.blk'
      include 'maiz4.blk'
      include 'ntrc1.blk'
C
C     Reduced the Leaf Number to Obtain the Correct Area
C
      IF(XN .LE. 6) THEN
          XXN = XN-xn/3
      ELSE
          XXN = XN-2
      ENDIF
      I = AINT(XXN)
C
C     Perform a Linear Interpolation on the Array "AREALF"
C
      PLANEW = AREALF(I)+((xxn-i)*(arealf(i+1)-arealf(i)))
      PLAG = PLANEW - PLA
      IF (PLAG .LE. 0) PLAG = 0.0
C
C     Reduce the Plant Leaf Growth if Appropriate
C
      IF(ISTAGE .EQ. 1) THEN
         PLAG = PLAG * SWDF2
      ELSE
         PLAG = PLAG *AMIN1(NDEF2,SWDF2)
      ENDIF
      PLA=PLA+PLAG
C     Call Detasseling Subroutine if Appropriate
      IF (ISEX .EQ. 2) THEN
         IF (DOY .EQ. IDET) THEN
            CALL DETASS
         ELSE IF (IDET .EQ. 999) THEN
            IF(SUMDTT .GE. 0.90*P3) THEN
               CALL DETASS
            ENDIF
         ENDIF
      ENDIF
 90   RETURN
100   format(/,2x,i2,2(2x,f7.2),2x,i2)
200   format(3x,3(3x,f10.2))
300   format(2x,4(f10.2,3x))
      END
```

APPENDIX A

A listing of the subroutine SNOW that simulates the melting of snowfall.

```
      SUBROUTINE SNOWFALL (TEMPMX, PRECIP, RAIN, SNOW)
C
C
C     Modified by A. Gerakis 8-20-91
C
      REAL TEMPMX, PRECIP, RAIN, SNOMLT, SNOW

      IF (TEMPMX.GT.1.) THEN
        SNOMLT=TEMPMX+RAIN*0.4
        IF (SNOMLT.GT.SNOW) THEN
            SNOMLT = SNOW
        ENDIF
        SNOW=SNOW-SNOMLT
        PRECIP=PRECIP+snomlt
      ELSE
        SNOW=SNOW+RAIN
        PRECIP = PRECIP - RAIN
        RAIN=0.
      ENDIF
      RETURN
      END
```

APPENDIX B

APPENDIX B

Output files of CERES-IM (CERES-MAIZE)

SUMMARY OUTPUT

```
 RUN    1 OUTPUT SUMMARY
 INST_ID :MS  SITE_ID: CN  EXPT_NO: 01  YEAR : 1989  TRT_NO:  1
 EXP.     :1989 LYSIMETER EXP INBRED 1 (CONSTANT)
 TRT.     :In 1 FE  - 180PP
 WEATHER :1989 Constant, MI
 SOIL     :ELSTON SANDY LOAM,
 VARIETY :PO2
 IRRIG.   :ACCORDING TO THE FIELD SCHEDULE.

 LATITUDE = 41.50, SOWING DEPTH =  5. CM,
 PLANT POPULATION =  5.2 PLANTS/SQ METER

 GENETIC SPECIFIC CONSTANTS P1 =200.00  P2 = .30  P5 =650.00  P6 = .85
                  G2 =1.15  G3 = 7.450  ISEX = 2  F:M RATIO =4.0


SOIL PROFILE DATA [ LOCATION:  CONSTANT     ]
SOIL ALBEDO=  .13  U=  8.0  SWCON=   .40   RUNOFF CURVE NO.=  78.0
```

DEPTH-CM	LO LIM	UP LIM	SAT SW	EXT SW	IN SW	WR	NO3	NH4
							---mg/kg---	
0.- 15.	.035	.177	.385	.142	.177	1.000	13.8	2.3
15.- 30.	.035	.177	.385	.142	.177	.900	4.8	1.7
30.- 45.	.037	.176	.385	.139	.176	.700	3.1	.5
45.- 60.	.037	.176	.385	.139	.176	.700	2.1	4.0
60.- 75.	.037	.176	.385	.139	.176	.500	1.7	2.7
75.- 90.	.028	.134	.375	.106	.134	.080	1.1	3.2
90.- 120.	.020	.110	.353	.090	.110	.040	.7	3.8
120.- 150.	.019	.105	.353	.086	.105	.005	.2	.5
150.- 180.	.019	.105	.353	.086	.105	.002	.2	.5
180.- 210.	.019	.105	.353	.086	.105	.002	.2	.5
T 0.- 210.	5.4	28.0	76.9	22.5	28.0		69.*	59.*

* NOTE: Units are in kg / hectare.

FERTILIZER INPUTS

DAY OF YEAR	KG/HA	DEPTH	SOURCE
136	180.00	1.00	UREA AMMONIUM NITRATE

APPENDIX B

SUMMARY OUTPUT (cont.)

THE PROGRAM STARTED ON, 121 DAY OF YEAR

DATE	CDTT	PHENOLOGICAL STAGE	BIOM	LAI	NUPTK	N%	CET	RAIN	PESW
			g/m^2		kg/ha		---mm----		cm
16 May	0.	SOWING							
17 May	5.	GERMINATION					33.	20.	21.
23 May	47.	EMERGENCE					13.	17.	21.
10 Jun	246.	END JUVENILE	3.	.05	1.1	3.92	63.	205.	26.
16 Jun	300.	TASSEL INITIATION	5.	.12	2.3	4.18	76.	226.	25.
22 Jul		FEMALE PLANTS DETASSELED							
24 Jul	840.	75% SILKING	371.	1.55	87.6	2.36	218.	317.	18.
4 Aug	1007.	BEGIN GRAIN FILL	571.	1.41	86.7	2.35	269.	421.	24.
9 Sep	1463.	END GRAIN FILL	1016.	.61	27.1	.99	395.	510.	19.
1 Sep	1491.	PHYS. MATURITY	1016.	.61	27.1	.99	399.	510.	19.

YIELD (KG/HA)= 6390. (BU/AC)=101.7 FINAL GPSM= 2318.
KERNEL WT.(mg)=232.9

ISTAGE	CSD1	CSD2	CNSD1	CNSD2	S T A G E OF G R O W T H
1	.00	.00	.00	.00	EMERG to END JUVENILE PHASE
2	.00	.00	.00	.00	END JUV to TASSEL INITIAT
3	.00	.00	.00	.00	TASSEL INITIATION to SILK
4	.00	.00	.00	.00	SILKING to BEGIN GRAIN FILL
5	.00	.00	.00	.00	GRAIN FILLING PHASE

* NOTE: In the above table, 0.0 represents minimum stress and 1.0 represents maximum stress for water (CSD) and nitrogen (CNSD), respectively.

5 IRRIGATION APPLICATIONS AT 1.00 EFFICIENCY

DAY OF YR	200	203	207	208	214
AMOUNT mm	16.	32.	37.	1.	51.

IRRIGATION THIS SEASON : 137. mm

	PREDICTED	OBSERVED
SILKING DATE	205	206
MATURITY DATE	254	270
GRAIN YIELD (KG/HA)	6390.	6551.
KERNEL WEIGHT (G)	.233	.233
GRAINS PER SQ METRE	2318.	2376.
GRAINS PER EAR	450.07	461.00
MAX. LAI	1.55	1.69
BIOMASS (KG/HA)	10164.	9545.
STRAW (KG/HA)	4765.	4009.
GRAIN N%	1.70	1.69
TOT N UPTAKE (KG N/HA)	119.0	129.2
STRAW N UPTAKE	27.1	35.7
GRAIN N UPTAKE	91.8	93.5

APPENDIX B

BIOMASS OUTPUT FILE

```
RUN   1          In 1 FE  - 180PP
INST_ID :MS  SITE_ID: CN  EXPT_NO: 01  YEAR : 1989  TRT_NO:  1
EXP.    :1989 LYSIMETER EXP INBRED 1 (CONSTANT)
TRT.    :In 1 FE  - 180PP
WEATHER :1989 Constant, MI
SOIL    :ELSTON SANDY LOAM,
VARIETY :PO2
IRRIG.  :ACCORDING TO THE FIELD SCHEDULE.
```

DAY	SDTT	BIO	LN	LAI	ROOT	STEM	GRAIN	LEAF	RTD	PTF	L1	L3	L5
OYR		g/m2			|----- Weight in g -----|				(cm)		|-- RLV--|		
149	59.	2.	3	.00	.23	.20	.00	.20	23.	.00	.1	.0	.0
156	143.	2.	5	.02	.38	.20	.00	.20	41.	.00	.1	.0	.0
163	217.	3.	7	.07	.94	.20	.00	.40	57.	.75	.2	.1	.0
170	35.	8.	9	.17	1.89	.20	.00	1.36	72.	.87	.3	.2	.0
177	147.	32.	12	.53	5.44	.71	.00	5.46	95.	.48	.8	.5	.3
184	240.	89.	14	1.08	14.46	4.20	.00	13.13	117.	.47	2.0	1.3	.8
191	362.	203.	17	1.59	24.64	17.95	.00	21.37	142.	.72	3.4	2.3	1.6
198	453.	319.	20	1.77	33.22	37.53	.00	24.46	164.	.38	4.3	3.0	2.1
205	10.	371.	17	1.55	35.48	42.70	.00	20.71	185.	1.00	4.7	3.5	2.5
212	113.	490.	17	1.44	38.01	50.00	.00	18.43	208.	.49	4.7	3.7	2.6
219	211.	612.	17	1.37	40.65	54.96	7.90	16.69	210.	.88	4.8	4.2	3.0
226	294.	713.	17	1.32	39.87	54.96	27.72	16.58	210.	1.00	4.7	4.2	3.0
233	380.	813.	17	1.23	39.06	54.29	47.90	16.46	210.	.94	4.7	4.1	3.0
240	475.	897.	17	1.06	37.90	49.30	69.32	16.35	210.	1.00	4.6	4.0	3.0
247	555.	979.	17	.85	36.73	45.72	88.95	16.23	210.	.99	4.5	4.0	2.9

APPENDIX B

SOIL WATER OUTPUT FILE

RUN 1 In 1 FE - 180PP
INST_ID :MS SITE_ID: CN EXPT_NO: 01 YEAR : 1989 TRT_NO: 1
EXP. :1989 LYSIMETER EXP INBRED 1 (CONSTANT)
TRT. :In 1 FE - 180PP
WEATHER :1989 Constant, MI
SOIL :ELSTON SANDY LOAM,
VARIETY :PO2
IRRIG. :ACCORDING TO THE FIELD SCHEDULE.

* Units are in MJ/square meter.

	---------- AVERAGE	---------					PERIOD	SW CONTENT W/DEPTH				TOTAL	
DAY OYR	EP (mm)	ET (mm)	EO (mm)	SR*	MAX C	MIN C	PREC (mm)	SW1	SW2	SW3	SW4	SW5	PESW (cm)
127	.0	2.8	3.5	19.	13.2	2.0	8.40	.13	.15	.16	.16	.16	21.4
134	.0	1.3	3.2	16.	16.4	5.0	10.50	.15	.15	.16	.16	.15	21.2
141	.0	2.0	4.0	18.	22.5	9.5	17.30	.15	.16	.17	.16	.16	21.5
148	.0	2.7	4.3	19.	22.9	13.1	16.00	.13	.15	.16	.16	.16	21.2
155	.0	3.5	3.9	16.	24.5	14.9	172.30	.21	.22	.25	.24	.23	29.9
162	.2	1.5	5.6	24.	25.3	11.9	.00	.17	.17	.18	.18	.17	25.7
169	.2	2.6	3.3	15.	21.7	13.5	20.80	.15	.16	.17	.18	.17	23.5
176	1.2	2.0	5.1	20.	29.0	17.5	.00	.12	.14	.15	.15	.15	20.7
183	2.7	3.9	5.7	24.	27.8	15.7	6.90	.09	.11	.12	.13	.13	18.3
190	4.1	4.9	6.1	25.	31.3	17.8	24.90	.17	.11	.08	.09	.10	17.3
197	3.0	4.6	4.6	20.	27.0	17.3	.00	.06	.07	.07	.07	.08	14.4
204	2.3	3.5	3.6	15.	26.9	16.5	59.70	.21	.17	.14	.07	.07	18.6
211	1.9	3.8	3.8	16.	28.7	17.9	49.20	.20	.19	.18	.16	.10	20.8
218	2.6	5.3	5.3	23.	29.5	16.7	79.40	.22	.22	.22	.21	.18	25.2
225	2.4	4.3	4.3	22.	25.9	11.7	6.90	.16	.16	.17	.16	.16	22.4
232	2.6	3.7	3.9	19.	26.5	13.7	20.10	.18	.17	.14	.14	.14	21.1
239	1.9	3.9	3.9	19.	27.3	16.2	2.00	.11	.13	.14	.13	.13	19.0
246	1.8	2.6	3.1	16.	25.5	14.7	.00	.08	.10	.11	.12	.12	17.2
253	1.1	2.5	3.0	15.	26.7	16.8	35.10	.17	.16	.12	.11	.12	19.1
260	.0	1.8	2.5	12.	19.3	10.1	29.60	.17	.17	.17	.16	.13	20.8
267	.0	1.4	3.5	17.	22.1	6.3	.00	.13	.14	.15	.15	.14	19.8
274	.0	.6	3.7	18.	21.5	4.2	.00	.12	.14	.14	.14	.14	19.4
281	.0	.5	2.0	11.	15.2	1.9	1.00	.11	.13	.14	.14	.14	19.2
288	.0	.5	2.9	14.	22.5	4.2	2.80	.12	.13	.14	.14	.14	19.1
295	.0	.7	1.1	7.	9.8	1.7	31.80	.19	.18	.17	.16	.14	21.8
302	.0	1.6	2.4	11.	23.4	5.8	.00	.14	.15	.16	.16	.16	20.7
309	.0	.6	.8	5.	12.6	2.9	5.90	.16	.15	.15	.16	.16	20.9
316	.0	.6	.8	5.	9.1	.9	15.20	.17	.17	.17	.17	.16	22.0
323	.0	.4	.6	5.	8.3	-2.3	33.80	.20	.20	.20	.19	.18	25.0
330	.0	.8	1.1	9.	6.5	-4.2	.00	.17	.17	.18	.17	.17	23.4
337	.0	.4	.5	5.	5.7	-4.6	10.70	.18	.18	.18	.17	.17	23.3
344	.0	.1	.2	4.	.3	-7.5	.30	.17	.17	.17	.17	.16	22.5
351	.0	.1	.1	7.	-7.0	-17.7	.00	.17	.17	.17	.16	.16	22.0
358	.0	.0	.0	6.	-9.9	-20.8	.00	.17	.17	.17	.17	.17	22.0
365	.0	.1	.2	4.	-.5	-8.6	.00	.16	.16	.17	.17	.17	21.9
7	.0	.3	.4	5.	2.1	-5.0	13.00	.18	.18	.18	.18	.17	23.0

APPENDIX B

SOIL WATER OUTPUT FILE (cont.)

DAY OYR	EP (mm)	ET (mm)	EO (mm)	SR*	MAX C	MIN C	PERIOD PREC (mm)	SW1	SW2	SW3	SW4	SW5	TOTAL PESW (cm)
	---------- AVERAGE					---------		SW CONTENT W/DEPTH					
14	.0	.3	.5	5.	3.4	-2.9	13.10	.20	.19	.19	.18	.17	23.8
21	.0	.4	.6	6.	5.1	-6.5	14.30	.18	.18	.19	.18	.17	24.4
28	.0	.3	.4	9.	-1.8	-13.9	.00	.17	.17	.18	.17	.16	23.0
35	.0	.8	1.2	10.	7.9	-6.0	.80	.15	.16	.16	.16	.16	21.7
42	.0	.7	1.0	7.	8.2	-.7	.80	.14	.15	.16	.16	.16	21.0
49	.0	.5	.7	7.	4.3	-5.7	4.00	.15	.15	.16	.16	.16	21.1
56	.0	.6	.8	12.	2.0	-9.0	88.60	.22	.22	.23	.22	.21	27.5
63	.0	.9	1.3	15.	2.6	-8.8	3.00	.17	.18	.18	.18	.18	25.4
70	.0	.6	.8	9.	7.2	-3.4	64.90	.27	.26	.25	.22	.20	29.1
77	.0	1.5	2.1	10.	18.2	9.9	4.90	.18	.19	.19	.19	.18	26.5
84	.0	1.2	1.7	14.	6.2	-2.7	30.20	.19	.20	.21	.20	.19	26.3

* Units are in MJ/square meter.

APPENDIX B

NITROGEN OUTPUT FILE

```
RUN   1          In 1 FE  - 180PP
INST_ID :MS  SITE_ID: CN  EXPT_NO: 01  YEAR : 1989  TRT_NO:  1
EXP.    :1989 LYSIMETER EXP INBRED 1 (CONSTANT)
TRT.    :In 1 FE  - 180PP
WEATHER :1989 Constant, MI
SOIL    :ELSTON SANDY LOAM,
VARIETY :PO2
IRRIG.  :ACCORDING TO THE FIELD SCHEDULE.
```

DAY OYR	TOPS N %	NFAC	VEG N UPTK	GRAIN UPTK	NO3 1	NO3 2	NO3 3	NO3 4	NO3 5	NH4 1	NH4 2	NH4 3
			- kg N/ha -		ug N/g soil							
127	4.40	1.00	.0	.0	14.4	5.6	3.1	3.9	2.6	1.9	1.4	.5
134	4.40	1.00	.0	.0	15.0	6.0	3.1	4.4	3.1	1.8	1.3	.6
141	4.40	1.00	.0	.0	74.6	17.2	4.0	4.8	3.4	5.8	1.9	.6
148	4.47	1.00	.9	.0	72.0	25.4	4.9	5.1	3.7	3.5	2.0	.7
155	4.50	1.00	.9	.0	16.5	23.6	23.8	20.4	13.8	2.6	1.8	.8
162	4.26	1.00	1.1	.0	18.4	19.8	17.7	17.6	14.9	2.4	1.7	.9
169	4.00	1.00	2.7	.0	15.0	17.7	17.1	18.2	17.0	2.0	1.6	.8
176	4.00	1.00	10.2	.0	16.2	16.5	15.7	16.8	16.1	1.8	1.5	.8
183	3.52	1.00	26.8	.0	15.4	14.9	13.9	14.8	14.8	1.7	1.4	.8
190	3.13	1.00	54.2	.0	10.7	14.4	12.1	12.7	12.4	1.5	1.3	.8
197	2.73	1.00	76.6	.0	7.4	11.8	11.3	11.6	11.1	1.5	1.2	.7
204	2.46	1.00	87.7	.0	2.9	10.0	13.4	11.3	10.9	1.5	1.2	.7
211	2.53	1.00	87.1	.0	2.0	6.2	12.2	16.6	12.1	1.6	1.3	.7
218	2.36	1.00	81.3	5.2	1.2	3.1	7.6	15.2	18.2	1.7	1.4	.7
225	1.95	1.00	64.1	21.6	1.8	3.0	6.0	12.3	17.3	1.6	1.4	.7
232	1.53	1.00	51.5	39.2	2.0	3.4	5.6	11.4	16.5	1.5	1.4	.7
239	1.34	1.00	44.3	57.9	2.0	2.8	4.8	10.3	15.7	1.5	1.4	.7
246	1.17	1.00	35.7	75.7	2.4	2.8	4.3	9.3	14.6	1.4	1.3	.7
253	1.04	1.00	27.1	91.8	1.8	3.1	4.2	8.8	13.7	1.4	1.2	.7
260	.99	1.00	27.1	91.8	1.6	2.8	4.5	9.5	14.1	1.4	1.2	.6
267	.99	1.00	27.1	91.8	2.1	2.9	4.3	9.1	14.4	1.3	1.2	.6
274	.99	1.00	27.1	91.8	2.6	3.1	4.3	9.0	14.4	1.2	1.1	.6
281	.99	1.00	27.1	91.8	2.9	3.3	4.3	9.0	14.4	1.1	1.1	.5
288	.99	1.00	27.1	91.8	3.2	3.5	4.3	9.0	14.5	1.1	1.0	.5
295	.99	1.00	27.1	91.8	2.4	3.9	4.8	9.3	14.5	1.0	1.0	.5
302	.99	1.00	27.1	91.8	2.8	3.7	4.6	9.0	15.0	1.0	1.0	.5
309	.99	1.00	27.1	91.8	3.1	3.9	4.6	9.0	15.1	1.0	1.0	.5
316	.99	1.00	27.1	91.8	2.6	4.1	4.8	9.0	15.1	.9	.9	.5
323	.99	1.00	27.1	91.8	1.6	3.2	4.4	8.3	14.7	.8	.9	.5
330	.99	1.00	27.1	91.8	1.6	2.8	3.8	7.1	13.3	.8	.9	.5
337	.99	1.00	27.1	91.8	1.4	2.6	3.6	6.7	12.8	.8	.8	.5
344	.99	1.00	27.1	91.8	1.4	2.6	3.5	6.5	12.2	.8	.8	.5
351	.99	1.00	27.1	91.8	1.4	2.5	3.4	6.3	11.8	.8	.8	.5
358	.99	1.00	27.1	91.8	1.4	2.5	3.4	6.4	12.0	.8	.8	.5
365	.99	1.00	27.1	91.8	1.4	2.5	3.4	6.4	12.0	.8	.8	.5
7	.99	1.00	27.1	91.8	1.1	2.3	3.4	6.4	11.6	.8	.8	.5

APPENDIX B

NITROGEN OUTPUT FILE (cont.)

DAY OYR	TOPS N %	NFAC	VEG N UPTK	GRAIN UPTK	NO3 1	NO3 2	NO3 3	NO3 4	NO3 5	NH4 1	NH4 2	NH4 3
			- kg N/ha -		ug N/g soil							
14	.99	1.00	27.1	91.8	.9	2.1	3.1	6.1	11.2	.8	.8	.5
21	.99	1.00	27.1	91.8	.7	1.5	2.5	5.1	10.2	.8	.8	.5
28	.99	1.00	27.1	91.8	.7	1.5	2.3	4.7	9.5	.8	.8	.5
35	.99	1.00	27.1	91.8	.8	1.4	2.3	4.6	9.1	.8	.8	.5
42	.99	1.00	27.1	91.8	1.0	1.5	2.2	4.5	9.1	.7	.7	.5
49	.99	1.00	27.1	91.8	1.0	1.6	2.3	4.7	9.1	.7	.7	.5
56	.99	1.00	27.1	91.8	.5	1.0	1.7	3.8	8.0	.7	.7	.5
63	.99	1.00	27.1	91.8	.5	.8	1.3	2.5	5.4	.7	.7	.5
70	.99	1.00	27.1	91.8	.4	.6	1.1	2.2	4.8	.7	.7	.5
77	.99	1.00	27.1	91.8	.4	.6	.7	1.4	3.0	.8	.8	.5
84	.99	1.00	27.1	91.8	.4	.5	.7	1.1	2.6	.8	.8	.5

APPENDIX C

APPENDIX B

MULTI-YEAR SUMMARY OUTPUT FILE

A-M	E-M	NLOSS	NIT	STRS	NUPTK	NIRR'	TOT	WAT	STRS	CET	RAIN	BIOMS	YLD	PLTS	NFT	NRATE
--DAYS-		kgN/h	3	5	kg/h		IRR	1	5	---	mm ---	-- T/ha	---			
86	119	17.	.00	.00	153.2	0	0.	.00	.00	523.	693.	13.51	7.55	5.15	2	180.
73	110	11.	.00	.00	114.7	3	57.	.00	.00	488.	564.	10.97	5.24	5.15	2	180.
79	116	17.	.00	.00	124.3	5	95.	.00	.00	447.	350.	11.60	5.06	5.15	2	180.
86	120	15.	.00	.01	127.4	6	114.	.00	.01	503.	403.	13.38	8.04	5.15	2	180.
74	105	27.	.00	.00	105.8	3	57.	.00	.00	453.	528.	9.83	5.03	5.15	2	180.
78	107	53.	.00	.00	104.8	2	38.	.00	.00	463.	482.	10.35	5.05	5.15	2	180.
72	123	11.	.00	.00	131.1	3	57.	.00	.00	460.	420.	12.25	6.30	5.15	2	180.
77	118	26.	.00	.00	122.3	2	38.	.00	.00	477.	500.	11.28	6.15	5.15	2	180.
78	120	29.	.00	.00	125.6	0	0.	.00	.00	494.	564.	11.34	6.17	5.15	2	180.
77	115	10.	.00	.00	112.9	1	19.	.00	.00	467.	524.	10.85	5.35	5.15	2	180.
69	103	5.	.00	.00	125.4	3	57.	.00	.00	406.	382.	11.55	6.31	5.15	2	180.
74	113	17.	.00	.00	117.8	6	114.	.00	.00	443.	365.	11.39	5.75	5.15	2	180.
69	103	32.	.00	.00	121.1	3	57.	.00	.00	467.	531.	11.38	5.47	5.15	2	180.
72	112	9.	.00	.00	104.7	10	191.	.00	.01	474.	338.	10.80	5.81	5.15	2	180.
75	111	15.	.00	.00	113.9	3	57.	.00	.00	487.	482.	11.00	5.17	5.15	2	180.
74	114	21.	.01	.00	122.8	7	133.	.00	.01	450.	359.	12.24	7.07	5.15	2	180.
78	119	19.	.00	.00	132.8	4	76.	.00	.00	452.	373.	11.77	6.72	5.15	2	180.
85	119	24.	.00	.00	134.6	1	19.	.00	.00	467.	502.	13.53	7.27	5.15	2	180.
81	115	16.	.00	.00	129.7	5	95.	.00	.00	482.	505.	11.48	6.81	5.15	2	180.
79	114	25.	.00	.00	121.8	7	133.	.00	.00	518.	522.	11.33	5.71	5.15	2	180.
78	108	13.	.00	.00	112.3	0	0.	.00	.00	445.	578.	10.65	5.19	5.15	2	180.
74	110	14.	.00	.00	118.8	3	57.	.00	.00	466.	525.	10.99	5.54	5.15	2	180.
70	101	11.	.00	.00	145.4	1	19.	.00	.00	420.	427.	12.82	7.12	5.15	2	180.
81	112	14.	.00	.00	119.3	7	133.	.00	.00	447.	306.	10.97	5.80	5.15	2	180.
70	102	20.	.00	.00	118.8	4	76.	.00	.00	445.	396.	11.40	6.38	5.15	2	180.
72	105	14.	.00	.00	120.7	5	95.	.00	.00	454.	431.	11.35	5.26	5.15	2	180.

APPENDIX C

Inputs used in the hybrid simulations

WEATHER DATA (1988/1989)

ID = MSCN
Latitude = 42.00
Longitude = 85.50
YR = Year
SOL = Solar Radiation (Mj m^{-2})
TMAX = Maximum Daily Temperature (^{o}C)
TMIN = Minimum Daily Temperature (^{o}C)
RAIN = Rainfall (mm)

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	1	5.6	- 6.7	-17.1	0.0	01 JAN 88
CVCP	88	2	8.7	- 3.4	-18.3	0.0	02 JAN 88
CVCP	88	3	6.7	- .1	-10.8	0.0	03 JAN 88
CVCP	88	4	6.1	- 3.4	-21.9	0.0	04 JAN 88
CVCP	88	5	8.5	-14.9	-26.4	0.0	05 JAN 88
CVCP	88	6	8.7	-10.2	-26.8	0.0	06 JAN 88
CVCP	88	7	5.7	- 8.7	-28.9	0.0	07 JAN 88
CVCP	88	8	8.3	- 3.7	-27.8	0.0	08 JAN 88
CVCP	88	9	6.2	- 4.4	-19.1	0.0	09 JAN 88
CVCP	88	10	8.4	- 7.0	-24.8	0.0	10 JAN 88
CVCP	88	11	8.2	.1	-15.9	0.0	11 JAN 88
CVCP	88	12	2.3	4.1	- 2.8	0.0	12 JAN 88
CVCP	88	13	5.8	- 2.9	-14.2	0.0	13 JAN 88
CVCP	88	14	8.0	- 5.5	-20.8	0.0	14 JAN 88
CVCP	88	15	8.8	1.5	- 8.9	0.0	15 JAN 88
CVCP	88	16	9.3	8.4	- 2.0	0.0	16 JAN 88
CVCP	88	17	.9	5.0	1.5	16.2	17 JAN 88
CVCP	88	18	8.6	7.4	- 3.4	1.8	18 JAN 88
CVCP	88	19	1.3	2.1	- 4.1	3.6	19 JAN 88
CVCP	88	20	.8	6.9	- .7	1.3	20 JAN 88
CVCP	88	21	6.6	.9	- 5.7	0.3	21 JAN 88
CVCP	88	22	3.0	- .1	- 5.8	0.0	22 JAN 88
CVCP	88	23	5.9	- 1.3	- 4.4	0.0	23 JAN 88
CVCP	88	24	3.5	1.1	- 8.5	0.5	24 JAN 88
CVCP	88	25	4.7	- 1.0	-16.5	0.0	25 JAN 88
CVCP	88	26	8.4	.6	-16.8	0.3	26 JAN 88
CVCP	88	27	10.5	- 6.1	-20.4	0.0	27 JAN 88
CVCP	88	28	8.0	1.1	-10.8	1.5	28 JAN 88
CVCP	88	29	9.6	8.6	- 5.9	0.5	29 JAN 88
CVCP	88	30	2.3	10.2	5.3	0.0	30 JAN 88
CVCP	88	31	.9	10.4	2.1	12.1	31 JAN 88
CVCP	88	32	1.0	2.1	- 1.9	2.8	01 FEB 88
CVCP	88	33	5.4	- 1.9	- 7.3	0.0	02 FEB 88

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	34	3.2	- 2.7	- 7.0	0.0	03 FEB 88
CVCP	88	35	10.1	- .8	-12.5	2.3	04 FEB 88
CVCP	88	36	10.4	- 8.2	-19.3	0.0	05 FEB 88
CVCP	88	37	10.8	- 6.9	-22.4	0.0	06 FEB 88
CVCP	88	38	5.0	- 4.3	-18.1	0.0	07 FEB 88
CVCP	88	39	9.8	- 1.1	-20.4	0.0	08 FEB 88
CVCP	88	40	9.5	1.1	- 8.3	0.0	09 FEB 88
CVCP	88	41	8.3	- 3.2	-10.6	0.0	10 FEB 88
CVCP	88	42	5.8	- 5.8	-11.7	0.0	11 FEB 88
CVCP	88	43	10.9	- 1.5	-17.6	0.0	12 FEB 88
CVCP	88	44	13.1	- 1.5	-18.5	0.0	13 FEB 88
CVCP	88	45	8.3	4.0	-17.6	5.7	14 FEB 88
CVCP	88	46	4.9	4.5	- 4.8	9.0	15 FEB 88
CVCP	88	47	7.6	2.0	- 7.1	0.3	16 FEB 88
CVCP	88	48	12.8	6.8	- 5.6	0.0	17 FEB 88
CVCP	88	49	13.7	7.7	- 9.3	0.0	18 FEB 88
CVCP	88	50	2.6	1.3	- 5.5	2.3	19 FEB 88
CVCP	88	51	8.2	.7	-17.6	0.3	20 FEB 88
CVCP	88	52	15.2	- 3.3	-19.6	0.0	21 FEB 88
CVCP	88	53	9.6	11.1	- 3.3	0.0	22 FEB 88
CVCP	88	54	12.3	2.4	- 5.7	0.0	23 FEB 88
CVCP	88	55	7.8	- 1.4	- 9.2	0.0	24 FEB 88
CVCP	88	56	8.1	- .4	-10.1	0.0	25 FEB 88
CVCP	88	57	15.4	10.8	-10.3	0.0	26 FEB 88
CVCP	88	58	11.5	3.3	- 5.1	0.0	27 FEB 88
CVCP	88	59	13.5	5.9	- 6.8	0.0	28 FEB 88
CVCP	88	60	15.1	8.8	- 3.1	0.0	29 FEB 88
CVCP	88	61	14.9	4.7	- 4.8	0.0	01 MAR 88
CVCP	88	62	16.4	11.6	- 3.1	0.0	02 MAR 88
CVCP	88	63	6.9	- .8	- 6.2	0.0	03 MAR 88
CVCP	88	64	17.1	3.4	- 8.2	0.0	04 MAR 88
CVCP	88	65	17.2	8.0	-11.2	0.0	05 MAR 88
CVCP	88	66	17.4	10.8	- 7.3	0.0	06 MAR 88
CVCP	88	67	13.8	13.7	- 1.7	0.0	07 MAR 88
CVCP	88	68	12.8	19.0	- 2.9	0.0	08 MAR 88
CVCP	88	69	2.2	9.5	- 1.3	2.3	09 MAR 88
CVCP	88	70	18.3	10.7	- 6.0	0.0	10 MAR 88
CVCP	88	71	17.5	13.9	- 2.8	0.0	11 MAR 88
CVCP	88	72	6.9	13.4	.9	4.3	12 MAR 88
CVCP	88	73	5.5	1.0	6.8	0.0	13 MAR 88
CVCP	88	74	14.0	.2	- 6.9	0.3	14 MAR 88
CVCP	88	75	12.0	.6	- 9.6	0.0	15 MAR 88
CVCP	88	76	6.0	2.2	- 6.5	0.3	16 MAR 88
CVCP	88	77	11.4	8.0	- 8.0	0.0	17 MAR 88
CVCP	88	78	13.0	7.1	- 4.3	1.0	18 MAR 88
CVCP	88	79	17.0	5.8	- 6.8	0.0	19 MAR 88
CVCP	88	80	13.3	2.3	-14.3	8.0	20 MAR 88
CVCP	88	81	20.0	3.5	-13.3	0.3	21 MAR 88
CVCP	88	82	17.4	9.2	- 6.3	0.0	22 MAR 88
CVCP	88	83	13.9	23.1	3.6	0.0	23 MAR 88
CVCP	88	84	11.0	19.3	6.9	10.3	24 MAR 88
CVCP	88	85	18.2	19.5	8.3	6.7	25 MAR 88
CVCP	88	86	11.5	13.7	- .2	0.0	26 MAR 88
CVCP	88	87	15.6	8.4	- 1.4	0.0	27 MAR 88
CVCP	88	88	2.8	10.5	- 1.5	1.3	28 MAR 88
CVCP	88	89	3.0	14.3	5.5	5.1	29 MAR 88
CVCP	88	90	17.6	11.5	.0	7.2	30 MAR 88
CVCP	88	91	14.8	12.3	- 2.6	0.0	31 MAR 88

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	92	8.7	14.1	1.5	1.3	01 APR 88
CVCP	88	93	4.8	15.4	7.1	.5	02 APR 88
CVCP	88	94	12.3	22.9	6.8	10.5	03 APR 88
CVCP	88	95	13.9	18.6	5.0	0.0	04 APR 88
CVCP	88	96	21.4	29.0	9.5	0.0	05 APR 88
CVCP	88	97	1.5	20.1	5.0	83.3	06 APR 88
CVCP	88	98	24.9	17.1	3.0	0.0	07 APR 88
CVCP	88	99	24.6	17.3	- 0.3	0.0	08 APR 88
CVCP	88	100	24.1	19.3	- 1.3	0.0	09 APR 88
CVCP	88	101	21.6	22.0	1.5	0.0	10 APR 88
CVCP	88	102	21.0	19.7	6.4	0.0	11 APR 88
CVCP	88	103	24.5	20.1	2.4	0.0	12 APR 88
CVCP	88	104	22.9	22.8	0.3	0.0	13 APR 88
CVCP	88	105	21.3	14.0	2.2	2.1	14 APR 88
CVCP	88	106	11.7	6.6	- 3.0	0.0	15 APR 88
CVCP	88	107	25.1	15.5	- 2.9	0.0	16 APR 88
CVCP	88	108	22.4	23.6	4.0	3.9	17 APR 88
CVCP	88	109	25.1	9.8	- 2.1	0.0	18 APR 88
CVCP	88	110	26.1	10.0	- 5.6	0.0	19 APR 88
CVCP	88	111	6.9	12.9	- 1.0	5.1	20 APR 88
CVCP	88	112	19.4	12.3	- 3.3	0.0	21 APR 88
CVCP	88	113	14.5	14.4	1.3	0.0	22 APR 88
CVCP	88	114	14.1	21.3	2.5	2.1	23 APR 88
CVCP	88	115	19.5	14.6	0.4	0.0	24 APR 88
CVCP	88	116	25.8	20.0	- 3.6	0.0	25 APR 88
CVCP	88	117	16.5	19.3	4.7	0.0	26 APR 88
CVCP	88	118	4.4	10.7	2.3	9.0	27 APR 88
CVCP	88	119	22.8	15.3	2.0	0.3	28 APR 88
CVCP	88	120	27.6	18.0	- 0.0	0.0	29 APR 88
CVCP	88	121	27.7	23.2	1.6	0.0	30 APR 88
CVCP	88	122	28.1	24.1	1.3	0.0	01 MAY 88
CVCP	88	123	28.3	24.5	2.3	0.0	02 MAY 88
CVCP	88	124	20.4	20.8	3.4	0.0	03 MAY 88
CVCP	88	125	21.1	20.0	0.7	0.0	04 MAY 88
CVCP	88	126	22.6	23.4	2.7	0.0	05 MAY 88
CVCP	88	127	28.8	27.4	3.1	0.0	06 MAY 88
CVCP	88	128	24.1	28.4	5.0	0.0	07 MAY 88
CVCP	88	129	19.9	29.0	12.8	1.8	08 MAY 88
CVCP	88	130	13.2	21.7	11.3	4.9	09 MAY 88
CVCP	88	131	10.2	17.7	7.4	0.0	10 MAY 88
CVCP	88	132	29.5	23.1	2.4	0.0	11 MAY 88
CVCP	88	133	14.0	26.8	9.9	1.0	12 MAY 88
CVCP	88	134	26.5	22.0	8.4	0.0	13 MAY 88
CVCP	88	135	29.0	24.7	4.1	0.0	14 MAY 88
CVCP	88	136	14.0	31.6	10.5	9.0	15 MAY 88
CVCP	88	137	23.5	19.4	8.8	0.0	16 MAY 88
CVCP	88	138	25.9	21.8	9.3	0.0	17 MAY 88
CVCP	88	139	29.1	24.6	6.1	0.0	18 MAY 88
CVCP	88	140	19.0	24.5	7.8	0.0	19 MAY 88
CVCP	88	141	17.0	26.4	13.1	0.0	20 MAY 88
CVCP	88	142	20.6	29.4	12.6	0.0	21 MAY 88
CVCP	88	143	25.5	32.3	13.4	0.0	22 MAY 88
CVCP	88	144	9.1	22.6	15.5	3.9	23 MAY 88
CVCP	88	145	28.7	21.8	7.2	6.4	24 MAY 88
CVCP	88	146	30.4	20.4	1.1	0.0	25 MAY 88
CVCP	88	147	30.3	25.8	2.9	0.0	26 MAY 88
CVCP	88	148	29.2	28.9	11.6	0.0	27 MAY 88
CVCP	88	149	27.8	30.8	13.1	0.0	28 MAY 88

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	150	28.9	32.5	14.7	0.0	29 MAY 88
CVCP	88	151	28.7	34.3	13.9	0.0	30 MAY 88
CVCP	88	152	29.2	34.5	13.5	0.0	31 MAY 88
CVCP	88	153	29.1	34.4	13.4	0.0	01 JUN 88
CVCP	88	154	8.6	20.5	10.6	5.9	02 JUN 88
CVCP	88	155	30.1	26.4	3.9	0.0	03 JUN 88
CVCP	88	156	30.1	26.4	3.9	0.0	04 JUN 88
CVCP	88	157	29.6	30.5	9.9	0.0	05 JUN 88
CVCP	88	158	27.7	33.5	15.0	0.0	06 JUN 88
CVCP	88	159	30.4	33.8	15.1	0.0	07 JUN 88
CVCP	88	160	23.5	27.5	9.7	0.3	08 JUN 88
CVCP	88	161	31.2	19.9	4.6	0.0	09 JUN 88
CVCP	88	162	30.8	24.1	3.2	0.0	10 JUN 88
CVCP	88	163	29.4	29.4	3.4	0.0	11 JUN 88
CVCP	88	164	30.0	33.0	10.3	0.0	12 JUN 88
CVCP	88	165	29.7	34.7	15.5	0.0	13 JUN 88
CVCP	88	166	28.5	35.4	18.9	0.0	14 JUN 88
CVCP	88	167	24.1	34.4	19.1	0.5	15 JUN 88
CVCP	88	168	27.1	29.7	13.9	0.0	16 JUN 88
CVCP	88	169	23.1	31.0	11.7	0.0	17 JUN 88
CVCP	88	170	30.3	34.4	12.7	0.0	18 JUN 88
CVCP	88	171	26.0	33.8	17.3	0.0	19 JUN 88
CVCP	88	172	22.3	32.9	18.8	9.5	20 JUN 88
CVCP	88	173	27.7	37.4	17.0	0.0	21 JUN 88
CVCP	88	174	16.8	35.4	20.9	0.0	22 JUN 88
CVCP	88	175	31.1	28.9	14.7	0.0	23 JUN 88
CVCP	88	176	24.7	31.7	15.5	0.0	24 JUN 88
CVCP	88	177	27.7	39.4	21.9	0.0	25 JUN 88
CVCP	88	178	24.7	25.6	12.5	0.0	26 JUN 88
CVCP	88	179	30.6	29.1	7.5	0.0	27 JUN 88
CVCP	88	180	12.2	27.8	10.3	1.5	28 JUN 88
CVCP	88	181	21.0	26.8	12.2	0.0	29 JUN 88
CVCP	88	182	27.4	25.3	5.8	0.0	30 JUN 88
CVCP	88	183	28.5	27.7	5.6	0.0	01 JUL 88
CVCP	88	184	28.0	30.8	6.1	0.0	02 JUL 88
CVCP	88	185	30.9	33.2	5.9	0.0	03 JUL 88
CVCP	88	186	30.4	36.6	8.2	0.0	04 JUL 88
CVCP	88	187	28.7	38.7	13.4	0.0	05 JUL 88
CVCP	88	188	26.8	39.5	15.9	0.0	06 JUL 88
CVCP	88	189	24.7	39.8	16.0	0.0	07 JUL 88
CVCP	88	190	27.0	40.0	17.8	0.0	08 JUL 88
CVCP	88	191	25.0	37.1	16.6	0.0	09 JUL 88
CVCP	88	192	8.1	28.0	18.7	10.3	10 JUL 88
CVCP	88	193	24.2	31.4	15.7	0.3	11 JUL 88
CVCP	88	194	25.5	31.8	11.6	0.0	12 JUL 88
CVCP	88	195	23.4	31.9	12.5	0.0	13 JUL 88
CVCP	88	196	28.1	34.4	17.0	5.4	14 JUL 88
CVCP	88	197	22.7	37.1	14.3	3.1	15 JUL 88
CVCP	88	198	20.1	36.2	21.5	15.7	16 JUL 88
CVCP	88	199	24.0	32.8	20.2	0.0	17 JUL 88
CVCP	88	200	4.5	25.7	19.4	3.3	18 JUL 88
CVCP	88	201	22.7	32.7	17.5	0.0	19 JUL 88
CVCP	88	202	8.0	23.4	14.5	9.5	20 JUL 88
CVCP	88	203	22.9	30.5	13.3	0.0	21 JUL 88
CVCP	88	204	21.7	28.1	14.9	0.0	22 JUL 88
CVCP	88	205	25.1	31.4	13.5	10.8	23 JUL 88
CVCP	88	206	27.6	31.0	14.3	0.3	24 JUL 88
CVCP	88	207	15.7	30.0	17.5	0.8	25 JUL 88

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ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	208	24.6	29.5	15.5	0.0	26 JUL 88
CVCP	88	209	27.1	31.8	11.5	0.0	27 JUL 88
CVCP	88	210	26.9	35.6	18.8	0.0	28 JUL 88
CVCP	88	211	26.0	34.0	18.1	0.0	29 JUL 88
CVCP	88	212	16.8	32.3	22.2	3.3	30 JUL 88
CVCP	88	213	26.4	32.3	15.9	0.0	31 JUL 88
CVCP	88	214	24.6	38.7	20.6	0.0	01 AUG 88
CVCP	88	215	24.9	37.0	22.2	0.0	02 AUG 88
CVCP	88	216	21.6	38.1	21.7	0.0	03 AUG 88
CVCP	88	217	21.7	36.5	20.5	0.0	04 AUG 88
CVCP	88	218	13.2	34.0	22.3	12.6	05 AUG 88
CVCP	88	219	27.2	31.5	16.9	0.3	06 AUG 88
CVCP	88	220	27.0	34.5	15.4	0.0	07 AUG 88
CVCP	88	221	23.8	34.6	16.5	0.0	08 AUG 88
CVCP	88	222	14.0	31.1	21.2	2.6	09 AUG 88
CVCP	88	223	14.2	33.3	18.5	4.6	10 AUG 88
CVCP	88	224	20.7	33.1	17.9	0.8	11 AUG 88
CVCP	88	225	23.8	36.2	20.7	0.0	12 AUG 88
CVCP	88	226	19.6	34.5	21.3	0.0	13 AUG 88
CVCP	88	227	20.4	34.3	23.4	0.0	14 AUG 88
CVCP	88	228	21.0	31.8	18.5	36.2	15 AUG 88
CVCP	88	229	23.1	34.7	15.2	0.0	16 AUG 88
CVCP	88	230	24.4	35.6	22.9	0.0	17 AUG 88
CVCP	88	231	11.8	28.6	17.4	11.3	18 AUG 88
CVCP	88	232	3.4	19.9	15.3	0.5	19 AUG 88
CVCP	88	233	23.8	27.9	15.2	0.0	20 AUG 88
CVCP	88	234	23.3	26.8	10.6	0.0	21 AUG 88
CVCP	88	235	18.4	26.7	10.5	0.0	22 AUG 88
CVCP	88	236	14.2	26.2	14.4	11.6	23 AUG 88
CVCP	88	237	23.6	26.8	13.9	0.0	24 AUG 88
CVCP	88	238	23.2	25.7	12.9	0.0	25 AUG 88
CVCP	88	239	20.6	26.0	9.1	0.0	26 AUG 88
CVCP	88	240	5.7	21.2	8.1	12.9	27 AUG 88
CVCP	88	241	18.7	24.5	9.3	0.5	28 AUG 88
CVCP	88	242	19.8	23.7	4.8	0.0	29 AUG 88
CVCP	88	243	17.7	25.0	5.1	0.0	30 AUG 88
CVCP	88	244	22.4	27.7	11.6	0.0	31 AUG 88
CVCP	88	245	21.6	27.8	9.1	0.0	01 SEP 88
CVCP	88	246	16.1	29.5	13.4	8.5	02 SEP 88
CVCP	88	247	8.3	23.1	15.8	15.7	03 SEP 88
CVCP	88	248	11.8	22.8	14.8	0.8	04 SEP 88
CVCP	88	249	18.1	16.4	7.1	0.3	05 SEP 88
CVCP	88	250	17.9	19.3	2.9	0.0	06 SEP 88
CVCP	88	251	22.8	22.8	2.8	0.0	07 SEP 88
CVCP	88	252	19.9	24.8	8.7	0.0	08 SEP 88
CVCP	88	253	21.5	26.7	8.0	0.0	09 SEP 88
CVCP	88	254	19.1	28.3	5.2	0.0	10 SEP 88
CVCP	88	255	18.7	28.0	8.6	0.0	11 SEP 88
CVCP	88	256	9.2	27.3	16.9	7.2	12 SEP 88
CVCP	88	257	18.5	21.6	8.9	0.0	13 SEP 88
CVCP	88	258	20.8	25.6	7.4	1.0	14 SEP 88
CVCP	88	259	19.8	22.9	5.0	0.0	15 SEP 88
CVCP	88	260	14.0	25.6	8.8	0.0	16 SEP 88
CVCP	88	261	12.4	29.2	18.6	0.0	17 SEP 88
CVCP	88	262	8.5	29.3	16.9	33.9	18 SEP 88
CVCP	88	263	2.5	21.5	13.2	49.9	19 SEP 88
CVCP	88	264	2.0	14.3	12.0	0.3	20 SEP 88
CVCP	88	265	7.9	17.7	11.4	0.0	21 SEP 88

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	266	4.7	23.0	11.9	15.7	22 SEP 88
CVCP	88	267	18.5	21.1	8.1	2.8	23 SEP 88
CVCP	88	268	16.8	20.4	3.9	0.0	24 SEP 88
CVCP	88	269	18.8	23.1	3.8	0.0	25 SEP 88
CVCP	88	270	18.3	24.5	5.7	0.0	26 SEP 88
CVCP	88	271	16.1	26.6	19.1	0.0	27 SEP 88
CVCP	88	272	7.7	17.4	10.5	0.0	28 SEP 88
CVCP	88	273	14.6	24.5	8.2	0.0	29 SEP 88
CVCP	88	274	13.3	26.3	12.1	7.2	30 SEP 88
CVCP	88	275	4.7	22.5	16.9	7.5	1 OCT 88
CVCP	88	276	8.3	17.4	7.1	19.3	2 OCT 88
CVCP	88	277	16.8	16.0	4.2	0.0	3 OCT 88
CVCP	88	278	8.9	11.1	3.2	6.9	4 OCT 88
CVCP	88	279	14.6	13.6	1.3	0.0	5 OCT 88
CVCP	88	280	12.2	13.9	-2.3	0.0	6 OCT 88
CVCP	88	281	13.1	15.0	-6.3	0.0	7 OCT 88
CVCP	88	282	8.6	16.2	6.3	0.0	8 OCT 88
CVCP	88	283	9.2	15.9	7.5	0.8	9 OCT 88
CVCP	88	284	10.1	17.5	5.7	0.8	10 OCT 88
CVCP	88	285	8.2	8.5	2.0	1.0	11 OCT 88
CVCP	88	286	8.6	8.6	-2.4	0.0	12 OCT 88
CVCP	88	287	15.7	11.2	-2.7	0.0	13 OCT 88
CVCP	88	288	14.3	20.5	1.7	0.0	14 OCT 88
CVCP	88	289	11.3	22.8	11.9	0.0	15 OCT 88
CVCP	88	290	2.0	15.6	10.5	17.0	16 OCT 88
CVCP	88	291	2.0	15.7	10.1	50.1	17 OCT 88
CVCP	88	292	9.0	14.9	2.6	1.0	18 OCT 88
CVCP	88	293	8.5	11.3	1.3	2.3	19 OCT 88
CVCP	88	294	6.8	9.5	-1.3	0.3	20 OCT 88
CVCP	88	295	1.5	7.4	4.9	4.6	21 OCT 88
CVCP	88	296	10.0	10.8	-1.3	0.5	22 OCT 88
CVCP	88	297	1.2	7.8	-1.9	11.6	23 OCT 88
CVCP	88	298	2.5	3.9	0.9	7.5	24 OCT 88
CVCP	88	299	2.6	3.0	0.5	0.0	25 OCT 88
CVCP	88	300	2.9	4.0	-1.7	0.0	26 OCT 88
CVCP	88	301	7.3	13.1	-2.6	0.0	27 OCT 88
CVCP	88	302	7.1	8.3	-1.5	0.5	28 OCT 88
CVCP	88	303	10.7	7.1	-4.2	0.0	29 OCT 88
CVCP	88	304	12.3	6.2	-7.4	0.0	30 OCT 88
CVCP	88	305	12.1	9.9	-7.0	0.0	31 OCT 88
CVCP	88	306	2.4	7.4	3.1	0.0	1 NOV 88
CVCP	88	307	5.2	7.5	-0.3	0.0	2 NOV 88
CVCP	88	308	7.3	14.9	-0.3	0.0	3 NOV 88
CVCP	88	309	1.2	14.7	11.1	4.6	4 NOV 88
CVCP	88	310	0.9	11.4	2.8	2.0	5 NOV 88
CVCP	88	311	2.1	2.8	-0.7	4.1	6 NOV 88
CVCP	88	312	4.5	6.7	0.5	4.1	7 NOV 88
CVCP	88	313	2.3	6.2	-1.1	1.5	8 NOV 88
CVCP	88	314	3.6	8.8	-0.7	24.7	9 NOV 88
CVCP	88	315	0.9	11.6	2.7	25.2	10 NOV 88
CVCP	88	316	3.3	4.1	-1.0	0.3	11 NOV 88
CVCP	88	317	2.2	6.3	-0.6	7.5	12 NOV 88
CVCP	88	318	7.4	9.5	3.8	1.8	13 NOV 88
CVCP	88	319	7.8	14.9	0.1	0.0	14 NOV 88
CVCP	88	320	7.6	17.9	0.9	0.0	15 NOV 88
CVCP	88	321	2.0	16.9	0.9	8.1	16 NOV 88
CVCP	88	322	10.2	7.6	-1.3	0.8	17 NOV 88
CVCP	88	323	7.4	12.2	-1.5	0.0	18 NOV 88

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	88	324	0.9	6.5	3.8	9.3	19 NOV 88
CVCP	88	325	0.9	5.5	0.2	17.0	20 NOV 88
CVCP	88	326	2.1	3.6	1.3	0.0	21 NOV 88
CVCP	88	327	2.8	3.7	-1.2	0.0	22 NOV 88
CVCP	88	328	7.7	6.3	-2.4	0.0	23 NOV 88
CVCP	88	329	9.0	13.2	-0.9	0.0	24 NOV 88
CVCP	88	330	8.2	14.2	2.8	0.0	25 NOV 88
CVCP	88	331	1.2	12.7	10.5	5.1	26 NOV 88
CVCP	88	332	1.2	11.2	0.5	3.9	27 NOV 88
CVCP	88	333	2.7	1.2	-3.0	0.8	28 NOV 88
CVCP	88	334	5.5	5.8	-3.9	0.0	29 NOV 88
CVCP	88	335	1.0	5.1	-1.3	0.0	30 NOV 88
CVCP	88	336	4.1	1.8	-7.2	1.0	1 DEC 88
CVCP	88	337	7.3	4.0	-6.9	0.3	2 DEC 88
CVCP	88	338	8.3	8.9	-1.3	0.0	3 DEC 88
CVCP	88	339	7.6	4.4	-6.7	0.0	4 DEC 88
CVCP	88	340	6.2	5.9	-2.1	0.0	5 DEC 88
CVCP	88	341	8.3	10.6	-0.2	0.0	6 DEC 88
CVCP	88	342	3.8	6.7	-1.0	0.0	7 DEC 88
CVCP	88	343	7.9	1.4	-6.7	0.0	8 DEC 88
CVCP	88	344	4.5	-2.1	-7.9	0.0	9 DEC 88
CVCP	88	345	5.5	-4.3	-12.6	0.0	10 DEC 88
CVCP	88	346	13.9	-4.7	-15.0	0.0	11 DEC 88
CVCP	88	347	8.7	-1.1	-10.6	0.0	12 DEC 88
CVCP	88	348	3.5	2.6	-6.3	0.5	13 DEC 88
CVCP	88	349	3.9	7.2	-0.5	0.0	14 DEC 88
CVCP	88	350	5.2	0.4	-10.2	0.0	15 DEC 88
CVCP	88	351	4.9	-9.1	-13.6	0.0	16 DEC 88
CVCP	88	352	5.1	-3.1	-10.6	0.0	17 DEC 88
CVCP	88	353	3.2	-4.9	-10.4	0.0	18 DEC 88
CVCP	88	354	7.3	9.6	-8.0	0.0	19 DEC 88
CVCP	88	355	3.7	13.5	1.1	58.1	20 DEC 88
CVCP	88	356	2.7	2.5	-3.5	0.0	21 DEC 88
CVCP	88	357	5.5	2.6	-3.9	17.5	22 DEC 88
CVCP	88	358	8.2	8.4	1.8	1.8	23 DEC 88
CVCP	88	359	2.5	3.8	-0.4	0.0	24 DEC 88
CVCP	88	360	2.5	1.8	-0.6	0.0	25 DEC 88
CVCP	88	361	1.7	-1.7	-7.1	0.0	26 DEC 88
CVCP	88	362	1.1	4.3	-1.7	20.8	27 DEC 88
CVCP	88	363	1.1	4.3	-1.7	0.0	28 DEC 88
CVCP	88	364	1.1	5.3	-1.7	0.0	29 DEC 88
CVCP	88	365	8.1	-0.9	-11.7	0.3	30 DEC 88
CVCP	88	366	7.8	3.1	-7.6	0.5	31 DEC 89
CVCP	89	1	7.0	2.2	-7.1	0.0	01 JAN 89
CVCP	89	2	2.6	-1.6	-10.2	0.3	02 JAN 89
CVCP	89	3	2.4	-0.9	-10.8	0.0	03 JAN 89
CVCP	89	4	8.0	-3.1	-16.8	0.0	04 JAN 89
CVCP	89	5	5.7	3.4	-9.2	3.1	05 JAN 89
CVCP	89	6	1.7	1.2	-0.9	3.6	06 JAN 89
CVCP	89	7	2.7	11.6	-0.9	15.7	07 JAN 89
CVCP	89	8	5.7	6.9	-10.3	0.0	08 JAN 89
CVCP	89	9	7.6	-5.4	-12.6	0.0	09 JAN 89
CVCP	89	10	6.7	2.9	-0.6	0.0	10 JAN 89
CVCP	89	11	8.4	3.3	-6.0	0.8	11 JAN 89
CVCP	89	12	6.6	4.7	-3.7	1.8	12 JAN 89
CVCP	89	13	9.4	0.3	-6.1	0.0	13 JAN 89
CVCP	89	14	1.5	-2.3	-7.0	0.0	14 JAN 89
CVCP	89	15	2.0	1.3	-2.6	2.6	15 JAN 89

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	16	8.9	1.9	-7.5	0.8	16 JAN 89
CVCP	89	17	8.5	5.9	-1.7	0.0	17 JAN 89
CVCP	89	18	8.2	7.8	0.1	0.0	18 JAN 89
CVCP	89	19	8.3	8.8	-1.0	0.0	19 JAN 89
CVCP	89	20	7.0	3.7	-8.3	0.0	20 JAN 89
CVCP	89	21	10.1	-0.3	-11.6	0.0	21 JAN 89
CVCP	89	22	10.3	6.8	-3.2	0.0	22 JAN 89
CVCP	89	23	10.3	9.9	-0.2	0.0	23 JAN 89
CVCP	89	24	2.9	6.4	0.0	0.0	24 JAN 89
CVCP	89	25	1.5	3.4	0.1	2.8	25 JAN 89
CVCP	89	26	1.5	8.3	-2.1	0.5	26 JAN 89
CVCP	89	27	10.4	6.1	-3.6	0.0	27 JAN 89
CVCP	89	28	10.5	10.0	-0.2	0.0	28 JAN 89
CVCP	89	29	1.7	4.8	2.0	5.1	29 JAN 89
CVCP	89	30	3.6	4.0	-0.6	0.3	30 JAN 89
CVCP	89	31	1.0	15.4	1.3	0.0	31 JAN 89
CVCP	89	32	1.9	10.3	-3.0	0.0	01 FEB 89
CVCP	89	33	1.3	-3.0	-5.8	0.0	02 FEB 89
CVCP	89	34	11.7	-3.3	-9.4	0.0	03 FEB 89
CVCP	89	35	4.3	-6.6	-10.1	0.0	04 FEB 89
CVCP	89	36	2.6	-4.8	-13.5	0.0	05 FEB 89
CVCP	89	37	4.1	-7.4	-17.5	0.0	06 FEB 89
CVCP	89	38	12.5	-4.6	-16.0	0.0	07 FEB 89
CVCP	89	39	11.3	-4.4	-12.6	0.0	08 FEB 89
CVCP	89	40	11.9	-9.4	-19.6	0.0	09 FEB 89
CVCP	89	41	9.9	-1.0	-11.3	0.0	10 FEB 89
CVCP	89	42	9.9	3.1	-9.1	0.0	11 FEB 89
CVCP	89	43	12.7	5.9	-8.6	0.0	12 FEB 89
CVCP	89	44	1.9	2.4	-3.6	18.5	13 FEB 89
CVCP	89	45	12.4	5.7	-1.0	0.0	14 FEB 89
CVCP	89	46	2.9	1.5	-3.0	1.0	15 FEB 89
CVCP	89	47	13.9	-1.3	-8.9	0.0	16 FEB 89
CVCP	89	48	12.6	-0.9	-12.5	0.0	17 FEB 89
CVCP	89	49	12.1	1.4	-12.7	0.0	18 FEB 89
CVCP	89	50	5.0	0.5	-7.2	0.0	19 FEB 89
CVCP	89	51	3.1	1.0	-3.0	2.1	20 FEB 89
CVCP	89	52	2.4	1.8	-5.2	0.3	21 FEB 89
CVCP	89	53	10.0	0.9	-13.6	0.0	22 FEB 89
CVCP	89	54	15.4	-5.6	-23.4	0.0	23 FEB 89
CVCP	89	55	15.9	0.9	-28.6	0.0	24 FEB 89
CVCP	89	56	11.2	4.9	-7.1	1.3	25 FEB 89
CVCP	89	57	8.6	2.0	-5.1	0.0	26 FEB 89
CVCP	89	58	12.0	4.5	-10.9	0.0	27 FEB 89
CVCP	89	59	10.1	3.1	-14.9	0.0	28 FEB 89
CVCP	89	60	16.2	-1.5	-11.9	0.0	01 MAR 89
CVCP	89	61	8.6	-1.1	-11.9	0.0	02 MAR 89
CVCP	89	62	5.2	-0.4	-5.5	0.0	03 MAR 89
CVCP	89	63	3.4	6.2	-1.6	27.0	04 MAR 89
CVCP	89	64	5.7	0.3	-7.4	0.3	05 MAR 89
CVCP	89	65	7.7	-2.8	-10.3	0.5	06 MAR 89
CVCP	89	66	17.9	-1.8	-12.4	0.0	07 MAR 89
CVCP	89	67	16.7	4.0	-13.0	0.0	08 MAR 89
CVCP	89	68	17.6	8.6	-7.0	0.0	09 MAR 89
CVCP	89	69	15.5	8.8	-1.4	0.0	10 MAR 89
CVCP	89	70	17.0	13.4	0.1	0.0	11 MAR 89
CVCP	89	71	6.9	1.9	-1.7	0.0	12 MAR 89
CVCP	89	72	10.4	8.5	-2.6	0.0	13 MAR 89
CVCP	89	73	10.3	14.6	-2.1	18.5	14 MAR 89

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APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	74	5.0	10.2	-4.8	1.8	15 MAR 89
CVCP	89	75	16.7	8.4	-5.0	0.0	16 MAR 89
CVCP	89	76	3.7	6.7	-1.1	9.3	17 MAR 89
CVCP	89	77	6.4	-0.3	-6.1	3.4	18 MAR 89
CVCP	89	78	19.9	2.7	-8.5	0.3	19 MAR 89
CVCP	89	79	4.9	2.2	-1.0	5.4	20 MAR 89
CVCP	89	80	19.3	0.9	-8.0	0.0	21 MAR 89
CVCP	89	81	21.1	4.6	-9.0	0.0	22 MAR 89
CVCP	89	82	21.1	10.4	-4.1	0.0	23 MAR 89
CVCP	89	83	20.4	16.6	-3.0	0.0	24 MAR 89
CVCP	89	84	19.8	20.1	5.0	0.0	25 MAR 89
CVCP	89	85	18.7	21.0	4.0	0.0	26 MAR 89
CVCP	89	86	14.9	24.9	12.6	0.0	27 MAR 89
CVCP	89	87	4.3	18.4	12.7	49.1	28 MAR 89
CVCP	89	88	14.7	12.7	5.0	0.0	29 MAR 89
CVCP	89	89	12.3	10.3	1.8	0.0	30 MAR 89
CVCP	89	90	6.1	3.8	-1.4	0.0	31 MAR 89
CVCP	89	91	15.3	7.9	-2.7	0.0	01 APR 89
CVCP	89	92	4.0	9.1	5.3	12.9	02 APR 89
CVCP	89	93	4.1	10.0	6.2	15.7	03 APR 89
CVCP	89	94	19.5	17.5	4.6	5.7	04 APR 89
CVCP	89	95	6.2	7.7	2.2	0.0	05 APR 89
CVCP	89	96	18.6	11.7	-1.9	0.3	06 APR 89
CVCP	89	97	13.3	8.1	-2.3	0.0	07 APR 89
CVCP	89	98	14.3	10.1	-1.9	0.0	08 APR 89
CVCP	89	99	13.5	2.0	-6.1	0.0	09 APR 89
CVCP	89	100	14.7	2.1	-10.2	0.0	10 APR 89
CVCP	89	101	18.4	9.1	-3.8	0.0	11 APR 89
CVCP	89	102	10.1	10.1	-1.6	0.0	12 APR 89
CVCP	89	103	24.6	11.8	-4.1	0.0	13 APR 89
CVCP	89	104	15.4	18.9	2.0	6.7	14 APR 89
CVCP	89	105	21.7	17.8	0.3	0.3	15 APR 89
CVCP	89	106	23.8	21.3	-0.9	0.5	16 APR 89
CVCP	89	107	8.0	18.7	3.1	3.3	17 APR 89
CVCP	89	108	8.0	6.8	0.3	0.0	18 APR 89
CVCP	89	109	25.6	15.3	-1.3	0.0	19 APR 89
CVCP	89	110	20.8	21.4	0.5	0.0	20 APR 89
CVCP	89	111	16.2	16.9	7.1	0.3	21 APR 89
CVCP	89	112	13.5	15.2	5.8	0.0	22 APR 89
CVCP	89	113	26.2	16.4	-0.4	0.0	23 APR 89
CVCP	89	114	25.2	21.1	0.9	0.0	24 APR 89
CVCP	89	115	21.0	24.1	10.1	7.2	25 APR 89
CVCP	89	116	25.3	24.4	11.4	0.0	26 APR 89
CVCP	89	117	20.4	24.5	10.7	0.0	27 APR 89
CVCP	89	118	7.1	12.4	6.5	1.8	28 APR 89
CVCP	89	119	9.0	16.9	7.4	0.0	29 APR 89
CVCP	89	120	25.2	17.6	3.6	0.0	30 APR 89
CVCP	89	121	25.3	17.4	3.3	0.0	01 MAY 89
CVCP	89	122	5.1	9.7	1.7	8.7	02 MAY 89
CVCP	89	123	26.6	17.8	0.9	0.0	03 MAY 89
CVCP	89	124	20.3	19.6	5.4	0.5	04 MAY 89
CVCP	89	125	22.6	19.8	5.9	0.3	05 MAY 89
CVCP	89	126	12.6	8.2	-0.9	0.0	06 MAY 89
CVCP	89	127	24.8	11.2	-4.4	0.0	07 MAY 89
CVCP	89	128	17.4	19.1	0.2	0.3	08 MAY 89
CVCP	89	129	9.7	16.5	7.4	0.5	09 MAY 89
CVCP	89	130	28.8	18.6	1.6	0.0	10 MAY 89
CVCP	89	131	29.4	17.5	3.2	0.0	11 MAY 89

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	132	11.8	17.8	5.4	7.2	12 MAY 89
CVCP	89	133	6.6	13.6	7.6	3.3	13 MAY 89
CVCP	89	134	13.3	17.7	6.9	0.0	14 MAY 89
CVCP	89	135	17.8	19.0	7.8	3.1	15 MAY 89
CVCP	89	136	25.6	23.6	4.5	0.0	16 MAY 89
CVCP	89	137	27.3	27.0	6.6	0.0	17 MAY 89
CVCP	89	138	16.5	26.1	12.1	0.0	18 MAY 89
CVCP	89	139	4.3	20.1	15.7	14.7	19 MAY 89
CVCP	89	140	13.9	23.6	10.9	2.1	20 MAY 89
CVCP	89	141	28.6	26.3	8.7	0.0	21 MAY 89
CVCP	89	142	21.7	26.9	8.2	0.0	22 MAY 89
CVCP	89	143	29.5	26.7	12.2	0.0	23 MAY 89
CVCP	89	144	17.4	26.1	9.5	0.0	24 MAY 89
CVCP	89	145	17.0	25.2	14.6	17.7	25 MAY 89
CVCP	89	146	29.7	24.6	12.1	0.0	26 MAY 89
CVCP	89	147	29.0	18.7	8.2	0.0	27 MAY 89
CVCP	89	148	27.5	22.2	2.2	0.0	28 MAY 89
CVCP	89	149	11.6	21.0	9.4	0.0	29 MAY 89
CVCP	89	150	13.1	29.3	16.2	2.1	30 MAY 89
CVCP	89	151	12.2	28.7	17.3	30.3	31 MAY 89
CVCP	89	152	7.7	22.3	17.2	23.0	01 JUN 89
CVCP	89	153	30.3	26.2	15.0	0.0	02 JUN 89
CVCP	89	154	7.7	21.9	13.7	16.3	03 JUN 89
CVCP	89	155	28.0	23.6	11.1	0.0	04 JUN 89
CVCP	89	156	18.8	24.2	12.0	0.3	05 JUN 89
CVCP	89	157	29.3	28.9	13.0	0.0	06 JUN 89
CVCP	89	158	27.0	30.6	14.8	0.0	07 JUN 89
CVCP	89	159	21.6	29.1	16.1	0.0	08 JUN 89
CVCP	89	160	21.3	24.8	11.7	0.0	09 JUN 89
CVCP	89	161	23.5	21.1	10.2	0.0	10 JUN 89
CVCP	89	162	29.2	25.6	6.7	0.0	11 JUN 89
CVCP	89	163	4.0	17.6	15.3	12.5	12 JUN 89
CVCP	89	164	18.2	24.8	15.6	1.5	13 JUN 89
CVCP	89	165	16.7	24.9	14.8	2.3	14 JUN 89
CVCP	89	166	15.6	20.9	10.9	0.0	15 JUN 89
CVCP	89	167	8.4	15.9	10.1	5.4	16 JUN 89
CVCP	89	168	26.9	25.4	9.9	0.0	17 JUN 89
CVCP	89	169	18.3	27.0	13.4	0.0	18 JUN 89
CVCP	89	170	13.6	26.9	17.7	0.8	19 JUN 89
CVCP	89	171	19.9	25.9	15.7	0.0	20 JUN 89
CVCP	89	172	27.9	29.3	14.2	0.0	21 JUN 89
CVCP	89	173	18.4	31.0	17.9	0.0	22 JUN 89
CVCP	89	174	24.6	33.2	18.5	0.0	23 JUN 89
CVCP	89	175	28.4	33.1	18.1	0.0	24 JUN 89
CVCP	89	176	28.5	33.9	15.9	0.0	25 JUN 89
CVCP	89	177	18.7	34.9	18.4	0.3	26 JUN 89
CVCP	89	178	9.1	25.9	18.0	15.7	27 JUN 89
CVCP	89	179	29.9	27.5	13.5	0.3	28 JUN 89
CVCP	89	180	31.4	24.8	7.2	0.0	29 JUN 89
CVCP	89	181	31.3	28.7	8.7	0.0	30 JUN 89
CVCP	89	182	29.8	31.9	12.7	0.0	01 JUL 89
CVCP	89	183	23.9	32.6	16.7	0.0	02 JUL 89
CVCP	89	184	18.0	28.4	18.3	0.0	03 JUL 89
CVCP	89	185	19.9	31.8	15.8	1.5	04 JUL 89
CVCP	89	186	27.4	32.5	16.6	0.0	05 JUL 89
CVCP	89	187	26.1	34.7	17.1	0.0	06 JUL 89
CVCP	89	188	27.7	33.2	16.0	0.0	07 JUL 89
CVCP	89	189	23.9	32.9	13.4	0.0	08 JUL 89

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APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	190	22.6	31.6	18.4	50.6	09 JUL 89
CVCP	89	191	26.8	33.4	23.2	0.0	10 JUL 89
CVCP	89	192	18.0	32.9	19.6	0.0	11 JUL 89
CVCP	89	193	5.8	20.6	15.3	0.0	12 JUL 89
CVCP	89	194	15.9	25.1	14.8	0.8	13 JUL 89
CVCP	89	195	28.7	27.7	9.3	0.0	14 JUL 89
CVCP	89	196	23.4	27.2	11.3	0.0	15 JUL 89
CVCP	89	197	28.9	30.0	11.4	0.0	16 JUL 89
CVCP	89	198	26.2	31.1	12.2	0.0	17 JUL 89
CVCP	89	199	20.6	31.2	12.1	0.3	18 JUL 89
CVCP	89	200	6.8	22.3	17.1	13.9	19 JUL 89
CVCP	89	201	4.6	19.0	17.2	18.8	20 JUL 89
CVCP	89	202	16.3	27.6	16.5	5.1	21 JUL 89
CVCP	89	203	22.9	30.1	16.7	0.0	22 JUL 89
CVCP	89	204	24.7	31.1	16.0	0.0	23 JUL 89
CVCP	89	205	21.3	31.7	18.5	0.0	24 JUL 89
CVCP	89	206	21.2	32.0	20.2	11.3	25 JUL 89
CVCP	89	207	17.6	32.0	20.5	0.5	26 JUL 89
CVCP	89	208	18.3	30.6	20.8	4.1	27 JUL 89
CVCP	89	209	22.0	25.9	13.8	0.0	28 JUL 89
CVCP	89	210	22.9	27.0	9.9	0.0	29 JUL 89
CVCP	89	211	4.5	19.6	14.4	9.5	30 JUL 89
CVCP	89	212	24.7	28.4	13.3	0.0	31 JUL 89
CVCP	89	213	26.1	29.6	13.1	0.0	01 AUG 89
CVCP	89	214	25.5	29.5	14.4	0.0	02 AUG 89
CVCP	89	215	22.3	31.8	17.7	0.0	03 AUG 89
CVCP	89	216	17.6	30.2	21.2	13.6	04 AUG 89
CVCP	89	217	23.8	30.5	18.6	12.9	05 AUG 89
CVCP	89	218	19.4	25.7	10.5	0.0	06 AUG 89
CVCP	89	219	25.2	20.3	6.1	0.0	07 AUG 89
CVCP	89	220	24.0	25.4	5.9	0.0	08 AUG 89
CVCP	89	221	22.2	26.7	9.6	0.0	09 AUG 89
CVCP	89	222	19.4	28.8	10.5	0.0	10 AUG 89
CVCP	89	223	22.4	29.4	10.7	0.0	11 AUG 89
CVCP	89	224	17.8	29.8	11.2	1.5	12 AUG 89
CVCP	89	225	23.8	28.4	11.4	0.0	13 AUG 89
CVCP	89	226	19.4	28.8	14.0	0.0	14 AUG 89
CVCP	89	227	15.0	27.4	14.6	1.0	15 AUG 89
CVCP	89	228	18.1	24.6	9.6	0.3	16 AUG 89
CVCP	89	229	25.2	27.8	7.0	0.0	17 AUG 89
CVCP	89	230	24.3	26.9	9.0	0.0	18 AUG 89
CVCP	89	231	22.0	29.2	9.9	0.0	19 AUG 89
CVCP	89	232	13.4	27.5	16.8	21.8	20 AUG 89
CVCP	89	233	24.6	29.5	15.1	0.0	21 AUG 89
CVCP	89	234	11.4	26.8	18.0	2.6	22 AUG 89
CVCP	89	235	11.7	25.8	17.8	0.0	23 AUG 89
CVCP	89	236	20.6	26.0	14.3	0.0	24 AUG 89
CVCP	89	237	23.9	27.3	10.2	0.0	25 AUG 89
CVCP	89	238	21.9	28.2	10.3	0.0	26 AUG 89
CVCP	89	239	17.5	31.1	16.2	0.0	27 AUG 89
CVCP	89	240	6.1	26.2	15.9	9.0	28 AUG 89
CVCP	89	241	7.1	26.9	18.9	1.3	29 AUG 89
CVCP	89	242	23.2	26.7	12.9	0.0	30 AUG 89
CVCP	89	243	16.6	28.6	9.9	0.0	31 AUG 89
CVCP	89	244	14.0	26.3	16.7	64.3	01 SEP 89
CVCP	89	245	22.5	24.0	10.4	0.0	02 SEP 89
CVCP	89	246	18.7	25.6	7.6	0.0	03 SEP 89
CVCP	89	247	19.9	25.6	8.8	0.0	04 SEP 89

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APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	248	17.7	28.5	12.7	0.8	05 SEP 89
CVCP	89	249	6.4	25.7	19.3	10.0	06 SEP 89
CVCP	89	250	14.9	29.3	18.1	4.9	07 SEP 89
CVCP	89	251	17.5	30.5	19.5	1.8	08 SEP 89
CVCP	89	252	10.2	27.9	18.2	5.1	09 SEP 89
CVCP	89	253	16.3	23.4	13.9	0.0	10 SEP 89
CVCP	89	254	11.9	25.2	12.8	0.0	11 SEP 89
CVCP	89	255	18.1	23.8	11.4	0.0	12 SEP 89
CVCP	89	256	1.8	11.4	10.1	6.4	13 SEP 89
CVCP	89	257	2.0	12.2	9.7	12.6	14 SEP 89
CVCP	89	258	21.8	21.2	4.0	0.0	15 SEP 89
CVCP	89	259	6.3	16.1	8.3	4.9	16 SEP 89
CVCP	89	260	19.2	23.8	5.4	0.0	17 SEP 89
CVCP	89	261	20.2	24.7	5.3	0.0	18 SEP 89
CVCP	89	262	19.3	25.1	7.3	0.0	19 SEP 89
CVCP	89	263	17.8	25.2	7.6	0.0	20 SEP 89
CVCP	89	264	15.2	26.1	9.3	0.3	21 SEP 89
CVCP	89	265	7.7	23.2	9.9	0.3	22 SEP 89
CVCP	89	266	15.9	13.8	0.6	0.0	23 SEP 89
CVCP	89	267	19.7	16.8	-2.7	0.0	24 SEP 89
CVCP	89	268	19.1	20.4	-1.4	0.0	25 SEP 89
CVCP	89	269	19.4	16.9	3.1	0.0	26 SEP 89
CVCP	89	270	19.1	18.2	-3.7	0.0	27 SEP 89
CVCP	89	271	18.9	22.7	0.9	0.0	28 SEP 89
CVCP	89	272	17.9	25.1	7.8	0.0	29 SEP 89
CVCP	89	273	18.1	24.2	4.3	0.0	30 SEP 89
CVCP	89	274	15.3	25.9	7.7	0.0	1 OCT 89
CVCP	89	275	4.0	20.3	6.7	0.3	2 OCT 89
CVCP	89	276	15.4	13.5	-2.1	0.0	3 OCT 89
CVCP	89	277	17.6	16.4	-2.9	0.3	4 OCT 89
CVCP	89	278	8.6	18.8	-1.8	2.1	5 OCT 89
CVCP	89	279	9.3	17.2	5.9	0.0	6 OCT 89
CVCP	89	280	8.3	11.8	-1.0	0.0	7 OCT 89
CVCP	89	281	10.4	12.4	-3.7	0.3	8 OCT 89
CVCP	89	282	14.0	12.9	-7.4	0.0	9 OCT 89
CVCP	89	283	5.7	14.4	7.1	5.1	10 OCT 89
CVCP	89	284	15.7	21.7	0.2	0.0	11 OCT 89
CVCP	89	285	16.2	23.5	2.3	0.0	12 OCT 89
CVCP	89	286	15.5	26.5	0.3	0.0	13 OCT 89
CVCP	89	287	13.8	29.6	8.7	0.0	14 OCT 89
CVCP	89	288	12.5	27.1	9.7	0.0	15 OCT 89
CVCP	89	289	7.8	25.2	8.2	0.3	16 OCT 89
CVCP	89	290	1.7	8.2	3.0	4.1	17 OCT 89
CVCP	89	291	10.8	7.4	-2.1	0.0	18 OCT 89
CVCP	89	292	2.0	1.1	-0.8	5.9	19 OCT 89
CVCP	89	293	3.2	3.3	-0.3	8.8	20 OCT 89
CVCP	89	294	7.9	9.9	0.3	2.3	21 OCT 89
CVCP	89	295	13.8	17.0	-2.3	0.0	22 OCT 89
CVCP	89	296	9.4	21.2	2.6	0.0	23 OCT 89
CVCP	89	297	11.8	24.6	10.6	0.0	24 OCT 89
CVCP	89	298	12.0	24.8	8.4	0.0	25 OCT 89
CVCP	89	299	2.6	3.0	0.5	0.0	26 OCT 89
CVCP	89	300	12.0	24.0	4.7	.0	27 OCT 89
CVCP	89	301	11.3	24.1	3.1	.0	28 OCT 89
CVCP	89	302	10.4	22.9	3.7	.0	29 OCT 89
CVCP	89	303	11.5	23.0	8.4	.0	30 OCT 89
CVCP	89	304	1.4	14.0	3.6	1.5	31 OCT 89
CVCP	89	305	10.3	13.9	-.3	.0	01 NOV 89

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ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	306	3.4	7.9	-1.3	.3	02 NOV 89
CVCP	89	307	6.8	5.3	-4.9	.3	03 NOV 89
CVCP	89	308	3.6	7.6	-1.2	.0	04 NOV 89
CVCP	89	309	4.3	14.4	3.9	2.1	05 NOV 89
CVCP	89	310	3.9	11.9	-1.8	.0	06 NOV 89
CVCP	89	311	2.2	5.2	-1.1	16.7	07 NOV 89
CVCP	89	312	2.4	8.8	3.3	.5	08 NOV 89
CVCP	89	313	7.2	8.2	1.6	1.0	09 NOV 89
CVCP	89	314	4.2	7.7	-1.0	2.1	10 NOV 89
CVCP	89	315	3.6	10.2	.5	.0	11 NOV 89
CVCP	89	316	9.7	9.7	-5.6	.0	12 NOV 89
CVCP	89	317	9.6	21.8	2.3	.0	13 NOV 89
CVCP	89	318	1.5	15.6	10.8	13.1	14 NOV 89
CVCP	89	319	.7	14.1	-.1	6.7	15 NOV 89
CVCP	89	320	4.7	.3	-4.0	2.5	16 NOV 89
CVCP	89	321	6.1	-1.9	-11.1	4.5	17 NOV 89
CVCP	89	322	8.1	-.3	-9.5	1.3	18 NOV 89
CVCP	89	323	8.3	6.5	-7.3	6.0	19 NOV 89
CVCP	89	324	9.3	11.7	.9	.0	20 NOV 89
CVCP	89	325	7.5	1.0	-4.1	.0	21 NOV 89
CVCP	89	326	3.7	-1.0	-7.9	.0	22 NOV 89
CVCP	89	327	5.3	-.8	-11.2	1.3	23 NOV 89
CVCP	89	328	9.2	4.8	-9.3	1.3	24 NOV 89
CVCP	89	329	5.6	9.8	1.6	.0	25 NOV 89
CVCP	89	330	9.1	11.4	-1.3	.0	26 NOV 89
CVCP	89	331	.8	15.2	1.8	0.5	27 NOV 89
CVCP	89	332	2.1	10.6	-5.7	1.3	28 NOV 89
CVCP	89	333	6.2	-1.8	-8.1	1.3	29 NOV 89
CVCP	89	334	8.9	5.4	-5.1	.0	30 NOV 89
CVCP	89	335	8.6	7.8	-4.2	.0	01 DEC 89
CVCP	89	336	3.4	3.1	-4.9	2.5	02 DEC 89
CVCP	89	337	6.2	-2.4	-9.2	1.3	03 DEC 89
CVCP	89	338	4.9	1.1	-7.8	.0	04 DEC 89
CVCP	89	339	2.0	1.4	-6.2	.0	05 DEC 89
CVCP	89	340	2.3	3.3	-6.6	.0	06 DEC 89
CVCP	89	341	4.7	-3.1	-8.5	.0	07 DEC 89
CVCP	89	342	8.4	-2.2	-10.9	.0	08 DEC 89
CVCP	89	343	4.7	-.4	-12.3	.0	09 DEC 89
CVCP	89	344	1.7	1.1	-2.7	3.8	10 DEC 89
CVCP	89	345	8.1	-.8	-7.0	.0	11 DEC 89
CVCP	89	346	6.6	-3.4	-15.1	.0	12 DEC 89
CVCP	89	347	4.9	-4.7	-18.4	2.5	13 DEC 89
CVCP	89	348	6.7	-7.4	-20.7	1.3	14 DEC 89
CVCP	89	349	4.8	-8.6	-22.3	1.3	15 DEC 89
CVCP	89	350	7.2	-6.9	-24.8	.0	16 DEC 89
CVCP	89	351	6.6	-9.5	-24.7	.0	17 DEC 89
CVCP	89	352	7.9	-6.1	-18.2	3.2	18 DEC 89
CVCP	89	353	1.9	-3.7	-12.9	1.3	19 DEC 89
CVCP	89	354	2.6	-8.8	-16.3	2.5	20 DEC 89
CVCP	89	355	6.3	-11.3	-29.0	.0	21 DEC 89
CVCP	89	356	7.1	-8.3	-33.8	.0	22 DEC 89
CVCP	89	357	7.8	-6.4	-25.6	.0	23 DEC 89
CVCP	89	358	5.6	-10.7	-26.6	.0	24 DEC 89
CVCP	89	359	2.2	-1.0	-12.2	5.0	25 DEC 89
CVCP	89	360	6.6	-.7	-15.1	1.3	26 DEC 89
CVCP	89	361	2.8	-4.2	-14.8	1.3	27 DEC 89
CVCP	89	362	5.0	.0	-6.3	.0	28 DEC 89
CVCP	89	363	2.6	1.7	-2.2	0.5	29 DEC 89

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ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	89	364	1.6	-.1	-3.7	16.0	30 DEC 89
CVCP	89	365	1.1	.5	-2.3	.0	31 DEC 89
CVCP	90	1	2.25	-.3	-3.9	.0	01 JAN 90
CVCP	90	2	8.26	3.6	-5.5	.3	02 JAN 90
CVCP	90	3	7.13	5.6	-2.2	.0	03 JAN 90
CVCP	90	4	1.52	5.3	-3.4	23.6	04 JAN 90
CVCP	90	5	3.12	-.8	-6.1	.0	05 JAN 90
CVCP	90	6	4.69	2.5	-4.6	.0	06 JAN 90
CVCP	90	7	8.06	6.3	-3.8	.0	07 JAN 90
CVCP	90	8	7.68	7.7	-3.1	.0	08 JAN 90
CVCP	90	9	1.31	3.7	1.3	15.1	09 JAN 90
CVCP	90	10	1.44	1.4	-1.8	.0	10 JAN 90
CVCP	90	11	3.31	3.4	-2.1	.0	11 JAN 90
CVCP	90	12	6.04	-2.1	-5.7	.0	12 JAN 90
CVCP	90	13	6.88	.3	-10.9	.0	13 JAN 90
CVCP	90	14	5.13	3.9	-6.2	.0	14 JAN 90
CVCP	90	15	7.19	7.7	-.2	.0	15 JAN 90
CVCP	90	16	1.38	10.3	1.6	.8	16 JAN 90
CVCP	90	17	.94	11.3	3.4	18.2	17 JAN 90
CVCP	90	18	1.35	3.3	-4.7	.0	18 JAN 90
CVCP	90	19	6.32	1.9	-6.6	.0	19 JAN 90
CVCP	90	20	1.39	.1	-2.0	.3	20 JAN 90
CVCP	90	21	2.17	.5	-1.3	.0	21 JAN 90
CVCP	90	22	2.30	1.6	-2.1	.0	22 JAN 90
CVCP	90	23	2.12	7.0	-3.4	.3	23 JAN 90
CVCP	90	24	6.07	7.5	1.9	.0	24 JAN 90
CVCP	90	25	1.70	9.1	-3.0	25.9	25 JAN 90
CVCP	90	26	7.37	1.1	-4.6	.0	26 JAN 90
CVCP	90	27	6.87	9.4	-1.3	.0	27 JAN 90
CVCP	90	28	9.36	4.2	-6.7	.0	28 JAN 90
CVCP	90	29	7.84	4.3	-5.7	.0	29 JAN 90
CVCP	90	30	7.99	6.5	-4.3	.0	30 JAN 90
CVCP	90	31	10.95	6.5	-6.7	.0	31 JAN 90
CVCP	90	32	1.13	6.8	.6	18.7	01 FEB 90
CVCP	90	33	2.20	3.1	-4.5	14.9	02 FEB 90
CVCP	90	34	1.14	-.4	-4.0	.8	03 FEB 90
CVCP	90	35	2.24	-1.0	-4.9	.3	04 FEB 90
CVCP	90	36	8.75	6.6	-4.6	.3	05 FEB 90
CVCP	90	37	6.07	6.3	-1.1	.0	06 FEB 90
CVCP	90	38	2.82	5.3	.3	.0	07 FEB 90
CVCP	90	39	11.19	14.4	-.2	.0	08 FEB 90
CVCP	90	40	6.63	12.7	.2	1.3	09 FEB 90
CVCP	90	41	12.03	5.2	-5.8	.0	10 FEB 90
CVCP	90	42	9.32	3.7	-5.7	.0	11 FEB 90
CVCP	90	43	9.31	7.8	-9.0	.5	12 FEB 90
CVCP	90	44	4.37	15.3	-1.5	.5	13 FEB 90
CVCP	90	45	2.41	-1.5	-5.7	.0	14 FEB 90
CVCP	90	46	1.96	-1.2	-5.6	.0	15 FEB 90
CVCP	90	47	3.89	2.6	-4.9	5.9	16 FEB 90
CVCP	90	48	13.54	4.8	-8.9	8.2	17 FEB 90
CVCP	90	49	14.53	4.5	-7.8	1.5	18 FEB 90
CVCP	90	50	15.03	1.2	-9.7	.0	19 FEB 90
CVCP	90	51	15.30	3.8	-14.1	.0	20 FEB 90
CVCP	90	52	13.66	8.8	-5.7	.0	21 FEB 90
CVCP	90	53	1.52	5.3	-.0	43.2	22 FEB 90
CVCP	90	54	13.56	4.1	-6.3	2.1	23 FEB 90
CVCP	90	55	10.75	-1.0	-11.5	.0	24 FEB 90
CVCP	90	56	15.77	1.6	-19.9	.0	25 FEB 90

APPENDIX C

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
CVCP	90	57	10.78	-.2	-16.0	.0	26 FEB 90
CVCP	90	58	11.77	7.3	-4.7	.0	27 FEB 90
CVCP	90	59	16.93	2.7	-10.9	.0	28 FEB 90
CVCP	90	60	16.80	5.8	-9.3	.0	29 FEB 90
CVCP	90	61	16.82	8.7	-2.8	.0	01 MAR 90
CVCP	90	62	16.42	2.4	-9.2	.0	02 MAR 90
CVCP	90	63	11.44	2.9	-11.5	.0	03 MAR 90
CVCP	90	64	3.09	-1.1	-4.7	.0	04 MAR 90
CVCP	90	65	18.09	.6	-11.6	1.0	05 MAR 90
CVCP	90	66	17.28	4.4	-15.3	.3	06 MAR 90
CVCP	90	67	5.34	6.0	-7.9	12.6	07 MAR 90
CVCP	90	68	4.61	6.6	3.7	1.3	08 MAR 90
CVCP	90	69	5.78	14.2	1.1	26.0	09 MAR 90
CVCP	90	70	7.86	23.1	5.5	4.6	10 MAR 90
CVCP	90	71	14.53	25.5	15.8	.3	11 MAR 90
CVCP	90	72	5.75	23.1	14.7	.0	12 MAR 90
CVCP	90	73	13.57	25.6	14.9	.0	13 MAR 90
CVCP	90	74	6.05	22.1	8.8	9.3	14 MAR 90
CVCP	90	75	13.93	16.0	6.8	.0	15 MAR 90
CVCP	90	76	11.00	11.3	1.4	.3	16 MAR 90
CVCP	90	77	10.75	6.0	-.8	2.1	17 MAR 90
CVCP	90	78	12.06	.6	-4.8	.0	18 MAR 90
CVCP	90	79	19.40	7.6	-8.6	.0	19 MAR 90
CVCP	90	80	1.79	7.9	3.1	11.7	20 MAR 90
CVCP	90	81	1.79	7.9	3.1	11.7	21 MAR 90
CVCP	90	82	1.79	7.9	3.1	11.7	22 MAR 90
CVCP	90	83	16.28	3.2	-5.7	.0	23 MAR 90
CVCP	90	84	18.96	5.3	-6.6	.0	24 MAR 90
CVCP	90	85	22.25	8.0	-6.4	.0	25 MAR 90
CVCP	90	86	20.28	6.7	-6.2	.0	26 MAR 90
CVCP	90	87	22.75	9.7	-9.5	.0	27 MAR 90
CVCP	90	88	18.45	13.1	-6.6	.0	28 MAR 90
CVCP	90	89	4.16	6.0	2.4	12.9	29 MAR 90
CVCP	90	90	6.86	8.6	3.8	.8	30 MAR 90
CVCP	90	91	5.30	9.6	4.2	4.3	31 MAR 90
CVCP	90	92	6.46	12.6	6.0	2.3	01 APR 90
CVCP	90	93	3.33	9.4	.8	4.8	02 APR 90
CVCP	90	94	11.09	7.7	-1.0	.0	03 APR 90
CVCP	90	95	15.09	11.5	-3.6	.0	04 APR 90
CVCP	90	96	9.64	6.8	-2.6	.0	05 APR 90
CVCP	90	97	14.92	7.0	-6.6	.0	06 APR 90
CVCP	90	98	15.77	6.2	-6.8	.0	07 APR 90
CVCP	90	99	12.14	12.8	-3.7	.0	08 APR 90
CVCP	90	100	9.41	14.7	6.0	.0	09 APR 90

APPENDIX C

SOIL NITROGEN BALANCE PARAMETERS (1988/1989)

TRT = Treatment number
STRAW = Weight of organic residue of previous crop (kg ha^{-1})
SDEP = Depth of incorporation of residue (cm)
SCN = C:N ratio of the residue of previous crop
ROOT = Root weight of previous crop
RCN = C:N ratio of roots of previous crop

CVCP8801 = MSCN (ID) 89 (Year) 01 (01 = RMP; 02 = CMP)

ID	TRT	STRAW	SDEP	SCN	ROOT	RCN
CVCP8801	1	9000.	5.	60.	2500.	40.
CVCP8802	1	9000.	5.	60.	2500.	40.
CVCP8901	1	7220.	5.	60.	4000.	40.
CVCP8902	1	7800.	5.	60.	4000.	40.

APPENDIX C

SOIL PROFILE PROPERTIES (1988/1989)

NOTE: These parameters are used for both the RMP and CMP simulations for both 1989 and 1990.

Soil Name = Oshtemo Sandy Loam
Soil Albedo = 0.11
Upper limit of stage 1 soil evaporation = 7.00 mm
Soil water drainage constant, fraction drained per day = 0.67
SCS runoff curve number = 62.00
Annual average ambient temperature = 9.4 (^oC)
Annual amplitude in mean monthly temperature = 15.5 (^oC)
Mineralization factor (DMOD) = 1.0

DLAYR = Thickness of soil layer (cm)
LL = Lower Limit of plant extractable soil water (cm^3 cm^{-3})
DUL = Drained Upper Limit of plant extractable soil water (cm^3 cm^{-3})
SAT = Saturated water content (cm^3 cm^{-3})
SW = Default soil water content (cm^3 cm^{-3})
WR = Root weighing factor to determine new root growth distribution
BD = Bulk Density (g cm^{-3})
OC = Organic carbon (%)

DLAYR	LL	DUL	SAT	SW	WR	BD	OC
15.	0.080	0.175	0.322	0.175	1.000	1.70	0.78
15.	0.085	0.155	0.315	0.155	.640	1.64	0.73
15.	0.083	0.139	0.311	0.139	.470	1.77	0.37
15.	0.085	0.133	0.302	0.133	.350	1.73	0.37
15.	0.071	0.128	0.299	0.128	.260	1.61	0.38
15.	0.073	0.126	0.297	0.126	.190	1.53	0.38
15.	0.073	0.133	0.296	0.133	.140	1.60	0.38
15.	0.072	0.133	0.296	0.133	.090	1.55	0.35
15.	0.069	0.135	0.320	0.135	.050	1.62	0.32
30.	0.069	0.135	0.320	0.135	.030	1.61	0.22
30	0.072	0.135	0.320	0.135	.010	1.61	0.12

APPENDIX C

SOIL PROFILE INITIAL CONDITIONS (1988)

TRT = Treatment number
DLAYR = Thickness of soil layer
SW = Soil water content (cm^3 cm^{-3})
NH4 = Soil ammonium content (mg elemental N per kg of soil)
NO3 = Soil ammonium content (mg elemental N per kg of soil)
PH = pH of soil in a 1:1 soil:water slurry

CVCP8801 = MSCN (ID) 88 (Year) 01 (01 = RMP; 02 = CMP)

01 CVCP8801

DLAYR	SW	NH4	NO3	PH
15.	00.175	2.3	0.9	5.8
15.	00.155	1.1	0.6	5.6
15.	00.139	1.9	0.5	5.7
15.	00.133	1.9	0.5	5.7
15.	00.128	0.7	0.3	6.1
15.	00.126	0.7	0.3	6.1
15.	00.133	0.5	0.1	6.1
15.	00.133	0.5	0.1	6.1
15.	00.135	0.3	0.1	6.1
30.	00.119	0.1	0.1	6.1
30.	00.128	0.1	0.1	6.1

01 CVCP8802

15.	00.175	4.0	0.9	7.5
15.	00.155	0.8	0.7	6.7
15.	00.139	0.8	0.5	5.7
15.	00.133	0.8	0.5	5.7
15.	00.128	0.8	0.6	6.5
15.	00.126	0.8	0.6	6.5
15.	00.133	0.8	0.6	6.5
15.	00.133	0.8	0.6	6.5
15.	00.135	0.6	0.5	6.5
30.	00.135	0.4	0.3	6.5
30.	00.135	0.2	0.1	6.5

APPENDIX C

SOIL PROFILE INITIAL CONDITIONS (1989)

TRT = Treatment number
DLAYR = Thickness of soil layer
SW = Soil water content (cm^3 cm^{-3})
NH4 = Soil ammonium content (mg elemental N per kg of soil)
NO3 = Soil ammonium content (mg elemental N per kg of soil)
PH = pH of soil in a 1:1 soil:water slurry

CVCP8901 = MSCN (ID) 89 (Year) 01 (01 = RMP; 02 = CMP)

01 CVCP8901

DLAYR	SW	NH4	NO3	PH
15.	00.175	2.0	0.4	5.8
15.	00.155	1.6	0.6	5.6
15.	00.139	1.5	0.6	5.7
15.	00.133	1.5	0.6	5.7
15.	00.128	0.9	0.5	6.1
15.	00.126	0.9	0.5	6.1
15.	00.133	0.9	0.5	6.1
15.	00.133	0.9	0.5	6.1
15.	00.135	0.4	0.4	7.3
30.	00.135	0.2	0.2	7.3
30.	00.135	0.1	0.1	7.3

01 CVCP8902

15.	00.175	2.3	1.2	7.5
15.	00.155	1.9	0.8	6.7
15.	00.139	2.6	1.1	5.7
15.	00.133	2.6	1.1	5.7
15.	00.128	1.4	1.1	6.5
15.	00.126	1.4	1.1	6.5
15.	00.133	1.4	1.1	6.5
15.	00.133	1.4	1.1	6.5
15.	00.135	1.2	0.9	5.5
30.	00.135	1.0	0.7	5.5
30.	00.135	0.8	0.5	4.5

APPENDIX C

IRRIGATION WATER APPLICATION DATA (1988)

TRT = Treatment
CVCP8801 = CVCP (ID) 88 (Year) 01 (01 = RMP; 02 = CMP)

DOY = Day Of the Year
AMIRR = Amount of irrigation water applied (mm)

CVCP8801

DOY	AMIRR
168	15.
169	8.
176	13.
178	13.
180	13.
182	13.
184	13.
186	13.
188	13.
190	16.
192	13.
197	13.
210	13.
211	13.
213	13.
215	13.
217	13.
225	13.
227	13.
231	7.
239	13.

CVCP8802

DOY	AMIRR
165	35.
167	16.
171	23.
174	16.
175	33.
180	37.
183	18.
191	12.
194	19.
196	28.
200	6.
202	18.
203	7.
210	6.
214	15.
215	9.
216	13.
217	10.
221	10.
222	16.

APPENDIX C

IRRIGATION WATER APPLICATION DATA (1989)

TRT = Treatment
CVCP8801 = CVCP (ID) 88 (Year) 01 (01 = RMP; 02 = CMP)

DOY = Day Of the Year
AMIRR = Amount of irrigation water applied (mm)

CVCP8901

DOY	AMIRR
176	1.
185	4.
198	15.
202	3.
227	13.
228	13.

CVCP8902

DOY	AMIRR
184	13.
185	13.
187	15.
188	15.
189	13.
198	15.
199	15.
200	13.
201	13.
226	15.
228	13.

APPENDIX C

NITROGEN FERTILIZER APPLICATION DATA (1988/1989)

CVCP8801 = CVCP (ID) 88 (Year) 01 (01 = RMP; 02 = CMP)

DOY = Day Of the Year
AMFERT = Amount of fertilizer nitrogen added (kg ha^{-1})
DFERT = Depth of incorporation (cm)
IFTYPE = Type of fertilizer used (see Table 9)

CVCP8801

DOY	AMFERT	DFERT	IFTYPE
126	10.0	5.0	6
169	40.0	3.0	1
190	80.0	3.0	1

CVCP8802

DOY	AMFERT	DFERT	IFTYPE
111	200.0	25.0	4
126	10.0	5.0	6

CVCP8901

DOY	AMFERT	DFERT	IFTYPE
140	10.0	5.0	6
176	30.0	3.0	1
185	35.6	3.0	1
202	47.5	3.0	1

CVCP8902

DOY	AMFERT	DFERT	IFTYPE
125	200.0	25.0	4
141	10.0	5.0	6

APPENDIX C

MANAGEMENT DATA (1988/1989)

Input management data for RMP and CMP simulations for 1988.

Day simulation began = 74

Day of sowing = 126

Plant population = 6.78 pl m^{-2}

Row spacing = 0.773 m

Planting depth = 5.0 cm

Input management data for RMP and CMP simulations for 1989.

Day simulation began = 101

Day of sowing = 140

Plant population = 8.29 pl m^{-2} (RMP) ; 7.29 pl m^{-2} (CMP)

Row spacing = 0.773 m

Planting depth = 5.0 cm

APPENDIX C

GENETIC DATA (1988/1989)

P1 = Growing degree days (base 8 ^{o}C) from seedling emergence to the end of the juvenile stage (d ^{o}C).

P2 = Photoperiod sensitivity coefficient (1 hr^{-1})

P5 = Growing degree days (base ^{o}C) from silking to physiological maturity (d ^{o}C).

P6 = New leaf area coefficient

G2 = New grains per plant coefficient

G3 = Potential kernel growth rate (mg $kernel^{-1}$ day^{-1}).

This genetic variety was used for all treatments for both 1988 and 1989.

Variety ID = PIO3475

P1 = 220.00
P2 = 0.30
P5 = 740.0
P6 = 1.0
G2 = 1.10
G3 = 8.90

APPENDIX D

APPENDIX D

Inputs used in the inbred simulations

WEATHER DATA (1989/1990)

ID = MSCN
Latitude = 41.50
Longitude = 85.40
YR = Year
SOL = Solar Radiation (Mj m^{-2})
TMAX = Maximum Daily Temperature (^{o}C)
TMIN = Minimum Daily Temperature (^{o}C)
RAIN = Rainfall (mm)

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	89	121	23.91	15.9	3.3	2.8	01 MAY 89
MSCN	89	122	6.71	9.3	2.9	3.8	02 MAY 89
MSCN	89	123	26.88	16.3	1.3	0.0	03 MAY 89
MSCN	89	124	21.34	19.0	6.0	1.8	04 MAY 89
MSCN	89	125	21.05	16.5	5.4	0.0	05 MAY 89
MSCN	89	126	12.87	6.8	-1.5	0.0	06 MAY 89
MSCN	89	127	23.31	8.6	-3.3	0.0	07 MAY 89
MSCN	89	128	16.99	16.3	-0.6	1.8	08 MAY 89
MSCN	89	129	11.49	16.8	7.5	1.3	09 MAY 89
MSCN	89	130	28.14	18.0	2.6	0.0	10 MAY 89
MSCN	89	131	29.11	16.9	3.4	0.0	11 MAY 89
MSCN	89	132	10.10	16.1	7.3	6.6	12 MAY 89
MSCN	89	133	7.22	13.9	7.7	0.8	13 MAY 89
MSCN	89	134	12.37	16.8	6.8	0.0	14 MAY 89
MSCN	89	135	13.35	17.8	8.7	0.8	15 MAY 89
MSCN	89	136	25.71	22.6	4.9	0.0	16 MAY 89
MSCN	89	137	28.14	25.8	6.7	0.0	17 MAY 89
MSCN	89	138	14.78	24.7	11.9	2.0	18 MAY 89
MSCN	89	139	5.15	21.1	16.1	14.0	19 MAY 89
MSCN	89	140	11.95	21.7	10.5	0.5	20 MAY 89
MSCN	89	141	28.53	24.0	7.9	0.0	21 MAY 89
MSCN	89	142	1.29	24.1	17.1	0.0	22 MAY 89
MSCN	89	143	29.34	25.9	11.5	0.0	23 MAY 89
MSCN	89	144	14.16	26.0	20.6	12.7	24 MAY 89
MSCN	89	145	7.36	24.4	18.8	3.3	25 MAY 89
MSCN	89	146	28.95	22.1	12.1	0.0	26 MAY 89
MSCN	89	147	27.67	16.8	7.9	0.0	27 MAY 89
MSCN	89	148	27.01	20.8	3.4	0.0	28 MAY 89
MSCN	89	149	12.42	21.3	9.8	0.0	29 MAY 89
MSCN	89	150	16.07	27.5	17.7	46.5	30 MAY 89
MSCN	89	151	9.16	28.3	18.1	99.6	31 MAY 89
MSCN	89	152	10.87	24.8	18.0	9.7	01 JUN 89
MSCN	89	153	29.76	25.3	15.1	0.0	02 JUN 89
MSCN	89	154	8.41	21.5	14.5	16.5	03 JUN 89

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APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	89	155	28.52	23.0	11.2	0.0	04 JUN 89
MSCN	89	156	20.05	24.3	11.8	0.0	05 JUN 89
MSCN	89	157	28.57	27.6	11.7	0.0	06 JUN 89
MSCN	89	158	25.23	29.2	15.6	0.0	07 JUN 89
MSCN	89	159	22.04	28.1	17.3	0.0	08 JUN 89
MSCN	89	160	20.41	23.8	12.0	0.0	09 JUN 89
MSCN	89	161	21.85	19.8	9.9	0.0	10 JUN 89
MSCN	89	162	29.51	24.5	5.3	0.0	11 JUN 89
MSCN	89	163	4.82	17.7	15.8	16.0	12 JUN 89
MSCN	89	164	11.98	24.1	16.5	0.0	13 JUN 89
MSCN	89	165	14.11	23.9	15.2	4.8	14 JUN 89
MSCN	89	166	13.98	20.0	10.7	0.0	15 JUN 89
MSCN	89	167	7.07	15.1	10.4	0.0	16 JUN 89
MSCN	89	168	26.22	24.3	10.6	0.0	17 JUN 89
MSCN	89	169	23.39	26.6	15.0	0.0	18 JUN 89
MSCN	89	170	8.16	23.3	17.4	0.0	19 JUN 89
MSCN	89	171	19.18	25.4	16.1	0.0	20 JUN 89
MSCN	89	172	24.32	28.0	15.2	0.0	21 JUN 89
MSCN	89	173	15.89	30.1	17.7	0.0	22 JUN 89
MSCN	89	174	21.05	32.5	19.1	0.0	23 JUN 89
MSCN	89	175	26.27	31.5	18.9	0.0	24 JUN 89
MSCN	89	176	28.41	31.9	17.9	0.0	25 JUN 89
MSCN	89	177	19.95	32.7	20.0	6.9	26 JUN 89
MSCN	89	178	8.69	24.8	19.2	0.0	27 JUN 89
MSCN	89	179	30.35	26.0	13.8	0.0	28 JUN 89
MSCN	89	180	30.85	23.5	8.9	0.0	29 JUN 89
MSCN	89	181	30.26	26.8	9.4	0.0	30 JUN 89
MSCN	89	182	28.06	30.0	20.5	0.0	01 JUL 89
MSCN	89	183	22.67	30.7	18.2	0.0	02 JUL 89
MSCN	89	184	24.54	27.4	19.3	0.0	03 JUL 89
MSCN	89	185	24.11	30.9	17.4	0.0	04 JUL 89
MSCN	89	186	26.31	31.8	17.1	0.0	05 JUL 89
MSCN	89	187	24.47	32.7	18.1	0.0	06 JUL 89
MSCN	89	188	27.12	32.8	18.5	0.0	07 JUL 89
MSCN	89	189	24.46	31.1	15.2	0.0	08 JUL 89
MSCN	89	190	22.63	32.2	18.7	24.9	09 JUL 89
MSCN	89	191	26.02	34.1	24.2	0.0	10 JUL 89
MSCN	89	192	16.91	32.1	21.2	0.0	11 JUL 89
MSCN	89	193	8.70	18.4	16.7	0.0	12 JUL 89
MSCN	89	194	14.76	24.6	16.3	0.0	13 JUL 89
MSCN	89	195	26.19	26.4	12.1	0.0	14 JUL 89
MSCN	89	196	23.06	25.9	17.0	0.0	15 JUL 89
MSCN	89	197	24.81	27.5	13.4	0.0	16 JUL 89
MSCN	89	198	28.04	28.6	13.4	0.0	17 JUL 89
MSCN	89	199	19.18	29.9	14.0	0.0	18 JUL 89
MSCN	89	200	5.20	21.9	17.7	7.6	19 JUL 89
MSCN	89	201	4.11	20.6	18.2	3.3	20 JUL 89
MSCN	89	202	11.87	27.1	18.0	0.8	21 JUL 89
MSCN	89	203	19.51	29.9	17.5	0.0	22 JUL 89
MSCN	89	204	19.83	30.6	16.6	0.0	23 JUL 89
MSCN	89	205	15.68	31.2	19.4	0.0	24 JUL 89
MSCN	89	206	15.59	32.2	21.4	0.3	25 JUL 89
MSCN	89	207	15.46	31.0	21.1	2.5	26 JUL 89
MSCN	89	208	16.94	32.2	21.7	0.0	27 JUL 89
MSCN	89	209	22.35	26.2	15.3	0.0	28 JUL 89
MSCN	89	210	23.53	27.1	10.4	0.0	29 JUL 89
MSCN	89	211	3.94	20.7	15.7	8.4	30 JUL 89
MSCN	89	212	23.98	27.9	15.1	0.0	31 JUL 89

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APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	89	213	25.06	28.8	14.5	0.0	01 AUG 89
MSCN	89	214	25.97	30.1	15.7	0.0	02 AUG 89
MSCN	89	215	22.96	32.8	18.2	0.0	03 AUG 89
MSCN	89	216	18.24	31.3	22.7	3.8	04 AUG 89
MSCN	89	217	23.76	30.8	19.4	24.6	05 AUG 89
MSCN	89	218	21.50	24.6	11.6	0.0	06 AUG 89
MSCN	89	219	25.24	19.4	8.1	0.0	07 AUG 89
MSCN	89	220	21.07	23.8	8.7	0.0	08 AUG 89
MSCN	89	221	20.24	26.0	11.9	0.0	09 AUG 89
MSCN	89	222	21.93	27.9	12.4	0.0	10 AUG 89
MSCN	89	223	21.87	28.3	13.4	2.3	11 AUG 89
MSCN	89	224	17.56	27.9	14.0	4.3	12 AUG 89
MSCN	89	225	24.88	27.9	13.3	0.3	13 AUG 89
MSCN	89	226	18.25	28.6	15.5	0.0	14 AUG 89
MSCN	89	227	15.73	26.6	16.4	0.3	15 AUG 89
MSCN	89	228	19.16	23.5	12.5	0.0	16 AUG 89
MSCN	89	229	23.10	26.2	10.4	0.0	17 AUG 89
MSCN	89	230	23.86	25.7	11.6	0.0	18 AUG 89
MSCN	89	231	21.26	27.2	11.2	0.0	19 AUG 89
MSCN	89	232	12.50	27.9	18.1	19.8	20 AUG 89
MSCN	89	233	24.98	28.9	16.2	0.0	21 AUG 89
MSCN	89	234	11.80	27.1	19.2	2.0	22 AUG 89
MSCN	89	235	9.88	26.1	19.4	0.0	23 AUG 89
MSCN	89	236	19.70	25.4	16.3	0.0	24 AUG 89
MSCN	89	237	24.25	26.1	11.6	0.0	25 AUG 89
MSCN	89	238	21.42	27.3	12.2	0.0	26 AUG 89
MSCN	89	239	18.40	30.4	18.4	0.0	27 AUG 89
MSCN	89	240	5.60	25.7	18.1	0.0	28 AUG 89
MSCN	89	241	7.16	26.4	20.6	0.0	29 AUG 89
MSCN	89	242	23.66	25.9	13.9	0.0	30 AUG 89
MSCN	89	243	16.43	27.8	11.5	0.0	31 AUG 89
MSCN	89	244	12.66	25.7	18.0	0.0	01 SEP 89
MSCN	89	245	23.43	22.9	12.2	0.0	02 SEP 89
MSCN	89	246	19.86	24.0	8.9	0.0	03 SEP 89
MSCN	89	247	20.09	24.5	9.5	0.0	04 SEP 89
MSCN	89	248	17.29	26.9	14.0	0.0	05 SEP 89
MSCN	89	249	5.53	24.6	19.4	11.2	06 SEP 89
MSCN	89	250	14.03	29.2	19.6	8.6	07 SEP 89
MSCN	89	251	16.12	30.0	20.2	8.4	08 SEP 89
MSCN	89	252	11.14	27.7	19.6	6.9	09 SEP 89
MSCN	89	253	17.77	24.2	15.1	0.0	10 SEP 89
MSCN	89	254	11.64	24.0	14.5	0.0	11 SEP 89
MSCN	89	255	18.98	22.5	12.8	10.2	12 SEP 89
MSCN	89	256	1.74	12.8	10.9	9.4	13 SEP 89
MSCN	89	257	1.51	13.1	11.1	9.4	14 SEP 89
MSCN	89	258	22.65	20.8	5.5	0.3	15 SEP 89
MSCN	89	259	7.43	18.4	10.3	0.3	16 SEP 89
MSCN	89	260	18.20	23.6	5.7	0.0	17 SEP 89
MSCN	89	261	19.89	24.3	7.0	0.0	18 SEP 89
MSCN	89	262	20.98	25.6	7.8	0.0	19 SEP 89
MSCN	89	263	16.63	25.6	9.0	0.0	20 SEP 89
MSCN	89	264	14.67	26.1	10.2	0.0	21 SEP 89
MSCN	89	265	7.90	24.3	10.6	0.0	22 SEP 89
MSCN	89	266	16.87	12.1	1.7	0.0	23 SEP 89
MSCN	89	267	19.78	16.4	-1.9	0.0	24 SEP 89
MSCN	89	268	18.94	19.3	0.4	0.0	25 SEP 89
MSCN	89	269	19.15	16.2	5.8	0.0	26 SEP 89
MSCN	89	270	18.98	17.5	-0.7	0.0	27 SEP 89

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ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	89	271	18.78	22.6	1.3	0.0	28 SEP 89
MSCN	89	272	17.07	25.4	9.5	0.0	29 SEP 89
MSCN	89	273	17.74	23.9	5.4	0.0	30 SEP 89
MSCN	89	274	14.98	25.5	7.5	0.0	1 OCT 89
MSCN	89	275	3.98	19.9	8.0	0.0	2 OCT 89
MSCN	89	276	16.03	13.0	0.0	0.0	3 OCT 89
MSCN	89	277	17.93	15.4	-1.6	0.0	4 OCT 89
MSCN	89	278	8.37	18.5	0.1	1.0	5 OCT 89
MSCN	89	279	11.20	16.4	7.1	0.0	6 OCT 89
MSCN	89	280	9.15	11.2	1.4	0.0	7 OCT 89
MSCN	89	281	9.56	12.1	-1.7	0.0	8 OCT 89
MSCN	89	282	15.11	12.1	-4.8	0.0	9 OCT 89
MSCN	89	283	7.59	13.1	6.0	2.8	10 OCT 89
MSCN	89	284	15.93	22.7	-0.7	0.0	11 OCT 89
MSCN	89	285	16.22	23.4	5.2	0.0	12 OCT 89
MSCN	89	286	15.57	28.1	2.7	0.0	13 OCT 89
MSCN	89	287	14.06	30.0	10.1	0.0	14 OCT 89
MSCN	89	288	12.16	28.1	10.8	0.0	15 OCT 89
MSCN	89	289	8.39	23.5	9.1	1.0	16 OCT 89
MSCN	89	290	1.75	9.1	4.0	4.1	17 OCT 89
MSCN	89	291	10.62	6.5	-0.3	0.0	18 OCT 89
MSCN	89	292	2.92	1.6	-0.5	2.3	19 OCT 89
MSCN	89	293	4.19	2.5	0.3	19.3	20 OCT 89
MSCN	89	294	6.91	9.1	0.6	4.8	21 OCT 89
MSCN	89	295	13.99	16.1	-1.6	0.3	22 OCT 89
MSCN	89	296	10.00	21.7	2.9	0.0	23 OCT 89
MSCN	89	297	12.41	24.1	7.9	0.0	24 OCT 89
MSCN	89	298	10.62	24.4	7.8	0.0	25 OCT 89
MSCN	89	299	11.78	23.7	5.9	0.0	26 OCT 89
MSCN	89	300	11.95	23.9	5.4	0.0	27 OCT 89
MSCN	89	301	11.51	23.4	4.7	0.0	28 OCT 89
MSCN	89	302	11.29	22.8	5.7	0.0	29 OCT 89
MSCN	89	303	1.28	23.3	14.0	0.0	30 OCT 89
MSCN	89	304	1.34	15.4	3.9	2.3	31 OCT 89
MSCN	89	305	10.40	12.8	0.0	0.0	1 NOV 89
MSCN	89	306	3.23	8.7	-0.3	0.0	2 NOV 89
MSCN	89	307	8.54	4.7	-1.9	0.8	3 NOV 89
MSCN	89	308	3.36	8.1	0.3	0.0	4 NOV 89
MSCN	89	309	4.57	14.9	4.4	2.8	5 NOV 89
MSCN	89	310	4.54	14.1	0.6	0.0	6 NOV 89
MSCN	89	311	2.43	6.3	1.6	12.9	7 NOV 89
MSCN	89	312	1.96	9.1	4.2	0.3	8 NOV 89
MSCN	89	313	7.93	7.4	1.9	1.0	9 NOV 89
MSCN	89	314	4.46	6.6	-0.1	1.0	10 NOV 89
MSCN	89	315	3.69	10.9	0.7	0.0	11 NOV 89
MSCN	89	316	9.43	9.5	-2.6	0.0	12 NOV 89
MSCN	89	317	9.74	21.9	3.6	0.0	13 NOV 89
MSCN	89	318	1.31	16.1	12.0	8.4	14 NOV 89
MSCN	89	319	0.58	15.6	0.7	21.3	15 NOV 89
MSCN	89	320	2.64	1.1	-4.6	0.5	16 NOV 89
MSCN	89	321	6.21	-1.3	-11.1	0.0	17 NOV 89
MSCN	89	322	8.45	-2.4	-9.8	0.0	18 NOV 89
MSCN	89	323	8.58	7.1	-6.9	3.6	19 NOV 89
MSCN	89	324	9.66	12.0	2.8	0.0	20 NOV 89
MSCN	89	325	5.94	2.8	-3.5	0.0	21 NOV 89
MSCN	89	326	3.51	-1.3	-7.7	0.0	22 NOV 89
MSCN	89	327	14.17	4.9	-10.2	0.0	23 NOV 89
MSCN	89	328	14.17	4.9	-10.2	0.0	24 NOV 89

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APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	89	329	5.43	9.6	1.6	0.0	25 NOV 89
MSCN	89	330	9.24	12.8	-2.1	0.0	26 NOV 89
MSCN	89	331	0.76	16.6	1.5	10.4	27 NOV 89
MSCN	89	332	1.81	11.6	-4.9	0.0	28 NOV 89
MSCN	89	333	7.88	-2.9	-7.0	0.0	29 NOV 89
MSCN	89	334	9.03	5.2	-4.3	0.0	30 NOV 89
MSCN	89	335	8.42	8.8	-4.1	0.0	1 DEC 89
MSCN	89	336	3.76	4.1	-5.1	0.3	2 DEC 89
MSCN	89	337	6.02	-3.5	-8.0	0.0	3 DEC 89
MSCN	89	338	5.30	0.9	-7.4	0.0	4 DEC 89
MSCN	89	339	2.46	2.2	-5.4	0.3	5 DEC 89
MSCN	89	340	2.04	4.2	-6.2	0.0	6 DEC 89
MSCN	89	341	5.49	-2.4	-8.2	0.0	7 DEC 89
MSCN	89	342	8.55	-2.7	-10.5	0.0	8 DEC 89
MSCN	89	343	4.76	-1.3	-11.2	0.0	9 DEC 89
MSCN	89	344	1.96	1.5	-3.3	0.0	10 DEC 89
MSCN	89	345	8.34	-0.6	-7.2	0.0	11 DEC 89
MSCN	89	346	7.80	-4.7	-15.4	0.0	12 DEC 89
MSCN	89	347	5.75	-5.3	-16.6	0.0	13 DEC 89
MSCN	89	348	7.12	-7.0	-19.3	0.0	14 DEC 89
MSCN	89	349	5.84	-10.4	-20.9	0.0	15 DEC 89
MSCN	89	350	7.88	-10.1	-20.7	0.0	16 DEC 89
MSCN	89	351	7.04	-10.6	-24.1	0.0	17 DEC 89
MSCN	89	352	8.26	-8.1	-18.6	0.0	18 DEC 89
MSCN	89	353	1.81	-3.5	-11.8	0.0	19 DEC 89
MSCN	89	354	3.94	-10.5	-16.9	0.0	20 DEC 89
MSCN	89	355	5.85	-14.0	-23.9	0.0	21 DEC 89
MSCN	89	356	8.09	-11.9	-26.5	0.0	22 DEC 89
MSCN	89	357	8.01	-10.1	-24.2	0.0	23 DEC 89
MSCN	89	358	5.72	-11.4	-23.7	0.0	24 DEC 89
MSCN	89	359	2.65	-0.2	-11.8	0.0	25 DEC 89
MSCN	89	360	7.22	-0.1	-13.7	0.0	26 DEC 89
MSCN	89	361	3.07	-3.1	-13.2	0.0	27 DEC 89
MSCN	89	362	4.87	0.5	-5.0	0.0	28 DEC 89
MSCN	89	363	2.93	1.3	-1.4	0.0	29 DEC 89
MSCN	89	364	1.56	0.6	-2.9	0.0	30 DEC 89
MSCN	89	365	6.72	-2.2	-11.9	0.0	31 DEC 89
MSCN	90	1	2.51	-0.3	-3.4	0.0	01 JAN 90
MSCN	90	2	8.48	3.0	-6.0	0.8	02 JAN 90
MSCN	90	3	7.39	5.5	-0.6	3.3	03 JAN 90
MSCN	90	4	1.00	6.4	-1.7	8.9	04 JAN 90
MSCN	90	5	4.26	-0.6	-4.7	0.0	05 JAN 90
MSCN	90	6	5.59	2.5	-4.5	0.0	06 JAN 90
MSCN	90	7	8.77	-2.0	-13.9	0.0	07 JAN 90
MSCN	90	8	7.81	8.1	-2.4	0.3	08 JAN 90
MSCN	90	9	1.10	4.3	2.0	4.6	09 JAN 90
MSCN	90	10	1.54	2.5	-1.3	0.0	10 JAN 90
MSCN	90	11	5.23	4.5	-1.6	0.3	11 JAN 90
MSCN	90	12	5.33	-1.6	-5.1	0.0	12 JAN 90
MSCN	90	13	7.02	-1.9	-8.6	0.0	13 JAN 90
MSCN	90	14	5.36	7.8	-3.3	7.9	14 JAN 90
MSCN	90	15	5.26	9.4	-5.6	6.6	15 JAN 90
MSCN	90	16	1.43	6.7	-1.0	7.1	16 JAN 90
MSCN	90	17	2.43	3.0	-6.1	0.0	17 JAN 90
MSCN	90	18	9.57	1.6	-7.9	0.3	18 JAN 90
MSCN	90	19	9.69	8.7	-1.3	0.0	19 JAN 90
MSCN	90	20	3.23	6.1	-9.5	0.3	20 JAN 90
MSCN	90	21	8.24	0.0	-13.8	0.0	21 JAN 90

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ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	22	10.35	-3.1	-15.0	0.0	22 JAN 90
MSCN	90	23	6.55	0.9	-8.1	0.0	23 JAN 90
MSCN	90	24	8.85	-5.8	-14.4	0.0	24 JAN 90
MSCN	90	25	10.81	-6.5	-15.5	0.0	25 JAN 90
MSCN	90	26	9.70	-5.5	-17.3	0.0	26 JAN 90
MSCN	90	27	6.07	-1.1	-15.9	0.0	27 JAN 90
MSCN	90	28	11.79	8.8	-11.4	0.0	28 JAN 90
MSCN	90	29	11.79	4.8	-11.4	0.0	29 JAN 90
MSCN	90	30	12.00	-4.1	-16.3	0.0	30 JAN 90
MSCN	90	31	12.00	3.9	-16.3	0.5	31 JAN 90
MSCN	90	32	11.15	9.4	-0.4	0.0	01 FEB 90
MSCN	90	33	11.65	13.0	0.4	0.0	02 FEB 90
MSCN	90	34	8.51	14.6	1.3	0.0	03 FEB 90
MSCN	90	35	4.16	13.4	0.5	0.3	04 FEB 90
MSCN	90	36	2.64	9.7	-1.5	0.0	05 FEB 90
MSCN	90	37	5.87	7.3	-1.0	0.0	06 FEB 90
MSCN	90	38	0.25	4.3	3.1	0.0	07 FEB 90
MSCN	90	39	11.77	14.6	1.1	0.0	08 FEB 90
MSCN	90	40	7.24	14.3	1.8	0.5	09 FEB 90
MSCN	90	41	12.20	4.5	-4.9	0.3	10 FEB 90
MSCN	90	42	8.23	3.0	-3.8	0.0	11 FEB 90
MSCN	90	43	10.21	9.5	-7.8	0.0	12 FEB 90
MSCN	90	44	4.69	15.3	-0.8	0.0	13 FEB 90
MSCN	90	45	2.13	-0.6	-5.1	0.0	14 FEB 90
MSCN	90	46	2.35	-0.8	-4.9	0.0	15 FEB 90
MSCN	90	47	4.50	1.9	-4.9	1.0	16 FEB 90
MSCN	90	48	13.65	1.1	-7.2	1.5	17 FEB 90
MSCN	90	49	14.89	4.0	-9.3	1.5	18 FEB 90
MSCN	90	50	15.53	-0.1	-7.3	0.0	19 FEB 90
MSCN	90	51	15.61	1.6	-13.0	0.0	20 FEB 90
MSCN	90	52	13.76	8.2	-9.5	27.9	21 FEB 90
MSCN	90	53	1.47	5.4	0.4	57.9	22 FEB 90
MSCN	90	54	13.31	4.1	-4.1	2.8	23 FEB 90
MSCN	90	55	10.40	-0.1	-10.5	0.0	24 FEB 90
MSCN	90	56	16.56	-5.2	-19.0	0.0	25 FEB 90
MSCN	90	57	10.36	-2.4	-18.8	0.0	26 FEB 90
MSCN	90	58	14.14	5.1	-4.6	3.0	27 FEB 90
MSCN	90	59	16.94	1.0	-8.3	0.0	28 FEB 90
MSCN	90	60	17.16	3.8	-9.5	0.0	01 MAR 90
MSCN	90	61	17.05	7.0	-2.8	0.0	02 MAR 90
MSCN	90	62	15.47	1.6	-7.7	0.0	03 MAR 90
MSCN	90	63	13.57	2.4	-10.0	0.0	04 MAR 90
MSCN	90	64	3.41	-0.3	-3.9	0.0	05 MAR 90
MSCN	90	65	18.12	-2.7	-9.6	0.0	06 MAR 90
MSCN	90	66	17.47	1.1	-15.9	0.0	07 MAR 90
MSCN	90	67	4.78	4.6	-6.6	22.7	08 MAR 90
MSCN	90	68	4.54	7.6	3.9	10.8	09 MAR 90
MSCN	90	69	5.37	16.0	1.3	19.9	10 MAR 90
MSCN	90	70	8.46	24.4	7.1	11.5	11 MAR 90
MSCN	90	71	13.53	25.5	17.1	0.0	12 MAR 90
MSCN	90	72	5.32	22.9	15.8	0.0	13 MAR 90
MSCN	90	73	12.43	25.0	16.0	0.0	14 MAR 90
MSCN	90	74	4.43	22.5	9.8	2.3	15 MAR 90
MSCN	90	75	13.98	15.7	8.1	0.0	16 MAR 90
MSCN	90	76	11.85	10.6	2.3	0.3	17 MAR 90
MSCN	90	77	10.82	4.9	0.1	2.3	18 MAR 90
MSCN	90	78	11.47	0.5	-4.2	0.0	19 MAR 90
MSCN	90	79	19.09	6.2	-7.3	0.0	20 MAR 90

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APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	80	14.48	13.6	-1.7	0.0	21 MAR 90
MSCN	90	81	1.76	8.9	3.5	30.2	22 MAR 90
MSCN	90	82	16.61	4.6	-4.8	0.0	23 MAR 90
MSCN	90	83	17.05	2.9	-5.7	0.0	24 MAR 90
MSCN	90	84	17.62	6.7	1.2	0.0	25 MAR 90
MSCN	90	85	20.38	6.0	-4.9	0.0	26 MAR 90
MSCN	90	86	22.10	8.1	-8.0	0.0	27 MAR 90
MSCN	90	87	17.39	10.5	-6.0	0.0	28 MAR 90
MSCN	90	88	2.32	6.4	2.4	12.7	29 MAR 90
MSCN	90	90	5.13	8.9	4.5	0.5	30 MAR 90
MSCN	90	90	4.48	10.0	5.2	2.5	31 MAR 90
MSCN	90	91	6.03	12.5	6.5	1.5	01 APR 90
MSCN	90	92	2.64	10.4	1.3	4.1	02 APR 90
MSCN	90	93	13.31	7.2	-0.3	0.0	03 APR 90
MSCN	90	94	12.75	10.3	-2.7	0.0	04 APR 90
MSCN	90	95	9.13	5.4	-1.4	0.3	05 APR 90
MSCN	90	96	14.66	4.4	-5.5	0.0	06 APR 90
MSCN	90	97	17.27	3.9	-6.9	0.0	07 APR 90
MSCN	90	98	11.69	13.7	-5.7	0.0	08 APR 90
MSCN	90	99	8.68	14.8	6.5	7.4	09 APR 90
MSCN	90	100	2.21	8.8	2.4	17.0	10 APR 90
MSCN	90	101	13.81	4.9	-2.1	1.8	11 APR 90
MSCN	90	102	18.67	6.2	-4.7	0.0	12 APR 90
MSCN	90	103	16.81	11.1	-1.3	1.5	13 APR 90
MSCN	90	104	4.82	8.4	2.6	7.4	14 APR 90
MSCN	90	105	12.44	12.3	1.2	0.0	15 APR 90
MSCN	90	106	17.17	15.2	-2.0	1.3	16 APR 90
MSCN	90	107	22.69	4.7	-2.8	0.3	17 APR 90
MSCN	90	108	26.33	12.1	-4.3	0.0	18 APR 90
MSCN	90	109	14.33	15.8	-0.3	0.0	19 APR 90
MSCN	90	110	2.04	15.3	11.3	16.3	20 APR 90
MSCN	90	111	26.06	20.9	8.9	0.3	21 APR 90
MSCN	90	112	26.42	22.8	3.5	0.0	22 APR 90
MSCN	90	113	24.83	25.0	5.7	0.0	23 APR 90
MSCN	90	114	21.72	29.7	12.6	0.0	24 APR 90
MSCN	90	115	23.91	30.9	16.6	0.0	25 APR 90
MSCN	90	116	22.71	29.5	16.3	0.0	26 APR 90
MSCN	90	117	23.23	29.6	13.7	0.0	27 APR 90
MSCN	90	118	14.10	25.0	14.4	0.5	28 APR 90
MSCN	90	119	21.31	22.0	12.0	0.0	29 APR 90
MSCN	90	120	12.38	22.7	6.6	0.0	30 APR 90
MSCN	90	121	24.60	15.8	2.9	0.0	01 MAY 90
MSCN	90	122	25.94	18.9	0.6	0.0	02 MAY 90
MSCN	90	123	8.48	16.6	5.9	1.0	03 MAY 90
MSCN	90	124	1.47	9.7	6.6	18.3	04 MAY 90
MSCN	90	125	25.87	17.1	6.6	0.0	05 MAY 90
MSCN	90	126	26.20	17.2	2.2	0.0	06 MAY 90
MSCN	90	127	27.52	24.5	6.9	0.0	07 MAY 90
MSCN	90	128	23.61	26.4	14.1	0.0	08 MAY 90
MSCN	90	129	20.67	26.1	14.1	0.0	09 MAY 90
MSCN	90	130	9.58	18.4	3.8	25.8	10 MAY 90
MSCN	90	131	29.78	15.2	2.2	0.0	11 MAY 90
MSCN	90	132	2.98	10.7	7.0	22.4	12 MAY 90
MSCN	90	133	22.87	19.1	9.0	31.3	13 MAY 90
MSCN	90	134	7.06	17.6	7.4	0.3	14 MAY 90
MSCN	90	135	6.45	20.3	10.8	2.3	15 MAY 90
MSCN	90	136	8.15	23.0	17.5	7.4	16 MAY 90
MSCN	90	137	15.59	18.8	11.1	0.0	17 MAY 90

APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	138	28.59	19.3	9.0	0.0	18 MAY 90
MSCN	90	139	10.49	21.7	8.4	0.0	19 MAY 90
MSCN	90	140	20.39	19.8	10.2	0.0	20 MAY 90
MSCN	90	141	10.98	15.7	9.3	0.3	21 MAY 90
MSCN	90	142	27.27	20.1	7.6	0.0	22 MAY 90
MSCN	90	143	20.15	20.4	6.2	0.0	23 MAY 90
MSCN	90	144	17.16	22.1	9.1	0.0	24 MAY 90
MSCN	90	145	6.07	16.9	14.0	11.4	25 MAY 90
MSCN	90	146	10.46	21.4	13.9	0.0	26 MAY 90
MSCN	90	147	25.21	25.0	10.7	0.0	27 MAY 90
MSCN	90	148	22.59	24.4	11.1	0.0	28 MAY 90
MSCN	90	149	29.24	20.9	9.5	0.0	29 MAY 90
MSCN	90	150	30.87	21.7	3.7	0.0	30 MAY 90
MSCN	90	151	31.04	24.0	6.2	0.0	31 MAY 90
MSCN	90	152	21.22	28.8	9.4	0.0	01 JUN 90
MSCN	90	153	12.24	26.6	20.3	2.8	02 JUN 90
MSCN	90	154	19.55	25.0	9.6	1.3	03 JUN 90
MSCN	90	155	26.19	17.9	5.9	0.0	04 JUN 90
MSCN	90	156	13.68	17.2	3.6	0.0	05 JUN 90
MSCN	90	157	18.14	25.6	13.0	0.0	06 JUN 90
MSCN	90	158	25.85	27.2	10.7	0.0	07 JUN 90
MSCN	90	159	15.56	27.3	17.0	10.9	08 JUN 90
MSCN	90	160	27.50	25.0	17.7	0.0	09 JUN 90
MSCN	90	161	26.08	24.1	14.2	0.0	10 JUN 90
MSCN	90	162	21.59	26.7	11.7	0.0	11 JUN 90
MSCN	90	163	26.14	29.1	18.0	0.0	12 JUN 90
MSCN	90	164	28.72	34.0	19.3	0.0	13 JUN 90
MSCN	90	165	19.50	30.9	20.5	3.3	14 JUN 90
MSCN	90	166	30.35	30.6	17.9	0.0	15 JUN 90
MSCN	90	167	25.79	31.4	15.6	0.0	16 JUN 90
MSCN	90	168	20.32	35.6	23.3	0.0	17 JUN 90
MSCN	90	169	29.74	29.3	16.1	0.0	18 JUN 90
MSCN	90	170	25.25	26.6	10.6	0.0	19 JUN 90
MSCN	90	171	9.43	24.2	17.0	7.9	20 JUN 90
MSCN	90	172	28.14	29.7	16.5	0.0	21 JUN 90
MSCN	90	173	8.18	22.8	14.7	5.3	22 JUN 90
MSCN	90	174	9.29	18.9	13.2	2.5	23 JUN 90
MSCN	90	175	29.33	23.1	11.1	0.0	24 JUN 90
MSCN	90	176	29.56	28.8	7.4	0.0	25 JUN 90
MSCN	90	177	13.39	25.5	14.8	0.8	26 JUN 90
MSCN	90	178	23.65	31.5	14.4	0.3	27 JUN 90
MSCN	90	179	14.44	29.6	19.1	15.1	28 JUN 90
MSCN	90	180	15.60	27.6	21.4	7.9	29 JUN 90
MSCN	90	181	24.62	31.3	20.6	0.0	30 JUN 90
MSCN	90	182	28.88	26.9	17.0	0.0	01 JUL 90
MSCN	90	183	30.31	28.5	14.4	0.0	02 JUL 90
MSCN	90	184	28.57	31.2	14.1	0.3	03 JUL 90
MSCN	90	185	28.39	37.7	24.1	0.0	04 JUL 90
MSCN	90	186	20.06	29.8	18.9	0.0	05 JUL 90
MSCN	90	187	21.34	24.0	14.2	0.0	06 JUL 90
MSCN	90	188	21.76	25.7	11.4	0.0	07 JUL 90
MSCN	90	189	25.79	35.5	17.0	0.0	08 JUL 90
MSCN	90	190	24.12	32.9	22.8	0.0	09 JUL 90
MSCN	90	191	8.86	26.1	20.9	0.3	10 JUL 90
MSCN	90	192	4.51	20.9	16.1	20.6	11 JUL 90
MSCN	90	193	18.93	24.7	17.4	0.0	12 JUL 90
MSCN	90	194	9.94	20.2	14.2	0.5	13 JUL 90
MSCN	90	195	7.94	22.1	15.1	1.8	14 JUL 90

APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	196	16.57	23.7	16.3	0.3	15 JUL 90
MSCN	90	197	19.69	27.4	14.7	20.6	16 JUL 90
MSCN	90	198	23.71	29.7	18.8	0.0	17 JUL 90
MSCN	90	199	25.29	31.9	18.3	3.3	18 JUL 90
MSCN	90	200	22.58	31.6	19.0	5.1	19 JUL 90
MSCN	90	201	9.01	26.0	19.9	25.3	20 JUL 90
MSCN	90	202	17.47	29.8	19.1	0.3	21 JUL 90
MSCN	90	203	8.52	21.3	15.2	35.8	22 JUL 90
MSCN	90	204	22.04	25.5	12.1	0.0	23 JUL 90
MSCN	90	205	26.11	27.8	12.4	0.0	24 JUL 90
MSCN	90	206	27.88	29.8	12.9	0.0	25 JUL 90
MSCN	90	207	20.67	28.7	15.8	0.0	26 JUL 90
MSCN	90	208	22.61	28.9	16.4	0.0	27 JUL 90
MSCN	90	209	22.26	31.1	18.3	0.0	28 JUL 90
MSCN	90	210	14.54	30.7	18.3	0.0	29 JUL 90
MSCN	90	211	13.55	26.4	18.8	0.0	30 JUL 90
MSCN	90	212	24.59	23.8	13.0	0.0	31 JUL 90
MSCN	90	213	28.54	26.8	9.1	0.0	01 AUG 90
MSCN	90	214	27.87	27.8	11.2	0.0	02 AUG 90
MSCN	90	215	25.47	29.4	12.7	0.0	03 AUG 90
MSCN	90	216	4.59	24.9	19.7	19.6	04 AUG 90
MSCN	90	217	17.96	25.8	15.9	0.0	05 AUG 90
MSCN	90	218	16.52	20.7	11.4	0.0	06 AUG 90
MSCN	90	219	25.56	23.0	10.9	0.0	07 AUG 90
MSCN	90	220	26.78	28.7	7.2	0.0	08 AUG 90
MSCN	90	221	24.56	28.6	12.5	0.0	09 AUG 90
MSCN	90	222	25.68	28.7	12.3	0.0	10 AUG 90
MSCN	90	223	16.44	27.4	14.9	7.9	11 AUG 90
MSCN	90	224	7.37	25.5	16.4	21.8	12 AUG 90
MSCN	90	225	15.69	23.1	15.3	4.1	13 AUG 90
MSCN	90	226	25.82	25.8	11.7	0.0	14 AUG 90
MSCN	90	227	22.08	28.3	14.0	0.0	15 AUG 90
MSCN	90	228	22.32	29.4	17.1	0.0	16 AUG 90
MSCN	90	229	12.34	27.0	17.1	0.0	17 AUG 90
MSCN	90	230	18.94	31.6	21.2	2.3	18 AUG 90
MSCN	90	231	12.47	29.1	20.1	0.3	19 AUG 90
MSCN	90	232	5.89	23.6	17.3	29.4	20 AUG 90
MSCN	90	233	2.45	21.5	19.9	5.8	21 AUG 90
MSCN	90	234	7.19	22.9	19.1	0.0	22 AUG 90
MSCN	90	235	8.86	24.6	18.3	0.0	23 AUG 90
MSCN	90	236	17.88	28.4	15.8	0.0	24 AUG 90
MSCN	90	237	20.51	29.5	16.2	0.0	25 AUG 90
MSCN	90	238	21.38	32.3	17.7	0.0	26 AUG 90
MSCN	90	239	21.17	33.6	20.1	0.3	27 AUG 90
MSCN	90	240	15.58	34.7	22.5	0.5	28 AUG 90
MSCN	90	241	23.96	30.3	18.8	0.0	29 AUG 90
MSCN	90	242	22.37	29.2	14.3	0.0	30 AUG 90
MSCN	90	243	22.90	30.1	14.4	0.0	31 AUG 90
MSCN	90	244	21.05	31.3	15.5	0.0	01 SEP 90
MSCN	90	245	19.70	31.2	19.3	0.0	02 SEP 90
MSCN	90	246	19.33	27.2	14.4	0.0	03 SEP 90
MSCN	90	247	20.69	31.8	16.9	0.5	04 SEP 90
MSCN	90	248	19.19	34.3	22.0	0.0	05 SEP 90
MSCN	90	249	18.98	36.5	21.0	3.0	06 SEP 90
MSCN	90	250	13.96	28.5	17.9	34.1	07 SEP 90
MSCN	90	251	17.35	26.3	14.2	0.0	08 SEP 90
MSCN	90	252	16.83	28.3	16.8	0.0	09 SEP 90
MSCN	90	253	15.16	29.3	17.5	0.0	10 SEP 90

APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	254	8.84	25.6	17.8	0.0	11 SEP 90
MSCN	90	255	16.80	29.9	16.2	0.0	12 SEP 90
MSCN	90	256	14.51	29.1	16.3	0.0	13 SEP 90
MSCN	90	257	7.67	25.6	16.4	22.6	14 SEP 90
MSCN	90	258	13.01	20.8	13.2	0.0	15 SEP 90
MSCN	90	259	9.04	18.2	10.6	14.2	16 SEP 90
MSCN	90	260	21.32	18.1	4.5	0.3	17 SEP 90
MSCN	90	261	11.00	17.7	6.0	1.5	18 SEP 90
MSCN	90	262	3.63	17.8	12.7	4.1	19 SEP 90
MSCN	90	263	8.81	22.3	11.9	0.0	20 SEP 90
MSCN	90	264	2.62	18.8	11.3	23.7	21 SEP 90
MSCN	90	265	14.55	18.3	8.9	1.5	22 SEP 90
MSCN	90	266	13.67	12.9	6.1	1.0	23 SEP 90
MSCN	90	267	14.56	18.9	4.6	0.0	24 SEP 90
MSCN	90	268	16.64	24.0	9.8	0.0	25 SEP 90
MSCN	90	269	18.59	25.6	10.2	0.0	26 SEP 90
MSCN	90	270	4.03	27.9	14.2	0.0	27 SEP 90
MSCN	90	271	5.25	23.5	10.8	1.3	28 SEP 90
MSCN	90	272	9.96	19.8	13.7	0.0	29 SEP 90
MSCN	90	273	15.43	17.0	5.8	2.0	30 SEP 90
MSCN	90	274	8.45	19.8	2.4	0.0	1 OCT 90
MSCN	90	275	17.57	21.7	5.2	0.3	2 OCT 90
MSCN	90	276	6.04	27.4	12.8	39.5	3 OCT 90
MSCN	90	277	1.20	14.9	10.3	0.8	4 OCT 90
MSCN	90	278	16.51	28.8	9.8	0.0	5 OCT 90
MSCN	90	279	16.31	29.0	18.0	0.0	6 OCT 90
MSCN	90	280	1.35	19.7	11.5	0.5	7 OCT 90
MSCN	90	281	1.46	11.5	7.8	8.1	8 OCT 90
MSCN	90	282	1.38	8.1	6.5	61.2	9 OCT 90
MSCN	90	283	1.39	11.6	5.2	0.3	10 OCT 90
MSCN	90	284	15.15	15.8	1.8	0.0	11 OCT 90
MSCN	90	285	13.31	17.8	0.0	0.0	12 OCT 90
MSCN	90	286	14.96	18.8	0.0	0.0	13 OCT 90
MSCN	90	287	10.53	21.9	4.2	5.6	14 OCT 90
MSCN	90	288	13.99	16.5	5.7	0.3	15 OCT 90
MSCN	90	289	8.74	19.4	4.6	0.0	16 OCT 90
MSCN	90	290	10.29	26.2	16.1	4.6	17 OCT 90
MSCN	90	291	3.72	17.5	4.3	4.6	18 OCT 90
MSCN	90	292	11.22	12.5	4.1	0.3	19 OCT 90
MSCN	90	293	14.35	18.1	2.6	0.0	20 OCT 90
MSCN	90	294	3.50	16.2	8.8	0.0	21 OCT 90
MSCN	90	295	14.21	14.6	1.1	0.0	22 OCT 90
MSCN	90	296	13.70	16.1	-2.8	0.0	23 OCT 90
MSCN	90	297	12.33	15.2	4.4	0.0	24 OCT 90
MSCN	90	298	12.13	10.0	-0.7	0.0	25 OCT 90
MSCN	90	299	13.38	11.6	-4.2	0.0	26 OCT 90
MSCN	90	300	10.67	16.8	1.5	0.0	27 OCT 90
MSCN	90	301	5.57	8.7	-1.0	0.0	28 OCT 90
MSCN	90	302	12.73	12.8	-5.1	0.0	29 OCT 90
MSCN	90	303	11.83	22.2	5.8	0.0	30 OCT 90
MSCN	90	304	10.71	23.3	5.3	0.0	31 OCT 90
MSCN	90	305	11.44	23.4	7.0	0.0	1 NOV 90
MSCN	90	306	9.06	22.0	13.7	0.0	2 NOV 90
MSCN	90	307	9.61	22.5	11.9	0.0	3 NOV 90
MSCN	90	308	1.35	18.0	4.0	27.9	4 NOV 90
MSCN	90	309	0.57	14.0	2.6	45.2	5 NOV 90
MSCN	90	310	3.84	7.2	2.5	0.0	6 NOV 90
MSCN	90	311	2.84	5.4	0.0	0.0	7 NOV 90

APPENDIX D

ID	YR	DOY	SOL	TMAX	TMIN	RAIN	DATE
MSCN	90	312	9.65	5.8	-4.7	0.0	8 NOV 90
MSCN	90	313	2.25	5.5	2.3	0.0	9 NOV 90
MSCN	90	314	8.74	10.9	-2.2	0.3	10 NOV 90
MSCN	90	315	3.36	5.7	-3.8	0.0	11 NOV 90
MSCN	90	316	10.72	7.3	-3.2	0.0	12 NOV 90
MSCN	90	317	9.48	8.2	-4.8	0.0	13 NOV 90
MSCN	90	318	10.11	16.5	-2.5	0.0	14 NOV 90
MSCN	90	319	9.95	21.7	9.1	0.0	15 NOV 90
MSCN	90	320	2.13	16.1	5.0	0.0	16 NOV 90
MSCN	90	321	9.28	9.9	-2.1	0.0	17 NOV 90
MSCN	90	322	5.08	8.9	-2.2	0.0	18 NOV 90
MSCN	90	323	5.03	12.2	-0.4	0.0	19 NOV 90
MSCN	90	324	8.83	14.3	-3.4	0.0	20 NOV 90
MSCN	90	325	1.72	19.0	6.5	0.8	21 NOV 90
MSCN	90	326	4.14	17.9	1.2	5.6	22 NOV 90
MSCN	90	327	6.31	10.0	1.2	1.0	23 NOV 90
MSCN	90	328	3.54	10.2	-2.1	0.0	24 NOV 90
MSCN	90	329	6.47	10.7	0.2	0.0	25 NOV 90
MSCN	90	330	2.12	17.5	-0.8	20.8	26 NOV 90
MSCN	90	331	0.79	20.6	15.8	68.9	27 NOV 90
MSCN	90	332	0.88	18.9	0.3	17.5	28 NOV 90
MSCN	90	333	5.72	2.5	-2.1	0.0	29 NOV 90
MSCN	90	334	8.66	7.7	-3.2	0.0	30 NOV 90
MSCN	90	335	4.20	9.4	2.2	0.0	1 DEC 90
MSCN	90	336	5.75	4.4	-2.9	0.0	2 DEC 90
MSCN	90	337	1.09	5.6	-1.2	16.4	3 DEC 90
MSCN	90	338	5.52	-0.1	-2.9	0.0	4 DEC 90
MSCN	90	339	7.17	2.3	-8.5	0.0	5 DEC 90
MSCN	90	340	2.66	4.5	-2.4	0.0	6 DEC 90
MSCN	90	341	8.30	4.8	-5.6	0.0	7 DEC 90
MSCN	90	342	6.51	7.0	-2.4	0.0	8 DEC 90
MSCN	90	343	8.42	12.3	-2.2	0.0	9 DEC 90
MSCN	90	344	7.73	9.5	-1.5	0.0	10 DEC 90
MSCN	90	345	7.85	12.3	-1.3	0.0	11 DEC 90
MSCN	90	346	4.35	15.0	3.6	0.5	12 DEC 90
MSCN	90	347	1.76	5.8	-5.1	0.0	13 DEC 90
MSCN	90	348	7.91	3.9	-9.4	0.0	14 DEC 90
MSCN	90	349	1.90	11.3	-0.3	6.3	15 DEC 90
MSCN	90	350	0.93	4.7	1.8	0.0	16 DEC 90
MSCN	90	351	1.48	6.0	0.5	2.3	17 DEC 90
MSCN	90	352	0.75	3.4	0.8	0.8	18 DEC 90
MSCN	90	353	4.98	5.4	-3.5	0.0	19 DEC 90
MSCN	90	354	5.63	8.7	-1.3	0.0	20 DEC 90
MSCN	90	355	1.49	8.9	-17.6	5.8	21 DEC 90
MSCN	90	356	7.06	-5.5	-15.1	0.0	22 DEC 90
MSCN	90	357	7.66	-4.9	-19.5	0.0	23 DEC 90
MSCN	90	358	4.08	-4.9	-17.1	0.0	24 DEC 90
MSCN	90	359	3.62	4.6	-7.2	0.0	25 DEC 90
MSCN	90	360	3.62	4.6	-7.2	0.0	26 DEC 90
MSCN	90	361	3.62	4.6	-7.2	0.0	27 DEC 90
MSCN	90	362	3.62	4.6	-7.2	0.0	28 DEC 90
MSCN	90	363	0.90	10.0	-1.4	76.2	29 DEC 90
MSCN	90	364	1.23	3.7	-10.5	0.3	30 DEC 90
MSCN	90	365	8.01	0.0	-10.3	0.0	31 DEC 90

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APPENDIX D

SOIL NITROGEN BALANCE PARAMETERS (1989/1990)

TRT = Treatment number
STRAW = Weight of organic residue of previous crop (kg ha^{-1})
SDEP = Depth of incorporation of residue (cm)
SCN = C:N ratio of the residue of previous crop
ROOT = Root weight of previous crop
RCN = C:N ratio of roots of previous crop

MSCN8901 = MSCN (ID) 89 (Year) 01 (Inbred number)

ID	TRT	STRAW	SDEP	SCN	ROOT	RCN
MSCN8901	1	500.	10.	20.	1500.	20.
MSCN8901	2	500.	10.	20.	1500.	20.
MSCN8901	3	500.	10.	20.	1500.	20.
MSCN8901	4	500.	10.	20.	1500.	20.
MSCN8902	1	500.	10.	20.	1500.	20.
MSCN8902	2	500.	10.	20.	1500.	20.
MSCN8902	3	500.	10.	20.	1500.	20.
MSCN8902	4	500.	10.	20.	1500.	20.
MSCN8903	1	500.	10.	20.	1500.	20.
MSCN8903	2	500.	10.	20.	1500.	20.
MSCN8903	3	500.	10.	20.	1500.	20.
MSCN8903	4	500.	10.	20.	1500.	20.

MSCN8901 = MSCN (ID) 90 (Year) 01 (Inbred number)

ID	TRT	STRAW	SDEP	SCN	ROOT	RCN
MSCN9001	1	4509.	10.	30.	2750.	30.
MSCN9001	2	4629.	10.	30.	2750.	30.
MSCN9001	3	4599.	10.	30.	2750.	30.
MSCN9001	4	4727.	10.	30.	2750.	30.
MSCN9002	1	7298.	10.	30.	2750.	30.
MSCN9002	2	6933.	10.	30.	2750.	30.
MSCN9002	3	6795.	10.	30.	2750.	30.
MSCN9002	4	6688.	10.	30.	2750.	30.
MSCN9003	1	5957.	10.	30.	2750.	30.
MSCN9003	2	6142.	10.	30.	2750.	30.
MSCN9003	3	6242.	10.	30.	2750.	30.
MSCN9003	4	5969.	10.	30.	2750.	30.

APPENDIX D

SOIL PROFILE PROPERTIES (1989/1990)

NOTE: These parameters are used for all treatments in both 1989 and 1990.

Soil Name = Elston Sandy Loam
Soil Albedo = 0.13
Upper limit of stage 1 soil evaporation = 8.00 mm
Soil water drainage constant, fraction drained per day = 0.40
SCS runoff curve number = 78.00
Annual average ambient temperature = 9.4 (^{o}C)
Annual amplitude in mean monthly temperature = 15.5 (^{o}C)
Mineralization factor (DMOD) = 1.0

DLAYR = Thickness of soil layer (cm)
LL = Lower Limit of plant extractable soil water (cm^3 cm^{-3})
DUL = Drained Upper Limit of plant extractable soil water (cm^3 cm^{-3})
SAT = Saturated water content (cm^3 cm^{-3})
SW = Default soil water content (cm^3 cm^{-3})
WR = Root weighing factor to determine new root growth distribution
BD = Bulk Density (g cm^{-3})
OC = Organic carbon (%)

DLAYR	LL	DUL	SAT	SW	WR	BD	OC
15.	0.035	0.177	0.385	0.177	1.000	1.52	1.04
15.	0.035	0.177	0.385	0.177	.900	1.55	1.04
15.	0.037	0.176	0.385	0.176	.700	1.72	0.71
15.	0.037	0.176	0.385	0.176	.700	1.62	0.71
15.	0.037	0.176	0.385	0.176	.500	1.63	0.47
15.	0.028	0.134	0.375	0.134	.080	1.61	0.47
30.	0.020	0.110	0.353	0.110	.040	1.56	0.42
30.	0.019	0.105	0.353	0.105	.005	1.56	0.17
30.	0.019	0.105	0.353	0.105	.002	1.58	0.00
30.	0.019	0.105	0.353	0.105	.002	1.58	0.00

APPENDIX D

SOIL PROFILE INITIAL CONDITIONS (1989)

TRT = Treatment number
DLAYR = Thickness of soil layer
SW = Soil water content (cm^3 cm^{-3})
NH4 = Soil ammonium content (mg elemental N per kg of soil)
NO3 = Soil ammonium content (mg elemental N per kg of soil)
PH = pH of soil in a 1:1 soil:water slurry

MSCN8901 = MSCN (ID) 89 (Year) 01 (Inbred)

NOTE: The same inputs were used for all three inbred for 1989.

TRT

01 MSCN8901

DLAYR	SW	NH4	NO3	PH
15.	.177	2.3	13.8	6.5
15.	.177	1.7	4.8	6.6
15.	.176	.4	3.1	6.8
15.	.176	4.0	2.1	7.0
15.	.176	2.7	1.7	7.0
15.	.134	3.2	1.1	7.0
30.	.110	3.8	0.7	7.0
30.	.105	6.2	0.5	7.0
30.	.105	1.0	0.5	7.0
30.	.105	1.0	0.5	7.0

02 MSCN8901

15.	.177	8.9	10.0	6.5
15.	.177	2.7	3.5	6.6
15.	.176	2.5	2.5	6.8
15.	.176	2.2	1.3	7.0
15.	.176	4.1	1.0	7.0
15.	.134	1.7	1.1	7.0
30.	.110	1.5	0.8	7.0
30.	.105	1.7	0.6	7.0
30.	.105	1.0	0.4	7.0
30.	.105	1.0	0.2	7.0

03 MSCN8901

15.	.177	1.9	10.6	6.5
15.	.177	2.4	5.1	6.6
15.	.176	3.2	2.7	6.8
15.	.176	2.3	1.6	7.0
15.	.176	4.2	0.9	7.0
15.	.134	1.4	0.8	7.0
30.	.110	3.3	0.9	7.0
30.	.105	1.7	0.5	7.0
30.	.105	1.0	0.3	7.0
30.	.105	1.0	0.1	7.0

04 MSCN8901

15.	.177	3.6	11.0	6.5
15.	.177	1.1	3.5	6.6
15.	.176	2.7	2.1	6.8
15.	.176	2.5	1.8	7.0
15.	.176	4.3	0.8	7.0
15.	.134	1.0	0.5	7.0
30.	.110	5.0	1.0	7.0
30.	.105	1.8	0.4	7.0
30.	.105	1.0	0.2	7.0
30.	.105	1.0	0.1	7.0

APPENDIX D

SOIL PROFILE INITIAL CONDITIONS (1990)

TRT = Treatment number
DLAYR = Thickness of soil layer
SW = Soil water content (cm^3 cm^{-3})
NH4 = Soil ammonium content (mg elemental N per kg of soil)
NO3 = Soil ammonium content (mg elemental N per kg of soil)
PH = pH of soil in a 1:1 soil:water slurry

MSCN9001 = MSCN (ID) 90 (Year) 01 (Inbred)

NOTE: The same inputs were used for all three inbred for 1990.

TRT

01 MSCN9001

DLAYR	SW	NH4	NO3	PH
15.	.177	2.5	4.9	6.5
15.	.177	2.3	4.7	6.6
15.	.176	2.0	4.3	6.8
15.	.176	1.5	3.4	7.0
15.	.176	1.3	3.0	7.0
15.	.134	0.6	0.9	7.0
30.	.110	0.6	0.8	7.0
30.	.105	0.5	1.1	7.0
30.	.105	0.6	1.4	7.0
30.	.105	0.6	1.6	7.0

02 MSCN9001

15.	.177	2.4	4.1	6.5
15.	.177	2.2	2.8	6.6
15.	.176	1.8	2.1	6.8
15.	.176	1.4	1.6	7.0
15.	.176	1.2	1.4	7.0
15.	.134	0.6	0.9	7.0
30.	.110	0.6	0.8	7.0
30.	.105	0.5	1.1	7.0
30.	.105	0.6	1.4	7.0
30.	.105	0.6	1.6	7.0

03 MSCN9001

15.	.177	2.1	4.1	6.5
15.	.177	1.8	3.5	6.6
15.	.176	1.3	2.5	6.8
15.	.176	1.6	2.1	7.0
15.	.176	1.8	1.9	7.0
15.	.134	0.6	0.9	7.0
30.	.110	0.6	0.8	7.0
30.	.105	0.5	1.1	7.0
30.	.105	0.1	1.4	7.0
30.	.105	0.1	1.6	7.0

04 MSCN9001

15.	.177	2.1	3.5	6.5
15.	.177	1.8	3.2	6.6
15.	.176	1.1	2.6	6.8
15.	.176	1.0	1.7	7.0
15.	.176	1.0	1.3	7.0
15.	.134	0.6	0.9	7.0
30.	.110	0.6	0.8	7.0
30.	.105	0.5	1.1	7.0
30.	.105	0.1	1.4	7.0
30.	.105	0.1	1.6	7.0

APPENDIX D

IRRIGATION WATER APPLICATION DATA (1989/1990)

TRT = Treatment
MSCN8902 = MSCN (ID) 89 (Year) 02 (Inbred)

DOY = Day Of the Year
AMIRR = Amount of irrigation water applied (mm)

NOTE: The inputs were used for all the simulation runs for all the inbreds in 1989. However, the last two irrigations listed for each treatment were applied only to the lysimeter plots and were not used for the other runs.

1 MSCN8902

DOY	AMIRR
200	16.
203	32.
207	37.
208	1.
214	51.
303	58.
304	57.

3 MSCN8902

200	12.
203	8.
207	11.
208	1.
214	27.
303	100.
304	100.

2 MSCN8902

200	16.
203	20.
207	33.
208	1.
214	34.
303	60.
304	60.

4 MSCN8902

200	16.
203	20.
207	27.
208	1.
214	30.
303	73.
304	73.

NOTE: These inputs were used for all the simulation runs for all the inbreds in 1990.

1 MSCN9001

190	18.
202	22.
220	23.

3 MSCN9001

190	18.
202	22.
220	23.

2 MSCN9001

190	18.
202	22.
220	23.

4 MSCN9001

190	18.
202	22.
220	23.

APPENDIX D

NITROGEN FERTILIZER APPLICATION DATA (1989/1990)

TRT = Treatment
MSCN8901 = MSCN (ID) 89 (Year) 01 (Inbred)

DOY = Day Of the Year
AMFERT = Amount of fertilizer nitrogen added (kg ha^{-1})
DFERT = Depth of incorporation (cm)
IFTYPE = Type of fertilizer used (see Table 9)

NOTE: These inputs were used for all the inbred simulations for 1989.

1 MSCN8901

DOY	AMFERT	DFERT	IFTYPE)
136	180.0	1.0	10

2 MSCN8901

136	30.0	1.0	10
200	50.0	1.0	1

3 MSCN8901

136	30.0	1.0	10
179	60.0	1.0	1

4 MSCN8901

136	30.0	1.0	10
179	150.0	1.0	1

NOTE: These inputs were used for all the inbred simulations for 1989 except for treatment 2. The 40 kg ha^{-1} shown here was only applied to inbred 1, not to inbred 2 or 3.8.

1 MSCN9001

122	180.0	1.0	1

2 MSCN9001

204	40.0	1.0	1

3 MSCN9001

122	30.0	1.0	1
179	60.0	1.0	1

4 MSCN9001

122	00.0	1.0	1

APPENDIX D

MANAGEMENT DATA (1989/1990)

NOTE: This data was used for all treatments and all inbreds for 1989 except for detasseling day and the day the male plants were removed.

Day simulation began = 121

Day of sowing = 136

Plant population = 5.15 pl m^{-2}

Row spacing = 0.762 m

Planting depth = 5.0 cm

	Inbred 1	Inbred 2	Inbred 3
Detasseling day	203	208	208
Removal of male plants	213	233	233

NOTE: This data was used for all treatments and all inbreds for 1990 except for the detasseling day and the day the male plants were removed.

Day simulation began = 115

Day of sowing = 122

Plant population = 5.15 pl m^{-2}

Row spacing = 0.762 m

Planting depth = 5.0 cm

	Inbred 1	Inbred 2	Inbred 3
Detasseling day	201	208	208
Removal of male plants	226	226	226

APPENDIX D

GENETIC DATA (1989/1990)

P1 = Growing degree days (base 8 °C) from seedling emergence to the end of the juvenile stage (d °C).

P2 = Photoperiod sensitivity coefficient (1 hr^{-1})

P5 = Growing degree days (base °C) from silking to physiological maturity (d °C).

P6 = New leaf area coefficient

G2 = New grains per plant coefficient

G3 = Potential kernel growth rate (mg $kernel^{-1}$ day^{-1}).

These genetics varieties were used for all treatments for both 1988 and 1989.

Variety ID = Inbred 1

P1 = 200.00
P2 = 0.30
P5 = 650.0
P6 = 0.85
G2 = 1.15
G3 = 7.50

Variety ID = Inbred 2

P1 = 220.00
P2 = 0.30
P5 = 700.0
P6 = 0.90
G2 = 1.14
G3 = 7.35

Variety ID = Inbred 3

P1 = 240.00
P2 = 0.30
P5 = 700.0
P6 = 0.75
G2 = 1.09
G3 = 7.10

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